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Prefabricating with Natural Elements. Eco-materials in the Age of Mechanical Reproduction[1]

Juan Carlos Bamba
Alejandro Jesús González

Prefabrication of natural resources builds a bridge that links agriculture with architecture, turning natural fibers into sustainable construction materials. The current research assumes natural resources as inexhaustible sources for architecture, suggesting the construction of emergency shelter prototypes built with eco-materials and taking them to their limit in extreme climatic conditions. The results generated out of the prototypes allow the evaluation of the mechanical, physical and chemical behavior of these eco-materials. Progressive improvement of the prototypes is aimed at the implementation of these eco-materials within the construction industry.

FROM AGRICULTURE TO ARCHITECTURE

The structure of the current report is based on the actual nature of the research, that is, the need of understanding the production of both prototypes as a process of progressive improvement of the characteristics of the prefabricated components and their adaptation to the specific conditions of each place. First, the premises of the research will be presented and the key characteristics common to both prototypes[4] will be described to subsequently establish a comparison that refutes false opposites and redefines the possibilities of prefabricated eco-materials within the housing industry **(figs. 02 and 03)**.

The lack of resources, the unrestrained exploitation of nature, the growth of population, the need for food and housing, and the technological advances have guided architecture towards the exploration of ancestral practices -towards "the primitive", but with an ability to mass-produce through prefabrication processes- "the future"- [5] linked to the basic needs of human beings; agriculture and architecture approach each other: food and housing. Natural resources are harvested as raw material and turned into construction materials through different processes. Human beings separate food from waste, and by recycling, this waste is given constructive value and a role in environmental protection.

This research project relies on the utilization of natural fibers, most of them discarded in agroindustrial processes, to develop new products for the construction industry -eco-materials- that are as useful as the conventional materials. It aims to innovate through traditional craftsmanship, to recover the "technology of what is necessary" mindset, but using prefabrication and standardization processes of raw materials into eco-materials that can provide solutions for contemporary housing. The use of natural materials to produce eco-materials for the construction industry seems to be the necessary tool to tackle two problems at the same time: massive demand of economic and sustainable housing, and waste of valuable natural materials.

In this research, what is considered "natural" is the group of "free raw material"[6] that can be classified according to their origin: "inexhaustible resources", those that can be harvested (bamboo, hay, cattail and loofah), "local materials", those that are mineral and inorganic and they are found in the same construction area (volcanic rocks at Mount Chimborazo and snow in Antarctica), and "waste material", those resources discarded after extracting food products (rice and corn husks, banana trunks, coconut shells and corn shanks) **(fig. 04)**.

With the "prefabrication of natural materials" as a medium of approximation to agriculture, architecture will gain access to unlimited resources, where nature will provide for the physical, mechanical and chemical requirements for the construction of habitat for human being. The complex process of transformation of raw materials into material is ecological in each phase (treatment, drying, extraction of fibers, gluing, pressing, and panelization) so the final product can be regarded as genuine eco-material **(fig. 05)**.

FROM TRADITIONAL CRAFTSMANSHIP TO MECHANIC INDUSTRIAL PROCESSES

The design process of the prototypes, just as the prefabrication process, is empirical and systematic. Each piece of the shelter is built in the factory so it can be tested; manufacturers make sure that the characteristics and measures are adequate for the conditions under which they will be put at test. In this way, mistakes and problems in construction can be detected and fixed in the design of the prototype. Therefore, this project is constantly being modified in accordance with empirical results to adjust it to the established construction requirements.

Conversely, this process, which solves the problems in the project, must be systematized to produce a manufacturing chain inside the factory that provides precise measures and mechanized steps. This systematization is a step added to the manufacturing process so it reaches the stage of prefabrication of standardized components or materials: we call this process "prefabricating with natural elements". The standardization of the measures of the elements of each module and the modulation itself, which is aiming at possible growth, allows to systematize the prefabrication process in the factory, which, yet being a research laboratory, acts as a drill for potential massive production in the construction industry. Therefore, the design process of the prototype shelter in the eco-materials factory is not linear, but empirical and systematic.

Ecuadorian construction, through the traditional craftsmanship that has been inherited in some communities, takes advantage of natural resources and uses them in their local architecture construction systems. In the Coastal Region, specifically, there are many natural fibers, originated out of traditional crops such as toquilla straw, palm leaves and bijao; clear components of the vernacular architecture which have solved housing issues through history. According to Desplazes, in the "construction of architectural projects as a growing chain"[7], the following steps take place: raw materials, modules, elements, structures, and the final construction. The manufacturing process turns the "raw material" into construction material as with bricks ("module"); prefabrication (or "*semifabrication*" according to Desplazes) involves optimized, systematized and standardized

processes that accumulate more energy and generate components as with the eco-material panels or with bamboo fans ("elements") **(fig. 06)**.

Prototype # 1 is produced within this framework of prefabrication, from specifics; the natural resources, the traditional craftsmanship ad the local workforce recover the cultural heritage of an entire region -the Highlands- , which knows the material and knows how to work with it. Desplazes also assures that the weave of the fibers before the panel pressing has a connection with textile art, which is the "original art" as a tectonic principle of the lightweight construction in the primal handicraft of men. The value of "handmade products" opposite to the industrialization of them, leads architecture to reduce its production, its precision, admits errors and variations, and replaces quantity with quality **(fig. 07)**.

FROM IRREDUCIBLE SPACE TO EXTRA SPACE

Prototype # 1 is conceived from the perception of the minimum space required, an irreducible space, with a capacity of four people, frontal and direct access from an outside staircase, with double door (outside and inside with a window) separated from the ground by a gabion superficial footing system, which protects it. The irreducibility of an object is the property of not altering its design unless something essential is taken away. When lacking resources, "the architect must produce as many solutions as possible. Architecture is similar to synthetizing: to say what one wants to say, but using two words instead of three, to solve the problem with the smallest amount of possible movements"[8] **(fig. 08)**.

Once the irreducible natural space has been defined, prototype # 2 seeks to build security levels through "extra space"[9], flexible and hybrid, which allows safer indirect and lateral access. Since it is a shelter in a hostile environment, where it is difficult to provide assistance, it needs the security of the workforce and the materials to protect it while being built. Thus, the concept of "the shelter of the shelter"[10] emerges as another condition. Besides, assembling and dismantling simplicity of the flexible structure of the second prototype allows the users to provide ideas for its design; the person adapts the space according to their personal needs. This is an idea already mentioned by Yona Friedman in her book *Ville Spatiale* in 1956: "architecture must provide a reference framework where the inhabitants build their homes in accordance with their needs"[11], or Habraken in his "theory of supports"[12] with the open participation of the inhabitant in their shelters. The incremental system enhances the programmatic modules by integrating new functions to the shelter, also extending its capacity and improving its facilities **(fig. 09)**.

The stability and permanence of the irreducible natural space of the first prototype contrasts with the growing and ephemeral character of the second one. These different characters are expressed clearly in constructive and structural logic, this is, the relationship between the structure and the enclosure of both prototypes. In the first one, the structural logic is similar to a "shell", or the internal structure of a bamboo fan (irregular and deformable), this means that the enclosure -the natural panels- in this prototype are structural: they match the enclosure. In prototype #2, the structural logic is similar to an "exoskeleton", with steel frames (regular and rigid), which protects the natural panels that couple it like a piece of furniture: the structure does not match the enclosure.

FROM "GENIUS LOCI" TO A MOBILE ARCHITECTURE

One of the conditions determining prefabrication more precisely is the capability of the prototype to be assembled and dismantled, whilst adaptability and durability is determined by the place. Architecture must supply the needs of the preexisting context where it was implanted, until it reaches the balance and the spirit of the place: the "genius loci"[13]. When the area where a structure is going to be built is unknown, when the place does not establish the project, it is not determined by the conditions of the place, and it needs to be adaptable to many conditions in different possible locations (atopic objects[14]).

Prototype #1 is characterized by its relation with the Chimborazo volcano, the location, the access roads, the previous shelter of the Guardian and the connection with the ground through a superficial gabion foundation filled with volcanic rock. Its architecture should be represented by the landscape, whose unique and necessary location determines the prefabrication system of the natural resources and at the same time defines the assembling and dismantling process, with the intention of making it last for long without changing its location **(fig. 10)**. Prototype #2 is not determined by its exact location. The fact that a specific place in the Antarctic islands is not necessary, the obligation of not invading or impacting the land, and the logistic difficulties to transport materials far from the "Pedro Vicente Maldonado" base made researchers think of mobility solutions. Linked to the need for providing opportunities to scientific researches so they are able to change their location, the project is divided into three movable units that can be transported together (train) o separately (sled) and it is possible to carry, dismantled and saved, the rest of components of the shelter. Dismantling, transportation and adaptation to the user determines the mobility capacity of the unit **(fig. 11)**.

FROM BOX TO CASE

In in-situ constructions the processes are dilated with time; a total plan of the project is required so every agent intervening in the project understands it; the final product depends on the constructive process and the precision in its execution; logistics can be altered during the process due to the margins of time. Prefabrication works along with precision and quality control of the product obtained, the construction deadlines are reduced, the modulation and measures of parts are adjusted to the endless and varied needs of the inhabitants and to the manipulation of the assembly and dismantling of the components of the unit. In prefabrication, transportation logistics, after manufacturing of the parts, determines the design, the utilization of resources and the constructive system. This is another stage in the project: the constructive process starts with logistics.

In a scenario where the point of production is close to the point of construction, logistics does not determine the process. Transportation by land to the building site is carried out in trucks chosen according to the dimensions of the components. Once the prototype has been designed and manufactured, a container capable of carrying all the components is selected; this means that the size of the components is not predetermined by the size of the container **(fig. 12)**. In the second prototype, logistics is part of the project generators: it determines the design, the cutting, the assembling and dismantling. The prototype must be adjusted to the space of a twenty-foot container, which will be transported by water from Guayaquil (Ecuador) to Greenwich Island or Dee Island (Antarctica). This implies a reduction on the size of the prototype components, which must be designed according to the dimensions of the container **(fig. 13)**. In this sense, the containers or the logistics and consequently the logic of the prototypes could be classified according to the simile often used when talking about housing: the box and the case; the container heading to Chimborazo would be the box and the one heading to Antarctica would be the case. Ignacio Patricio says:

> "The case is a protecting package which is adjusted to the shape of the object inside. The strict shapes of lens or even cutlery are reproduced carefully in the case. (...) The box, on the other hand, is a featureless protecting wrapping which can carry many objects"[15].

In the case of this research, the process is reversed and it is related to the kind of vehicle carrying the prototype. Prototype #1 has been projected for a "box" which could contain great diversity of elements related to the size, shape and location inside the container, whilst prototype #2 was conditioned by the size and shape of the twenty-foot "case", which was assigned for the expedition of the INAE in Antarctica.

BETWEEN THE UNIVERSALITY OF MECHANICAL REPRODUCTION AND THE SPECIFICITY OF VERNACULAR CONSTRUCTION

Reflections on the current essay lead us to establish connections with the idea of "mechanical reproduction" proposed by Walter Benjamin in his essay "The Work of Art in the Age of Mechanical Reproduction":

> "One might generalize by saying: the technique of reproduction detaches the reproduced object from the domain of tradition. By making many reproductions it substitutes a plurality of copies for a unique existence. And in permitting the reproduction to meet the beholder or listener in his own particular situation, it reactivates the object reproduced. These two processes lead to a tremendous shattering of tradition"[16].

With this thesis, the identity or "aura" of the "original" object that could be similar to the local or handcrafted products is distressed before the "manufactured" object, which loses that quality and gets closer to the global or industrialized architecture: the ideal of perfect architecture with an "international style" encouraged by the image of the machine and the possibility of rationalizing and standardizing everything. In contrast, "sensitivity to vernacular values" according to Terrados is one of the ways of "informal" attitude in the production of architecture:

> "Efficient and productive use of limited resources often flows out into informality. Imperfection, management of composition collage techniques, *already made* culture and the double and triple interpretation of multipurpose elements"[17].

On the one hand, a state-of-the-art attitude before technology, which understands it as an invisible entity; on the other hand, an emphasis on the local and specific needs, not only regarding users but also implementing elements that are responsive to specific weather conditions. As mentioned before, this is about the dialectic that confronts these two opposites: the trinomial that states the global industrialized architecture "form+style+visible technology", against the duality of the local vernacular architecture "user+invisible technology". Prefabrication of natural resources as an integral means to solve housing issues in developing countries such as Ecuador refuses these false opposites and establishes the fundamentals not only for scientific and strict, but also for sustainable and social architecture, which solves the housing problems and the lack of resources.

Prefabrication of natural elements reviews the current economic and political situation in the Latin-American context, and it also studies the possibility of taking advantage of natural resources produced by mankind for their consumption, as a basic need, in the manufacturing of natural materials that enables the construction of decent and sustainable dwelling. The products and techniques used by men for feeding are reinterpreted and applied in their protection and shelter.

Eco-materials in the age of mechanical reproduction present a new scenario of reflection about the value of handicraft when it is taken to industrialization due to social needs. In a context of increasing social inequality, it is necessary to link the country with the city, agriculture with architecture, craftsmanship with manufacturing. This is also taken as a relevant instrument in politics because it deals with the problems of the "new urban situation"[18]

A third industrial revolution, based on the theories of communication and renewable energy, sustains this research in its temporal context, from human need for finding solutions for housing needs of society. A contemporary redefinition of the relationship between agriculture and architecture that changes the process of going from craftsmanship to industrialization **(figs. 14 y 15)**.

Juan Carlos Bamba
Architect from the Technique School of Architecture of Seville and Master in Advanced Architectural Projects from the Polytechnic University of Madrid where he is currently a candidate for the PhD in Advanced Architectural Projects participating as a member of the Research Group NuTAC. He is currently a professor and researcher at the Faculty of Architecture and Design of the Universidad Católica de Santiago de Guayaquil where he is the Coordinator of the Master's Degree in Criticism and Advanced Architectural Project and Coordinator of the Research Department. Recently winner in the category of International Architectural Design at the Bienal Panamericana de Arquitectura de Quito with the project "Cabañón DLPM". He is a member of the Editorial Board of the DOMUS Magazine, Ecuador.
Orcid ID 0000-0001-6395-1565

Alejandro Jesús González
Architect, Master and doctoral candidate in Advanced Architectural Projects by the School of Architecture of the Polytechnic University of Madrid. He has practiced in the Netherlands, Spain and Ecuador. National and International Award in the BAQ2016. Professor and researcher at the Faculty of Architecture of the Catholic University of Santiago de Guayaquil. Director of research in the project Ecuadorian Antarctic Refuge (RAE). Active member of the ARKRIT group in the ETSAM, UPM.
Orcid ID 0000-0003-2187-5378

Notes

01. The title refers to the essay "The Work of Art in the Age of Mechanical Reproduction" written by Walter Benjamin between 1935 and 1936, which was an organized group of theses regarding art and its relationship with technological changes.

02. Ecuadorian Antarctic Refuge (RAE) is a research project subsidized by the SINDE (System of Investigation and Development) of the UCSG with a budget of USD $172.712, developed from 2015 to 2018 by 18 researchers (teachers, students and freelance professionals) whose objective is to build a refuge for Ecuador in Antarctica.

03. The Eco-materials Academic Research Unit is part of the IHADIC and belongs to the Faculty of Architecture of the Catholic University of Santiago de Guayaquil. It is in charge of developing research through experimentation with different kinds of natural and recycled fibers, such as guadua, and residual fibers produced by the agroindustry such as rice husks, coconut coir, banana, corn, abaca, and so forth. The unit has some patents registered in the IEPI system.

04. The Guardian of Mount Chimborazo (prototype # 1) is the first prototype refuge of the research project located on the Chimborazo volcano (Ecuadorian highlands), at 15912.07 ft. above sea level, which allows monitoring its effectiveness in extreme weather conditions. The Ecuadorian Antarctic Refuge (prototype # 2)4 is a refuge prototype proposed to be built in Dee Island, located in Antarctica, at 0 ft. above sea level, in front of Greenwich Island, where the Ecuadorian station "Pedro Vicente Maldonado", of the INAE, is located. Prototype # 1 has already been built on Mount Chimborazo and prototype # 2 has been assembled and dismantled at the university to verify the assembling process and it is ready to be transported to Antarctica as its final location.

05. "Primitive Future" is the *leitmotiv* of architecture that projects Sou Fujimoto in the homonymous book: an opportunity to learn from the an-

cestral techniques used in the past to project the architecture of the future.

06. See the article *Technology of what is free. Taking advantage of the discarded natural fibers as construction materials* published at "The power of the skin. New materials in contemporary architectonic projects" organized by COMPAC The Surfaces Company and the research Group ARKRIT of the Technical University of Madrid.

07. DESPLAZES, Andrea, *Changing the architecture of raw materials into a building, A manual*, Barcelona, Gustavo Gili, 2010, p. 12.

08. KIMMELMAN, M., (June 8th, 2016), *Interview with Alejadro Aravena -Alejandro Aravena, architect who saved an entire country,* New York, USA, New York Times.

09. Term used for describing certain spaces of the architecture of Lacaton and Vassal in the text of Ilka and Andreas Ruby called "Extra, Extra Large Space" which appears in the introduction of the book *2G Book Lacaton & Vassal.*

10. This concept facilitates fast assembly of the metallic structure, which is the skeleton of the prototype, and then it is necessary to cover it with a plastic poncho that instantly generates space to protect construction materials and tools from inclement weather, start assembling the panels of the shelter with the workforce already protected.

11. Abstract of the text "Ville Spatiale" included in the manifesto *L'architecture mobile* that Yona Friedman presented in 1956 at the International Congress of Modern Architecture n. 10 held in Dubrovnik, Croatia, published and translated years later.

12. Habraken, John, *Design of Supports*, Barcelona, Gustavo Gili, 2000.

13. In modern architecture theory, the "genius loci" has profound implications in the projection of public spaces and it is linked to the philosophical branch of phenomenology. Christian Norberg-Schulz in *Genius Loci. Approximation to an architecture phenomenology,* talks about the importance of the environment of the place.

14. According to Antonio Miranda in *Neither Robot, nor jester* design is the "graphic creation for the manufacturing of atopic objects without a specific place, and prototypes. The architecture project, conversely, refers to the construction -not the creation- of objects for a specific place.

15. IGNACIO, P., *Building habits. Alternatives for housing: from the case to the box.* Live Architecture, 49, 1996, pp. 20-21.

16. BENJAMIN, W., *The Work of Art in the Age of Mechanical Reproduction and other texts*, Buenos Aires, Godot, Argentina, 2012, pp. 28-29.

17. TERRADOS, J., *Lightweight Habitat Prefabrication. New premises,* Sevilla, University of Sevilla, publications bureau, 2012, p. 183.

18. SECCHI, B., *The Rich City and the Poor City,* Madrid, La Catarata, 2014.

Images

01. Doors open of the "Guardián del Chimborazo" (prototipe #1).

02. East facade of the Ecuatorian Antartic Refuge (prototipe #2).

03. Southwest facade of the "Guardián del Chimborazo" (prototipe #1).

04. Gathering of raw materials (rachis, coconut, lechuguin and corn husk) in the Ecomaterials plant of the UCSG.

05. Samples of panels 50x50x5 cm(from top to bottom): páramo straw, large loofa, totora, banana rachis, abaca, tiny lufa, abaca residue, coconut fiber, rice husk, wool residue, and balsa residue.

06. External abaca skin of the "Guardián del Chimborazo" (prototipe #1).

07. Protective galvanized bamboo mesh in the Ecuatorian Antartic Refuge (prototipe #2).

08. Floor Plan of the "Guardián del Chimborazo" (prototipe #1).

09. Floor plan of the Ecuatorian Antartic Refuge (prototipo #2).

10. Access on the southwest facade of the "Guardián del Chimborazo" (prototipe #1).

11. Access on the eastern facade of the Ecuatorian Antartic Refuge (prototipe #2).

12. Landing of materials of the "Guardián del Chimborazo" (prototipe #1).

13. Container of the prototypes components of the Ecuatorian Antartic Refuge (prototipe #2).

14. Doors opened of the "Guardián del Chimborazo" (prototipe #1).

15. Ecuatorian Antartic Refuge (prototipe #2).