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“The fifth element: biodigital & genetics”

Alberto T. Estévez

Introduction: The Fifth Element

In the context of this book, entitled “Air, Water, Food, and Energy – the four life-supporting elements”, it can quickly come to mind which in one way or another has fluttered by human thought since the beginning of history, the fifth element.

For some of our generations, immediately, this will remind the fantastic film by Luc Besson, *The Fifth Element* (1997), a classic of science fiction, not without symbolism, to be also applied to our days. It takes place in the 23rd century, and it deals with the survival of planet Earth against a great evil that is approaching. Such salvation can only be achieved if four stones, that contain the essences of the four mythical elements (air, water, earth and fire), are joined. And these must be activated with the fifth element, which, in the form of a humanoid (genetically reconstructed from only a piece of living cells), is able to combine the power of the other four into a “Divine Light”.

But curiously, at the end, the humanoid no longer wants to save the world, because she has seen the brutality of human violence and refuses to release the “Divine Light”: “What's the use of saving life when you see what you do with it?”, she said. Luckily, the protagonist makes her feel something, for what she does deserve to save the world, love, which will be discovered precisely as the authentic fifth element. (In the background there is also a sceptical look at capitalist consumerism, at the obsession with technology, and at the same time the tension in front of it that must be solved: nothing far from our present).

Actually, human violence is nothing new, since it could be said –symbolically– that it exists since there were more than three people in the world. So the new great evil, genuinely of our times, is the planetary unsustainability. And the survival of planet Earth against this great evil that is approaching can only be achieved joining really global efficient solutions for air, water, food and energy.

As the four elements proposed by the Greeks are air, water, earth and fire, it can also be said that “the four life-supporting elements” are “Air, Water, Food, and Energy”. Understanding food as earth: after all food is a kind of earth transformation. And understanding energy as fire: after all, fire is pure energy, and symbolically can be said that fire is the primary original energy, the best symbol for energy. Furthermore, they are not separate elements: necessarily they have certain connections between them.

But the four physical elements must be activated in a right way, with the fifth element, that at Luc Besson's movie comes under the form of a humanoid; in our case, only humans can do it, and have the responsibility for do it, because only humans are to blame of what is happening. The humanoid is genetically reconstructed from only a piece of living cells; and in our times we are discovering day by day how big is the potential of genetics. Genetics needs to be managed with intelligence, that symbolically is a kind of "Divine Light", able – in the film– to combine the power of the other four elements; the four elements that are life-supporting, as it is entitled this book. And love, as conclusion of *The Fifth Element*, that in mankind is also "life-supporting": the fifth element as humanoid, as intelligence, as "Divine Light", as love… in the movie as in the reality.

Obviously, if we talk about a fifth element, it is because before there is a certain agreement on four elements. Although, due to scientific advances in our contemporary age, speaking about the four elements has come to have something of poetic symbolism. However, an interesting symbolism, to help the analysis of what happens today, and thus convey a synthesis that is useful to us, to understand our existence and achieve solutions to our current problems.

It is a fact that the considerations around the four elements, and something that can be ascribed to a fifth element has gone through all historical eras and human traditions. From the oldest writings of the Bible ("the Word", "a mighty wind", "the breath of life"), to the most ridiculous esotericism we see today on the Internet. Greeks, medieval Europeans, Hindus, Buddhists, Chinese, Japanese: *aether*, *quinta essentia* (from Latin, literally translated, fifth essence), *akasha*, void, spirit, word, wind, blow, breath, light, life, live, love… Call it whatever you want.

Without being the purpose of these lines to write a history of this topic, see for example one of the main alchemy treatises of all times, for its complexity and for its erudite composition, the *Book of the Secrets of nature or of the Quintessence* of Ramon Llull (Llull, 1989), written in the 13th century. A title that curiously also recalls the contemporary words of Gaudí, when he was "searching in nature its mysterious image and turn it into architecture, forging the shape of the idea, discovering the laws of the universe in all its secrets", as he said. Something inspiring for our own research, in the understanding that nature has all the answers that our world needs for its sustainability.

It is clear that there must be something, when the classical 4 elements and the fifth element even appear frequently used in pop culture, music, literature, comic books, video games, movies, etc. Something that fits well in the brains and thinking of all the people. Considering that, of course, the idea of the fifth element has actually been changing from generation to generation. So, it is time to say what would then be the idea of the fifth element for the present, that of the third decade of the 21st century.

Biodigital & Genetics

We know that the answer is in nature and nature is the answer. The more the 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 2007). We are exploring and interrogating “the question”, through interdisciplinary endeavours involving fields such as material science, biology, genetics, art, architecture, civil engineering, design, computer graphics, and human-computer interaction. We are exploring the frontiers of knowledge… One main interdisciplinary cross-point for really arriving at these frontiers is where genetics meets biology and the digital, applied to architecture and design in our case (and also applied to art or civil engineering, etc.). This is the cross-point at which we find ourselves, the cross-point that this chapter is about.

Things that we do not attach importance to or are scattered and disconnected, sometimes they end up converging in a total picture where all those previous aspects can be appreciated together. Or, perhaps, it is just the previous existence of these scattered aspects which allows us to reach the point where we are today. So, perhaps because of these previous latent interests, which in any case should be explained in a different (autobiographical) framework, the Genetic Architectures Research Group & Office and the Biodigital Architecture Master Program was founded at the ESARQ, the School of Architecture of UIC Barcelona (Universitat Internacional de Catalunya). This is the scene where we work to create architecture and design, with geneticists focused on architectural objectives, and architects researching the fusion of biological and digital techniques.

Perhaps it is not a coincidence that in this same city of Barcelona, that of Antoni Gaudí, where Salvador Dalí prophesied that “the architecture of the future will be soft and hairy (furry)” (Dalí, 1956), the year 2000 saw the real application of genetics to architecture, with the creation of the first real genetic architecture laboratory on the planet, with the creation of the first digital production workshop in a Spanish school, with the creation of the first official postgraduate, master's and doctoral program on these genetic-biodigital issues .

Certainly with this the aforementioned prophecy of Salvador Dalí is fulfilled. More when he realized that for it was simply a matter of having the necessary technique, the one from genetics, which took half a century more to arrive: “in 1925 I met Mr. Le Corbusier (...) he asked my opinion regarding the future of architecture. I replied that I saw her 'soft and hairy (furry)'. I have not changed my mind and I hope that the technique reaches me one day, because I'm still a bit ahead of it.” (Dalí, 2003). Although starting from a surrealist *boutade*, he was not mistaken, corroborated today in the shape of “biodigital”, genetic, and “tidied” –enabled– by means of computing. Both for architecture and design, as for any other field.

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.

Truthfully, more and more –no doubt about the way forward– we can see how today 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.

And, 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. It is in this way that around the term biodigital we find others such as biology, life, computing, nature, cybernetics, genetics, mathematics, DNA, algorithms, emergence, morphogenesis, artificial intelligence, surrealism, digital organicism, genetic architecture, robotics, biomanufacturing, 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 (Figure 1). Biology and digital: if we also understand working with DNA as if it were a natural software, and with the software as if it were an artificial DNA: the new materials of the future, as concrete and steel were for modernism.

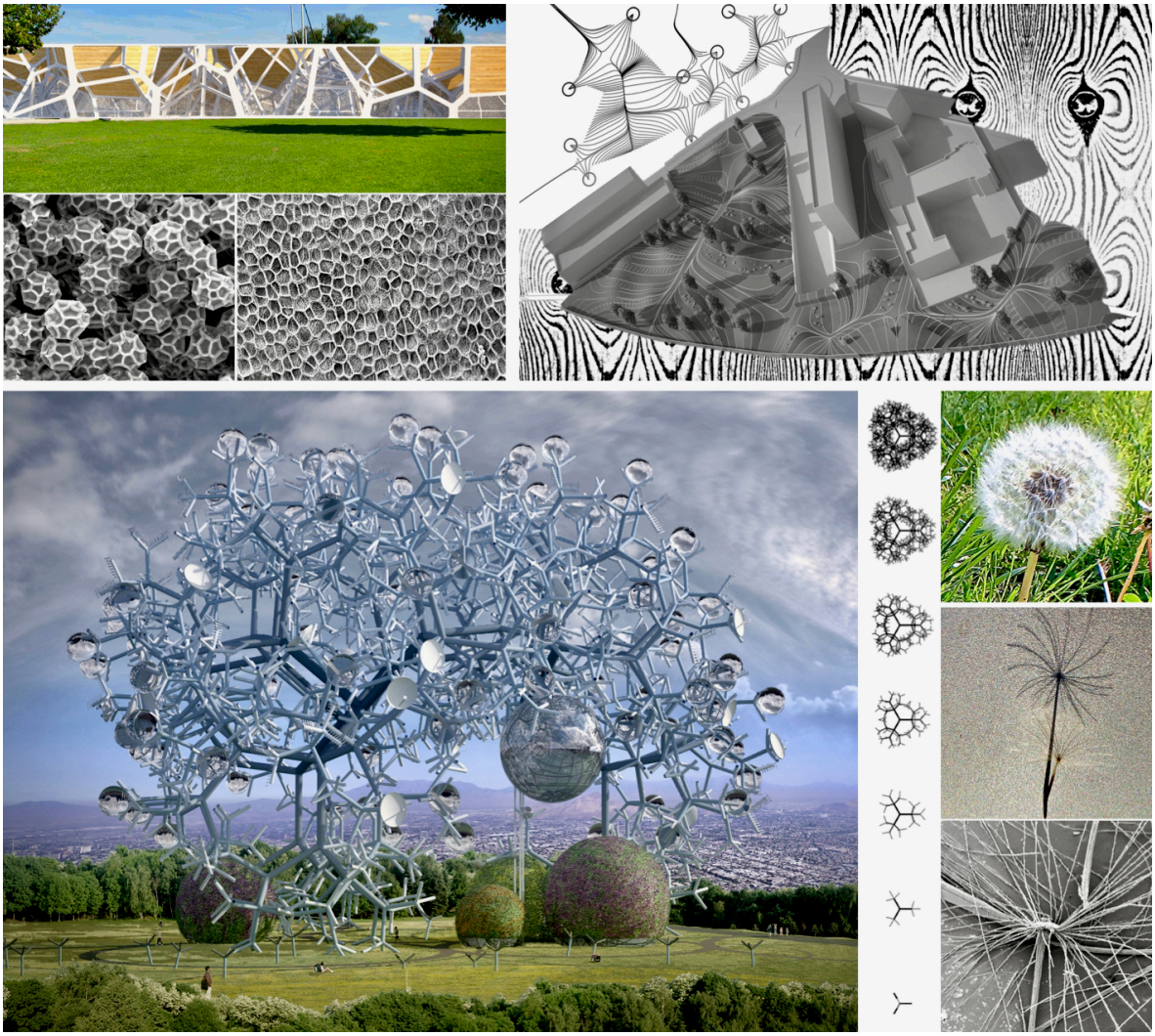

Figure 1. Example of biodigital architecture and design: photos and images by Alberto T. Estévez - Genetic Architectures Office. Above left, *multifunctional building and park*, Hard, designed from the design strategy of digital voronoi structures: below, photos of biological voronoi structures taken with SEM, scanning electron microscope (pollen, 1600x, and rose petal, 800x). Top right, *park*, Cornellà del Llobregat, designed from the design strategy of structures of attractors and digital force fields: presented on photos of the biological linear structures of wood. Below, *telecommunications building*, Santiago de Chile, designed from the design strategy of digital fractal structures: right, photos of biological fractal structures of dandelion, in three different scales; the lower one taken with electron microscope (pollen, 200x).

A bit of (genetic) history

It might now make a little sense to give a little history on the subject: between December 1999 and January 2000 a snippet of information went viral with the media publishing increasingly more information on it and constantly "infecting" each other. In this case, it was about genetics: press, radio and television were very quickly inundated by news and reports on this subject.

Then, watching how genetics offered such a huge field in the world of health and nutrition, I wondered about the application of genetics to architecture and design. For that reason, we created (already more than 15 years ago) the aforementioned research group and Master's degree program, and also connected it to a PhD program.

Without knowing it yet, at the same time (2000) Eduardo Kac was working on Alba, with the GFP gene responsible for bioluminescence, becoming the most famous bunny of the 21st century. As is it known, this gene encodes the synthesis of the GFP protein (green fluorescent protein) which is widely used in genetics as a marker, an indicator that allows for easy verification of the genetic transformation success. And though it is now supplied to genetic laboratories without problems, the natural source of this gene was originally a jellyfish called *Aequorea victoria*, from the Northeast Pacific, in which the GFP is responsible for glowing in the dark. After the transformation of the cells that have been required for each case, the gene synthesizes the protein, allowing the cells to emit a bright green color when exposed to blue or black light. However, the Green Fluorescent Protein is also present in hundreds of sea species, with green, orange and red colors, as in sharks, eels, seahorses, fish, coral, etc. This discovery has recently given rise to *fluo diving,* night diving in fluorescent underwater marine life, as if one were floating in the *Avatar* movie: another fantastic film, this time by James Cameron, *Avatar* (2009), another classic of science fiction, not without symbolism, to be also applied to our days, show a whole planet –Pandora– in the way that we was researching from 2003, when we started the research about bioluminescence.

One day in January of 2003, talking with the geneticists in our group about the use of GFP in research, Dr. Miquel-Àngel Serra asked "what else can the GFP be used for other than being an indicator?" As an architect it was clear to me: "for illuminating architectural spaces!" At that moment we began research for getting trees to work as "lamps" illuminating streets, plants illuminating homes, vegetation illuminating the roadsides without electricity: the creation of plants with natural light by genetic transformation for urban and domestic use had emerged.

So, in October of 2005, thanks to our geneticist Dr. Agustí Fontarnau along with Dr. Leandro Peña, we successfully obtained the first 7 lemon trees with luminescent leaves (Figure 2), provided by GFP. These transformed lemon trees get their green fluorescent protein through the expression of the GFP gene. That gene was transferred to the lemon tree cells into a transforming in vitro culture experiment using a DNA vector containing GFP genes (the DNA containing the GFP gene was not spliced; it was inserted into the lemon

tree genome and kept intact inside of it): some of the transformed cells regenerated a new plant with its cells expressing GFP, knowing that the glowing properties can be seen by microscope from the beginnings of its cellular transformation. In two months, the trees was approximately 30 cm. high, so that we were able to directly see the bioluminescent properties with our own eyes, taking photos with blue light and a conventional reflex camera, or along with Dr. Josep Clotet, also from our University, taking photos with our special UV camera.

Figure 2. Alberto T. Estévez, *Genetic Barcelona Project*: The magic light of the GFP lemon trees. Center, image of a possible world. Right, real 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 (author's images and photos).

We started with the GFP, since it is the most studied one, as geneticists use it as a common cellular marker. The functionality of the objectives was clear: the trees in this project were made with the objective of being of architectonical and urban use; it was the first time in architectural history that geneticists had worked for an architect; in 2005 we also presented this research under the name of the *Genetic Barcelona Project* to the mayor of Barcelona. The durability results were good: today, more than 13 years later, the leaves have the same luminescence, and the initial little lemon trees continue to grow depending on soil availability. They can be also multiplied by planting their branches, becoming non-manufactured "lamps", for free! But from the beginning the lightning efficiency was very poor and needed special light input in order to achieve enough brightness.

So, through a second phase of this project, to make more efficient and useful bioluminescent vegetation, we arrived at "Biolamps" (Figure 3): in 2007 we started to research bacterial bioluminescence for urban and domestic use. We also were involved with the research of how to achieve bioluminescent plants with a bacterial genes group that are the responsible for bioluminescence at the same time.

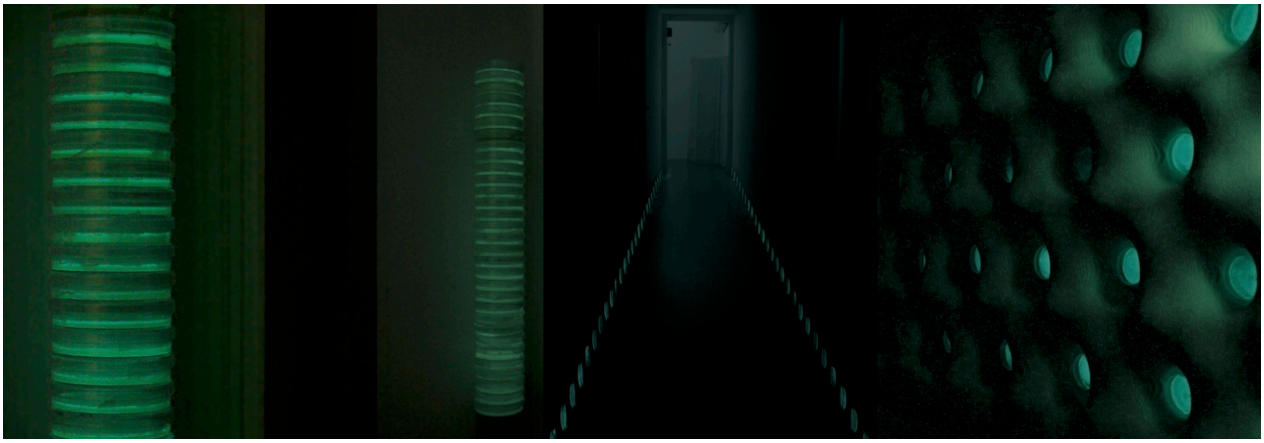

Figure 3. Alberto T. Estévez, "Biolamps": the first systematically fully illuminated apartment with living light (human eye view: photos by the author, taken with a conventional reflex camera).

In this phase, in 2008 we began to create “Biolamps”, a kind of “batteries” with bioluminescent bacteria that are originally found in abyssal fish. With them, we created the first systematically fully illuminated living light apartment without electricity. For the first time in architectural history –without an electrical installation– a whole home was illuminated using bioluminescence. And as in Pandora, it is that the night lighting that we really need, just to “mark” the environment and who circulates through it. It is needless the enormous waste of light energy that we spend today, illuminating things and whole cities. The fact that we dazzle ourselves uncomfortably when seeing a focus already tells us how unnatural our system is. It is enough that things, walkways, remain “marked” with light.

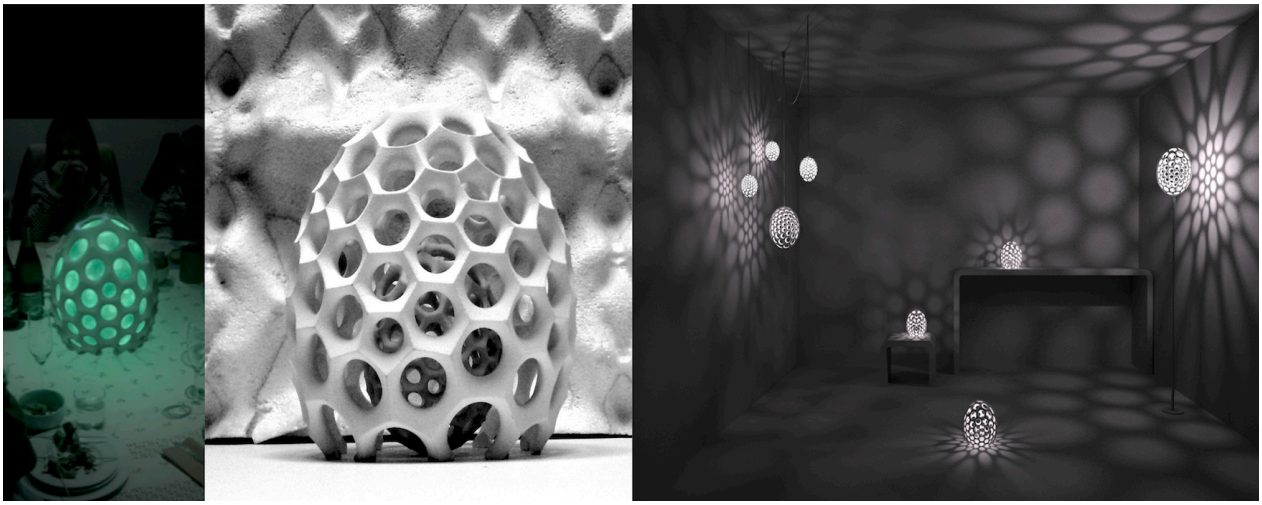

Figure 4. Alberto T. Estévez - Genetic Architectures Office, *Biodigital Lamps Series*, being used as "Biolamps" digitally 3D printed.

The digital design and manufacturing of the Biodigital Lamps Series and their use as “Biolamps” had also begun (Figure 4). These lamps are based on an analysis of radiolarian structures and pollen. This analysis was applied to the digital development of architecture and design, by first using a SEM (we have used it from 2008 to now). This continues along the lines with the idea of “bio-learning”, which offers the benefits of the structural, formal and processual efficiency that we can learn from nature. Using CAD-CAM technology and once we consider that the drawings have reached the desired result, will we proceed to its digital manufacturing, directly on a scale of 1:1. In this case, we can take advantage of

different parts or levels where this technology allows for interscalarity. This allows us to easily change the scale of the jewellery and lamps to that of the pavilion. Research starts by choosing a system and a structural, architectonical, and design idea using geometry in order to draw it. Finally, in order to manufacture this, research with digital machines needs to be carried out with the confidence that "what can be drawn can be built" (Figure 5).

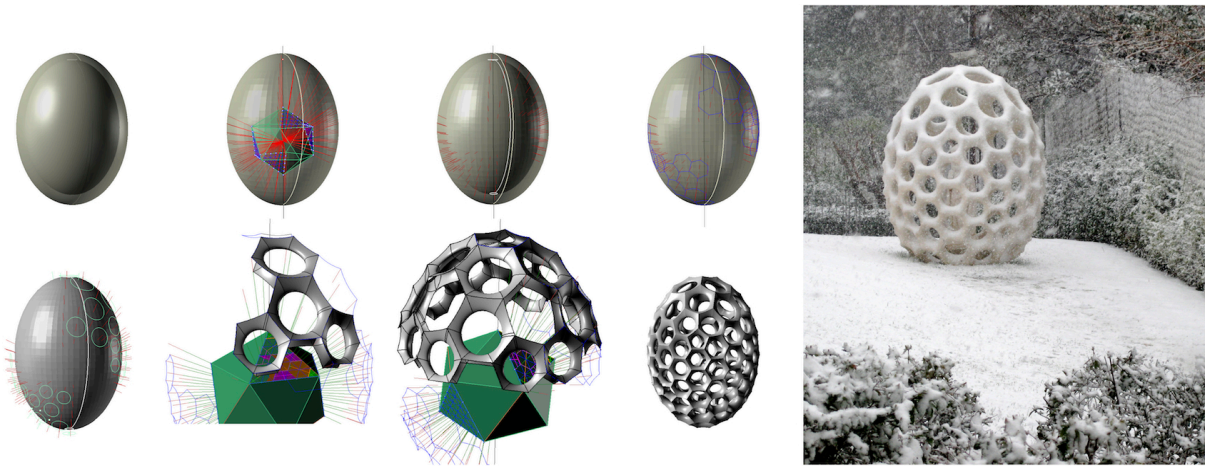

Figure 5. Alberto T. Estévez, *Biodigital Barcelona Pavilion*. Some images of the drawing process, and digitally manufactured pavilion (right, author's photo of the *Biodigital Barcelona Pavilion* and previous drawings with the collaboration of Daniel Wunsch).

Paradoxically, the second phase of this bioluminescence research was very effective for lighting, not as the GFP lemon trees, but too problematic in terms of durability: every 10 days the "bio-batteries" needed to be changed. The other option was fabricating a lamp that could guarantee the required air-tightness, oxygen, and food for the bacteria. However, it was determined that the lamp was too complicated to manufacture compared with a simple bioluminescent plant or tree: our research includes a "democratical" goal, to achieve something for the whole society, not only for those who have high purchasing power.

We are now in the third phase, trying to introduce the genes responsible for bioluminescence in ornamental plants. First, we obtained two stable lines using bioballistics with the plasmid pLDLux integrated into the genome of the *Nicotiana tabacum W38* chloroplast, and we can assert that the expression of the bacterial operon luxCDABE is correct and stable. We have also done the same using bioballistics with different species of ornamental flowers as *Begonia semperflorens, Codariocalyx motorious, Mathiola incana, Dianthus caryophyllus* (Figure 6). However, due to the low bioluminescence provided by the pLDLux vector (probably due to a lack of LuxG gene whose mission is to participate in the turn-over of FMN, flavin mononucleotide), our efforts are now being focused on finalizing a vector of chloroplast transformation possessing LuxCDABEG genes. A work in progress!

Figure 6. Author's photos of the current research with different species of ornamental flowers already genetically transformed, but with too low bioluminescence.

After its presentation in congresses and publications in 2005, 2006, 2007, etc. (1), we can say that the diffusion of this research has been a success. In 2010, the American "Bioglow" company took our idea for producing plants which can illuminate human spaces. Soon thereafter, in 2012, the "Glowing Plant Project" began to search for the same ones (but not without controversy). "Bioglow", led by a geneticist, has also seen this as a potentially powerful niche. The second one, the "Glowing Plant Project", led by a businessman, also saw this as a great business opportunity. Since then there have even been different cases when the forgetful mass media has occasionally come out with the "amazing" news about the "novel" idea of illuminating trees illustrated using Photoshop (2).

Towards the frontiers of knowledge

We can see the enormous potential nature offers us in order to assure a better future for our planet. This is the path towards the frontiers of knowledge. After all these years of work, a big difference remains between what we can imagine and what we can achieve because everything depends on getting money for research.

For example, we have already opened three ways of bioluminescence in order to drastically reduce energy consumption for night lighting and the pollution it produces. We are now at the threshold of a fourth possibility which can be much more effective using bioluminescent fungi (we are preparing the identification of the responsible genes for bioluminescence of *Mycena*, *Gerronema* and *Armillaria*). A fifth possibility is researching bioluminescent yeast which is more experimental and perhaps more spectacular.

This is thereby the beginning of a revolutionary change in the cultural understanding of light, city and architecture. This is also applicable to heat and habitat. What is at the end of the road? The satisfaction of meeting three of the most basic humans needs solved in the most natural and sustainable way: natural light, heat and habitat and living without consuming energy and producing pollution, fuelled by the ancestral power offered by nature. Trees and plants can offer biolight and bioheat through the most natural way for streets and homes; there are even vegetable genes responsible for providing warmth. Imagine living biohouses like trees or mushrooms with inhabitable conditions that can be

purchased in malls; seeds which can be planted in the ground and grow alone; this all opens up an infinite unexplored horizon.

How can we visualize future cities and future houses? As “soft and furry (hairy)” architecture, living cities and houses (Figure 7). As has been said before, the city of the future will be 50% biological technology and 50% digital technology (100% biodigital). Living houses that grow alone, trees that give light at night, plants that provide warmth in the winter: a city that is more like a forest than a landscape shipping containers on the port. After all, where do we prefer to live, in boxes or in 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!

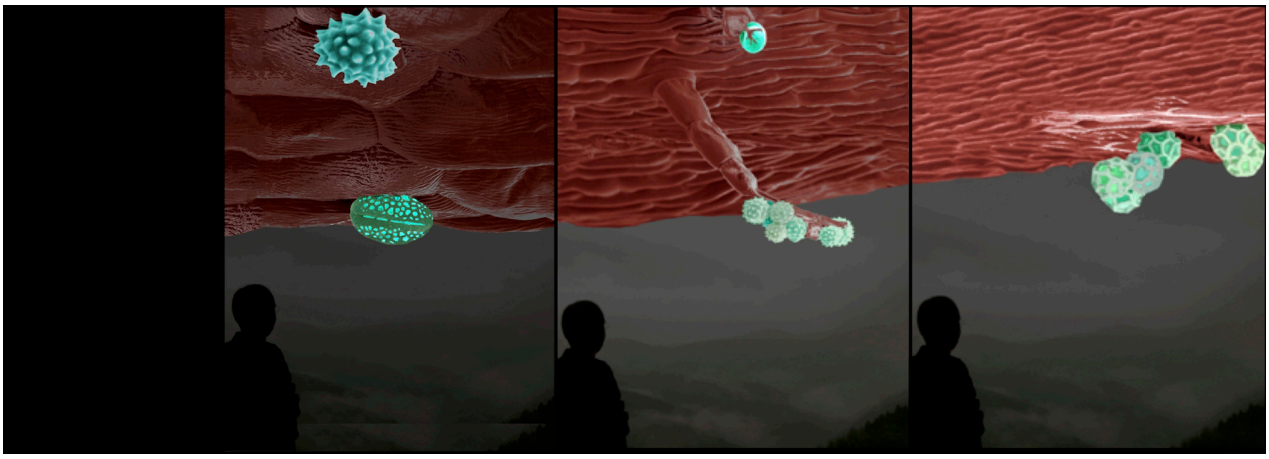

Figure 7. Author’s images of biolamps and bioceilings based on research with SEM (scanning electron microscope).

(Gen)ethics

In our triplet of research-teaching-profession we work from (gen)ethics, yes, from responsibility, too, without forgetting that “humanity has the responsibility to have a future” (*It's not enough! Manifesto*, New York, Autumn 2010), for which we must already urge a non-conservationist vision of nature: the human being in the first instance, need to overcome such vision to survive. It is plasticity the most characteristic feature of nature. To the point that it would be against nature to want to “freeze” life in each of its always changing appearances already known. nature is not an exotic collection of diverse species. It is more the fluidity with which it always presents itself under diverse infinite facets. And the human being is its most powerful vector. “Make it flow!” (*Bioplasticity Manifesto*, Barcelona, Spring 2010).

Genetic research for architecture also requires precautions –by avoiding accidents and contamination– like in conventional medical research, or in simple heart surgery. Science requires responsibility and we are establishing strict procedures for testing in hermetic environments, breeding plants without pollen, or by acting in chloroplast to avoid pollination problems. Our team includes philosophers dealing with bioethical matters, like Dr. Josep Corcó and Dr. Xavier Escribano. We hyphenate the word “gen-etics” meaning “ethics” in our research when the need for planetary sustainability justifies our work.

Nonetheless, from an objective point of view, there is no ethical difference between acting on “the surface of things” and acting at the intramolecular level. Once we accept the organic and fluid configuration of nature, there is, ethically speaking, not much difference between the production of a Japanese bonsai and a fluorescent rabbit. Bonsais are socially accepted even though they are the result of “tormented” living matter, while a fluorescent rabbit is not less happy than a black or white one.

What’s more, the most extreme action would be eating a living being because we simply don’t kill it but instead we make it disappear into our own cells. However, nobody is put in jail for eating a chicken sandwich. Since this applies to even the most extreme action –eating–, it automatically follows that any other less drastic action is permissible, excluding ill treatment.

But of course, if we work with genetic material we must accept our responsibility as illustrated by the “domino effect” that takes place in time and space, and that has been explained using the example of a butterfly. In spatial terms, there is the “butterfly effect”, where the beating of a butterfly’s wings in China is said to be able to trigger a storm in US. In terms of time, we can refer the dramatic book *A Sound of Thunder* (Bradbury, 1953) where a prehistoric butterfly is accidentally killed by a traveller from the future thereby changing life millions of years later.

Precisely, it’s not only our actions on genetic material, but all of our actions that have a corresponding domino effect millions of years later. At least everything is part of nature, but with genetics “a new and vast territory is removed from the realm of randomness and enters into the realm of morality. We are captives of our own competence, of our own capabilities, by which we recreate what we only wanted to represent, or we transgress the natural order that we only pretended to repair” (Rubert De Ventós, 2015).

Kac's affair

Furthermore, the way Eduardo Kac explains his work should be approached in terms of ethics. He defined Transgenic art as “a new art form based on the use of genetic engineering techniques to transfer synthetic genes to an organism or to transfer natural genetic material from one species into another, to create unique living beings” (Kac, 1998). The only wrong and confusing aspect of this definition is the word “unique”, like when he claims to be some kind of God-Creator and oversteps the definitions that humans have agreed on. This transgression does not do science any favors. The account that he likes to offer in public (like the following excerpt from an interview) does more harm than good:
– “it took –seven years!– of work on the Edunia petunia before I managed to introduce my own DNA into it. (...) I put my DNA into its ‘veins’, and now it is producing my human proteins. The green phosphorescent rabbit and the “plantimal” aren’t nature… I created them! (...) With Alba (2000) and the plantimal Edunia (2003), I also relieve God of his status as a creator-myth and turn him into a lab worker, a technician working in a transgenic workshop.”

– “You don’t seem very humble.”
– “I don’t copy reality: I create it” (Amiguet and Kac, 2012).
It has a negative effect that somebody with a strong presence in the media speaks without any scientific accuracy demonstrating terminological and ideological confusion. In addition, the necessary clarifications and criticism below are not arguments taken from the author’s subjective point of view because they have a background that is substantiated by the previously mentioned scientists, geneticists and philosophers in our research group:
· It is not true that he spent seven years on this project, it simply took seven years to happen.
· It is not true that he inserted his DNA into the plant, it was more like having a “microbrick” inserted into an enormous set of many thousands of “microbricks” in any case, this “microbrick” is identical to the ones that we all have and it is not in any sense specifically or uniquely “his”.
· It is not true that the resulting plant produces “his” human proteins. Rather, it produces human proteins that are chemically identical to those of any human.
· It is not true that by inserting a gene taken from an animal into a plant, it becomes a “plantimal”. Just like a virus can mutate our cell’s DNA and cause a tumour, this does not make us a “humanirus”.
· It is not true that the rabbit and the plant in question “are not nature”.
· It is not true that he created this rabbit and this plant.
· It is not true that he relieves God of his status as a creator-myth and turns him into a lab worker, a technician in a transgenic workshop, because the common definition of “God” – as human agreement– includes he who “creates from nothingness”. Genetic manipulation simply involves repositioning existing “microbricks”.
· It is not true that he “creates reality”, because the gene that he integrates into an enormous pre-existing genetic structure already existed before. Therefore, he doesn’t create a single gene, he simply changes its position.

Basically, by inserting a gene from another being into the rabbit and the plant, they did not cease to be “natural”; they did not cease to be nature. This gene “repositioning” has been carried out anonymously by the pharmaceutical and agricultural food industries long before Kac’s projects, with more complexity and implications, and on a large scale.

Deconstructing nature

However, this emergent character of life is what humanity has to take advantage of, and this is why we are interested in investigating how genetics can be applied to architecture. The idea is to take advantage of nature’s capacity for self-organisation, growth and reproducibility “for free”. Therefore, we look for plants that emit light or heat and will help find the energy saving mechanisms that our world needs, that will be usable as construction materials and even as entire habitats. We can begin to imagine, in a not so distant reality, “streetlights”, “heaters”, and even entire houses that grow on their own.

Given that this research also focuses on the use of genetics, we can also consider possible architectural uses at the level at which undefined cellular masses emerge and self-

organise, as the first structural step: research on the genesic level where masses of cells organize themselves into primigenic structures, in order to find structures and to learn typologies that could be of interest for architecture, below illustrated as an alternative landscape of the future. We are study this with a SEM (scanning electron microscope), which has an extremely high resolution allowing to us see images magnified thousands of times. This opens up a little-known dimension of reality, which, depending on how the images are read or interpreted, can lead to a fascinating level of surreality (Figure 8). As a result of research carried out in this framework, it was possible to create strange and surprising new images: “altered” photographs of natural structures at their most Genesis-like and primitive level. Artistic works and architectural plans based on biotechnological work that have an enigmatic evocative power. Always justified for being behind the first laboratory’s effort that began the real application of genetics to architecture, fighting for the sustainability of our entire planet and a better world.

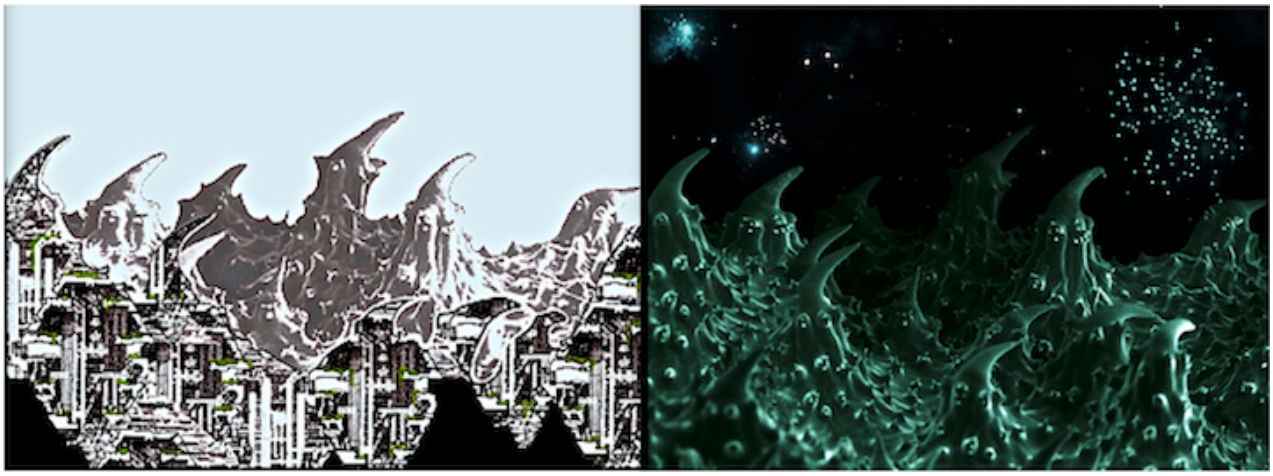

Figure 8. Alberto T. Estévez, *Living city*: the enigmatic evocative power of SEM images (author’s images).

To conclude, describing the future development of our work and providing a reasonable projection of the research into future applications, it can be said that the equilibrium of our planet –for our own survival– needs several things: accurate and precise reset of our behaviour, education, our basic habits, food, our ability to manage waste, and consumer goods. For example, we have to get used to the idea that we don’t need so much light at night (our eyes have a wide range capacity that we don't use) like we put on a sweater if it is cold.

Consumption of energy must be radically reduced: a middle-sized European city of only 100 km^2 spends 10 million Euros annually just on the maintenance of its street lights (new lamps, repairs, repainting) in addition to electricity consumption. If multiplied by all the cities on the five continents, the figure is absolutely astronomical. Therefore bioluminescence will substitute artificial lighting, at some levels; there is no doubt about that. Nature is always teaching us, in this case with in many bioluminescent ways, from bacteria and plankton to algae, fungi, insects… It would be like suicide for the next generations if we didn’t learn about it.

And this is only a fraction of the possible scope of the application of genetics for

architecture and design. When the architect stops needing conventional construction industries and starts working with geneticists, who are the bricklayers of the future, we may design evolving science, architecture and design collaborations where genetics becomes integral to architectural research and production, with infinite possibilities.

The research into 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 becomes 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).

Learning from nature, also for beauty

Everything that has been explained so far comes from bio-learning. And bio-learning –of course– is contained in “learning from nature”. Although the preposition used provides nuances: learning “from” nature also means learning “with” and learning “in” nature, even “knowing nature” itself, without any preposition. Each expression has its significant nuances, which should not be discriminatory, but enriching when considering them as an interactive interrelated whole. This understanding leads to define genetic architecture as something that is no longer about building “in” nature, but building “with” nature, and even building nature itself, equally without any preposition.

On the other hand, it has been confirmed that nature is an eternal mirror for human aesthetics, as well as for its aspirations. Generation after generation, nature never becomes obsolete and it never tires. It has always been, is and will be, as perennial as an open book, unique and indivisible. Nature is an inexhaustible source of inspiration, imitation and/or learning. Biodigital architecture and genetics, defined as directly involved in its incardination “with” nature, thus ensures aesthetic “durability”. It could even be said that it is a guarantee of “classicity”, and adapts to the times. Even more so when new techniques open up new fields that are still unexplored. We are living a great epic and heroic age. It is an age of opportunities where the brave and daring will launch themselves onto the unexplored and become the pioneers of the biodigital and genetics age.

Thus, the closer the processes of architectural creation are to nature, the less obsolete and more “eternal” the result will be. It is necessary to listen to the language of nature and reply to it coherently if, in the end, nature and the entire universe are written in mathematical language, as Galileo Galilei suspected. We are talking about languages that are always valid and reduce the arbitrariness of our decisions when harmonising them. Thanks to digital tools, this provides us with control, efficiency and a harmonious accuracy that enables us to exclude arbitrariness as much as possible.

Everything can indeed be solved by learning (in depth) from nature. At all its levels, from the most “internal” and intra-molecular one, accessible today thanks to genetics, to the most “external” and superficial one, which has also been imitated by human beings from the moment they came into existence. It is not a coincidence, for instance, that human

beings are attracted to the sight of the air (clouds, smoke), water (the sea, waves), earth (rocks under the action of water and wind, geological crystals under the action of physical and chemical processes), and fire. It furthermore coincides with the four roots of Empedocles, the four primitive elements, which confirm how their changing forms permanently remain configured by actions or laws that affect the whole as well as every part alike. Architecture and design, which also follow similar laws, equally evoke a similar attraction: something invisible to the human eye that "from the inside floods" each cell, its entire appearance and even its most remote corners (continuity). It resounds in all its parts, configures the whole (Alberti's *concinnitas*) and inevitably controls its constant evolution (emerging system).

Why do we like looking at clouds (air), waves (water), cliffs (earth), bonfires (fire)? We never tire of them, as they calm us, attract us and we all agree we perceive beauty, "objective beauty" in them. Furthermore, as they move, our interest becomes addictive. Their shapes do not bore us and because of their complexity, because they change (without us moving), they even surprise us. When each and every part responds to the whole, because of objective laws, physical and chemical determinants, genetic ones in the case of living beings that need to carry out specific functions; when "each part is reflected in the whole and the whole is reflected in the parts" (the most classic definition of beauty), an organic, organised continuous, coherent, united connection exists; when each and every one of these words turns into a value for architecture and design, always moved, created by common external physical-chemical forces and/or internal ones driven by DNA.

When the determinants are almost purely and exclusively genetic, or at least still mostly genetic, when the consequences of a specific diet, habits, climatology, a specific and distinguishing genetic inheritance, or whichever other random external determinant, are still not completely reflected, it is then when the emerging character of life driven by DNA "clearly shows" its own force more: it is then when unanimous, spontaneous and popular qualifying adjectives such as "cute", "lovely", "sweet" are on everyone's lips, something common when ones sees a puppy or a baby.

All this supports the "objective beauty" Antoni Gaudí talked about, when something has certain characteristics that make the definitions of beauty comply and that, in addition, coincide in qualifying it as such. However, in the time of Antoni Gaudí genetics did not exist and he therefore did not know about the consequences of the "natural computer", which is DNA. And, of course, he did not have any digital computers that could organise a complex and united whole, and at the same time measure it with absolute accuracy and control it. This is why he had to invent his own non-digital computers: catenary ropes hanging freely in space, which, thanks to the strategic position of little sachets filled with lead, could simulate to scale the real loads the building would have to support, ordering its lines "automatically", "parametrically"; lines the author did not directly and with pinpoint accuracy decide upon, but rather the "computer" supervised by him to configure an objective, harmonious, mathematical beauty.

“Objective beauty” thus turns into “necessary beauty” when it becomes a human need and a duty of architects and designers towards humanity. Willing to create architecture and design in an equally complex way, that cannot be used up in the blink of an eye, nor be understood in a second, where every point of view is different (as we are the ones that move) and therefore awakens interest and responds to a coherent whole at the same time. It is nature that shows us the way to create and develop it...

Conclusion: Integral Ecology

The four life-supporting elements are exactly this, supports of the fifth element, life! Understood at the same time in a literal sense and in a metaphorical sense. Paradoxically the four elements need the fifth element to be activated as life-supports (the fifth element, life, intelligence, knowledge… call it whatever you want). 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 save life.

And, 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, one which simultaneously consider as an indivisible whole 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 aspects of the planet –physical, chemical and biological– are interrelated, so too living species are part of a network which we need to explore and understand, and genetics is the most advanced tool. 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, included in it and thus in constant interaction with it. Recognizing the reasons why a given area is polluted requires a study of the workings of 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 to protecting nature and at the same time combating poverty.

We, as architects and designers, have the personal responsibility to achieve a vision of architecture 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, as an approach to architecture and design, itself 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 for really solve problems (Figure 9).

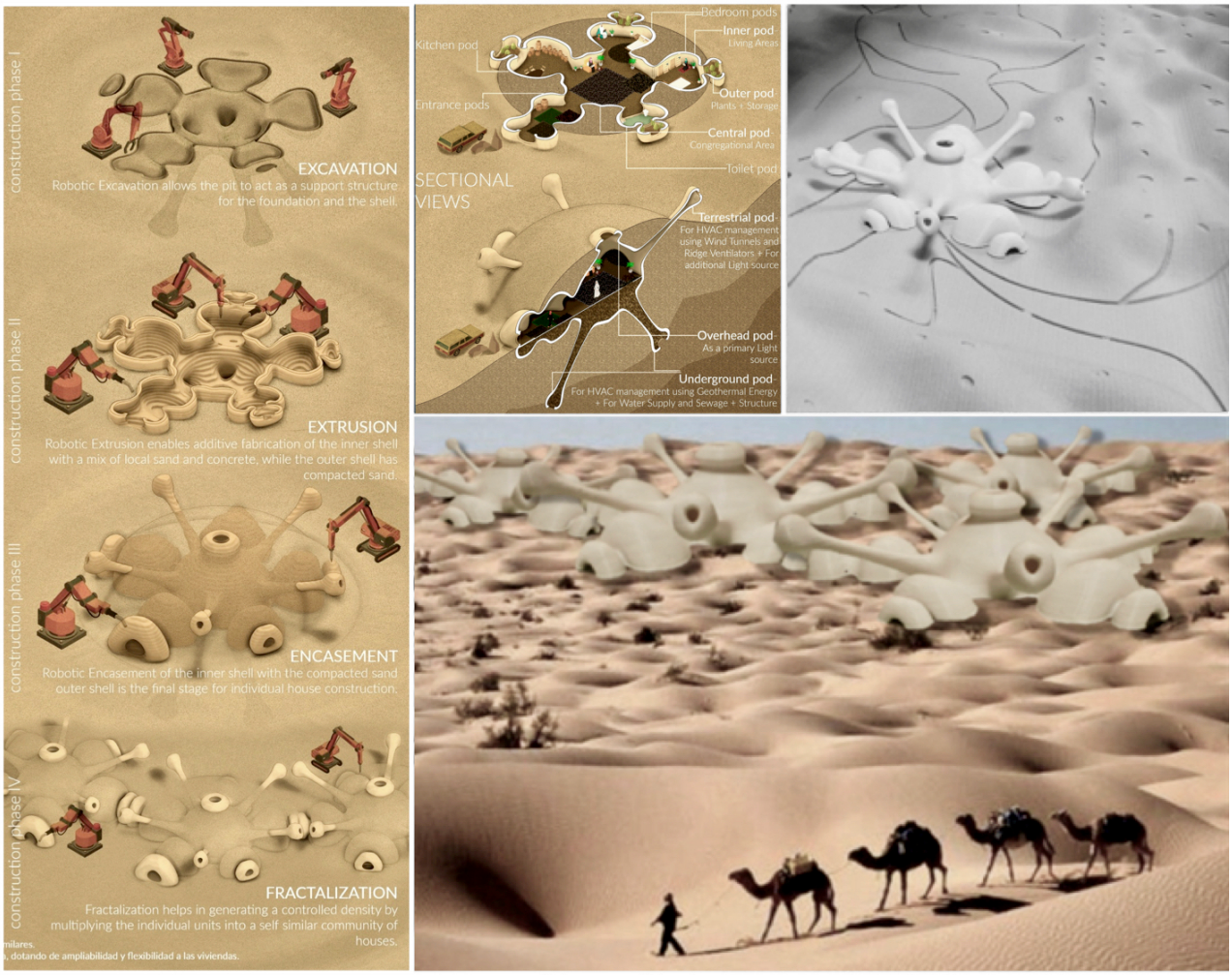

Figure **9.** Alberto T. Estévez - Genetic Architectures Office, *3D Printed Sahara House Project*, 2017. Integral ecology example, digital design and digital manufacturing, on-site, using the desert sand itself, abstracting in the conception of the project elements of the vernacular architecture typologies, with building climate control by means of passive systems.

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 existing a great responsibility in terms of politics both at an international and a local scale. Ultimately, when it is convenient to have a new lifestyle. This is all what the *Zeitgeist* calls us to do.

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, we will find together a real salvation of our beautiful Blue Planet.

Notes

1. For example, see ESTÉVEZ, Alberto T. "Genetic Barcelona Project". *Metalocus*, n. 17. Madrid, Fall 2005, pp. 162-165; ESTÉVEZ, Alberto T. "Genetic Barcelona Project: Cultural and lighting implications". *Urban Nightscape 2006*. Athens: International Commission on Illumination, 2006, pp. 86-88; DOLLENS, Dennis and ESTÉVEZ, Alberto T. "The genetic creation of bioluminescent plants for urban and domestic use". *Leonardo*, n.40 (1), February 2007, pp.18 and 46.

2. For example, see Paul Rincon, *BBC News*, 24th January 2013, about a team of undergraduates at Cambridge University; Alexandra Daisy Ginsberg, *Restorative Design*, 9th May 2013, about the Massachusetts Institute of Technology; Katherine Brooks, *Huffington Post*, 30th March 2014, about a Dutch artist/designer/architect; etc.

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