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Coherence and contradiction in Prefab Modular Aggregative Systems

Early experiences of organic growth based on the addition of prefab cells

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Synopsis

Technology has been a fundamental factor in understanding the great social changes that took place during the 20th century. The progress made in the implementation of industrial organizational processes led to a quick development of aeronautics, the automotive industry and, to a lesser extent, construction. The application of industrialization techniques to the collective dwelling generated new formal compositions and architectural theories. Occasionally, idea and construction have advanced together (coherence), developing buildings based on the aggregation of prefabricated three-dimensional cells. In other cases, some projects tried to replicate the proper forms of three-dimensional modular aggregation, without using the characteristic technology that generates these forms (contradiction).
This paper analyzes the relationship between the architectural concept (idea) and the technological system (construction) in post-war prefabricated housing buildings. Different compositional (shape) and structural (matter) models are identified, and the concept of “basic prefabricated module” and its variants are defined: geometric (modular frames), functional (housing unit) and / or constructive (cell or capsule).

Key words: Aggregative systems, Modular grids, Three-dimensional cells, Prefabrication, Collective housing.

1. Previous concepts

Despite being related, there are small traits that differentiate prefabrication and industrialization. "*Prefabrication*" is a generic term that indicates only that some of the elements used during the construction of a building (*on-site*) have been previously prepared in another location (*off-site*). On the other hand, "*industrialization*" is a much more precise and concrete concept, which implies the establishment of an organized, standardized, serial (repetitive) and usually mechanized process, to maintain continuity of production and guarantee high productivity. Indirectly, industrialization implies prefabrication (but not vice versa), and also implies an improvement in quality and a reduction in costs and time of execution.

2. First attempts

We can say that there has been prefabrication in building since very early times of humanity (carving stone blocks for the pyramids of Egypt, for example), but there has been no industrialization until 20th century (mass production of precast panels for the Soviet housing blocks, to give another example).

Industrialization in architecture started very late, and today still it has not finished its evolution if we compare it with other activities. Obviating specific cases and previous experiments, one of the key moments in the evolution of constructive technique occurs when, at the beginning of the 20th century, the structure acquires its own relevance and dissociates from the enclosure.

2.1. La "machine à habiter"

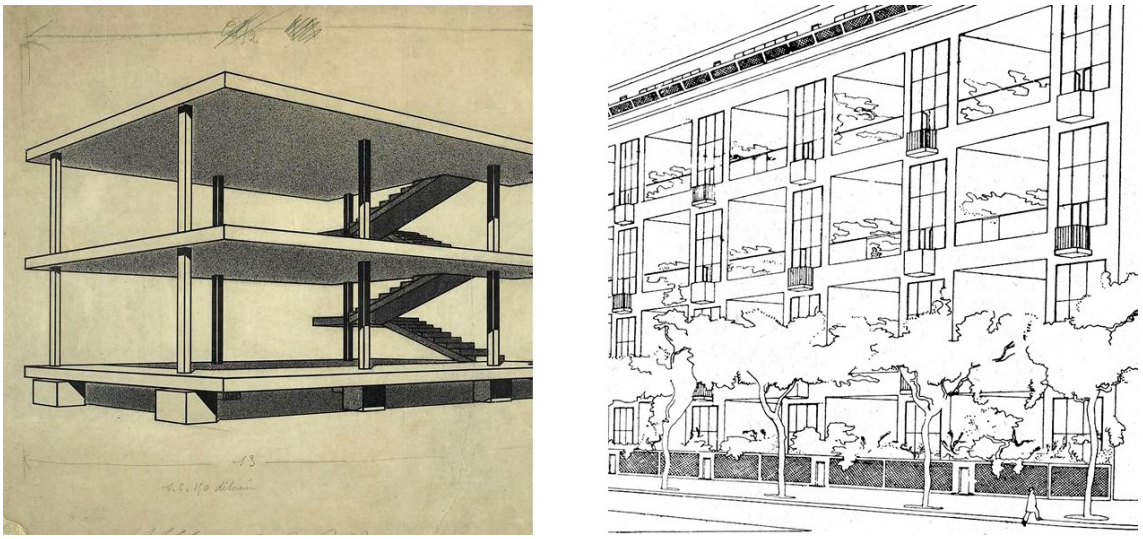

Figure 1. Dom-ino (1914) vs. Immeuble-villa (1922).

Le Corbusier, aware that the reconstruction of cities destroyed by wars had to be solved by mass-produced houses, presented 'Dom-Ino' in 1914 (fig. 1). In this novel structural scheme, which already shows his famous "Five points for a new architecture"[1], we can see some reinforced concrete elements that could be

[1] In 1927, Le Corbusier sent Alfred Roth (technical direction of the 2 dwelling in the Weissenhof Stuttgart) a manuscript with the "*Five points for a new architecture*". This manuscript is published in a promotional brochure of these two houses, called "*Zwei Wohnhäuser von Le Corbusier und Pierre Jeanneret*"

industrialized in order to achieve mass construction.

'Dom-Ino' houses were still proposals linked to single-family dwelling type. Years later, in 1922, Le Corbusier studied for the first time the three-dimensional grouping of this housing type and formulated his project 'Immeuble-villa'[2], a block in height formed by the superposition of two-floors isolated houses.

2.2. "Bouteille" et "Bouteiller"

The evolution of these aggregation models will culminate two decades later with the conceptual development of the 'Unités d'Habitation'. At first, Le Corbusier understands the Marseille apartments as prefabricated, autonomous and independent entities ("bottle"), which can be placed anywhere in a regular mega-structure ("bottlerack"), a reinforced concrete skeleton designed as a three-dimensional grid of pillars and beams (fig. 2).

In total, five 'Unités' were built: Marseilles (1947-52), Nantes (1953-55), Berlin (1957-58), Briey (1959-61) and Firminy (1964-66). None of these 'Unités' use prefabricated apartments [constructive module] as initially proposed[3]. However, in Marseille, each of the housing units (bottle) has its own independent metal structure [functional module] that rests on the main concrete beams and pillars modular grid (bottlerack) of the building [geometric module].

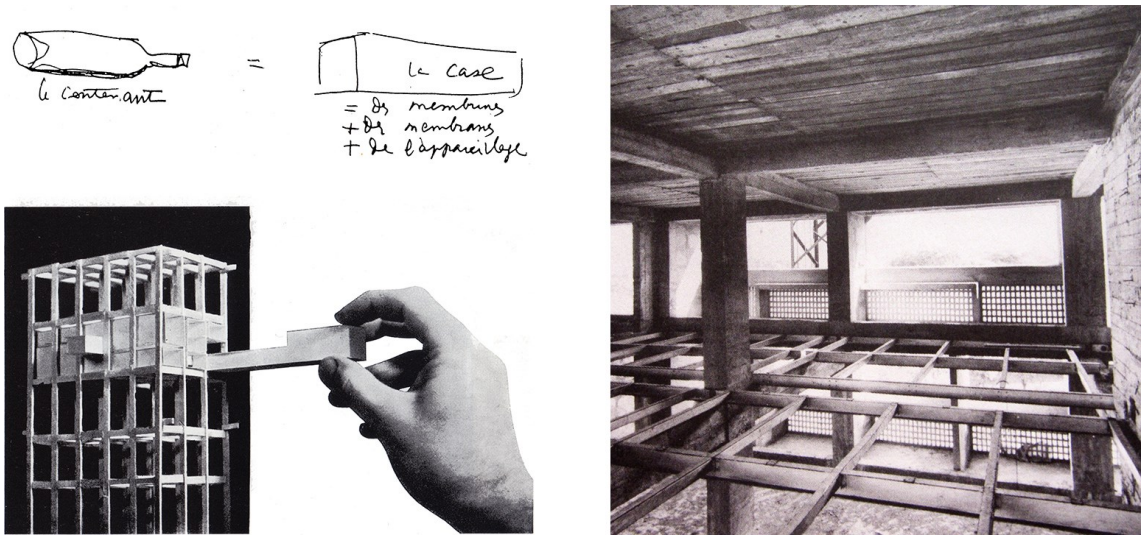

Figure 2. Unité d'Habitation, Marseille FR (1947-52): Idea vs. Construction.

3. Coherence

Mass reconstruction that took place after the devastation caused by WW II showed the need to introduce systems that would rationalize the construction process to reduce execution times and costs, thus optimizing the scarce resources.

[2] Le Corbusier built in 1925, on the occasion of the Exposition Internationale des Arts Décoratifs in Paris, one of the basic homes that are a part of the Immeuble-villa. This prototype was called 'Pavillon de l'Esprit Nouveau'.

[3] Aware of the impossibility of industrializing housing (mainly for economic and technical reasons), Le Corbusier writes: "*The bottles could, one day, be manufactured from scratch in the workshop, in decomposed elements, then mounted on the job (at the foot of the building) and, by means of efficient lifting, to be housed one by one in a frame*".

In the mid-50s, coinciding with the decline of ideas derived from the first CIAM (embodied in the "Athens Charter"[4]), discordant voices with the Modern Movement and the International Style began to rise. It was the moment for new proposals based on the modulation and standardization of construction components.

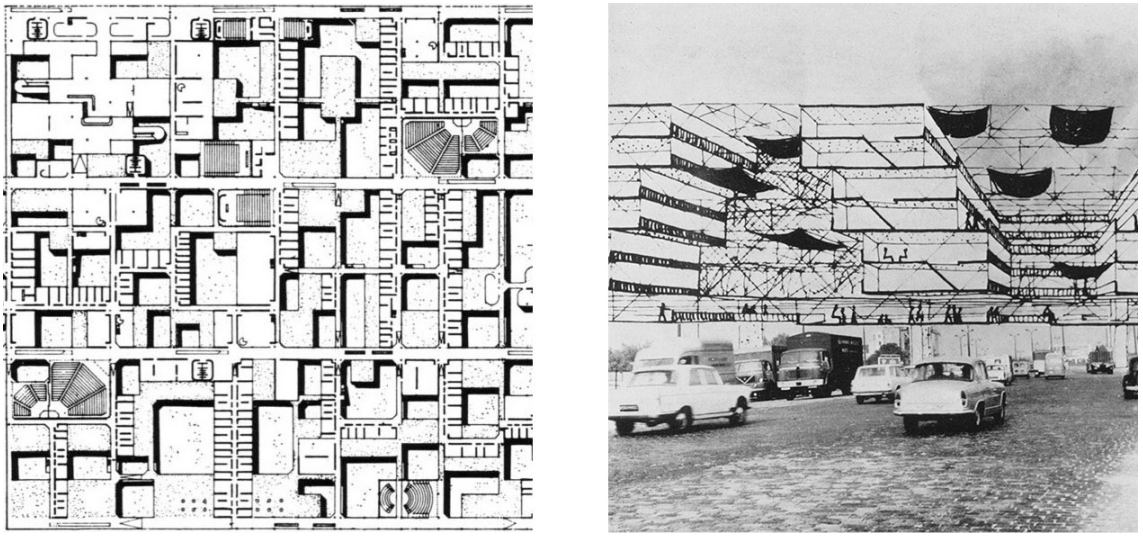

Figure 3. Freie Universität, Berlin DE, 1963 (Candilis, Josic, Woods) vs. Ville Spatiale, Paris FR, 1968 (Friedman).

On the one hand, new generations of architects grouped under the name of Team 10[5], began to work after the X CIAM of Dubrovnik 1956 for a new architecture based on mobility, flexibility and variability. The Smithsons were the creators of the concept 'mat-building'[6], a type of building whose compositional structure based on a strict modular net allows it to grow and transform over time (fig. 3). For the purposes of this paper, we will define as [geometrical module] each of the spaces delimited by this modular net.

It was also in that X CIAM when Yona Friedman presented the "Manifeste de l'architecture mobile". His project 'Ville Spatiale', a space-frame megastructure[7] for hanging volumes freely imagined by the user, was the starting point of influential movements such as Archigram and the Japanese Metabolists (fig. 3). Each of these three-dimensional prefabricated volumes configure a [*constructive module*]. If, in addition, each volume establishes a complete individual housing unit, then it will also be a [*functional module*].

3.1. Archigram: the capsule

Archigram emerged as a movement of reaction against the static and sterile London architectural landscape. With strong beliefs in the advances of technology, they relied on the advantages of mass-production: repetition and

[4] This manifesto, published by Sert and Corbusier in 1942, includes IV CIAM conclusions (1933)

[5] Among the most active members of this collective are the Greek G. Candilis, Dutch J. Bakema and A. Van Eyck, British A. and P. Smithson, Italian G. De Carlo and American S. Woods

[6] The article "*How to recognize and read mat building*", published in 1974 in the magazine Architectural Design, contained a collection of projects from different periods that would respond to the Smithsons' idea of this concept

[7] More than 20 years later, in 1976, Reyner Banham used this name as the title of his well-known book where he compiled numerous constructed examples and projects

standarization, but they also bet on the possibility of exchanging pieces depending on individual needs and preferences.

Warren Chalk was the first in using the concept "*capsule*". Inspired in the space capsules, the new prefabricated dwellings of his project 'Plug-in Capsule Homes' (1964) were attached ("plug-in") to a tower mega-structure (fig. 4). Two years earlier, Peter Cook had already worked in his 'Metal Cabin Housing', using the same idea. In all these projects, the capsule constitutes a [*functional and constructive module*] at the same time, and the final image (form) is not something sought after, but a direct consequence of the technology used.

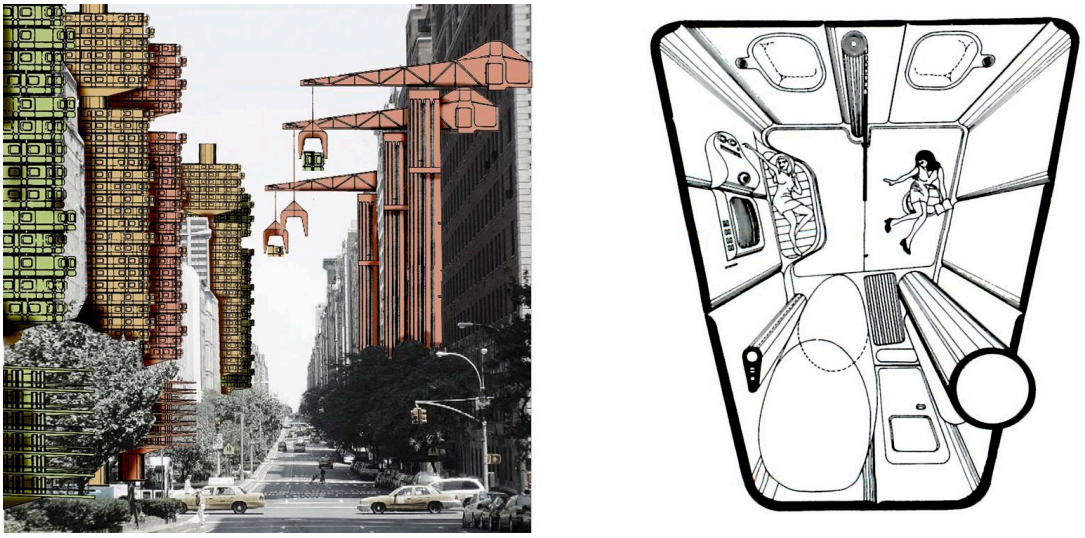

Figure 4. Plug-in Capsule Homes (1964): Megastructure vs. Capsule.

3.2. Japanese Metabolism: the cell

Al igual que Archigram, Shinchintaisha[8] talks about mobile, ephemeral, nomadic architecture, and organic biological growth based on megastructures where pre-fabricated dwelling cells could be attached. These ideas were mixed with the Japanese tradition: Buddhist concept of continuous renewal and regeneration.

Kenzo Tange, who was invited to Otterlo 1959 (last of the CIAM), was the leader of this group, despite he didn't participate in their written manifesto[9]. The largest and most representative concentration of metabolic buildings took place during the World Exposition in Osaka in 1970. However, the iconic building of this movement, 'Nakagin Capsule Tower' (fig. 5), was built two years later in Tokyo.

[8] Japanese word, meaning "replacement of the old with the new", and translated literally as Metabolism

[9] The document "*Metabolism 1960. The proposals for new urbanism.*" was presented during the Tokyo World Design Conference of 1960. Structured around 4 essays, it mainly contained proposals from Kenzo Tange classmates and students: Noboru Kawazoe, Kiyoshi Awazu, Kiyonori Kikutake, Kisho Kurokawa, Fumihiko Maki y Masato Osaka

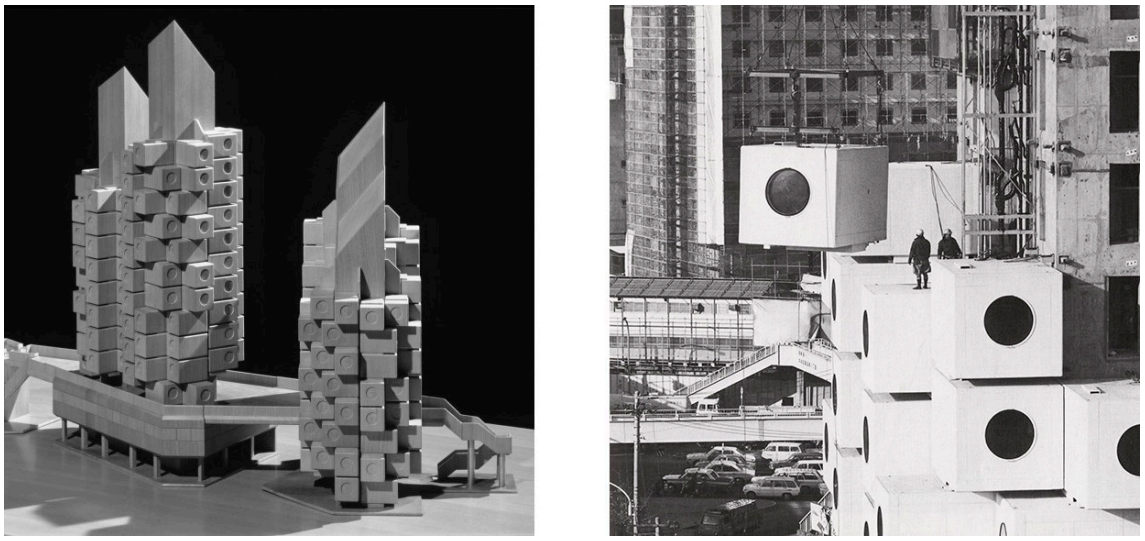

Figure 5. Nakagin Capsule Tower, Tokio JP (1972): Idea vs. Construction.

Kurokawa's research about prefab cells and three-dimensional steel framework started in Osaka ('Takara Beautillion'). Nakagin is made with 2 concrete core towers, containing stairs and lifts, in which 140 prefab capsules [*functional and constructive module*], made with light steel welded trusses, are plugged in.

3.3. Soviet Modernism: heavy prefab

Figure 6. Romashka, Chisinau MD (1978-84): Idea vs. Construction.

On the other hand, Soviet countries bet hardly on industrialization[10], and created a multitude of plants where standardized concrete panels were made. With them, rigid type-blocks based on symmetry and repetition were built, which have generated the typical image of the periphery of any Eastern Europe city (fig. 6).

[10] Khruschhev, one year before becoming USSR president in 1955, delivered a long speech about prefabricated housing, titled: "*On the extensive introduction of industrial methods, improving the quality and reducing the cost of construction*"

In these construction models ("2D prefab"[11]) the housing unit does not have its own construction entity, being only the usable space left in the middle of a bidirectional net of concrete load-bearing panels. In other words, the houses are adjusted to one or more [*geometric modules*]: the modular net.

Figure 7. Habitat 67, Montreal CA (1967): Idea vs. Construction.

Halfway between Archigram, Metabolism and Heavy Prefab, we find a unique and influential project by M. Safdie (fig. 7). Built in Montreal on the occasion of the Universal Exposition of 1967, 'Habitat 67'[12] is a vertical aggregation of 354 precast independent concrete modules. The combination possibilities of these [*constructive modules*] ("3D prefab") allow to create up to 16 different housing types[13].

4. Contradiction

Sometimes, the appearance of some buildings seems to indicate that prefab modular aggregation technology has been used [*constructive modules*], but in fact they have been built with conventional systems and traditional techniques (fig. 8). On other occasions, buildings are ordered based on strict modular nets [*geometric module*], but not a single prefab component has been used.

[11] 2D prefab structural systems are those that use flat prefabricated elements (two dimensions) to configure the building. The assembly of the different panels (vertical) and slabs (horizontal) usually follow a modular Cartesian (rectangular) net, although there are built examples that follow another type of ordering nets.

[12] The building that was finally constructed is a shortened version of Safdie's thesis Project (1961), titled "A Three-Dimensional Modular Building System".

[13] Analogous to 'Immeuble-villa', Safdie combines two antagonist typologies: the detached house, and the apartment blocks, so that every housing unit can have an outer space ("gardens in the sky").

Figure 8. Residential house, Bobruisk BY, 1980 (Galushchenko, Kozhich) vs. Krstarica, Split HR, 1973 (Gotovac).

Despite having theoretical approaches (project idea) in accordance with the principles outlined above, it was not always possible to have a coherence between concept (idea) and technology (construction), mainly due to financial problems, but also due to the lack of materials, or even constructive know-how. This is the case of two pioneers in the introduction of prefab in Spanish architecture: Leoz and Bofill.

Figure 9. 218 viviendas experimentales, Torrejon de Ardoz ES (1975): Idea vs. Construction.

Rafael Leoz conducted a rigorous research on the possibilities of industrialization in order to produce mass social housing. In 1960 he presents his 'modulo HELE'[14], a "molecule" formed by four equal cubes arranged in the form of "L", whose aggregation allows to obtain complex shapes. In his book "Redes y Ritmos Espaciales" (1968), he tackles his theory on the modular aggregation and ordering of architectural space through geometric principles.

[14] Acrostic formed by the first two letters of the surnames of Joaquin Hervas and Rafael Leoz, which also refers to the "L" shape of the group of four cubes. The 'modulo HELE' was presented in the article "*Un nuevo módulo volumétrico*" (Arquitectura, nº 15, 1960), and a year later, in the VI Bienal de Sao Paulo, 1961.

Leoz could only materialize two buildings: the 'embassy of Brasilia', and a group of 218 experimental houses in Las Fronteras (Torrejón de Ardoz, Madrid), in 1973-76 (fig. 9). Despite being based on the 'modulo HELE' [geometric module], the housing block was built by using local systems and simple and humble materials: reinforced concrete structure and brick cladding[15].

Figure 10. Walden 7, San Just Desvern ES (1974): Idea vs. Construction.

On the other hand, Taller de Arquitectura Ricardo Bofill developed a powerful investigation on the aggregative systems[16], and built interesting examples: 'barrio Gaudi' in Reus (1964), 'Castillo de Kafka' in Sitges (1965), 'Xanadu' (1966) and 'Muralla Roja' (1968), both in the Manzanera creek in Calpe (Alicante), and the spectacular 'Walden 7' (1970) in Sant Just Desvern (fig. 10). In spite of being strongly influenced by Archigram[17], in all these examples the constructive systems were "traditional": structures made by bidirectional slabs and reinforced concrete pillars[18].

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[15] According to Garcia (2013), "*the technology available in Spain in the 70s was practically non-existent.*".

[16] Although Ricardo's own sister, Anna Bofill, wrote a PhD where she relates mathematics and geometry, entitled "*Contribución al estudio de la generación geométrica de formas arquitectónicas y urbanas*" (1975), the role of this was irrelevant in the creative process, since this document was written after the execution of the works.

[17] Peter Hodgkinson, one of the members of Taller de Arquitectura, studied at the Architectural Association in London and was a student of Ron Herron, with whom he worked briefly.

[18] Ricardo Bofill himself acknowledges, in relation to the 'barrio Gaudí', that "*the economic limitations and the lack of available technology discouraged the general use of industrially produced construction elements, although the results were considered very positive, and are clearly visible in the complete scheme*".
Text posted on http://www.ricardobofill.es/projects/barrio-gaudi-2/

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Biography

César Daniel Sirvent Pérez. (Alicante, 1974) Dr. Architect, he studied Architecture at ETSA Valencia (1999) and Construction Engineering in the EPS Alicante (1996). Professor of Architecture at University of Alicante since 2000, he teachs a subject about 'Unique Construction Systems" (lightweight prefab construction and aggregative modular systems). He also has been a visiting professor in several universities, mainly in Eastern Europe, where he developed his thesis on workers' housing with collective spaces in countries of the former USSR.

He has developed international workshops in order to design emergency shelters for natural disasters using lightweight prefabricated systems. He also has written several books where he develops a method to generate new architectural formalizations based on the use of lightweight prefab technologies. Currently he works in several research lines: construction with prefab three-dimensional cells, aggregative systems and organic growth based on modular frames, and ephemeral / nomadic construction using sea freight containers.