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Sustainable Nature-Inspired Architecture

Alberto T. Estévez

Abstract

It is of the utmost importance, crucial, and urgent that we achieve planetary **sustainability** before it is too late. This is already commonly agreed. Therefore, each one, from their own field of action and life, must strive to achieve it. All of our individual acts make a difference, whether to facilitate sustainability or hinder it. In today's world, with its growing population, and with the same limited number of resources as from its origins, only the sum of all the members of society can somehow solve such an immense problem, that has now grown to be our highest obstacle that will sweep away and block out our near future. Thus, and particularly for us as architects, it is our competence and responsibility to resolve the sustainability in this plot that we have been entrusted: the architecture. Thus, offering a search field for a solution to everyone, how do we propose a sustainable architectural design? Well, let's look around us, at **Nature,** an infinite quarry of lessons in sustainability and efficacy, an eternal mirror of **inspiration for architecture.** And not just inspiration, but above all, learning, which is what we really need. However, if each one did not apply the same solution method in their field and their lifestyle, it would be completely useless to propose sustainable architectural solutions. The current situation is unprecedented as the whole of humanity has never had to face something of this magnitude. It is as if the last intelligence test is being presented to humanity: are you intelligent enough to solve this problem? Well, if not, you no longer deserve to live on this Earth, which is actually a gift with the potential to be paradise, as soon as we know how to do it well. This is in summary the ideas to which the pages that follow refer. And to help understand these questions, the text will follow a path through topics such as Gaudí's ideas and works, the efficiency, the bio-learning, the self-sufficiency of nature, and other specific lessons that can be extracted from nature in order to be applied to architecture and to human life itself. (For a better and more clear conceptual foundation, from the beginning it should be stated that what follows is the articulation of a view of sustainability which contains marked normative and aesthetic elements, interwoven with conceptual interpretations of Nature. The reader must be warned about what to expect: not a sober compilation of cases and examples but a passionate plea in favour of biolearning, Gaudi’s work and biodigital architecture. It is not a compilation of specific scientific recommendations but a proposal of a specific approach to sustainable architecture, illustrated with relevant and elegant examples).

1. Sustainability?

(First, acknowledge that there is not an established and operational definition of sustainability. It must be emphasized that defining sustainability is a difficult task that necessarily implies a normative aspect, which contains both ethical and aesthetic choices. In this regard, Norton's (1999, 2005) work can be taken as a reference.)

As we enter the third decade of the twenty-first century, everyone has become aware of the necessity of living in a sustainable world. Throughout the last half-century, the growing global problems and events that have occurred on our planet has made every one of us realise this fact without exception. No corner on Earth is unaffected. Sustainability has become a main and global problem for all the inhabitants of this world (Ching, 2014). However, this serious and urgent challenge has a solution that seems invisible yet so obvious: the solution is Nature (Estévez, 2020 A). Of course, knowing that this same Nature has produced both ecosystems in equilibrium and episodes of plagues and dramatic invasions of foreign species that break this equilibrium. But also, this is "Nature", from where to learn. Plagues or invasions exist, but it can be considered that it is inscribed in the same natural process of the "bio-plasticity of nature" (Estévez, 2010).

Yes, right there in Nature is the answer to solving such a great question. So, let's ask ourselves first about what surrounds us: Nature. And let's see later that this is where we can learn something to solve planetary sustainability. Hence, from Nature. The wisest and oldest teacher. The one with the most experience. And thus, the most sustainable. Therefore, if we want a sustainable world, what better way than to go to Nature to tell us how to achieve it? Are we so blind? It is the fault of humanity that had begun to dissociate itself from the sustainability that it had been living for millennia. Of course, it has mainly been due to the vertiginous population increase in just a century. But it is also something driven by the lack of social equity, by the lack of balance between economy and ecology, by the lack of solidarity and generosity. And there is no doubt that all these go hand in hand. And cannot be solved separately. If we want to achieve this planetary sustainability, we have to solve every aspect at once, with an integrated solution, economy, social equity, education, and responsibility. Hence, when the so-called "rich countries" cry out so that the "poor countries" do not destroy their environment, the equatorial forests, for example, the "poor countries" reply that it is easy to claim from others that care that they have not had in their own countries to get equally rich. We tear our clothes because in the so-called "third world", they are destroying primary forests. But perhaps that is the only way they have for their precarious survival. In contrast, we are sitting in soft armchairs with full bellies.

For some years now, we have known that a true ecology is an integral ecology: you cannot really maintain the environment if you do not simultaneously solve poverty. And we know that everything is interconnected. Environmental problems affect everyone, although in that specific neighbourhood, in that specific city, in that specific country, they have very good ecological policies. Still, the effects of the gigantic forest fires we are experiencing will also come to them; the ozone hole will open over their heads. They will get skin cancer before anyone else. They will lose, like everyone else, the incalculable wealth that planetary biodiversity provides. But now, with the COVID-19 pandemic, another issue has joined the game, health. It's another factor that clearly is also understood to be global. Consequently, now the equation to be solved as a whole is one of the suddenly inseparable variables of health, ecology, economy, social equity, and education.

2. Nature!

And now, let's look around. We do not need to go far. It is right there, before our eyes, in our own cells, bones, and physiological systems. It is present in all plants and animals, large and small, that surround us, even if we do not see it (Estévez, 2020 B). This is where to find the model, the top model for sustainability: Nature, what else? (Allow us to talk about “Nature” as the human convention provided by its definition, as an abstract entity, as a human figuration of the set of elements that form our environment).

Nature’s “laboratory” has been improving living beings for millions of years, with the main objective of just “living”. It has developed from the simplest to the most complex. Therefore, it would be foolish not to go to the source of that vast experience and wisdom to adjust our main objective today, which is “living” and the survival of our planet. Our goals, those of Nature and those of humanity, converge. Nature, however, has a huge advantage over us as far as its “science” and applications are concerned. Therefore, we have to focus on learning from it through biolearning (Estévez, 2014).

Each field of human knowledge must find its own biolearning path. In our case, we will try to undertake biolearning and apply it to the field of architecture. This is where a great champion, a great pioneer, Antoni Gaudí, enters the scene. He was the first to transcend the immediate inspiration that Nature offers beyond the purely formal application to architecture, which is what architects sometimes do.

3. Nature, and Gaudí

Most people know his unique works, which attract millions of tourists to Barcelona every year. Thanks to the Internet, it is easy to find out about aspects of his biography, so we are not

covering this in the present chapter (or check Estévez, 2002 A, 2010). However, only a few know what is behind the forms of his architecture: real and deep biolearning of Nature. When someone asked Gaudí where he had learned his architecture, he pointed to a tree near his workshop, saying: This is my teacher! (Bergós, 1974). Indeed, when he was a child, because of his delicate health, he spent long periods in the countryside, surrounded by mountains and stones, trees and flowers, birds and insects, transforming his weakness into his strength. “Little Gaudí collected the purest and most pleasing images of Nature, that Nature he always called ‘my teacher’, and he remembered them with pleasure even in his old age” (Bergós, 1974). At the same time, being “blessed with a remarkable gift of observation, he developed a personal architecture based on applying what he learnt from Nature to his work” (Bonet, 2000). That is also the lesson of Gaudí for each one of us. To learn from Nature from the point of view (“with glasses on”) of our work, which, in the case of Gaudí, was architecture.

It is easy to marvel at the forms of Nature seen from the outside, but that is not enough. As soon as we pay closer attention, its processes and functionalities become fascinating. Sunflowers, for instance, rotate their heads during the day to track the sun’s movement across the sky. Gaudí paid tribute to sunflowers at the beginning of his professional career, integrating them into his first two works in ceramic designs. It is as if he felt from the very beginning not only that he was going to stick to a formal inspiration of Nature but that he would be the first architect in history to transcend to a deeper level of learning from Nature, of biolearning. Undoubtedly, his special sensitivity for Nature provided him with it. When Gaudí was working on his first house, Casa Vicens, he felt sorry for the little yellow flowers on the construction site that were doomed to disappear. So, he decided to preserve them forever in the decorative ceramic tiles, which covered the whole building. The palmetto leaves in the iron fence were included for the same reason. Antoni Gaudí was a magnificent example of someone who respected the environment long before anybody spoke about ecology (Estévez, 2002 A).

In that sense, the fact of going beyond the mere exterior form of Nature, until —as he said— he was discovering the secret laws of the universe. “Gaudí’s work is an advance from traditional architecture to new architectural structures based on the mechanics and experiments such as those of the catenaries, but, at the same time (...) it truly penetrates in the world of natural morphology, which does not copy but transfigures and integrates into an architectural or structural-ornamental factor” (Cirlot, 2001). Gaudí did not adopt the different arches defining each architectural style (Roman, Visigoth, Romanesque, Gothic, Renaissance, Mannerist, Baroque, Mudejar-Mozarabic, Hindu, etc.), as his contemporaries did in the architecture of the late nineteenth and early twentieth centuries. He would have his own, the catenary arch. That is, his own constructive system, which cannot be identified with any previous historical style. This functioning of the catenary arch can be understood by looking at a free-hanging chain (catenary). He created string models, hanging from the ceiling and tying bags of sand to them

to calculate the weight proportional to that of the real construction. When turning the photo of the model upside down, the structure of the designed building emerged in the most structurally efficient way (Figure 1).

Figure 1. Left: catenary (free-hanging chain) and parabolic-catenary arches (Gaudí, Teresian College, Barcelona, 1887-1888). Right: an image of the string model, hanging from the ceiling with bags of sand to calculate the weight proportional to that of the real construction, following Gaudí's peculiar architectural design methodology. When turning the photo of the model upside down, the structure of the designed building emerged in the most structurally efficient way. (Photos: Alberto T. Estévez).

Only engineers using mathematics and physical science in the construction of bridges, railway stations, and iron markets, and the Catalan masons applying centuries-old traditions and popular experience have approached the catenary arch, as it is the most consistent with the natural function of structures. Gaudí went further than those engineering infrastructures and popular anonymous constructions and, by using his artistic rationality, he was the first to take architecture to a whole new level. He was scientifically aware of its structural efficiency. This fact confirms that Nature was his definitive source of inspiration and learning. He found inspiration not only in its "flesh", formal and external but also in its "bones", in its structures and functions.

Gaudi's works are never dressed arbitrarily, but they respond to the same criteria of tectonic functionality as those of Nature. He managed to provide maximum structural efficiency to the traditional compression architecture by following those criteria, closing that chapter to start modern traction architecture. Thus, Gaudí offered the alternative, which is the unbeatable catenary arch in architecture compared to the poor static performance of arches of historical styles (semi-circular, pointed, horseshoe, etc.), which presented structural deficiencies in roofs, vaults, walls and vertical pillars too. The catenary arch solves everything better, converted into a surface via successive repetition (which forms the characteristic diaphragm arches in Gaudinian spaces), repeated through space along a curve that is perpendicular to its own and

of similar geometry. These catenary arches, and their similarity to the parabola, and their corresponding vaults of ruled geometry and resulting inclined pillars follow the natural line of thrust of the loading: they achieve the ideal structural work in the buildings with the minimum necessary material and with the minimum energy cost, as Nature does.

4. Nature, efficiency

Gaudí innovated the history of architecture by taking compression construction to its highest point. Furthermore, we should recognise that these resulting sinuous curves are those of Nature. The most appropriate structural geometries have been selected through natural evolution so that plants and bones are —apart from cost-effective— maximally strong. Trunks, branches, stems, and all the apparatus of living beings are made from this geometry, of conoids, ellipsoids, hyperboloids, paraboloids, and helical growth patterns (Estévez, 2002 B).

As we can see in Nature, paraboloids, hyperboloids, and helical growth patterns govern the formation of trees. And Gaudí, learning from Nature, designed with paraboloids, hyperboloids, ellipsoids, and helicoids the whole interior of the Sagrada Familia Church, for example, where the pillars of the Basilica spread out like tree branches, following the natural lines of thrust from the structure above (Figure 2).

Figure 2. "This tree is my teacher"... Left, paraboloids and hyperboloids of a tree, paraboloids and hyperboloids of the Sagrada Familia Basilica columns. Right, the pillars spread out like tree branches, following the natural lines of thrust from the Sagrada Familia structure above, done by paraboloids, hyperboloids, ellipsoids and helicoids, inside the Sagrada Familia. (Photos: Alberto T. Estévez).

Nature never stops teaching us, patiently, from the origin of life on this planet, as if it was waiting for us to be sufficiently prepared and mature. We only need open and curious minds with sensitive and attentive spirits to learn its lessons. For example, plant leaves achieve the most efficient balance when using the minimum material (less energy needed in the internal processes of growth), the minimum thickness, and covering the largest possible area, to absorb the greatest amount of light and to allow water to flow, to avoid overloads in case of rain. To do

this, their surface curls, giving greater rigidity to the whole, more than if the surface is flat, which is the case of conventional human buildings, furniture, and numerous objects. Gaudí knew this and designed, for example, the roof of the Sagrada Familia Schools, following the same concept of efficiency using twisted ruled surfaces: conoids in this case (Figure 3).

Figure 3. Left: plant leaves achieve the most efficient balance when using the minimum material, the minimum thickness, and covering the largest possible area to absorb the greatest amount of light and allowing water to flow, thus avoiding overloads in cases of rain. To do this, their surface curls, giving greater rigidity to the whole. Right: Gaudí, Sagrada Familia Schools, 1908-1909, design of the roof, following the same concept of efficiency using twisted ruled surfaces (conoids). (Photos: Alberto T. Estévez).

Similarly, bones in Nature achieve the most efficient balance when using the minimum material (less energy needed in the internal processes of growth) and their resistance, following hyperbolic forms. They are more resistant than the shape of a cylinder with the same amount of material as those found in conventional architectural columns. Again, Gaudí knew this, and in Casa Batlló or the Sagrada Familia Church, he designed the vertical elements with hyperboloids, following the same efficiency principle (Figure 4).

Figure 4. Hyperboloids in an image of bones (left), balustrade (Gaudí, Casa Batlló, Barcelona, 1904-1906), and pillars of a gallery (Gaudí, Sagrada Familia Church, Barcelona, 1882-present). (Photos: Alberto T. Estévez).

Many details can be learned from Nature, as long as we keep our eyes wide open. Like the tiles of Gaudi's Casa Batlló that follow the principle of fish scales; besides, they are provided with hydro dynamicity because they need to let the water flow in the best possible way.

Gaudí only needed Nature and its guiding principles to develop all his work as an architect. He also managed to synthesise a basic point of Nature, which ended up configuring a value, a value of intelligence, an indicator of quality: continuity. And he said: "the continuous forms are the perfect ones. (...) Polyhedral forms and those mistakenly called geometric forms do not flourish in Nature. Even those that man makes flat (doors, tables, boards) become warped over time" (Puig-Boada, 2004). The continuity of forms is an essential characteristic in Nature, where each part and each function is solved with continuity of the whole. This is undoubtedly because continuity provides better structural and growth conditions. Gaudi's architecture offers even greater advantages by designing his works with the same continuity as Nature. This can be seen in the exterior of Casa Milà or the interior of Casa Batlló. Exterior continuity helps the flow of air and water. Interior continuity improves thermal and acoustic characteristics. This is form and function in perfect convergence and harmony, learned from Nature.

5. Nature, our origin

Gaudí had no doubts because even his reading of history was made under the principle of "return to the origin". For example, he said, "we do not have to stick with what our ancestors did. They came to Nature to learn" (Matamala, 1999). Nowadays, in the greatest and most serious challenge that humanity faces, paradoxically, to go forward, we must look "backwards" towards the origin of everything. We must learn from Nature and from all its potential to teach us the most perfect understanding of sustainability that we can apply. That is the origin and the most effective source we can turn to for solving the sustainability of the entire planet. In fact, Nature had already ensured such sustainability for millions of years before the human being disrupted it in just a few decades. Nature solves the planetary sustainability with life. Human beings must follow the same path. Something shouted out loud for many years: from the origin to today's evolution in architecture, taking us to concepts such as Genetic Architecture (Estévez 2003), Biodigital Architecture (Estévez, 2015), and Metabolic Architecture (Dollens, 2017).

Sometimes we are able to introduce solutions from Nature, with living elements, in a very simple and traditional way: living plant elements, which are sustainable, renewable, recyclable, applied to architecture; façades, which block the direct incidence of the sun with its shadow on the walls, prevent heating in summer, emit oxygen and absorb CO_2 and dust. Today, any gesture in favour of introducing life into architecture should not only be well received but should be necessary.

However, virtually all academics (with few exceptions) of current architecture consider including life in architectural projects suspicious, as they are still governed by the principles of an obsolete architecture, devised in the 1920s and 1930s of the last century (e.g. Le Corbusier, 1923), very far away from the understandings of current avant-garde architecture, of biodigital architecture: which includes keywords as biology and digital, concepts like natural intelligence and artificial intelligence, bio-learning and machine-learning, organic forms and digital tools, and bio-manufacturing and digital-manufacturing. If Gaudi currently lived, would he fit into this?

We must pay attention to the signs of the times, to the *Zeitgeist*, or we will look ridiculous when our history is written, as today, in addition to the great development experienced by biological technology, we can count on the immense help of digital technology. To the power of the media that we have in our hands today, we have to add intelligence and willingness to face the challenge of our time. Sensitively, for adjusting the objectives and research methodologies and the applications of the results.

6. Nature, Inspiration

Considering what is colloquially and commonly understood by the whole world as “Nature”, it could be said that this has always been the main inspiration for human beings in their work. Based on the fact that the first ornamental objects came directly from Nature. Flowers in the hair, shells, conches or bones around the neck, etc. Non-functional elements, not useful for the physiological needs or strict the physical survival of the human being (to protect themselves from heat and cold, to quench their hunger and thirst, to sleep safely and comfortably). When governed by the regulation of the same DNA, in all the cells of any living being, subject to that single genetic law of formal, functional, and growth composition, Nature produces everything in harmony. From the tiniest part to the whole. Thus, being configured according to the most classical definition of beauty. The harmonic relationship of the parts with the whole and the whole with the parts. But with small random errors, thanks above all to the interaction with external agents, which providentially remove the coldness in an absolute and mathematically perfect way, for the benefit of a perception that we humans understand as more “warm”, more “human”.

Ornaments, the most primitive elements with which to aspire to a better ideal, a greater attractiveness, a special singularity. Something with which to distinguish oneself from others, feel unique, increase the existential feeling of one's own self. A very human need to feel admired. A need that, if not properly satisfied, can cause more frustration and disgust than the non-resolution of more physical aspects. Leading to suicide, even if all physiological needs are well met. Hence, the phrase by Herman Muthesius, paradigmatic of the later triumphant rational-functionalism, “houses are to live and not to be admired («Häuser sind zum wohnen

und nicht zum anschauen»)" (Estévez, 1996), is to be considered half true and half lie. And that if it is believed dogmatically, it leads to the enormous misunderstanding that rational-functionalist architecture has caused for decades, with its objectivity and dry materiality, well expressed with the original term of *Neue Sachlichkeit*, which became a systematic architectural movement (*sachlich*: objective, material) almost a century ago (Scheerbart, 1914). Yes, houses are to live in, but also to be admired. Making its inhabitant feel happy to arouse such admiration among those around them. It is the same primal human need of the first to put a flower in the hair or a necklace around the neck. No one is happy living in a home that they would feel ashamed of.

For centuries now, the main sources of inspiration for architects were the ideals of classical Rome and Greece. Followed by the nineteenth century's different historical styles. Until the search for the style of the new modern era, and therefore refuting all the styles of the past, they began to look for what that new modern architecture would be like. And then it was discovered to what extent Nature could inspire architecture. Although as has been commented, only Gaudí had seen beyond the ornate surface, seeking to solve the mysteries and secrets of the laws of the universe, exclaiming how Nature was his teacher, showing profoundly, not just of skins but also of souls, of systems, of structures.

Thus, an easy first method to explain this notion would be to refer to a Nature-inspired architecture. But it is really about going beyond mere inspiration. It is about learning from Nature. And that is not only superficially inspired by Nature, like someone who inspires a volatile and ephemeral smoke. Although after learning in Nature, biolearning, learning about life, about living beings, it could be said that this inspires solutions, methods of doing things. But really, it is learning, not just inspiration. Learning from Nature –bio-learning– all the good that can be learned for planetary sustainability. "This tree is my teacher..." (Bassegoda, 1989).

So, in this learning, the parallelism between the biological and the digital is verified. Genetic similarities between DNA, chains of biological information (as if it were a kind of a natural software), and software, chains of digital information (as if it were a kind of an artificial DNA). Between the power of natural intelligence and artificial intelligence. Between the power of conception, design, and manufacture of Nature and of computation: biological architecture and digital architecture. An understanding that would reach its maximum degree of possibilities in its biodigital fusion. Being able to think, as a possible opinion to be considered, that the future of cities will be 50% biological and 50% digital, or there will be no future. Not as a mere inspiration, but rather should be understood as true learning. That is where the understanding of creating architecture following a generative design, a design of open systems rather than of concrete, specific, closed forms, also emerges. An architecture whose conception steps would be, yes, first an initial inspiration, attending to the natural attraction and interest that the vision

of living beings trigger in humans. Followed by learning about their systems, their relational functionality, and their sustainable efficiency. To develop a generative design that meshes all the architectural requirements. Because it is generative, it "emerges" as biological life "emerges" and grows in a process that is both evolutionary in its conception and design. Knowing that the digital tool will also guarantee its harmony as a whole and in all its parts (Figure 5 and Figure 6) and that it can undergo machine-learning and artificial intelligence processes, considering a large number of options.

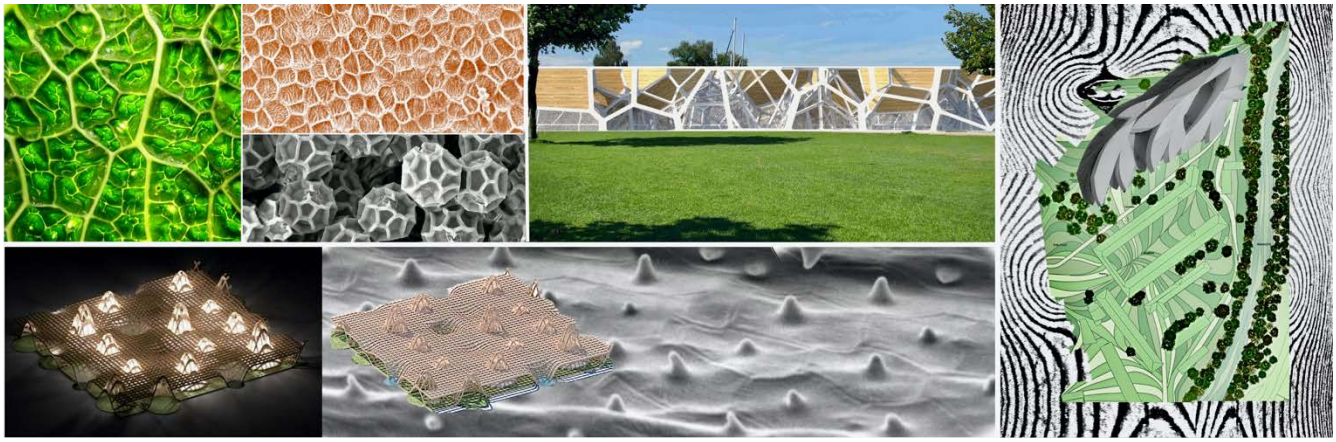

Figure 5. Examples of generative design, learning of biological systems applied digitally to architecture: Alberto T. Estévez - Genetic Architectures Office, above, centre, *multifunctional building*, Hard, 2014, digitally designed with voronoi and voronoi fractal systems, next to photos at left of biological voronoi and voronoi fractals, of a cabbage leaf, a rose petal and pollen grains, and below, *Kindergarten*, Vilobí del Penedès, 2009, night and day views of the roofs of the building on a background of the microscopic photo of the surface of a leaf, and right, *passive solar housing and park* (with pre-existing rectangular buildings), Innsbruck, 2016-17, digitally designed with force fields system, presented on the photo of a background of biological wood grain. (Author's images).

Figure 6. Examples of generative design, learning of biological systems applied digitally to architecture: Alberto T. Estévez - Genetic Architectures Office, left, centre, *Qatar University of Applied Arts & Design*, Doha, 2013, next to microscopic photos of a pollen grain and of a radiolaria, and right, *market*, Casablanca, 2012, next to a photo of calla lilies, *Zantedeschia*. (Author's images).

Indeed, what such a design contains is beyond mere inspiration. It is learning. And it is not simple imitation. It is biolearning that merges with machine-learning. Thus, it develops in an evolutionary way, like Nature, with iterations that follow and are instructed by its "digital DNA"

until it reaches what would be considered the most satisfactory result. From the examination of the characteristics as a whole and separately, the one that is “stronger” will emerge, globally. "Strong" not physically but conceptually. Although in Nature, when one talks about the survival of the “strongest”, it also refers to the most efficient, which is more conceptual than physical. Although architecture is also made for the human being, it requires answers not only for their physical and physiological needs but also for metaphysical and psychological needs. All this builds an authentic architectural design methodology that does not focus on designing a single building but a whole building species - a system that generates specimens with their own DNA. It could be said that they are "species of buildings", or "breeds of buildings", or “races of buildings” since their "digital DNA" can be mixed to produce a new "building being". This is what biologically differentiates species (cat, dog, etc.) and breeds, races (golden retriever, German shepherd, etc.).

Which by the way, when a few years ago I innocently wrote about "breeds of buildings" ("races of buildings"), a paranoid about eugenics had objected in a book, seeing something suspicious in such an expression. I suppose they’re unaware that, properly speaking, there are no human "races" in the plural because biologically, there is only one human race to which all human ethnic groups belong equally. It could be that whoever still thinks of humans when the word "race" appears might actually be a racist, or at least ignorant. Please, nobody see anything strange about it because the only thing they would do is project themself in their obsessions and phobias, fulfilling the saying that "we do not see reality as it is, but as we are".

In short, to learn from Nature, we must always be wondering about what Nature beings are like and how they live in biodiversity. Rich in species, subspecies and races. It shows us that it is capable of solving the same functions in a thousand very different ways. Yes, living beings are sustainable; they do not destroy their own vital environment. They live integrated, with exact precision as a perfect set in the climatic environment in which they are, in a cycle capable of maintaining the necessary resources for centuries. And all without exception participate collectively in life until their natural death. They are self-sufficient without needing resources from the other side of the planet. They are collaborators with each other; they live in symbiosis. They need each other for their survival, and therefore they survive thanks to their mutual cooperation, even if they are not even aware of it. But they don't take more than they need to live on the bare minimum. And they always take only what they have around them. And if they don't have it nearby, they go and migrate to where the necessary resources are, but nobody brings the resources to where they are, nor does anyone prevent them from migrating.

All these lessons of sustainability apply to architecture but also our life. To our customs, to our social understanding, with knowledge, with rationality, with depth. For example, it does not make sense to buy fruit that, because it is out of its natural season, comes from the other side

of the planet because they come in polluting planes. Or it does not make sense that in certain towns in the Pyrenees, between Spain and France, out of respect for the traditional architectural context, it is legally enforced that roofs of the houses must be built with black slate. However, the slate from the Pyrenees is more expensive, so the slate used is brought from Brazil with the corresponding pollution that such transport entails and the consequent loss of non-renewable resources from the other part of the world. Cases like these can no longer be sustained. They are not sustainable. And this is where the intelligence of the honest politicians who dictate the laws should come into play so that we see the issues that we must address in our personal education and responsibility.

7. Biomimicry does not necessarily imply sustainability

It is one thing to be inspired by Nature to achieve more sustainable buildings when learned from Nature in the right way. While the inspiration from Nature without implying greater sustainability is another thing which would not be learning from Nature in all the depth that it offers us. Biomimetics in architecture, the mere external and formal imitation of Nature, does not necessarily imply any advantage over non-biomimetic buildings. On the contrary, it could be the case that buildings that are not biomimetic are developed with greater intelligence than others that are biomimetic. There is no objection to architecture that is not inspired by Nature on being much more advantageous in its physical aspect and much more attractive in its metaphysical aspect. But that would only mean that the learning that we can extract from Nature has not been sufficiently deep. For example, anyone would say that artificial grass is a biomimetic product, but what a great contradiction it is for the environment (Figure 7).

Figure 7. Contradictions: artificial grass versus natural grass (Photos: Alberto T. Estévez).

The sustainability of this world is because every living being actively participates in it. It can be generalised that there is no living being voluntarily or involuntarily left out of biogeochemical cycles and trophic chains. Of course, they do not know that they are promoting planetary sustainability with their life and their natural tasks. But they are. And if it weren't for the sum of

each of them, biological Nature could not exist. Instead, we are surrounded by Nature, which is wonderful in each of its beings, no matter how small. Thus, the inspired lesson –learned– from Nature would be that every human being must actively participate in the sustainability of this world. And no one can be left out, no matter how small. The only thing that matters is that the human being is also aware that they act sustainably or not. Therefore, they have a responsibility and possible fault if it is the case.

Either we work together to achieve planetary sustainability, including all levels of society, or we will never achieve it. And it is because of this contemporary culture, with so many positive values, which at the same time is marked by a serious disease: individualism. And if we do not unite to achieve global sustainability, in an integral ecology, even when nobody sees us, when nobody rewards or fines us, we will continue on a battlefield between selfish, anonymous, and individualistic interests where the only be losers will be the human race.

And whoever they were, being powerful or rich, intelligent or clever, active or initiative, by good luck, or whatever, accumulates wealth and patrimony instead of making it flow to the weakest, breaks the cycle, creates gaps in planetary sustainability. (And is actually "weak" in quotes, for having less intelligence, less initiative, less luck, no inheritance, or whatever). Even so, everyone, and some more than others, must participate in creating new jobs, preserving existing ones, and, above all, in the change of mentality always to put the human at the centre and not use a purely economic logic. Certainly, it requires a certain dose of imagination because nothing will be solved by the strict application of a dry justice. Only a generous excess of natural justice can really solve the world crisis, as Nature is generously "excessive" itself in the creation of life in all corners.

In Nature, as can be considered from a certain point of view, there are no imperialisms or ambitions. Living beings in Nature live with the minimum. It is true that human ambition has led us to the scientific, technological, and cultural advances that we now enjoy. Although it must be concluded that it is not an authentic advance if it is not a humanising advance. Tigers, panthers, lions, or other predators each have their own hunting area necessary for their strict survival. They have neither more nor less but have only just enough to survive. And it would not be said that they are unhappy. Thus, they do not conquer neighbouring hunting areas by putting "governors" who bring taxes to their "thrones" in the centre of their empire. They are self-sufficient, they don't make anyone hunt for them, and they don't accumulate their scraps or their neighbours' scraps. And when they are satisfied, they leave their prey half-eaten and do not keep it or hide it in a bank. Then many others can freely take advantage of it, from large to small, vultures, hyenas, crows, even ants, worms, and bacteria. But it was us that have given all these negative connotations, while these creatures being themselves, as they are, they are neither better nor worse than others. They are all existentially equal, and this is the social

system that Nature teaches us, without erecting walls, on a planet that is naturally all freely passable. It is only the human being who encloses themselves with barriers and high fences, either so that they do not enter or do not leave.

And why do these questions arise here? Because as in Nature, everything is interwoven. For example, in the last thirty years, the average surface area of the houses in the United States has doubled and is already triple the average surface area of houses in Great Britain. This means a greater expenditure of non-renewable materials and energy, greater pollution produced by it, greater crushing of the natural soil so that it is hermetically closed and built on. But that does not mean that North Americans are three times happier than the British. But it is three times less sustainable than the British. In fact, of course, out of the need for survival, the most socially disadvantaged teach us sustainability lessons, in their great capacity for recycling, for making use of resources. If the whole world lived like the so-called first world, we would need two whole planets, and we only have one. The need for survival already reaches everyone. Well, it is useless to think about sustainable architecture, and to strive for it, if, at the same time, we do not think that everything goes together, planetary ecology, global economy, and social equity. We can now add human health to this equation, verified thanks to the pandemic suffered worldwide.

8. Nature, self-sufficiency

Indeed, in favour of planetary sustainability, and as Nature teaches us in every living being, in every area, in every territory, likewise every building, every city, every country must tend towards self-sufficiency (Estévez, 2020 C). And therefore, everything must be designed with that trend in mind. And even further, if possible, even producing an excess of beneficial resources that generously flow freely. Like Nature, which is overturned regardless of expense for the processes that have to do specifically with reproduction, which a human would associate with love, a perfect metaphor to see in that eternal inspiring mirror that is Nature. It is the case that Nature is tremendously efficient and precise in the expenditure of resources for everything that configures living beings, the skeletal system, the respiratory system, the digestive system, etc. But not so when it comes to reproduction, where it delights in spreading millions and millions of pollen grains, seeds, eggs, etc., all over the world. Seeing the complexity that life has come to achieve, it would not have been so difficult that reproduction’s expenditure of resources would have been equally sparse and reduced. And yet, as a new lesson, this is not the case.

As an example of self-sufficiency and participating in producing an abundance of resources, one could cite the project for a telecommunications tower in Santiago de Chile (Figure 8).

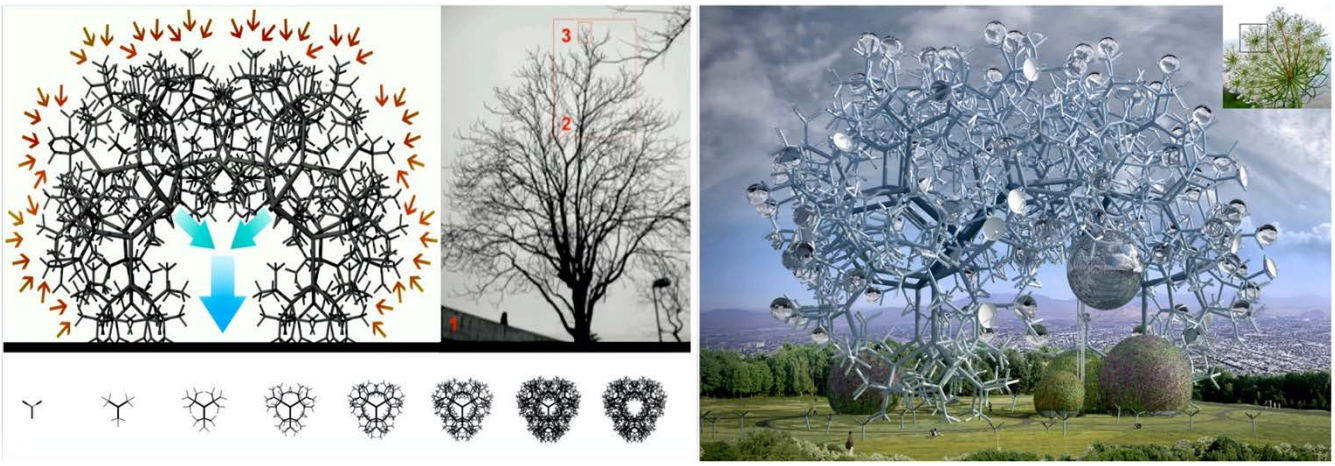

Figure 8. Alberto T. Estévez - Genetic Architectures Office, *Telecommunications building*, Santiago de Chile, 2013-14. Biodigital architecture project about biolearning, learning from Nature, discovering the secret laws of the universe. Developed digitally and fractally, which at the same time is a "purifying air machine" (left). Following the fractality of Nature, of dandelions, trees and other flowers. However, its uniqueness is only a symbolic fact because of the acute contamination suffered by Santiago de Chile, where the project is located, with a meadow of dandelions around. At night, spherical luminaries surround the building's surface at its last fractal level. By day, spherical solar collectors of the same size placed on the same level will also offer their brightness as a "crown" of the landscape (right).

In this project, using digital design development, the whole structure emerges by fractal development that captures the values of complexity, unity, harmony, organicity, and continuity—the values of beauty that every living being has in Nature. The structure will support everything necessary for its function as a telecommunications antenna and belvedere overlooking the city. And in parallel offers potential 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 produced during the day with the brightness of the spheres. It shows as a crown instead of one of those telecommunications towers that populate the mountains and skylines of cities.

On the other hand, all that structure of hollow tubes, with fans inside, inhale the surrounding contaminated air through its interior, so that filtrated air comes out purified to the central zone, where an area for entertainment for those who go up to the top of the mount is located. 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. The fractality in the structures of Nature is yet another lesson (Estévez, 2020 C), and current digital technologies make it easier to use them. Well, the structures of Nature are not massive, and

the human being must be able to learn about it to reach an optimal adjustment in the expenditure of material and energy in architecture (Figure 9).

Figure 9. From left to right, a 20th-century solid massive pillar (of Le Corbusier), and what could be a 21st-century non-solid non-massive “pillar”, next to views of the interior of calla lilies stems: a light and efficient stem, almost two meters high, with an exquisite internal voronoi structure, enough to sustain itself with a minimum of resources. (Photos: Alberto T. Estévez).

Another indicator of Nature's self-sufficiency is that its beings have a certain capacity for autonomous self-regeneration, for self-healing. In this regard, there has been no lack of research on the "self-regeneration" of buildings. As a certain "self-healing" of possible cracks that may arise in the various construction materials, for example, of “living tissues” that would grow autonomously in the areas affected by some pathology, or to achieve reinforcement (see, for example, El Gazzar et al., 2021).

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

9. Nature, life

The entire planet is covered with a skin of life, both on land and in water; green, plants, algae, plankton, as long as the climate permits. And with great resilience, because if any area of the ecologic system dies for whatever cause, it can soon recover. If it wasn't so, how would biological Nature have taken over all the inert artificial human surfaces, roofs, walls, furniture, cars, and objects in Chernobyl, for example? After the nuclear explosion of 1986, thinking that the area would be without life for millennia, in just 30 years, the biodiversity is even greater than before, simply due to the human absence.

Another lesson was learned worldwide through the recent confinement due to COVID-19. Just for a couple of months of keeping humans locked up in their homes, all kinds of animals have come out to walk the streets, wild boar, antelope, monkeys. River water has become cleaner. By not cutting the grass during that period, the smaller life forms have proliferated better. Above all, the plants, which have filled every fissure in height and width. Leaves and flowers were appearing in places that have never seen them before. That inspired the urban action "Let life grow!" (Figure 10), placing signs with that motto next to the cracks where plants began to grow or installing signs prohibiting mowing. Even through something as terrible as the spread of this virus –Nature after all– has brought new lessons to teach us, a more generalised understanding of the planet as an absolutely global and interconnected system, of solidarity, responsibility, and generosity. Although some might think of conspiracies or something like that, it would almost be more a case of a conspiracy by Nature itself against human beings and their abuses if we imagine Nature with its own conscience as humans have.

Figure 10. Above, wonderful plants and flowers that, thanks to COVID-19, have appeared for the first time in these places, photographed there just after the officially decreed confinement. (Photos: Alberto T. Estévez, Barcelona, 2020). Below, Alberto T. Estévez, *"Let life grow!" urban action*, Barcelona, 2020.

What are we humans waiting for to follow that lesson of Nature, which once it is allowed, proliferates everywhere? Let's cover everything in green, with life, without leaving a centimetre square dead and dry. And the sustainability benefit will be immediate. Each living being, no matter how small, carries within it beneficial conditions for the environment. All of them are integrated into it, expand and enrich it with their mere presence.

An example of this is something as simple as designing all the roofs of our habitats with green landscapes. (Figure 11). The benefit of thermal insulation, both in winter and in summer, is immediate, with the consequent energy savings and reducing the effects of urban heat islands (Estévez, 1998). As well as an immediate growth of biodiversity, better absorption of CO_2, dust from the streets, and noise, as the architectural envelopes are no longer hard and lifeless but rather smooth and lively. "Soft and hairy" cities, protected by a green blanket of life, gives permanent shade, avoiding overheating due to the direct incidence of the sun. Obviously, better use of the grey and black water must be associated with this, which cities throw down the pipe by tons, instead of ensuring their self-sufficiency. "That tree is my teacher", which uses most efficiently only the water that it has at its disposal, in the place where it is, without wasting a drop, without needing huge infrastructure works that bring water to it for its survival from miles away, where it gets discarded immediately as only humans do. The tree, which also teaches us natural pumping systems, without motors or electricity, can raise water more than 100 meters high, as in sequoias. Existing millions of years ago, humans have not yet been able to apply such wise systems. And today, with the possibility of digital design and manufacturing technology, pipes that have been learned from Nature could already be designed and implemented.

Figure 11. Green overall: Alberto T. Estévez, *Green Barcelona Project*, Barcelona, 1995-98. A huge interconnected park on the roofs of all the buildings of the city.

10. Nature, passive solar energy

The sun is a source of energy and a source of primaeval life. Thanks to its heat and light, received in the exact orbital position of the Earth, our star activates the water cycle and allows photosynthesis. And Nature teaches us that it lives entirely from it. Even other sources of energy that humans also use come indirectly from solar energy. The wind, waves and tides, rain and therefore water from hydraulic energy, but also from living beings such as coal, oil, biomass...

The sun (fire), air, water, and earth, are "the 4 elements" that produce life. Neither burning materials nor radioactivity produces life. On the contrary, they destroy it. Then, again taught by Nature, we are shown the right and wrong ways to obtain vital energy for a sustainable world. Roots fed by water and earth and leaves by sun and air. But with what engines do living beings work? Certainly not with metal gears and plungers or chips. They only "work" with sustainable, renewable, recyclable materials and highly efficient systems that human beings have not yet been able to emulate. Not even that of the smallest insect because they didn't comprehend the lessons that Nature gives them daily - even in every corner of their own home. And at most, they try to imitate, but not to learn and apply.

Thus, learned from Nature, it is more direct to take advantage of the sun's own heat and light as a sustainable energy source than any other. And Nature is not wrong. After millions of years of experience, this energy is the most sustainable and the most efficient. Another thing is that human limitation does not understand it, does not see it, or does not want to see it. But the tiniest leaf of the simplest plant shows how wonderful Nature's solution for sustainability is. A perfect solar collector, which extends and opens so that we can learn from it.

And although today we are in the prehistory of the application of solar energy in architecture, at least we have a first stone to put in its line: thermal energy harnessed from solar heat and photovoltaic energy harnessed from sunlight. Of course, the latter is still expensive, complex to manufacture and therefore undemocratic and not accessible to everyone, and based on systems and materials that are not fully renewable or easily recyclable. Thus, it sure won't be that of a truly sustainable future. On the other hand, experiments for creating electricity by living beings are already appearing through their totally natural systems (see, among other possible references, for example, Abdallah et al., 2019). Well, the definitive solution is yet to be discovered. Surely, it will appear through a still secret door, which is most likely right under our noses, and obviously, we do not even see it. But we can perhaps intuit it, there, in the DNA genes responsible for the processes of photosynthesis.

Meanwhile, there is no reason to prevent the design of our buildings with passive solar energy criteria, optimising the architecture design to reduce heating and cooling needs (Serra, 1995). If this were done worldwide, the sustainability benefit would be enormous. "Passive", which

means not leaving the control in the hands of active systems, which are those that require motors, and therefore, again, are non-renewable and unsustainable mechanisms that are nonexistent in Nature. Passive solar energy criteria, or at least popular and vernacular building criteria, like animals and plants, live adapted to their place and climate, which has allowed them to survive there for centuries with its own human building tradition. And for this, in one way or another, they have also experienced a similar and necessary "natural" evolution. And it is their millenary survival that precisely guarantees their ideal adaptation to the place and climate with the least expenditure of resources. Therefore, discovering in themselves the optimal characteristics of sustainability. Only now, certain technical advances and accessibility to new materials can incorporate greater benefits. And therefore, they should necessarily start now with new types of vernacular constructions, with the conclusive advantage of having certain scientific support.

Figure 12 exhibits an example of the wide range that passive solar criteria can be applied to. It shows a chronological order of different projects of the author. He signs these lines, of passive solar architecture, throughout the different periods in which an evolution in the understanding of avant-garde architecture has developed—from the so-called postmodernism in the late 70s and early 80s up to the current digital organicism of the twenty-first century, passing through the minimalism of the second half of the 80s and a certain neo-expressionism of the early 90s. The avant-garde, that, at the end of the 90s, initiated the process of what would later be consolidated at the beginning of the twenty-first century as biodigital architecture, as it began to be defined as “Genetic Architectures: the new cybernetic-digital project and the new ecological-environmental project” (Estévez, 2000 and 2002 C).

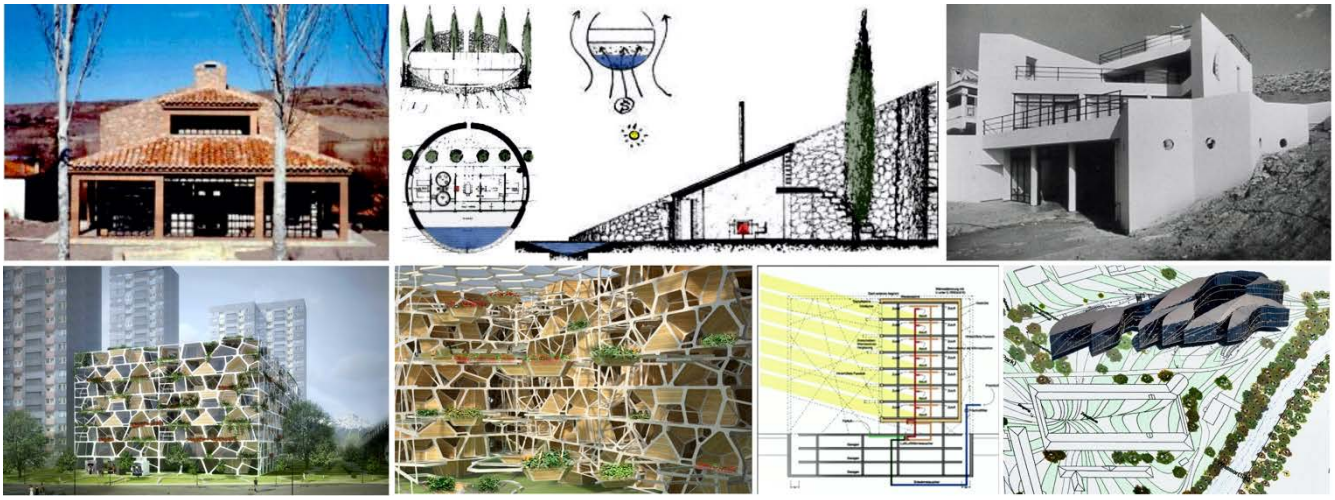

Figure 12. A chronological sequence of different passive solar architecture projects, developed respectively within the evolution in the understanding of avant-garde architecture, from the 80s to the present: postmodernism, minimalism, neo-expressionism, and digital organicism (biodigital architecture). Alberto T. Estévez, House G., Sigüenza, 1983-85 / House P., Cervià de les Garrigues, 1989 / House G., Almerimar, 1993-95 / Passive solar biodigital housing, Innsbruck, 2014-15 and 2016-17.

Conclusion: Blue planet? Green planet!

Green planet! Because “green is not a color” (Estévez, 2017), it is an attitude. It is a will. It is a necessity. We need to “live Green”, in “Green architecture”, in “Green cities”, on a “Green planet”, for planetary sustainability! And genetics (biomanufacturing) becomes a cornerstone of our “Green future”; precisely because it is at the cross-point between Nature and computation. Because it is the science that can command both, from “inside”. All this becomes justified for the “green economy” that humanity needs today. Because this is our reality: our Mother Earth now cries out to us because of the harm we have inflicted on it by our irresponsible use and abuse of its goods. We have come to see ourselves as its lords and masters, entitled to plunder it at will. The violence present in our hearts is also reflected in the symptoms of sickness evident in the soil, water, air, and all forms of life. We have forgotten that we are dust of the Earth; our very bodies are made up of its elements, we breathe its air, and we receive life and refreshment from its waters. This is our reality. We all generate small or great ecological damage, so we are called to admit our contribution, smaller or greater, to the destruction of our planet. For human beings to destroy the biological diversity; for human beings to degrade the integrity of the earth by causing changes in its climate, by stripping the earth of its natural forests or destroying its wetlands; for human beings to contaminate the earth’s waters, its land, its air, and its life – these are crimes, against the natural world, against humanity, against our future.

This is our reality, the same in Europe, in America, in Asia, in Africa, in Australia. Our planet’s forests lose double the surface size of Portugal every year: 16 million hectares of trees disappear every year. This is our reality, with so many contradictions. For example, we read in the newspapers how 78,000 people have signed up in just two weeks for a journey of no return to Mars. The mission (of billions of Euros) plans to install a permanent colony on Mars in a survival as dangerous as capricious, when is our planet that needs “permanent colonies” on the deserts, to give them life again, and that at a much lower price and with less danger than on Mars. Of course, it is “cooler” to go forever to Mars than to the Sahara. Contradictions, such as if we ask ourselves whether we would prefer to live in a forest or a harbour landscape of containers. But our cities are more similar to a harbour landscape of containers than to a forest. Only that forests are sustainable, and harbours are not.

It would seem obvious what has been exhibited through this work so far. Issues that are not so complicated to see and understand. And yet, why have they not been solved? How come that so few are in line with such basic principles, and this writing is necessary? Well, everyone should participate equally in keeping this world sustainable. Each one from their own field and task. And not only as passive consumers but above all as active workers. The contractor and the builder; the intellectual and the manual worker; the artist and the craftsman; the scientist

and the technician; the teacher and the student; and the architect (and the engineer), which would be the case that now concerns these lines, since it focuses on the work of its author, architecture. But without a job with fair social equity for all, no matter how sustainable architecture is planned and built, it will be completely useless for its global and main purpose, planetary sustainability.

I'm a bit tired of hearing the useless discussions about whether there is climate change or not, some believe it, and some do not. It's that yes, that no. There are even denyers of the COVID-19 pandemic! Well then, let's think about how talking about climate change doesn't matter that much. Let's talk about the unquestionable for all and remedy that, without discussing whether or not the average temperature of the planet will increase.

Let's talk about the mass extinction of species whose DNA will be lost forever. A bit of those molecular chains of life, from which (living) beings emerge, each one perfection unattainable by the human hand, is worth more than all the (inert) diamonds in the world. A simple grasshopper is actually worth infinitely more than the largest gold piece. But we exchange stones. Perhaps the day will come when we realise and exchange living beings again instead of pieces of metal—an egg for a cabbage, a fish for a melon, a cow for an apple tree.

Let's talk about the rampant global pollution, air, land, water. Let's talk about urban conglomerations with inhumane conditions. Let's talk about the difficulties of accessibility to drinking water for millions of people. No, let's not talk anymore. How many trees have you planted today? At this time, I have already planted another.

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