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“Sustainable Living? Biodigital Future!”

Alberto T. Estévez

1. Introduction

Within the context of this book, entitled “Sustaining Resources for Tomorrow”, it can quickly come to mind how and why we got here now: why after millennia of human history it is so necessary to talk about “Green Energy and Technology”, within which this writing is framed. Actually, to raise these issues today would seem rhetorical, because at this point of the 21st century everyone knows how and why we have reached this point. Even in the most disadvantaged or remote places one can, in one way or another, get access to a television, a mobile phone, the Internet. The fact that we continue to feel the need and urgency to address these issues makes us realise how little resolved are still at the global level. Few are those who act 100% in consequence of such a situation. And we can find so many contradictions in our daily life...

In 1973, the first oil crisis, paradoxically motivated by political issues and not of genuine environmental awareness, was the instance in which society became aware that natural resources are limited. So maybe it was providential, and we have arrived in advance to the knowledge of the problem, of which we might have realized later. Yes, the Organization of Arab Petroleum Exporting Countries stopped the production of oil and established an embargo for oil shipments to the West. Arab exporters reduced production by 30% and prices rose by 17%. This came to quadruple the price of the barrel, causing a crisis with many short- and long-term effects on global politics and economy.

The crisis started the conversation, at first timidly, about ecology. Gradually “the greens” and political parties with environmental programs were appearing, and other ecological movements, seeing that natural resources are limited, and the damage to nature was beginning to be noticeable on a larger scale, accompanied by demographic growth. So until today, “we are eating the planet”, literally. Such a situation is actually not so new in the evolution of humanity. It is not the first time, that such a relatively “sudden” phenomenon humanity has to faces. Since prehistorical times, societies have suffered different types of sudden changes, that have been transformed or not into catastrophes. The most similar to the one we face today was the sudden change in resource exploitation strategies by Paleolithic inhabitants (Estévez-Escalera, 2005), when they contributed to the extinction of the Eurosiberian, American and insular megafauna. Especially in current Europe, thanks to the demographic increase and the technological improvement of hunting, the Palaeolithic inhabitants literally ate all the large mammals that populated the globe until then. Forced to look for solutions, even if it took them thousands of years, they finally invented agriculture

and livestock. This critical fact can be seen as a precedent of current global change that, unlike the previous ones, and for the first time in the history of mankind, we can study, anticipate and try to avoid its possible catastrophic effects. Although it must be something that each individual one on the planet must take as commitment and collaborate, because there is no longer lacking information, avoiding the contradictions in which we fall, that make us retreat the steps that we manage to advance.

Contradictions in the age of the 4th industrial revolution

In the face of current environmental and technological changes, at least, as architects and designers, we need to think about the meaning of the architecture and design in the age of the 4th industrial revolution, about the times that we are living, and to think of the contradictions of this age. Referring to these written lines, not only from the point of view of someone dedicated exclusively on theoretical criticism, but from the point of view of someone that is dedicated mostly to the research, practice and teaching of what is happening in our times. Yes, it is true that today we live in a moment of profound and accelerated changes in the way we perceive and interact with the world. But this obligate as also more, to think really what is happening: who we are, where we came from, where we are going with this 4th industrial revolution, because it seems that we are running crazy, to nowhere, if we do not think about the meaning of all this in which we are involved. Please, let's stop for a moment for doing that.

The question of what we want our future urban spaces and architecture to look like cannot be separated from what kind of people we aspire to be. We must go beyond the individuals' right to have access to the resources in order to live with dignity, towards an architecture and design (and the advanced research behind it) that allows it. Knowing and recognizing the contradictions with which we live, that are at the heart of capitalism (Harvey, 2014): its drive, for example, to accumulate capital beyond the means of investing it, it's imperative to use the cheapest methods of production that leads to consumers with no means of consumption, and its compulsion to exploit nature to the point of extinction.

To exploit nature to the point of extinction is the worst of all the contradictions, which, after all, is reached by a sum of contradictions. Starting for example with our self-contradictions and our poor knowledge of how our own thinking works (Johnson-Laird and Wason, 1977). Indeed, some in the academic and public interest research community are beginning to raise questions about the claims of the emerging conventional wisdom. For example, perhaps the sharing economy is not moving us forward, but is in fact setting us back in terms of economics (Sundararajan, 2016). When the capitalist system needs the continuous expansion of the principle of rationality to solve the problems of organization and efficiency that the operation of the economy demands. But simultaneously, the culture of capitalism increasingly accentuates the values of an opposite sign, such as feeling, personal gratification and hedonism, reactive response to the old ethic of order and work that accompanied the rise of the bourgeoisie (Bell, 1996). Ending with the human greed, because we've known for a long time that every day the sun

bombards us with ten thousand times more energy than we consume. If we could cover one-tenth of 1 percent of the Earth's surface with solar cells and each cell would achieve only 10 percent energy efficiency, we could meet all our energy needs using only this source. We do not need oil. Nor would there be carbon dioxide guilty of the greenhouse effect (Sargent, 2005).

And the smaller our contradictions seem to us (against the need for planetary sustainability that we have) the more devastating can be the effects. Because those are more easily multiplied by millions of individuals around the planet every day. The problem is that until the politicians do not force a change with laws in our habits, solutions do not generalize at all. Luckily it seems that little by little seeps the examples of the most sensitive countries, that start to forbid something as simple as plastic straws for soft drinks for example, that 36,500 million are consumed every year only in Europe, when it is not necessary even for drinking. Or the countries where it is already forced to pay for plastic bags in stores, or even seeks to prohibit them. But there is still so much to do... Plastics that can take up to 500 years to decompose in our environment, causing very serious damage to marine ecosystems. Between 40-60% of turtles ingest plastics. And in some species of birds that percentage rises up to 93%. More than a million birds and more than 100,000 marine mammals die every year as a result of all the plastics that reach the sea. Up to 12 million tons of plastics enter the oceans every year, drowning ecosystems, causing damage to wildlife and entering the food chain.

It is already known that the demographic increase, and (paradoxically) the industrial technological development and consumerism, are leading to a limit situation of sustainability and planetary survival. It is not that human misery or the differences between rich and poor is something new, because that reality has unfortunately always existed in our history. The reality of our time, and that is what we have to deal with, which is new, of just over half a century, is that if we all live as we currently live in the so-called developed countries, we would need the resources of two whole planets, and it turns out that at short-term we have only one ("One World!").

And this reality is full with contradictions, as for example, the case that in just two weeks after the call, 78,000 people had signed up to go to a one-way trip to Mars, under the mission of establishing a permanent colony on the red planet. Obviously, this pioneering journey of a handful of "privileged" that should be selected from among those thousands is an exorbitant cost. And it is clear that with that budget it could help the lives of thousands of people, for example colonizing decently the deserts of our own planet. Without problems of oxygen deficiency. Without being at 55 degrees Celsius below zero on average (with minima of down to -143ºC), or under extremely strong winds and dust storms, which darken the planet for weeks and even months. In addition, being able to see the family again, if it is desired. But it turns out that leaving with all the expenses paid to cross interplanetary space is much "sophisticated" ("cooler") than not solving the urgent problems that we have just around the corner.

Almost as a “manifesto” on this issue is what led us to design a prototype house in Sahara, the *3D Printed Sahara House Project*, an “integral ecology” example (Figure 1), digitally designed and digitally manufactured: it would be constructed by printing it with robots on-site, at a scale of 1:1, using part of the building material the desert sand itself. That is, practically the same building type and with the same process of construction as the one that would be done realized on Mars, only without risks and for a very small part of the budget. In the conception of the project are included also elements of the vernacular architecture typologies, in its form, ventilation, distribution of rooms around larger spaces and central open patios. Of course, thinking with simple systems of geothermal conditioning, semi-buried, and the necessary solar energy exploitation, with building climate control by means of passive systems.

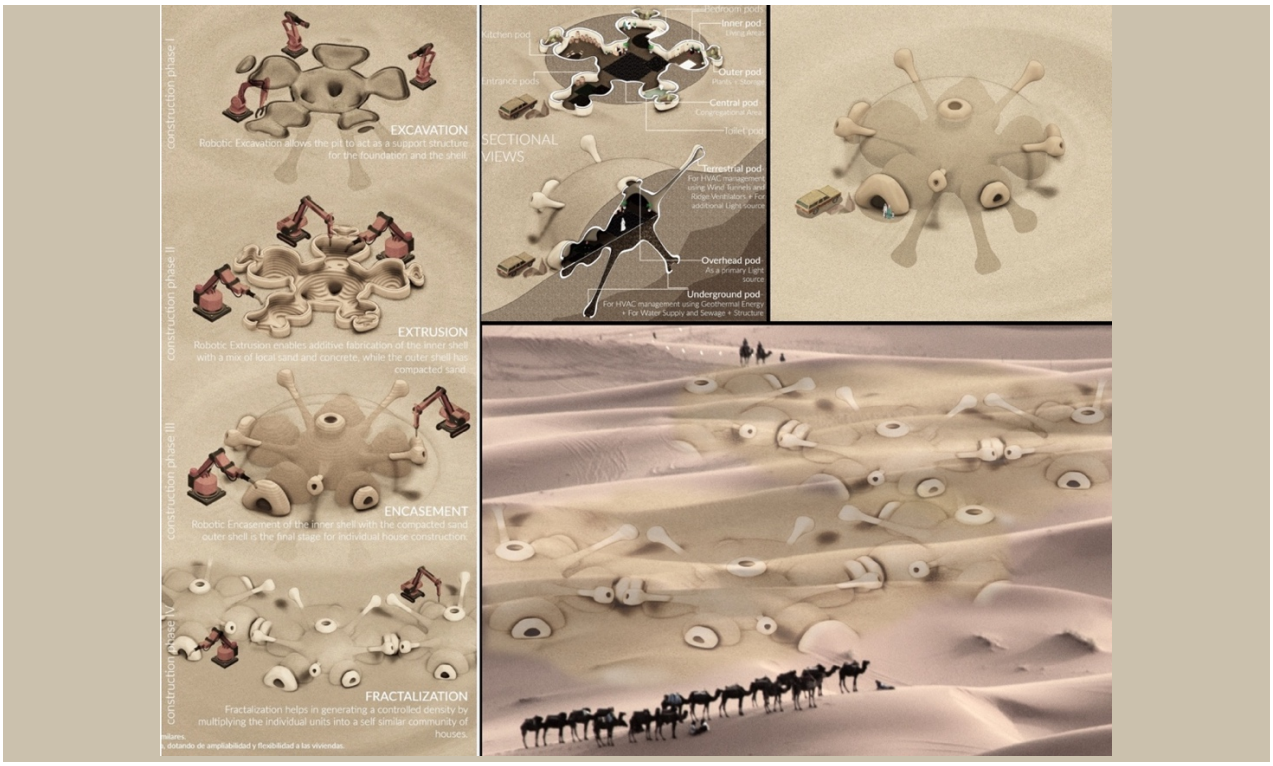


Figure 1. Alberto T. Estévez (with Angad Warang, collaborator), *3D Printed Sahara House Project*, 2017. Digital design and digital manufacturing: it would be solved by printing it with robots on-site, at a scale of 1:1, using as part of the building material the desert sand itself, abstracting in the conception of the project typical elements of the typologies of vernacular architecture.

It is expected that expenses such as those planned for the planet Mars of the year 2029 will not leave us the planet Earth as it is “painted” for the year 2049 in the last film of Blade Runner 2049 (Denis Villeneuve, 2017). Would that be our reality? Yes, and worse, an absolute collapse, if we don’t do our part.

Let's see the present, right now, that urgently demands our responsibility. That is our reality. Our reality in the whole world. It is enough to see the shocking images of overpopulated cities that stretch tight to the horizon. We live in the largest anthill of the known universe. Immense interconnected colony to which we all have to contribute our grain of sand for their survival. The problems become planetary, and some pay the irresponsibility of the others.

For example, New Zealand, which, being one of the most respectful countries as for the environment, is nevertheless the one with the highest rate of skin cancer. Since it has been his luck to be under the ozone hole of the atmosphere in which we have all participated. They can't leave their houses without a hat, nor can they go to the beach in a swimming suit, but only fully clothed.

"Do not eat cherries at Christmas", was the laconic answer from Jorge Wagensberg years ago to my question about what we could do to avoid the alarming proliferation of jellyfish in the Mediterranean, since I liked to bathe in the sea. Definitive, since that day I stopped taking fruit that was not seasonal and of nearby origin: tons of goods move every day polluting the entire planet simply to satisfy unnecessary whims. Our own responsible action and the teaching should be attentive to all those tremendous contradictions in our daily life.

2. Research presentation

So, these pages will introduce (more as method for the discussion) a brief presentation of projects. Taking as example one project of each moment of the architectural ideas evolution of recent times. Thus, from the different understandings of the architecture of each example, all of them remain as an excuse to discuss the concepts of sustainable architecture that every construction should consider today, as a commitment. But also taking one of each type of climate. Following then a chronological thread that spreads from the beginnings of our professional practice until the latest investigations of our current biodigital projects, with biological and digital design strategies, bio-manufacturing and digital-manufacturing, based also on our outcomes with the scanning electron microscope (SEM), to produce images of samples by scanning surfaces and sections with a focused beam of electrons. What follows our investigation in genetics applied to architecture (Estévez, 2016), and our research in computation applied to architecture (Estévez, 2019).

The research for the architectural application of cutting edge biological and digital techniques (with the benefits that come from the inclusion of genetics: efficiency, economy, renewable use, self-replication), is crucial, relevant and urgent before it is too late for our planet which has reached the limits of its sustainability. "We have, because human, an inalienable prerogative of responsibility which we cannot devolve" (Sherrington, 1940).

The first steps: the influence of Rafael Serra

Everyone can participate in improving the world with, for example, simply planting a tree throughout his/her life. I already did it, and I will do it again to replace those who didn't. Of course, what the Cuban poet says could happen: "I had a tree but it dried up". However, as every day approximately 372,960 people are born in the world, every 3 seconds 13 trees could be planted, a huge forest full every day! And the good thing about being a teacher is that, besides, planting a "tree of knowledge" you can go much further in space and time.

This is what Rafael Serra (1942-2012), architect and professor in Barcelona, did. In a different architectural approach from that of the “official” and dogmatic, of the realism and rational-functionalism, of the so-called “Barcelona School”, anchored in the *Neue Sachlichkeit* of the 20s and 30s, he was the only one that in the 70s and 80s had a vision of what is even fashionable today, the attention to environmental issues, the use of alternative energies, passive solar architecture, etc. “Good architecture by definition is sustainable”, he told us in class. For instance, I will always remember how he showed us a project of a complex, something “hippie”, built in the middle of the countryside, as a protest and example in front of a nuclear power station: it was clear that no cable was coming to the project, because he revealed how all the electricity and the necessary air conditioning were solved in a self-sufficient way.

This nowadays can no longer surprise anyone, but at that time no one else taught these things, which I found very inspiring, full of common sense and full of reason, which made me sign up for his courses. So, as soon as I graduated as an architect, as soon as I began my professional career, from my first house built (House G., Sigüenza, 1983-85), I intended to apply those principles that I learned from him. In fact, I was the only one of my generation who then followed his postulates of passive solar architecture. Then, when about 15 years later the words ecology and sustainability became more fashionable, little by little others of my generation were already approaching such understandings.

From the origins of humanity, architecture has fulfilled as a first function the protection against atmospheric elements. Buildings are barriers against rain, wind, shelters against the cold or filters against heat or light. Among other things, Rafael Serra was the most advanced in teaching how to build in the best sustainable and self-sufficient way possible, according to the variety and complexity of climatic situations (Serra, 1989 and 2013). In any climatic condition, what architecture always seeks is to achieve a certain degree of comfort. The attainment of a certain level of well-being results, in practice, as a complex phenomenon involving numerous parameters that are not always quantifiable. And yet now we have the duty not to squander resources, energy, to achieve such comfort. And maybe we can’t rule out that we even have to lower our level of comfort, towards the planetary sustainability. As less comfortable is having to separate waste and take them to the appropriate recycling place, or having to dress more warmly at home in winter to have to heat less.

So we can now go through some chosen projects, to briefly review the different principles applied. Then we will see how the sense and the sensibility that moved us to get into those paths of sustainability is just what led us to conclude in bio-digital architecture.

Three houses, three principles, and something else

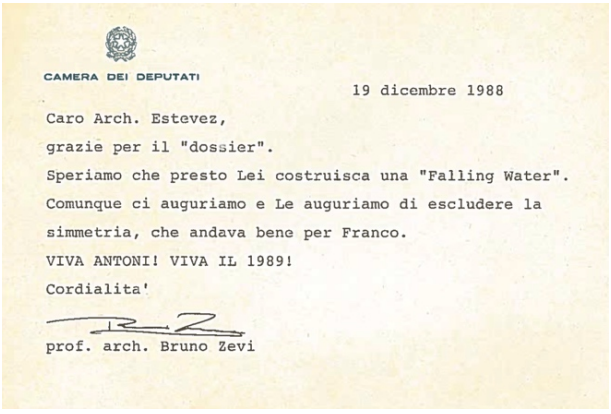
To begin with, three examples of three small houses that explain how, with a low budget, you can also create easily buildings that provide some sustainability benefits.

Figure 2. Alberto T. Estévez, *House G.*, Sigüenza, 1983-85. Views from the south and from the north.

I started designing the first building of my generation with considerations of passive solar architecture at the end of my architecture studies, when I was still 22 years old (Figure 2). Very open to the south, with a narrow greenhouse of fine glass in front, flush with the facade, as a gallery, of the optimum depth, for a better “greenhouse effect”, and insulating glass behind. Very much closed and protected to North, with only one opening with double insulating window, not to miss the beautiful views of the valley. Closed fireplace with heat recuperator in the center, capable of heating the whole house, with stones also inside to accumulate thermal inertia, in a cold climate in winter which-fortunately-does not need air conditioning in the summer. Due to the technological limitations of the place and the early time of the project, solar panels were not yet available, nor other advances that were easier to obtain later. Although due to municipal regulations the roof had to be covered with Arabic tiles.

Of course, in view of this work is that, and fleeing from the rational-functionalist and realistic dogmatism that all the students were forced to design in the famous School of Barcelona, my first professional steps were in the dazzling Vienna of the postmodern epicenter years, fascinated by their big protagonists, as Hans Hollein (HSAK), Gustav Peichl (AKBILD) and Rob Krier (TUWIEN), with personal encounters: there, I also started my academic career, teaching my first classes at the university.

However, this “postmodern pull” was short-lived, because, raised before as child in the shadow of the buildings of Antoni Gaudí in Barcelona, as a young architect it occurred to me to send something to Bruno Zevi, who in just few words radically changed my vision:



CAMERA DEI DEPUTATI

19 dicembre 1988

Caro Arch. Estevez,
grazie per il "dossier".
Speriamo che presto Lei costruisca una "Falling Water".
Comunque ci auguriamo e Le auguriamo di escludere la
simmetria, che andava bene per Franco.
VIVA ANTONI! VIVA IL 1989!
Cordialita'

prof. arch. Bruno Zevi

CHAMBER OF DEPUTIES
19 December 1988

Dear Arch. Estevez,
thanks for the "dossier".
We hope that soon you build a "Falling Water".
However we hope and wish to exclude the
symmetry, which was fine for Franco.
HURRA ANTONI (GAUDI)! HURRA THE 1989!

Friendly'
prof. arch. Bruno Zevi

And on the other hand, little by little, the pure, simplified, abstract geometry of people like Donald Judd, was also more striking: exemplified in this other project (Figure 3), resolving it conceptually with the minimum possible lines. And nevertheless collecting basic principles, like closed to the north winds of winter, with a circle as a good way to repel such winds, and with high trees there against them, stone walls with greater thermal inertia, creating a microclimate in the patio, all the house covered with solar panels to south, water-pool in the south to humidify the environment with the south winds during the summer (necessary for the climate in which this project was located), centered chimney, and also a narrow greenhouse-gallery, which opens in summer and becomes a shaded porch.

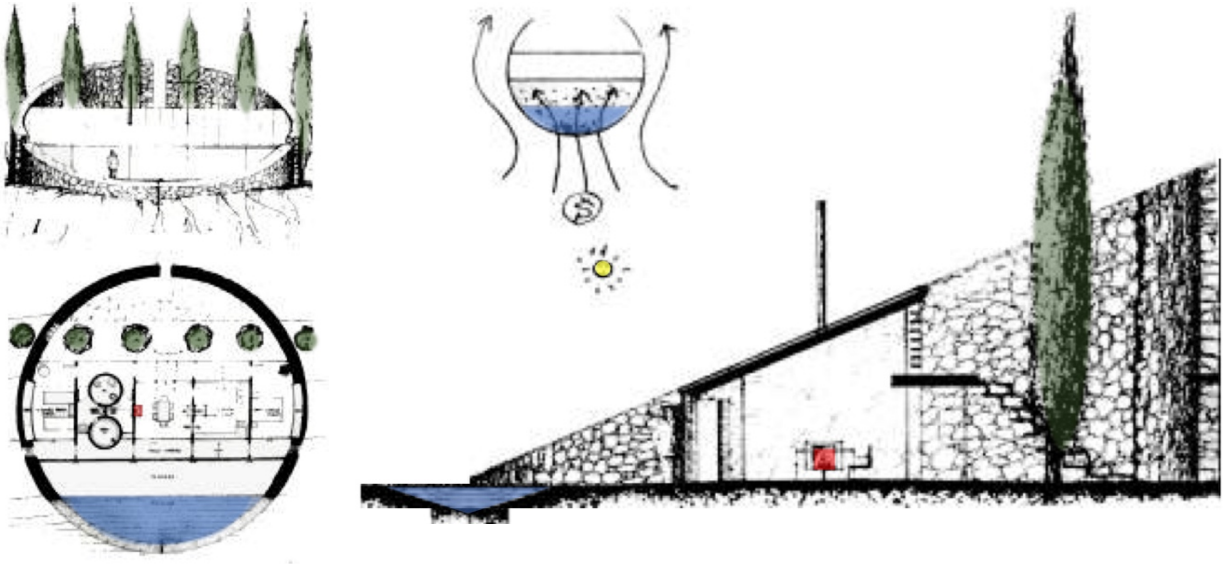


Figure 3. Alberto T. Estévez, *House P.*, Cervià de les Garrigues, 1989. Greenhouse to the south, water for the south winds, closed to north with a patio microclimate, with high trees against the north winds, and with solar panels on the roof.

Later, once experienced the design strategies of maximum reduction of appearances, once exhausted by the work of the application of the famous motto “less is more” of Ludwig Mies van der Rohe, it comes a moment in which another types of possibilities appear, as those that open new ways. This is how one would arrive to the following case from this trio of initial examples of this writing (Figure 4): a house that breaks, plastically and expressively, in broken lines of acute angles, a house that is “sharp”, alive, looking for dynamic and emphatic movements.

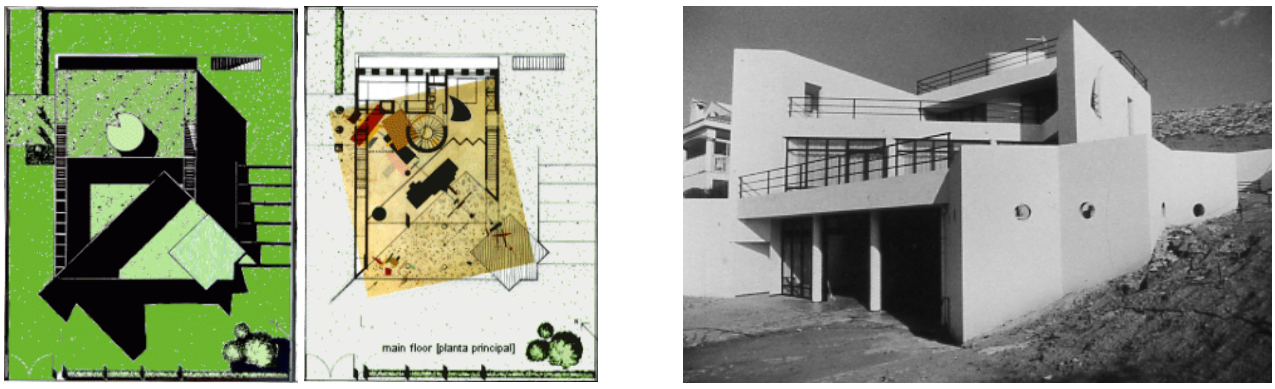


Figure 4. Alberto T. Estévez, *House M.*, Almerimar, 1993-95. Green roofs, main floor with greenhouse turned 45 degrees to face south, with water in the south, closed to north, with open side galleries, and lower floor half-buried and aerated.

The turn that is seen in the main floor is also due to face the south, which is at 45 degrees in relation to the plot. This allows to install the greenhouse-gallery well oriented. And at the same time let to protects the house more from the west sun, which in the case of the climate of this work is more critical, hot in summer. For this reason, narrow galleries are built on each side, open from the top. This permits a constant circulation of air, always without direct sun impact on the walls of the interior spaces. And with the possibility that also air circulation is available underneath, through a half-buried whole floor, which opens behind in an open ditch-gallery. Ahead, water-pool to south, to humidify the environment when hot winds blow. While still protected to the north, with a thicker wall, with earth inside as cheap thermal insulation and higher thermal inertia.

Here, finally, a dream came true: a whole house, really build, with green roofs, soil and grass. Having been again the first house of my generation to be built in such a way, and the first of all in that geographical area. Nowdays things have become easier, and there are many specialists on these solutions, so it should be almost always appropriate to build green roofs: cheap and good thermal insulation for both summer and winter, and ecological, natural, simply made with earth. With the vegetal leaves that (like the hairs on the head) they do not let the sun's rays hit the deck directly. And with a better possibility of self-management of rainwater. A roof that instead of overheating in summer it produces oxygen, it retains pollution and dust, and offers a pleasant surface to be used, and to live. The advantage in this case is also having the green roofs connected directly to the surrounding garden, as it is sloped down.

In short, basic principles, simple, not so difficult to apply in reality, and yet so poorly applied. Although it is true that, compared to 25 and 35 years ago that is when these houses were built, little by little more architects are aware of all this. But it is not known if it is in a greater proportion or not, because the number of architects has skyrocketed in the last decades.

These three examples participate of the evolution of ideas in architecture: architecture is a living entity, dynamic in conceptualizations and experimentations. And we can see how basic principles of passive solar architecture are applicable under different architectural approaches and considerations. Something that constitutes movements, and trends: post-modernism at the beginning of the 80s, (neo-)minimalism at the end of the 80s, and (neo-)expressionism at the beginning of the 90s. All of them were avant-garde movements at their time, although up to this day, there are so many architects who follow them. All those tendencies (as happens with contemporary art) are here to stay, indifferent to the fact that the avant-garde is always moving forward.

Green architecture

This is how, finally, at the turn of the century and the millennium, the main goal of the cutting-edge projects was the integration of real green elements in architecture. Starting with the green roofs, as the easiest application of green. This, taken on a larger scale, should already been a rule in every urban area. Ideal to combat the superheated thermal

islands of large cities, pollution, dust, electrical overload of air conditioning devices in winter and summer (Figure 5).

Figure 5. Alberto T. Estévez, *Green Barcelona Project*, Barcelona, 1995-98: hug interconnected park on the roofs of the buildings, when Barcelona is also the city with fewer parks.

As an example, the Green Barcelona Project (Barcelona, 1995-98) presents the creation of a huge interconnected urban park, landscaping the roofs of the entire city, which fortunately in Barcelona are usually flat terraces. Thus, the project is improving the thermal inertia of attics, with the consequent energy saving, both in winter heating and summer air conditioning. Reducing the increment of the temperature of the urban zones. In short, making the whole building more pleasant.

This project was presented to two successive mayors of the metropolis, and they seemed very interested about it, but at the end it only remained dozing on the table of the bureaucrats. Politicians have to legislate, to direct the planet towards its sustainability. When day by day the headlines seen in the media hurt. Between hundreds and hundreds, the following are samples, randomly taken, by day and by newspaper (in this case, *La Vanguardia*, Barcelona, 2011-today):

> The forests of our planet lose twice
> the area of Portugal each year
>
> **ENVIRONMENT**
> Each year 16 million hectares of trees disappear due to large industry.

CO2 is 40% higher than in the pre-industrial era,
absorbed by 30% of the oceans, causing acidification

ENVIRONMENT
The increase of the level of the oceans and the acidification of the water create a dangerous scenario for the ecosystems.

The concentration of greenhouse gases in the atmosphere has grown to unprecedented levels

ENVIRONMENT
The effects of climate change are close to the point of no return: part of the CO2 emitted will remain in the atmosphere for at least 1,000 years

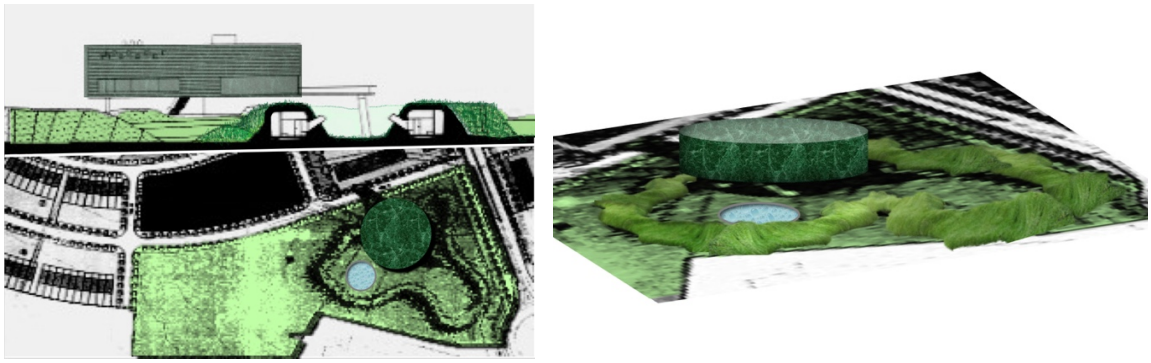


Figure 6. Alberto T. Estévez, *Hotel*, Salou, 1999: the rooms are inside of a continuous green grass “hill”, around a central open space with the pool and solarium.

Meanwhile, an underground and/or green architecture is an alternative to return to a planet entirely covered with living nature, which is the best self-regulating system of sustainability: life. Something that can be solved for whatever building type or functional use would be: a hotel (Figure 6), for example, or a cow farm (Figure 7 and 8). In both cases, a green roof solution has been achieved, and also the continuity of the vegetal mantle, alive, as semi-buried architecture, with all its benefits of thermal insulation and thermal inertia. In addition to recreate natural landscapes, is certainly more easily perceived as humanly pleasant environments, instead of stacks of “boxes” artificially constructed, which unfortunately is the aspect of our cities and neighbourhoods.

Figure 7. Alberto T. Estévez, *Cow Farm*, Paraguay, 2007. The mysterious “crop circles” serve as inspiration for the geometrical landscaping of the complex, which organizes the land with continuous green roofs, pergola of solar panels as an open-air warehouse, and a wind turbine at the other end of the project.

The earth itself is the resource. The integration of life in the architectural concept, is to obtain more advantageous results at all levels, physical and psychic. Plant life in this case, whose introduction is always automatically accompanied by greater integration of animal life. In short, semi-buried buildings and green roofs, are apparently a certain improvement for climate and landscape.

After all, this follows the same understanding applied to the architecture as contemporary painting and sculpture conquered: the fusion of the figure and the background. Contemporary art and architecture, for decades, are beyond the creation of differentiated objects from their environment. As Umberto Boccioni proclaiming “the absolute and complete abolition of the finite line and the closed statue. Let's open the figure wide and enclose the environment in it” (Cirlot, 1993). The finite physical limits of artistic and architectural objects have been erased in relation to what surrounds them. The closed object is faded, being both the figure and the background, as a single artistic and architectural object. It is a green continuous tapestry of nature, that from all the surroundings not only climbs above architectural spaces, but actually creates them. It is not only surrounding them. It is part of the architecture itself. Where can it really be seen where the building begins or, and where the landscape ends? Everything must already be one, everything must be designed at the same time, everything must work together.

Figure 8. Alberto T. Estévez, *Cow Farm*, Paraguay, 2007. General view and view of the guard house.

One step further would be with that integration of life seen or called for in other ways. As it would be the case of applying it also in vertical walls. But it is always about looking for a simple way, that really is a solution for our global planetary problem. Applicable equally for rich and poor, expensive or cheap. It is then necessary to always discard sophisticated

solutions, of high technology, only for the privileged, or with difficult maintenance. It can't be that the "alleged" planetary solutions are more costly for the economy and for the environment than doing nothing. Therefore, it should follow a way non-horizontal architectural elements can be covered with life without requirements of irrigation facilities, which add complexity. One could think, for example, about lichen, as a living being that would fulfill such requirements of simplicity and autonomy. Therefore, this is integrated into the design presented here (Figure 9), involving the color variations that are specific to lichen.

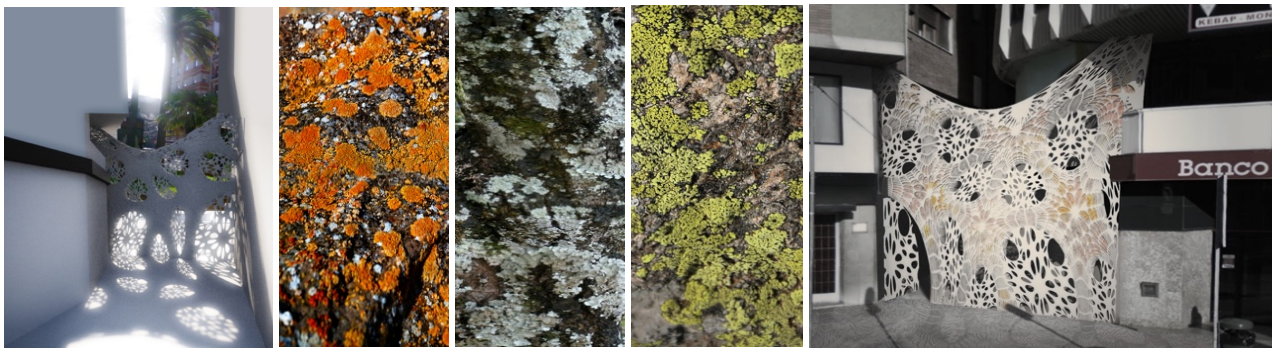


Figure 9. Alberto T. Estévez - GenArqOffice, *Urban door*, Castellón, 2011. In the center, views of lichens of different colors to be applied on the surface of this structure, prepared for it.

And entering the XXI Century as it is, the research about the use of digital tools for the design and manufacture of architecture and objects becomes almost something unavoidable. Therefore, as shown in these projects, they will now follow the processes and take the forms that such advanced tools allow, taking advantage of the benefits that are offering, for its conception, development, control and execution. Thus, the conjunction of the biological and the digital reaches the possibility of the birth of the biodigital architecture. And therefore we must adapt to the times. Making the effort to get out of our comfort of doing things "as always". Discovering the new freedom that corresponds to this era.

It is not difficult to understand. The introduction of steel and concrete in the architecture of the last century led to a radical change of construction systems, and thus forms. And vice versa, because we should not just think that the forms go behind existing systems and materials. Not always the technical possibilities allow certain creations. On the contrary it also works: the longing for certain ideas, materialized in designed forms, also propitiates and accelerates the arrival of the systems and materials that allow them. Thus, the introduction in the present century of the digital constructive systems and the computational design possibilities of controlling have also to expect a radical change in the architecture. An architecture that, in this way, fulfill the need to work only with green energy and technology, perfectly suited for sustaining resources for tomorrow.

Biodigital architecture

And once entered fully into the conformations that only digital technologies allow, it is clear that the will to integrate basic and simple principles of passive solar architecture must be maintained, together with other possible extracted inputs from vernacular architecture.

This, after all, is to take into account the "trial-error" evolution of hundreds of years of human habitat in that particular place, as nature does. Nature adapts to its surrounding reality, to the climate of each region. Living beings are different according to the climatic regions in which they live. With architecture and design should happen the same. But instead we see how today buildings are usually equal on all continents. So, starting from the corresponding climate, begins the study to optimize the possibilities of insolation that the environment allows, conditioned by an urban situation or not (Figure 10). Consequently the architectural forms are emerging, as guided by the sun, as would any living vegetable. Greenhouses are installed in the sunny areas, and non-sunny areas are well insulated, ventilation and air flows are strategically planned, geothermal use is also created, and green roofs are built.

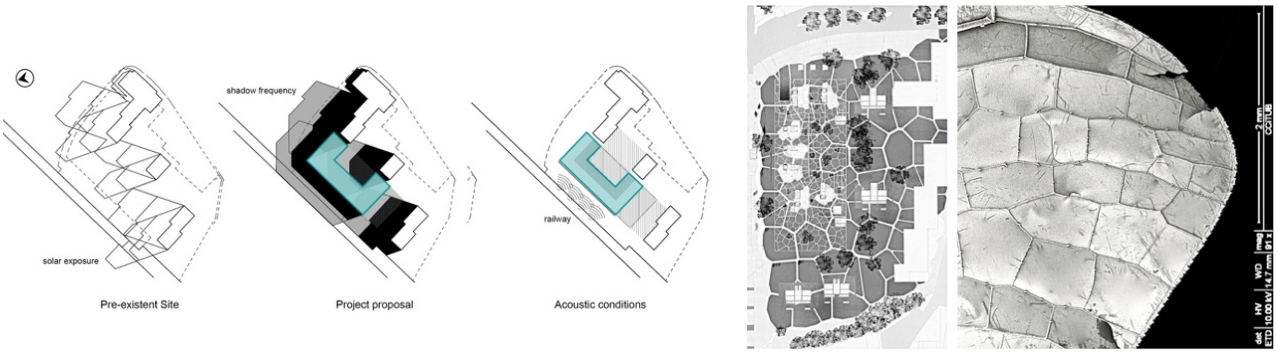


Figure 10. Alberto T. Estévez - GenArqOffice, *Passive solar housing*, Innsbruck, 2014. From left to right, previous studies of the building's location, its ground floor with 2D voronoi, and dragonfly wing on the right (91x) with 2D voronoi.

Meanwhile, in the line of bio-learning (now that everywhere the discussion is machine-learning), the research of primigenial and genesiac structures with an electron microscope becomes relevant for an architect: the moment when the amorphous masses of living and growing cells genetically start to order themselves. An order which resists (in the most efficient and economical way, as nature always does) gravitational external forces and the own weight of the respective living being. There, then, appear different systems and complex geometries that must find a response with the corresponding graphic strategy and digital conception (Estévez, 2019). In this case, an apartment building in Innsbruck (Figure 10, 11 and 12), it was decided to be developed based on a voronoi structure.

Figure 11. Alberto T. Estévez - GenArqOffice, *Passive solar housing*, Innsbruck, 2014. Above, general view of the building. Below, from left to right, natural structures of bees and vernacular structures of Innsbruck, urban agriculture in roofs, flowers in balconies as it is usual in this area, scheme of the passive solar performance of the building, urban beekeeping and interior voronoi space with hanging orchards.

Thus, in its maximally efficient growth, in the trinomial of a good relationship between quantity of material used, energy expended with it and satisfaction of the function (structural in this case), both plants and animals integrate in their structures this complex geometry of voronoi (Figure 12). Today, thanks to digital tools, it can be designed and controlled without too much difficulty. And for that reason it can be built in reality. With the plus of rational and emotional interest that has a complex, unitary, harmonic, organic and continuous structure like this one. Then, the floors of the project are designed in 2D with this geometry. Voronoi that is scaled in three levels, one within the other, according to the size in plan or the function to solve. Then, consequently, the same geometry is developed in space, in 3D, configuring its interior and exterior structure, and a large central open space to obtain a microclimate. There, on roofs, balconies and terraces, agriculture and urban beekeeping will be available. All this in pursuit of the energy & resources self-sufficiency.

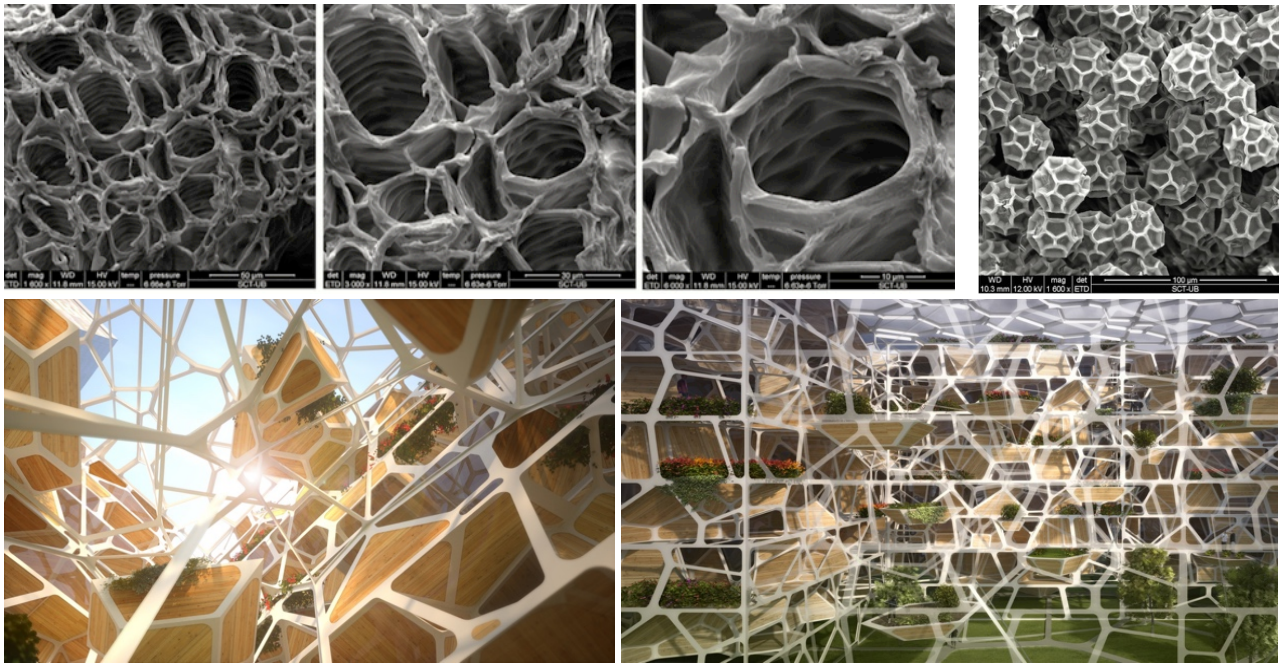


Figure 12. Alberto T. Estévez - GenArqOffice, *Passive solar housing*, Innsbruck, 2014. Above, cactus section (1600x, 3000x, 6000x) and pollen grains (1600x) with interior and exterior 3D voronoi respectively (photos: Alberto T. Estévez). Below, views of the voronoi 3D structures of the residential building, which support urban orchards, kitchen-gardens and hanging gardens.

Being in the line of an idea of self-sufficiency, of passive solar architecture, sometimes having additionally some proper learning from vernacular architecture, is aligned with an idea of low technology, which, after all, is closer to a more “natural” way, more sustainable, more economical, and even more “democratic”.

This would be the ideal to build, in a tendency to search for self-sufficiency, where each house, each building, each city, tend to self-sufficiency. And therefore to the self-management of their resources: to get models of buildings that only need the fire of the sun, the wind of the air, the water of the rain (or of the humidity), and the heat of the earth. These would be the genuine “sustaining resources for tomorrow”, the four classic elements (Vasel and Ting, 2019), the usual ones. With the same words before said, also applicable to resources: the most “natural”, sustainable, economical and democratic resources, renewable and ecological. And on the other hand, applying intelligence, to think housing modules that could act almost like companies that manage their resources (and wastes) that are produced by them.

Understanding that the economy that nature teaches us (bio-learning), after millions of years “testing” natural structures with survival objectives, with maximum efficiency and sustainability, looking for optimal ways of survival in the environment that corresponds to it, it turns out that we also arrive to a discovery of the organization of the cells in different levels of fractality. Of course there are examples of fractality that are seen with the naked eye, in different plants for example. But even the sustainability of the planet must also be achieved “fractally”, with the sustainability of each country, each region, each city, each house.

Something definitive is to see that there is also such fractality at the microscopic level. For this reason, we continue the work with the electron microscope, discovering how at a microscopic level the structures are replicated in a fractal patterns, up to three successive levels. For example, a bamboo is made up of small “little bamboos”, which, so to speak, are made up of microscopic “little bamboos”. Or a sea sponge is made up of small “little sea sponges”, which are made up of microscopic “little sea sponges” (Figure 13). The structures created in this way are what we should always consider in our works, and being not massive, as has always been. This acquire a greater resistance with less material and with less energy spent in its construction. And again, now, with digital technology design and manufacturing, using large-scale 3D printers that are already starting to exist, it can now become a reality.

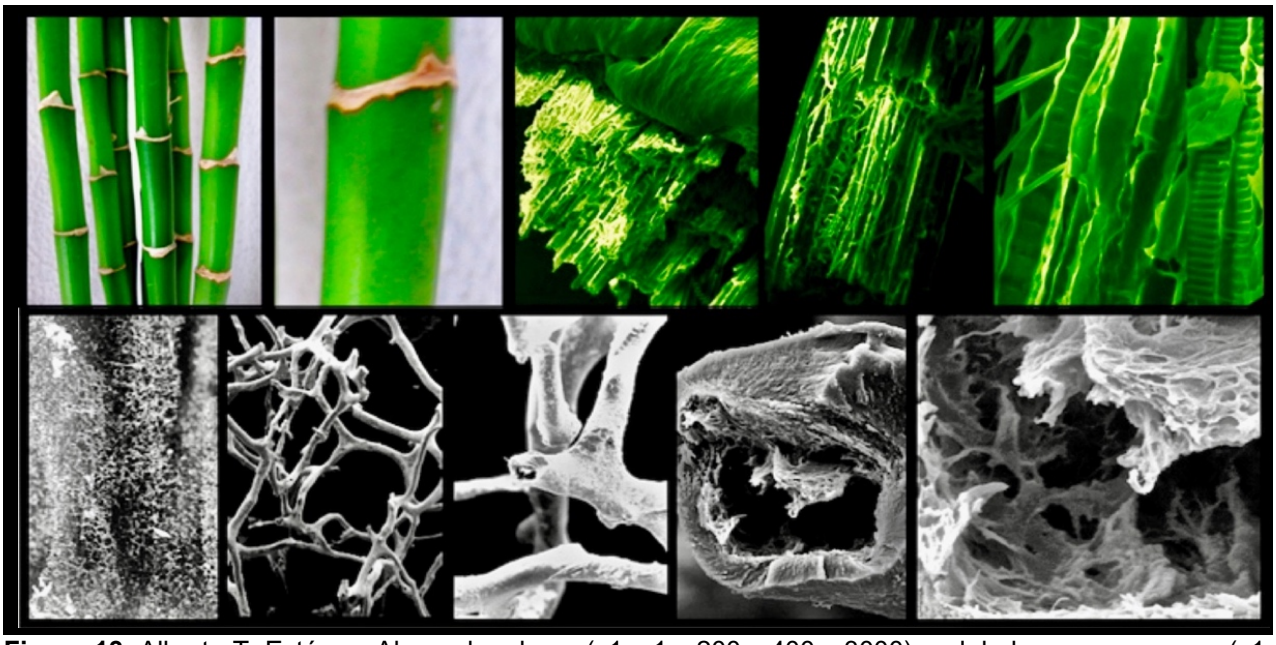


Figure 13. Alberto T. Estévez. Above, bamboos (x1, x1, x200, x400, x3000) and, below, sea sponges (x1, x100, x400, x3000, x7000), 2008-09: photos taken with scanning electron microscope, that allows to appreciate the structural fractality.

Then, the fractality opens the possibility of becoming itself a design strategy, and is applied in the following project presented here (Figure 14, 15 and 16).

Figure 14. Alberto T. Estévez - GenArqOffice, *Antenna Tower*, Santiago de Chile, 2014. Instead of appearing on the top the typical telecommunications tower, here is offered as an alternative a crown, a bright (Bruno Taut’s) “Stadtkrone”.

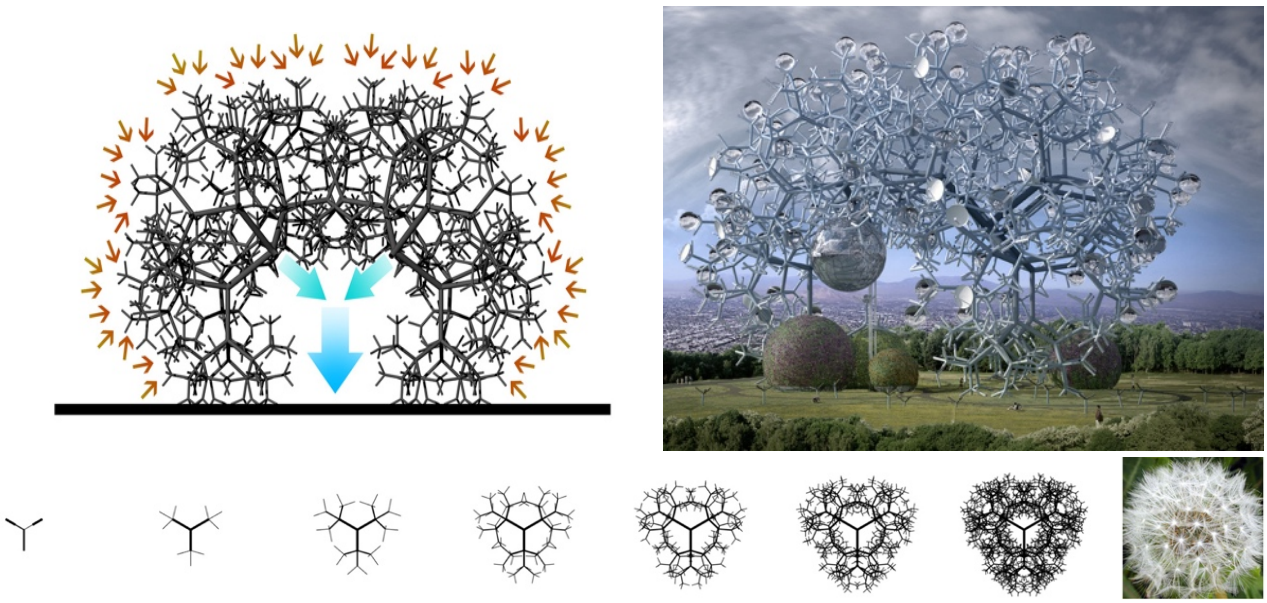


Figure 15. Alberto T. Estévez - GenArqOffice, *Antenna Tower*, Santiago de Chile, 2014. Developed digitally and fractally, which at the same time is a “purifying air machine”. Although its uniqueness is only a symbolic fact, because the acute contamination suffered by Santiago de Chile, where the project is located (right, a meadow of dandelions around).

By means of a digital design development, the whole structure emerges, by such fractal development, that captures the values of complexity, unity, harmony, organicity and continuity: the values of beauty. The structure will support everything necessary for its function as a telecommunications antenna and belvedere overlooking the city. And in parallel is offering the possibility of energy self-sufficiency, by incorporating spherical solar collectors (Beta Torics) in its last level of fractal development. There are also planned parabolic and linear antennas. As well as spherical luminaries that at night create (on the top of the mountain where this building is located) the image of “the crown of the city”, following the idea of the “Stadtkrone” of Bruno Taut (Taut, 1919). That same effect is given during the day with the brightness of the aforementioned spheres (Figure 16). A crown, instead of one of those telecommunications towers that populate the mountains and skylines of cities.

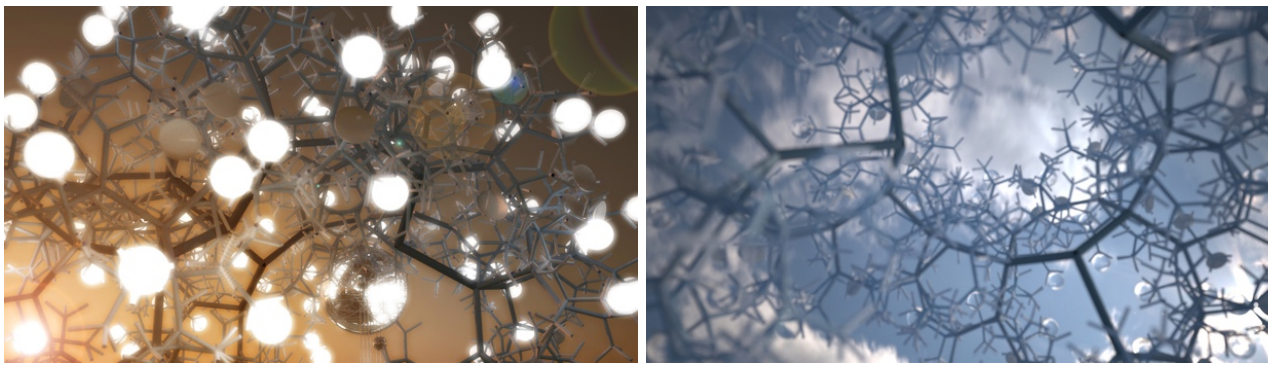


Figure 16. Alberto T. Estévez - GenArqOffice, *Antenna Tower*, Santiago de Chile, 2014. At night, spherical luminaries surround the building's surface at its last fractal level. By day, spherical solar collectors of the same size and placed on the same level will also offer their brightness as a “crown” of the landscape.

On the other hand, all that structure of hollow tubes, with fans inside, will inhale the surrounding contaminated air through its interior, so that filtrated air comes out purified to the central zone, where is located the area for the entertainment of the people who go up to the top of the mount. In fact, thanks to being a “decontaminating machine”, the whole project is symbolically presented as “environment healing”. For this reason it is also surrounded by a meadow of dandelions, a well-known medicinal plant, a small-scale poetic participant of the building fractality.

In conclusion, all buildings should be designed today as self-sufficient. There is no longer any technical excuse against this. Everyone should start from a fine design of sustainability. Learning from nature (bio-learning), in biological symbiosis with it, and the use of digital tools for a proper adaptation to our time, from the conceptualization of its design and architecture: biodigital architecture.

Genetics

Within biology, genetics also offers us paths to explore, which applied to architecture can offer unimaginable sustainability benefits. Benefits as powerful as are the almost infinite potentials intuited in genetics. The precarious state of our world even obliges us having the responsibility to search into this field, without delay due to laziness, myopia or a very closed mindset. For the moment genetics is only applied to health and nutrition. But humans have one more basic need, its habitat. For this reason we created 2000 the Genetic Architecture Research Group and the (official) University Master in Biodigital Architecture, as well as a Doctorate Program. For the first time in history geneticists and architects begun to collaborate and to set genetic research objectives applied to architecture: building, light and heat would be the general goals to be followed to satisfy the basic human need for habitat. Thus, the first real result occurred on our bioluminescence research (Figure 17).

Figure 17. Alberto T. Estévez, *Genetic Barcelona Project*, 2003-2006. Left, the magic light of the GFP lemon trees. Center, image of a possible world. Right, comparison between a lemon tree leaf with GFP and another without GFP from the same tree type: above photo taken with conventional reflex camera, and below photo taken with special UV camera.

So, in 2005, 7 lemon trees with the GFP gene (Green Fluorescent Protein) began to illuminate the planet (years later other people in different parts of the globe also took this idea that we started of bioluminescence applied to the domestic and urban space). In addition, in 2008, the first house in history was illuminated with “living light”, bio-lamps of different design were placed throughout the house, that made the installation of electric light unnecessary (Figure 18). Nevertheless, we continue with other possible solutions, like introducing the genes responsible for bioluminescence in various types of ornamental plants, or those genes from other species, whose results could be more effective and durable for the required use.

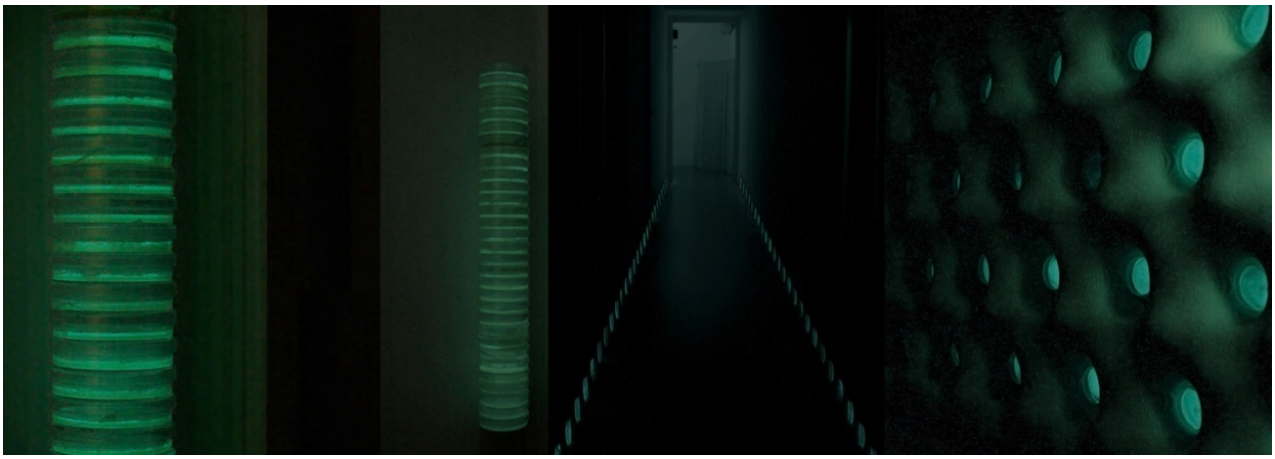


Figure 18. Alberto T. Estévez, *Bio-lamps*, 2007-2008: the first systematically fully illuminated apartment with living light (human eye view: photos by the author, taken with a conventional reflex camera).

As has been said before, and with genetics it can also be said that “the longing for certain ideas, materialized in designed forms, also propitiates and accelerates the arrival of the systems and materials that allow those ideas to come true”. Thus, the introduction in the present century of the biological constructive systems and their possibility of control by means of genetic design, suggest a radical change in the architecture. An architecture that in this way can fulfil the need to work only with green energy and technology, perfectly suited to sustaining resources for tomorrow.

Having today that possibility in the scientific and technological horizon, it is clear that sooner or later the necessary genetic research will be developed enough, in parallel with architectural and constructive objectives, so that a house can be “planted” and will grow alone, in the most “natural” way, more sustainable, more economical, and even more “democratic” (as it has been stated before for biodigital architecture paradigm): having greater possibilities of freely reproduction. In addition, the possibility of genetic creation of new species can stop the dramatic disappearance of the ones that we have propitiated.

Specifically, working in genetic research to obtain living elements, building materials and useful living spaces for architecture. One more example, illustrated with figures, is the *Sporopollenin Houses* (Figure 19). Architectural objectives with the application of genetics. Research is being carried out into the genetic control of growth, to develop living cells that are converted into building materials and habitable space. “Directed” by means of their specific genetic design, thereby are producing architecture that is 100% ecological and

sustainable, with maximum energy-saving throughout the construction process and with no need for manual labour, as its growth is naturally emerging.

Figure 19. Alberto T. Estévez, *different views of Sporopollenin Houses*, 2009-10: genetic research on growth control which makes live cells grow for architectural material and habitable spaces

From the same research on cellular structures by means of scanning electron microscope, this project of the *Sporopollenin Houses* (Estévez, 2009) emerged as well as single-family houses that grow alone formed of sporopollenin, the material of pollen grains, the material most durable, that does not rot, or rust, or fall apart, even if thousands of years pass. Here is when durability is a requirement of architecture.

3. Conclusions: Biodigital future

So, at this point, looking at our results and the results of all the other colleagues, that are working being aware of the 4th Industrial Revolution we are crossing, a possible conclusion is to think about what is the authentic meaning of all these efforts. A critical moment to ask if we are really working for something that is absolutely useful for mankind.

We know that the answer is in nature and nature is the answer. The more science advances, the more we know of what we call nature and the more we understand that nature is the answer. But, “if nature is the answer, what was the question?” (Wagensberg 2008). We are exploring and interrogating “the question”, through interdisciplinary endeavours involving fields such as biology, genetics, computation, art, architecture, design, civil engineering. We are exploring the frontiers of knowledge… One main interdisciplinary cross-point in this exploration is the point where genetics meets biology and the digital, applied to architecture and design in our case (and similar to art or civil engineering, etc.). This is the cross-point at which we find ourselves, and also this writing is about. This is the scene, in which to create architecture and design, we join forces with geneticists and philosophers focused on architectural objectives, together researching the fusion of biological and digital techniques.

It all started with a word. And after, let’s say, an infinite succession of words, which started emerging as calls from the darkness of nowhere, this word, “biodigital”, emerges (Estévez, 2018). Truthfully, more and more, no doubt about the way forward, today, we can see in our own results how biodigital is the future: the houses, the cities, the landscapes, will be 50% biological and 50% digital, and the fusion of them both. It is certainly the great potential of new biological and digital techniques that can lead to the sustainable and social

efficiency the planet needs, so the human being can have a future.

Biodigital has in itself its own set of words. At the same time each one of them is related (at least, neurologically) to many others. In this manner, around the term biodigital we can include others such as biology, life, computing, nature, cybernetics, genetics, mathematics, DNA, algorithms, emergence, morphogenesis, artificial intelligence, surrealism, digital organicism, genetic architecture, robotics, bio-manufacturing, digital production, bio-learning, programming, scripting, parametric, among others. This cloud of words, in constant change depending on how one aspect or another is intensified, like if it were a pointillist mosaic, ends up illustrating what the term biodigital really is and what it can be. Biology and digital, if we understand working with DNA as if it were a natural software, and with software as if it were an artificial DNA: those are the new materials of the future, as concrete and steel were for modernism.

How can we visualize future cities and future houses? The city of the future will be 100% biodigital, improved by biological & digital technology, or maybe there will be no future. “Learning from trees” (Bassegoda, 1989): a city that is more like a forest than like a landscape of shipping containers on the port. After all, where do we prefer to live, surrounded by boxes or by trees? Our cities are destroying nature wherever they grow. We need to assure that every human footprint becomes a creator of life. We need to change our reality with life.

This has a poetic point of view: we will solve our planetary problems with life; but it has also the exactly description of the real and scientific path to follow, through biodigital and genetics, life for saving life. A world view that leads naturally to a philosophy of reverence for life (Schrödinger, 1964). Marveled at the mystery of life, the miracle of the self-formation of the delicate, sophisticated and perfect that each living being is, the fascination with the problem of the phenomenon called life: Sherrington began studying the primal cell and curiously this took him on his journey up to the concept of altruism. Not in vain did he impress the scientists and thinkers who followed him: Schrödinger, Atson, Crick and Prigogine, on the one hand, and Loeb, Popper on the other (Sherrington, 1940).

We live with the contradictions that this age has: where does it is really taking us all this research around AI, digital thinking, digital design, digital manufacturing, big data, BIM, CIM, GIS, CAAD, virtual and augmented reality… Where we are going with these series of disruptive concepts and innovations, like the smart-phone, social networks, online gaming, internet of things, smart materials, interactive environments, personal fabrication, 3D printing, drones, self-driving cars or the smart cities… Which is really this radically new world…

Of course, like in the past, if the world changes, architecture and design cannot remain indifferent. Architects and designers must understand and adapt to the new circumstances. But this declaration is not absolutely true, because, the evolution of the architecture and design, and the novel understandings and technological possibilities that come from this is also a motor of changes. Furthermore, are the digital technologies oriented to what this

world really needs right now? When, effectively, digital technologies are at the core of the emerging paradigm. Yes, we have this advantage. So, we have also this ethical responsibility. We must orient all this to the increasingly exigent demands on our planet, and not to what separates, more and more, in two worlds.

In the film *Elysium* (Blomkamp, 2013), and it is not the only one that in recent times illustrates it, appears as in the future humanity is radically divided in two: the film takes place on both a ravaged Earth, and a luxurious space habitat called Elysium. Some people have access to extraordinary advancements in areas like mobile communication, artificial intelligence, big data, cloud computing, blockchain, nanotechnology, biotechnology, facial recognition, robotics or additive manufacturing, and others not (Figure 20).

Figure 20. Symbolic photomontage of an image of the film Elysium with an image of the Rohingya refugee camp in Kutupalong (Ukhia, Cox's Bazar, Bangladesh). Dream and reality: reality and future?

But that is not the future, it is already our present, when the human population is already divided into two increasingly separated halves. When one half can live as it lives because the other half can't. That is why all of us have to focus on our research exclusively to achieve this planetary unity of life. And to do this we have also to put ourselves all in line with an intelligence that integrates the results of cognitive sciences, neurology, artificial intelligence, philosophy; able to direct the behaviour using the information that it captures and elaborates itself; a creative intelligence that discovers new possibilities in reality, selects its goals and executes them, and that therefore is aimed at action (Marina, 2000). A knowledge of our intelligence that can amplify our efforts in our struggle for the sustainability of the world (Kaufmann, Fustier and Drevet, 1970).

Integral ecology

In conclusion, since everything is interrelated, and today's problems call for a vision capable of taking into account every aspect of the global crisis, we need to urgently

consider the idea of integral ecology, which simultaneously considers as whole indivisible entity its environmental, economic and social dimensions.

Ecology studies the relationship between living organisms and the environment in which they develop. This necessarily entails reflection and debate about the conditions required for the life and survival of society, and the honesty needed to question certain models of development, production and consumption.

Just as the different (physical, chemical and biological) aspects of the planet are interrelated, so living species are part of a network too, which we need to explore and understand, and genetics is the most advanced tool for it. Even a good part of our genetic code is shared by many living beings. It follows that the fragmentation of knowledge and the isolation of bits of information can actually become a form of ignorance, unless they are integrated into a broader vision of reality.

When we speak of the “environment”, what we really mean is a relationship existing between nature and the society which lives in it. Nature cannot be regarded as something separate from ourselves or as a mere setting in which we live. We are part of nature, in constant interaction with nature. Recognizing the reasons why a given area is polluted requires a study of the society, its economy, its behaviour patterns. Given the scale of change, it is no longer possible to find a specific, discrete answer for each part of the problem. It is essential to seek comprehensive solutions which consider the interactions within natural systems themselves and with social systems. We are faced with one complex crisis which is both environmental and social. Strategies for a solution demand an integrated approach for protecting nature and at the same time combating poverty.

We, as architects and designers, have the personal responsibility to achieve a vision of architecture and design that helps to develop sustainable and safe societies. And this goal, in our present reality, is not only relevant but also urgent. Hence, we have the personal responsibility to create and engage ideas of environmentally responsible architecture, that means at the same time socially responsible architecture; and the biodigital integration, biology and digital, is the most advanced tool for architects and designers. Biodigital, as a tool, but, before that, as an approach, as an understanding of architecture and design. While we are at this work, little by little, almost as if by magic, the understanding about what our times demand will grow. In an integral two-sided reality, on one side, seeing that architecture and design can improve the world by improving the lives of the least fortunate; on the other side, learning from nature’s laws (bio-learning) and finding computation as the most powerful tool to really solve problems.

Yes, the path to follow is clear, in a world where everything is already connected, with an intimate relationship between the poor and the fragility of the planet. When it is necessary to develop critical thinking towards the new paradigm and the forms of power resulting from technology. When it is necessary to search for new ways of understanding economy and progress, the value of each person, and the human sense of ecology. When there is an urgent need of sincere and honest debates, there exists a great responsibility in terms of

politics both at an international and local scale. Ultimately, when it is convenient to have a new lifestyle. This is all what the *Zeitgeist* calls us to do, when in sight of all are the signs of our times.

At least this world is our common home that sustains us, and that we must guarantee its own sustainability, that it is ours too. Everything that discriminates the integral ecology will not prevent the ruin of our entire world. There will only be a real future if there is one for all. Only working for an integral ecology, with, of course, proportional generosity and sacrifices on the part of each and every one, which means fighting against the contradictions of our era, we will find together a real salvation of our beautiful Blue Planet.

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