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## THE GENEALOGY OF ITERATIVE GROWTH

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## THE GENEALOGY OF ITERATIVE GROWTH

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### Abstract

Over the last few decades, there have been many proposals for collective housing in which architectural forms have arisen from processes of infinite iteration. These designs put special emphasis on the concept of the element or basic unit, but also focus on the mechanisms by which these elements and units relate to one another and grow. This essay is an exploration of the historical precedents that inform these proposals, as well as a parallel comparison of the geometry behind infinitely iterative inhabitable cells and those strategies found in other creative disciplines, nature, and in the internal structures of compounds.

### 1. Introduction

*"If you wish to reach the infinite, set out for the finite in all directions".<sup>2</sup>*

J. W. Goethe

In a text published in 1999, Stan Allen undertook an analysis of systems in which elements were joined by spatial or formal matrices. As these systems feature entities that can be iterated and interwoven without losing their individual identity, it is critical that one define the shape of the component parts, as well as the internal relationships between them; it is these relationships that determine the behavior of the whole. The result is a scheme for organizing elements that has been designed from the base up, which is reliant not on geometric diagrams but rather on a pattern of simple or complex local connections. Form is thus rendered an open process of iteration, which can be continued or restricted without upsetting the totality of the underlying process.<sup>3</sup>

Such compositions are dominated by the concept of the element or basic unit, but also focus on the specific mechanisms by which these elements and units relate to one another and grow. The terms that describe these mechanisms – interval, repetition, seriation, and system –

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<sup>2</sup> GOETHE, J. W. (1766-1833), original quote: "Willst du ins Unendliche schreiten/ Geh nur in Endlichen nach allen Seiten". TUNZ, E., ed., *Goethe Gedichte*, pp. 304

<sup>3</sup> ALLEN, S., *Points + Lines. Diagrams and Projects for the City*, pp. 1-9; 92-103

enlighten us that it is not the overall shape of the result, but rather the shape of the individual elements and, above all, the links between these elements that are essential.

The axioms of classical architecture, such as symmetry, repetition and sequence of forms, are used – along with others – to organize component elements so as to lend shape to any form. An open system can also have mechanisms by which its elements relate to one another, but the fundamental difference is that these are not constrained by a specific limit. Furthermore, such a system's internal order does not reflect a hierarchy that prioritizes some parts over others. If, as Alberti posits, “beauty is a certain harmony between the parts that comprise something, such that one cannot add, take away or change anything without making the thing less worthy of praise”<sup>4</sup>, here we are able to add or subtract as many elements as we desire without the whole losing its defining traits.

Over the last few decades, there have been many proposals for collective housing whose architectural forms have been created by processes of infinite iteration. In some of the projects submitted to the European competitions<sup>5</sup>, in the new plan for the docks at Borneo and at Sporenburg in Amsterdam, and in Kazuyo Sejima's generic studies on metropolitan housing (fig. 1), inhabitable units and the adjacent open spaces are iterated in two or three directions in keeping with geometric laws that allow them to repeat infinitely. In these examples, their authors have explicitly departed from any emphasis on spatiality, and, in some of them, almost all of the component pieces used in their construction have been systematized. In Spain, since 2005, there have been designed aimed at stitching together highly deteriorated urban fabrics and proposals for residential units with gardens and greenhouses. These have strived to reconcile iterative patterns for low-density buildings with open spaces, while simultaneously trying to attain a difficult equilibrium between novelty and tradition, and nature and artifice.<sup>6</sup>

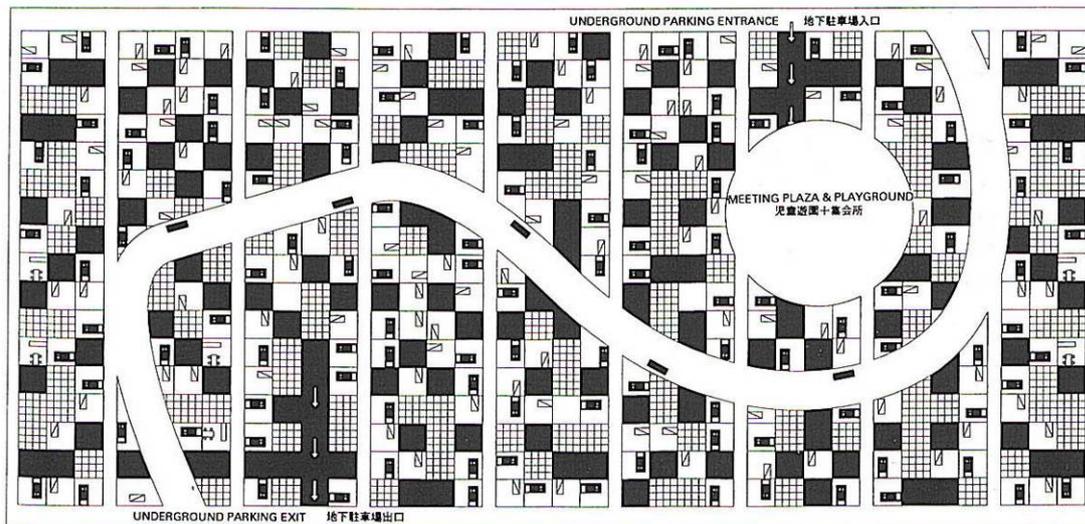
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<sup>4</sup> ALBERTI, L. B., *De re aedificatoria*, lib. VI, cap. II, pp. 245-247

<sup>5</sup> For example, in the European 1993 competition, one finds the proposal for an urban island in Yverdon by T. Roagna, H. Ehrensperger and M. Cennini; or H. De Clercq, J. Van der Ploeg, P. Weijnen and A. Willemen's proposal for 'S-Hertogenbosch. GAUSA, M., *Habitatge. Nous sistemes urbans*, pp. 50-79

<sup>6</sup> Amid other examples we find E. Pérez de la Cruz and I. Bisbal's system for habitable buildings in urban centers, D. Rodríguez's dwellings and greenhouses in Igará and I. Chinchilla's *Eco de Montaña* (“Mountain Echo”) residence-style housing units. HERNÁNDEZ PEZZI, C., *Soluciones Urbanas 2005: Un concurso para la ciudad sostenible*, pp. 87-100. CHINCHILLA, I., *Las Dehesillas-Espartalia. Contrato urbano vs. Contrato doméstico vs. Contrato del agua*, pp. 69-74

Figure 1. K. SEJIMA, Study for groupings of low-rise housing, 2001



Source: SEJIMA, K., *MHS. Estudio sobre la vivienda metropolitana*. Kazuyo Sejima en Gifu. Barcelona, Actar, 2001.

Juan García Millán has reflected on the noteworthiness of process in some contemporary designs.<sup>7</sup> Faced with the foolhardiness of designing categorically given the ever-accelerating pace of scientific discovery, some architects have deliberately laid out general guidelines that allow for elements to be incorporated or subtracted from their designs without upsetting the whole. The results are instruction manuals that place a greater importance on the process of generating an object than on the object itself.

In addition to the absolute modernity of these proposals, one sees the impact had in many cases by the rapid advances in technology. These make the decisions of the designer that much less personal, insofar as the larger scale of growth dictated by the program yields a proliferation of units and is also what responds to exceptions or unique situations. Thus, many of these examples show notable variations whenever the program, location, or even the building systems require it, and the underlying morphological matrix remains unchanged.

## 2. Historical precedents

Open-ended systems for iterating architectural elements are not exclusive to the last several decades. The Modernist movement produced many examples of grouped courtyard-houses in which – despite the lack of modern-day computer technology– one can identify the same morphological characteristics. Some of the most representative architects of the first half of the 20<sup>th</sup> century –in order to guarantee space and comfort while addressing hygienic issues of light and ventilation– designed iterative dwelling units by repeating infinite patterns. In 1929, Ludwig Hilberseimer, for example, designed a limitless, homogenous network of houses made of up

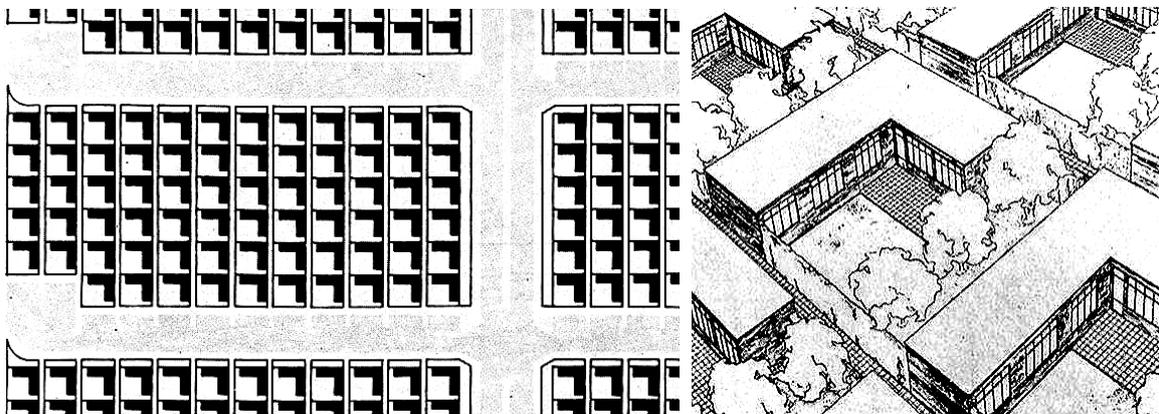
<sup>7</sup> GARCÍA MILLÁN, J., *Arqueología de las arquitecturas informales. ¿Un cambio de paradigma?*, pp. 76-86.

two L-shaped bays, all of which had a courtyard, yard or outdoor garden. Using the cells of this matrix, he experimented with different ways of occupying parcels of land and demonstrated that it was possible to reach high population densities without sacrificing quality of life or closeness with nature (fig. 2).

This way of understanding land use and city planning based on an infinitely iterative dwelling unit is closely related to the Mechanist parameters that dominated the ideology of the first few decades of the 20<sup>th</sup> century. The machine was viewed as liberator, and drew admiration for its ability to reproduce the same object time and again; this was why artists, artisans and architects drew from mechanized processes when generating their own proposals.

The Mechanist context was to have a decisive influence on new teaching methods at Europe's new schools of art and architecture. Both the Vkhutemas, in the USSR, and the Bauhaus, in Germany (where Ludwig Hilberseimer taught, along with Walter Gropius and Hannes Meyer), accentuated economy of materials and means as a way of simultaneously incorporating Mechanist parameters –such as simultaneity, movement, repetition and seriation– into their works. These same parameters were transformed into instruments for designing collective housing, and also for constructing urban fabric (fig. 3a, 3b). As was pointed out by G. C. Argan, these architects saw space as nothing more than the dimension of infinite possibility. Thus, unburdened by limits, any and all buildings were seen as unending processes yielding a limitless series of forms.<sup>8</sup>

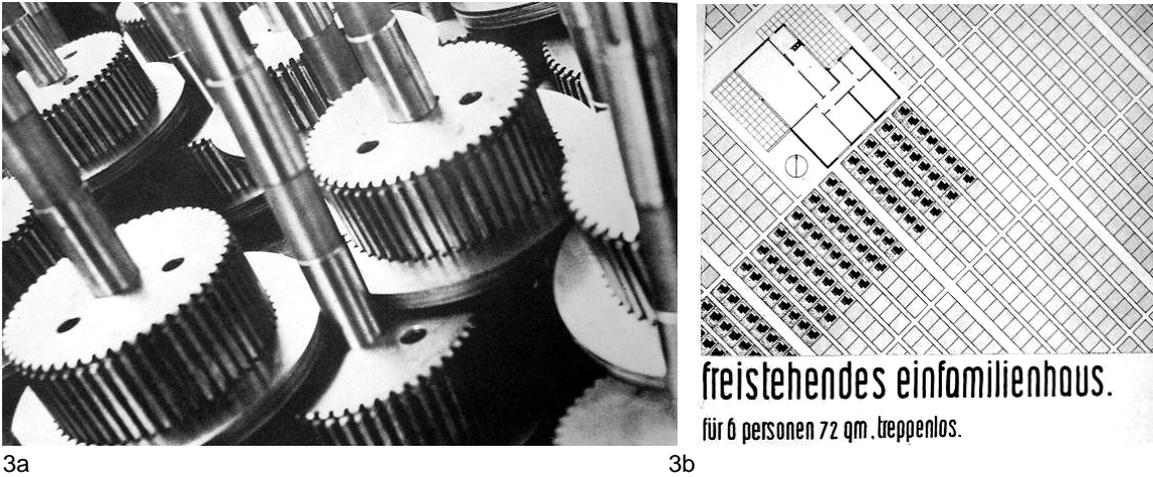
Figure 2. L. HILBERSEIMER, *Horizontal city*, 1929



Source: BENÉVOLO, L., MELOGRANI, C., LONGO, T. G., *La proyectación de la ciudad moderna*. Barcelona, Gustavo Gili, 1978.

<sup>8</sup> ARGAN, G. C., *Walter Gropius y la Bauhaus*, pp. 49: "Architecture will no longer be determined by its uniqueness, but rather for its ability to be mass-produced, prefabricated and repeated ad infinitum. Buildings should not be unique. Architecture should go from prefabrication to urban design."

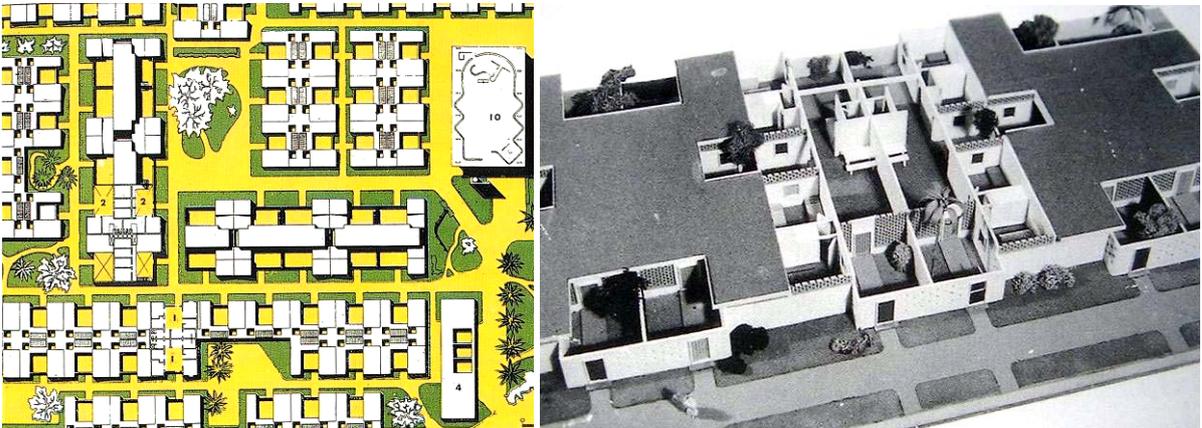
Figure 3. Mechanized processes and limitless series of forms: 3a. RODZCHENKO. Gears, 1930. / 3b. Bauhaus course material L. Hilberseimer. W. J. Hess, 1931



Source: 3a. KARGINOW, G., *Rodzenko*. Wydawnictwa Artystyczne i Filmowe. Warszawa, 1981 / 3b. DROSTE, M., *Bauhaus. Bauhaus Archiv 1919-1933*. Köln, B. Taschen, 1993.

The experimental fields of study that marked the early decades of the 20<sup>th</sup> century remained dynamic throughout the 1950s and 1960s in Europe, Asia, Africa and the Americas. Shortly after World War II, new patterns were developed for iterative dwelling units, with a variety of modifications and a more complex systematization. In these newer examples –unlike the universally reproducible nature of the more Utopian projects of earlier decades– the introduction of local factors, such as materials, climate, economics, society or culture, imposed limits on what had been seen as limitless systems. Such was the case with the one-story dwellings that Josep Lluís Sert designed in 1948 for the city of Chimbote, Peru. Here, the houses' courtyards were transformed into entryways, and the various rooms were arranged around them (fig. 4). Sert's proposal reflected the subsistence economy of inhabitants, but was respectful of it; his design was not solely an abstract and generalized system, but was rather one that could adapt to autochthonous ways of life.

Figure 4. J. L. SERT, Plan drawing and model of Chimbote, Perú, 1948

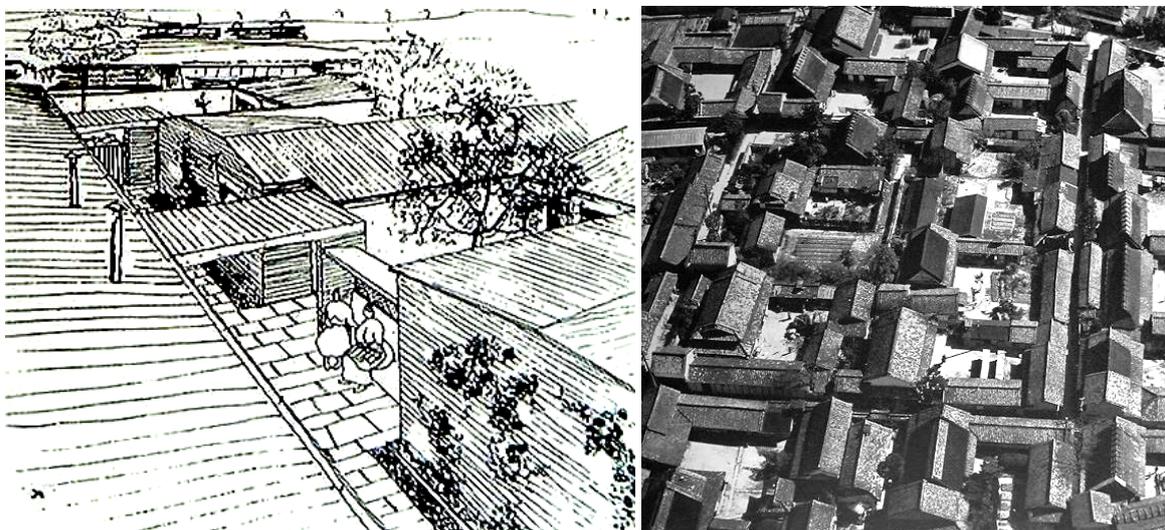


Source: ROVIRA, J.M., *Josep Lluís Sert. 1901-1983*. Milano, Electa 2000.

Another significant example is the intervention undertaken between 1950 and 1955 by Adalberto Libera in Rome's Tuscolano neighborhood. Libera's system of one-story, L-shaped units were uniquely grouped in fours, which then extended around three courtyards enclosed inside the block and one that was semi-open to the street. There were also pedestrian alleys, canopies and greenswards, such that the configuration of the dwellings was easily adapted to urban outlines that –as in this example– were non-orthogonal (fig. 5a).

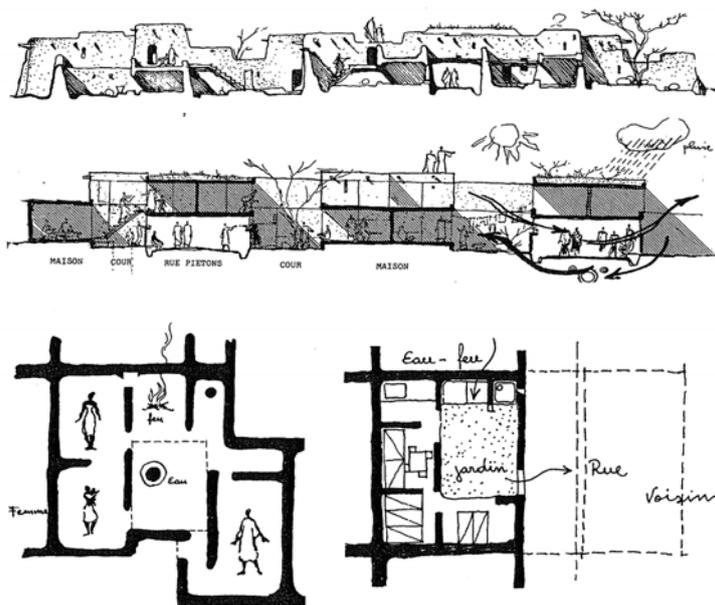
In these and other examples dating from this time period in other countries, one should acknowledge the debt that iterative housing owes to vernacular architecture; this is fundamental in order to understand how individual morphologies came about on other continents. It was not coincidence that both Sert and Libera had traveled to coastal North Africa and became fascinated with the complex and intelligent arrangement of dwellings both in city centers and in more rural villages. Many such groupings of dwellings in historical cities on different continents became paradigmatic case studies upon whose models Sert and Libera – and other, emerging architects, such as Jorn Utzon, Christopher Alexander and the members of Team X – reformulated their proposals. It was these dwellings' rich variety of formal and building solutions, their adaptation to climatic and geographic requirements, their perfect response to function, the indoor-outdoor dialogue they established through transitional spaces, and their capacity for lending shape to the urban fabric that led the heirs of the Modernist movement to reconsider vernacular architecture in forging a more realistic take on the issue of the dwelling (fig. 5b, 5c).

Figure 5. Iterative housing and vernacular architecture: 5a. A. LIBERA. Dwellings in Tuscolano. Rome, 1950-55. / 5b. Jori-Sei village. Yamamoto Plain. Japan. / 5c. CANDILIS, JOSIC, WOODS. Comparative study between popular architecture and proposal. Fort Lamy. Chad, 1962



5a

5b



5c

Source: 5a. VIERI QUILICI, *Adalberto Libera, l'architettura come ideale*. Roma, Officina ed., 1981. / 5b. RUDOFISKY, B., *Architecture Without Architects*. Albuquerque, University of New Mexico Press, 1964. / 5c. AVERMAETE, T., *Another modern. The post-war architecture and urbanism of Candilis, Josic, Woods*. Rotterdam, Nai Publishers, 2005.

Furthermore, assembly-line production –that had been so lauded by the avant-garde– became intimately linked to these architectural schools of thought. Assembly-line production lent the

advantage of being able to incorporate different solutions without the system losing its identifying characteristics. This, together with the anonymity of these designs, further highlights Modernist architects' intent to distance themselves –ideologically– from any absolute personalization of their solutions; this was to facilitate a universal understanding of the underlying operations and thus offer an ideal platform for self-perpetuation and infinite reproduction.

### 3. Elements and systems of relationships

In practice, the varying typologies of courtyard-houses all exhibit the morphological processes of repetition and association, which are to be found not just in architecture but also in nature and the applied arts. The common ground, then, that bridges the gap between artificial and natural constructions is geometry and the system of patterns defined therein. Thus, in these structures, basic elements are as important as are the mechanisms that allow them to associate with one another and to grow.

Euclid's shapes, as one can glean from Renaissance-era treatises or even some significant texts from the 20<sup>th</sup> century, are understood as entities that have inherent value. Likewise, they are testament to the historical labor of identifying them as the basic units that underlie the panoply of shapes present in the universe.<sup>9</sup>

It was Kepler who, in 1596, in contrast to his ancestors, opened a new field of possibilities regarding the reproduction of geometric shapes, by studying them not as isolated entities of greater or fewer facets, but as units that had the potential to associate with one another – via open systems – so as to occupy planes as well as space (fig. 6).

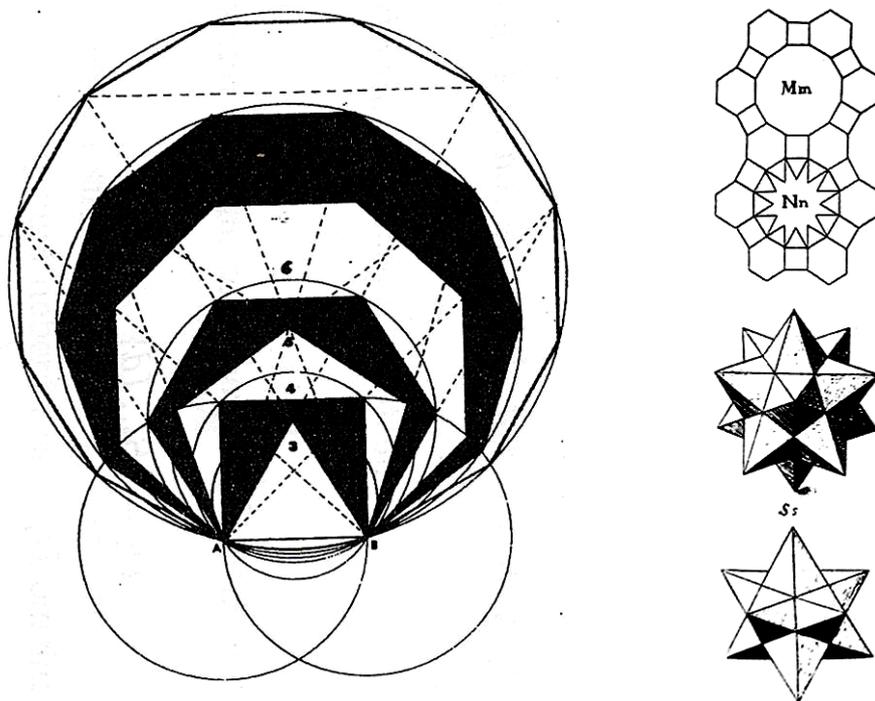
During the 18<sup>th</sup>, 19<sup>th</sup> and 20<sup>th</sup> centuries, mathematicians, scientists and artists sought to create instruments to mechanically produce repeated shapes. It was patterns, then –matrices whose morphology included the mechanisms needed for reproduction – that were found to be the ideal instrument for these operations. Indeed, one finds countless geometrical matrices –potential patterns– in handicraft and in nature, as well as in the organic and inorganic components of matter.<sup>10</sup>

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<sup>9</sup> Since Platos' *Timaeus*, in which five geometric bodies were identified that coincided with the five elements that make up the world, until Le Corbusier, who in 1920 illustrated through five geometric bodies the pages of *L'Ésprit nouveau*, there have been many treatises on Platonic bodies and the geometric potential therein. Luca Paccioli in 1505, Dürer in 1528, Hirschvogel in 1543, Rivius in 1547 and Jamnitzer in 1563 are all examples of the writers whose works focused on the broad field of the formal possibilities of the tetrahedron, the cube, the octahedron, the dodecahedron and the icosahedron.

<sup>10</sup> E. Gombrich affirmed that daily life offers us an infinite variety of patterns that – even though we ignore them – include a rich universe of formal extension. See: GOMBRICH, E., *El sentido del orden*, pp. 63-94

Figure 6. J. KEPLER. 7 polygons drawn from one side, 1619



Source: SANZ M. A., MORATALLA, A., *Geometría y arquitectura*. Vol. II. Cuadernos del Instituto Juan de Herrera. Madrid, ETSAM, 1999.

One of the first to establish a system for reproducing and combining elements –in the field of applied arts– was the Frenchman Douat. In 1722, he proved that via different permutations, one could produce an infinite number of compositions in which two-tone ceramic tiles could combine to yield a plethora of solutions. The basic movements used by Douat were isometric relationships or movements in a plane: translation, axial symmetry, central symmetry and rotation (fig. 7a, 7c).

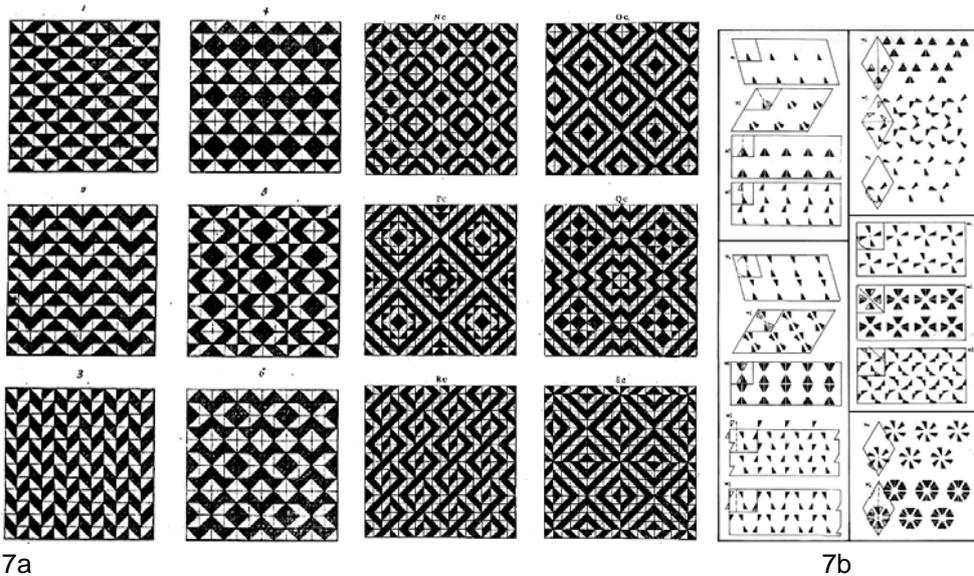
In 1891, the crystallographer Fedorov demonstrated that there are only 17 groups of symmetries in a plane, which in turn corresponded to the structure of crystals. Four decades later, mathematician Andreas Speiser –while researching the geometrical laws governing the repetition of forms– established that the repetition of an element subjected to three basic operations (translation, rotation and reflection), yielded 17 possible symmetries: the same relationships as were defined by Fedorov (fig. 7b).

From this point onward, many researchers continued with the formidable task of defining a map of the world of shapes, which opened up working systems to a wide range of designers.<sup>11</sup> In

<sup>11</sup> Wilhelm Ostwald, Charles Blanc, Wolfgang von Wersing and, currently, Roger Penrose are, among others, scientists and artist that have design manuals on opening new ways of combining forms. Also see: GOMBRICH, E., *El sentido del orden*, pp. 63-94

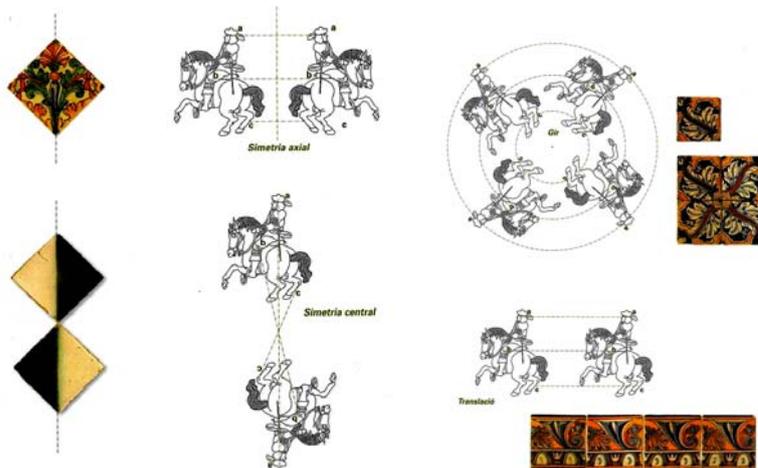
more recent years, these perspectives have remained open and their potential has been multiplied ad infinitum thanks to computer technology. It is precisely this technology that can classify multitudes of shapes and establish countless combinations between them while still allowing for the creation of reproducible patterns.

Figure 7. **Isometric relationships or movements in a plane and infinite number of compositions: 7a. Douhamel du Monceau DOUAT, Permutation of two-tone tiles, 1722. / 7b. ANDREAS SPEISER, 17 symmetries. / 7c. Catalan tiles. Movement or isometrics in plane**



7a

7b

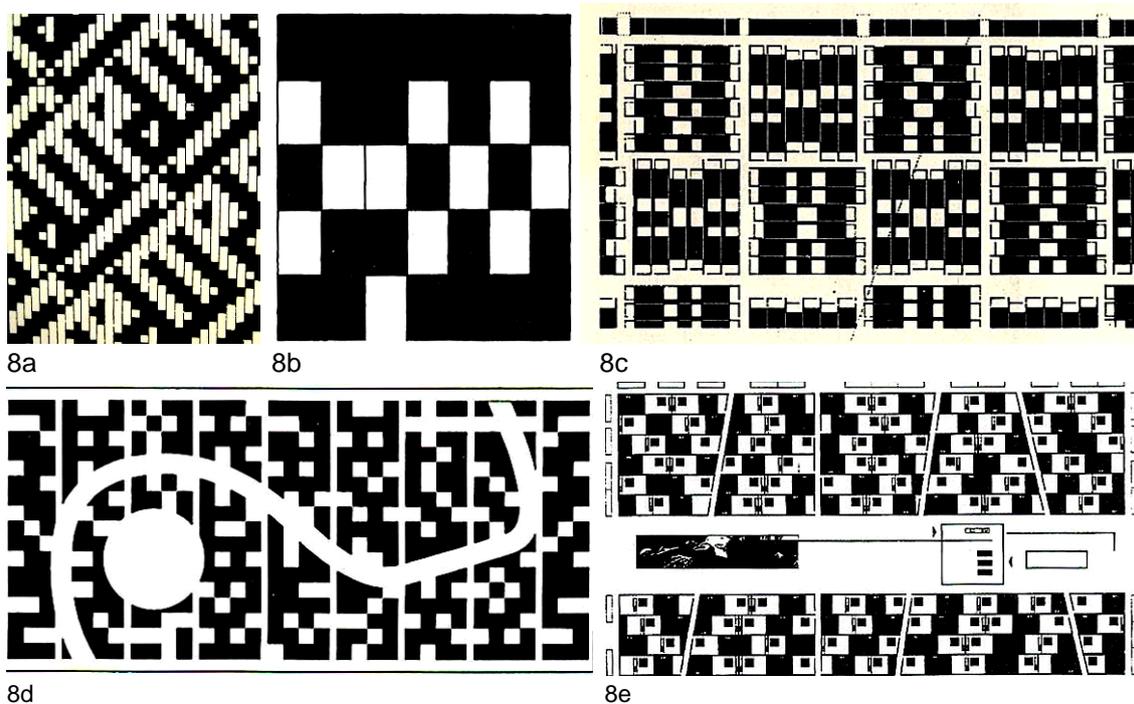


7c

Source: 7a. *Vanités de faïence. Entre Provence et Languedoc, carreaux de céramique espagnols Xvème-XVIIIème siècle*. Museon Arlaten, 2001. / 7b. ALSINA, C., TRILLAS, E., *Lecciones de Álgebra y Geometría*. Barcelona, Gustavo Gili, 1984. MARCH, L., STEADMAN, P., *The geometry of environment*. London, Methuen & Co Ltd. RIBA Publications, 1971. / 7c. MINGUELL, J.C., *Dibuixant parets amb una rajola. Simetries, girs i traslacions*. In CanTinturé. Col·lecció de rajola de mostra Salvador Miquel. Ajuntament d'Esplugues de Llobregat, 2003.

These patterns, which use the full range of isometric operations to multiply geometric units across planes or in space, are also used in systems for designing reproducible dwelling spaces. Mechanisms such as axial symmetry, central symmetry, rotation and translation –and the multiple variants thereof– are found in the designs of many iterative dwelling units. If one draws a graphic comparison between tiles and the networks generated in some courtyard-housing proposals, one can see to what extent these techniques of montage are related. This is corroborated by the representational tools used by architects such as Hilberseimer, Alexander, Sejima or Geyer, who drew their iterative residential systems as sets of two-tone pieces – identical to tiles – so as to distinguish built volumes from open spaces (fig. 8a, 8b, 8c, 8d, 8e).

Figure 8. Graphic comparison between tiles and the networks generated in some courtyard-housing proposals: 8a. Tiles. Cairo 15<sup>th</sup> century. / 8b. X. De GEYTER. Borneo Sporenburg. / 8c. C. ALEXANDER. Groupings. 1969. / 8d. K. SEJIMA. Groupings of low-rise housing, 2001. / 8e. T. ROAGNA, H. EHRENSPERGER, M. CENNINI. European 1993



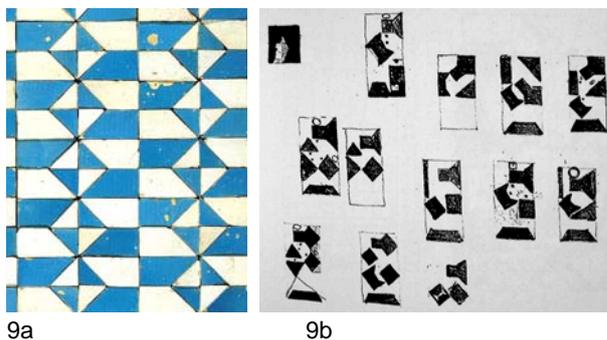
Source: 8a. GOMBRICH, G.H., *El sentido del orden. Estudio sobre la psicología de las artes decorativas*. Madrid, Debate, 1999. / 8b, 8e. *Quaderns d'Arquitectura i Urbanisme*, 221. Barcelona, COAC, 1996. / 8c. BENÉVOLO, L., MELOGRANI, C., LONGO, T. G., *La proyectación de la ciudad moderna*. Barcelona, Gustavo Gili, 1978. / 8d. SEJIMA, K., *MHS. Estudio sobre la vivienda metropolitana*. Kazuyo Sejima en Gifu. Barcelona, Actar, 2001.

Architects such as Louis I. Kahn and Moshe Safdie took this even further, and made graphics demonstrating the analogies between their design processes and tile patterns (fig. 9a, 9b).

If one uses the manifold proposals for low-density iterative housing as a starting point, one can draw a series of comparisons that help to identify the genealogical processes upon which their

construction is based. Furthermore, we can prove how these mechanisms are involved in the delineation of patterns and in other natural formations. Take, for instance, one-directional supports, orthogonal or hexagonal two-directional meshes, iterative spatial structures or other complex systems for growth such as interweaving or exchanges: these all represent primary systems that regulate individual units. Likewise, they constitute the internal limits of a series of systems that can be reproduced across planes and in space via the wide range of options offered by the patterns.

Figure 9. Analogies between tile patterns and design processes:  
9a. Tiles. Lisbon, 16<sup>th</sup> century. / 9b. L. KAHN, Fine Arts Center 1959-73



Source: 9a. Picture: Magda Mária. 9b. BROWNLEE, D., DE LONG, D., *Louis I. Kahn: In the Realm of Architecture*. New York, Rizzoli, 1991.

#### 4. Unidirectional supports

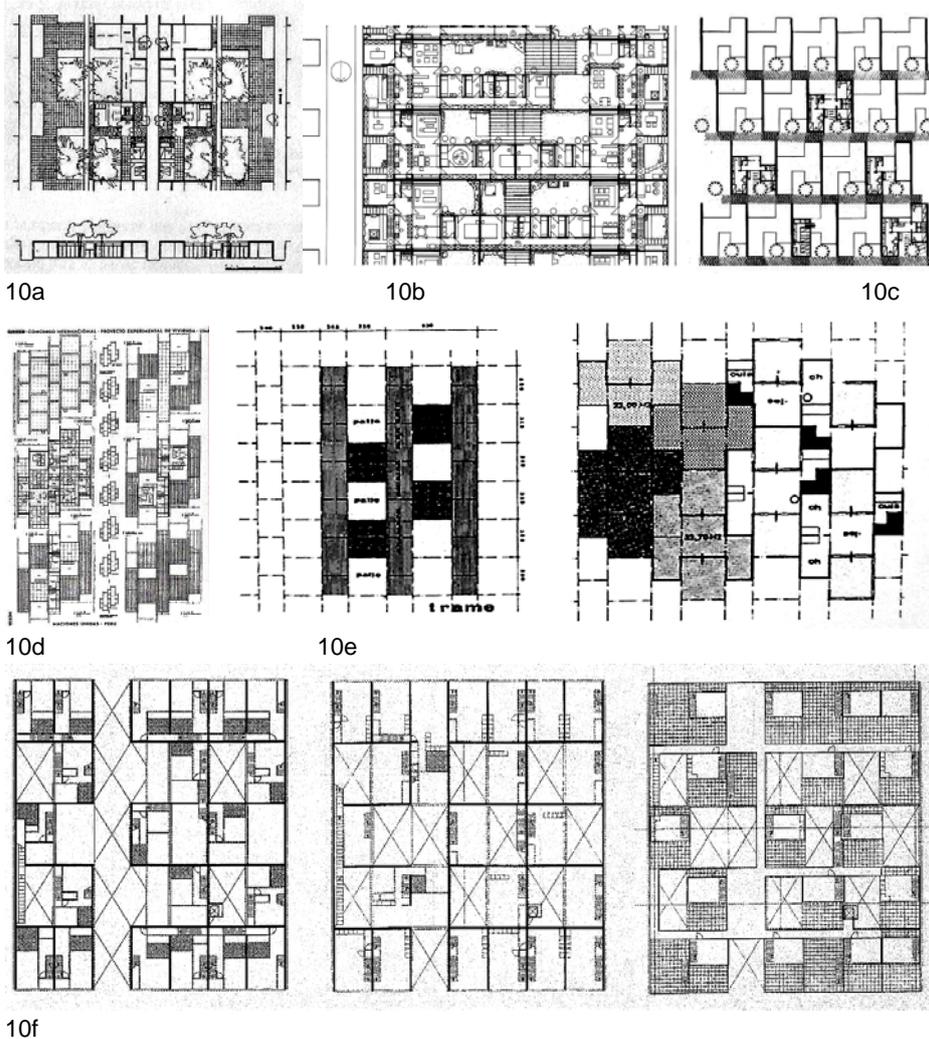
One of the neutral diagrams used to regulate iteration is the unidirectional design. As though they were pentagrams, these series of parallel lines are capable of subsuming a wide variety of entities and operations. Ribbons or bands, whether equal or uneven, regulate the alternation between built and open spaces, the cohabitation of natural and artificial, and the negotiation between public and private spaces. This allows for elements to flow in and out and alternate with one another. It is between these rails – so to speak – that all the flexible components of the system are organized.

Significant examples of this *modus operandi* can be found in some of Hilberseimer's horizontal cities, in Diotallevi, Marescotti and Pagano's urban proposals from 1943 and 1945 (fig. 10a), or in Egon Eiermann's 1964 *Teppichhaussiedlungen* (fig. 10b). In these cases, the L-shaped dwelling units are able to increase the number of rooms along parallel guidelines, by alternating with courtyards and green spaces. This enables one to have distinct vehicular and pedestrian streets whose character further highlights the unidirectional nature of the system.

In the set of courtyard-houses designed in 1952 by Hans Scharoun for Heligoland, the dwellings themselves also relied on a unidirectional guideline (fig. 10c). Here, the movement of units broadened the depth of field of the courtyards, and – similarly to Libera's proposal for Tuscolano

– a series of marquees combined covered areas with pedestrian thoroughfares open to the elements.

Figure 10. Unidirectional supports: 10a. DIOTALLEVI, MARESCOTTI, PAGANO, *Horizontal City*, 1940. / 10b. E. EIERMANN, *Teppischhaussiedlungen*, 1964-66. Plan drawing typologies. / 10c. H. SCHAROUN. *Courtyard-houses in Heligoland*. Contest, 1952. / 10d. CANDILIS, JOSIC, WOODS. *Previ neighborhood*. Lima, 1962. / 10e. CANDILIS, JOSIC, WOODS. *Puzzle houses*. Bacarés-Leucaté, 1969. / 10f. X. De GEYTER. *Borneo Sporenburg*



Source: 10a. BENÉVOLO, L., MELOGRANI, C., LONGO, T. G., *La proyectación de la ciudad moderna*, Barcelona, Gustavo Gili, 1978. / 10b. *Egon Eiermann 1904-1970. Bauten und Projekte*. DVA, 1993. / 10c. BLUNDELL JONES, P., *Hans Scharoun*. Hong Kong, Phaidon Press Ltd., 1995. / 10d, 10e. AVERMAETE, T., *Another modern. The post-war architecture and urbanism of Candilis, Josic, Woods*. Rotterdam, Nai Publishers, 2005. / 10f. *Quaderns d'Arquitectura i Urbanisme*, 221. Barcelona, COAC, 1996.

In S. Chermayev and C. Alexander's studies made in the 1960s, the various typologies of dwellings were organized according to a concatenation of dwellings and courtyards along an axis, which gave birth to a rigid hierarchy of structures and transitional spaces. The different

typologies were multiplied along a unidirectional guideline to yield square, 20-unit blocks, such that the central courtyards of the dwellings would not be shared with those of neighboring residences. Candilis, Josic and Woods' project for Lima's Previ neighborhood, as well as their project for the French village of Bacarés, were also structured around two horizontal bands of different widths that lent order to the built volumes and open spaces (fig. 10d, 10e). By alternating indoor courtyards, entryways and rooms throughout the ground and first floors, they achieved a system for managing the bedrooms, living rooms, courtyards and urban thoroughfares that –despite its apparent simplicity– achieved a fairly complex spatial development. More recently, proposals made by H. de Clercq, J. Van der Ploeg, P. Weijnen and A. Willemen in 1993 for Europan 3 in 'S Hertogenbosch, and the upper part of the compact block designed by T. Ragna, H. Ehrensperger and M. Cennini (likewise, for Europan 3) in Yverdon, demonstrated the effectiveness of the model and its capability for yielding form within a system of parallel guidelines (fig. 10f).

## 5. Bidirectional meshes

The lines that shape the internal order of a design need not solely be oriented in one direction, but can also be given a bidirectional orientation, which broadens the case history with respect to program and volume. If, to this, one adds spatial development, one finds an overall system that lends order and based on which formal possibilities are infinite.

Candilis, Josic and Woods defined the key role played by meshes as that of lending internal order. By skillfully using the right formal analogies (*vis-à-vis* their use of new terms such as 'mat', 'stem', 'grille' and 'grid'), they used the association between concepts such as 'grille & type' to conceptualize their proposals for dwellings. The mesh or 'grille' is understood as the structure that is capable of accommodating multiple, unique developments by adapting itself to heterogeneous solutions and facilitating transitions between general and particular circumstances. The 'type', in a single entity, allows for elements to be repeated in series and also guarantees the uniqueness of the proposal, by constituting the psychological framework upon which to generate the network; it is this network that should then be intelligent enough so that it can adapt to different circumstances without suffering undue trauma. In their projects built in Casablanca and in other North African cities (where groupings of courtyard-houses are doubtless inspired by traditional kasbahs), these architects linked to Team X demonstrated how a symbiosis between dwellings and urban mesh could yield modern yet universal proposals, considering the centuries of tradition latent in the specificities of the culture of the place (fig. 11).

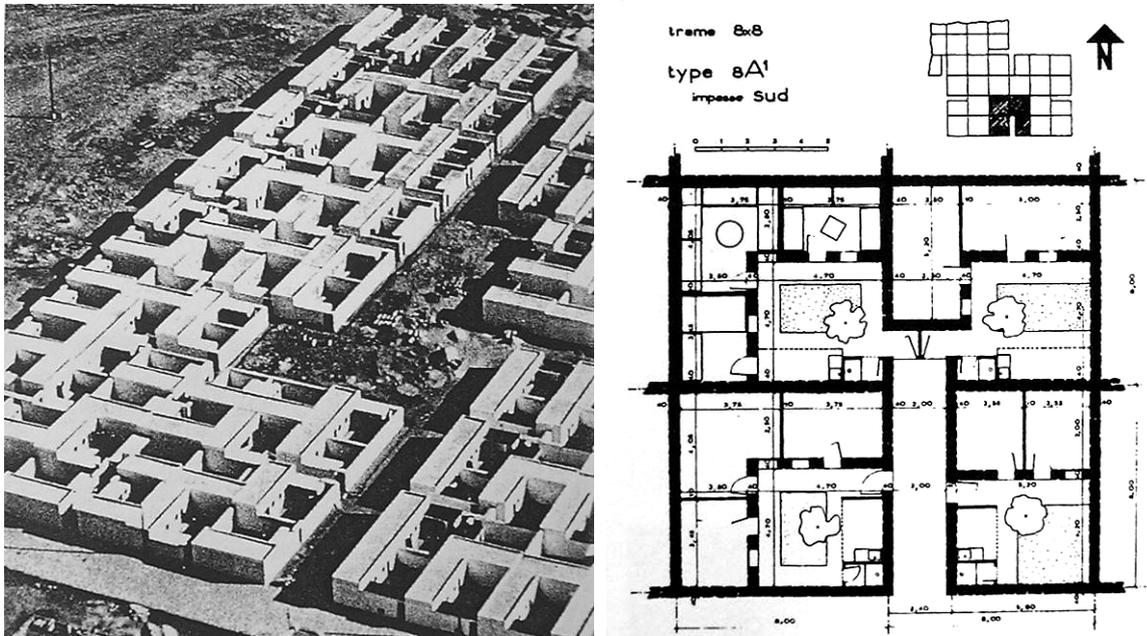
During the same time period, isotropic bidirectional meshes were used in a number of designs for iterative patterns of single-family dwellings. In Spain, Alejandro de la Sota designed a project of 1,480 dwellings on the Mar Menor.<sup>12</sup> In order to demarcate his design as being different from the typical pattern of isolated buildings surrounded by residual spaces, de la Sota compressed the groups of dwellings by linking them to a bidirectional network, such that his building model could be multiplied in a balanced – and limitless – fashion. The ground levels of the buildings,

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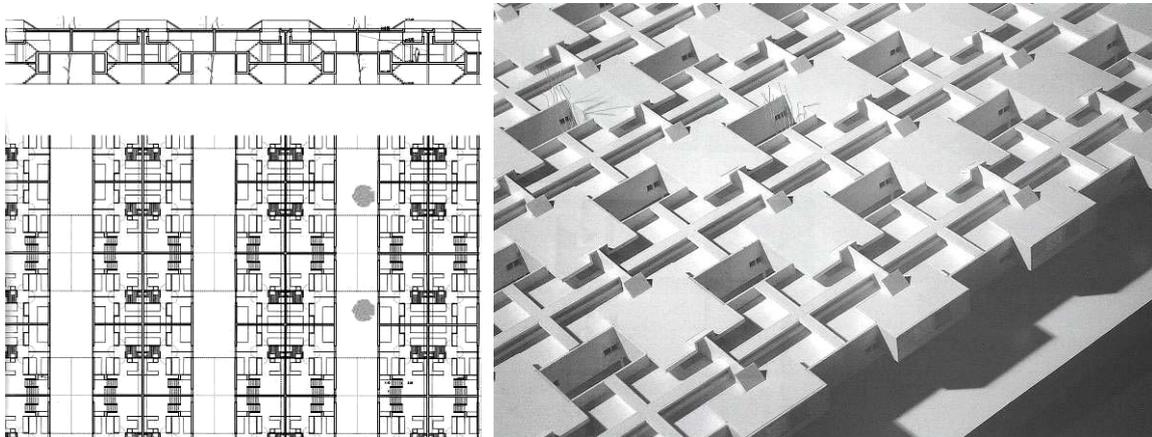
<sup>12</sup> For an in-depth analysis of this proposal, see: MARTÍNEZ ARROYO, C., PEMJEAN, R., *Alejandro de la Sota. Cuatro agrupaciones de vivienda: Mar Menor – Santander – Calle Velázquez – Alcudia*, pp. 17-51

organized around split-levels, exhibit a clear directionality. From the third level on, the design made use of the urban space and crosses the network in perpendicular fashion (fig. 11b).

Figure 11. **Bidirectional meses:** 11a. CANDILIS, JOSIC, WOODS. *Horizontal City*. Casablanca, 1951. / 11b. A. de la SOTA. *Mar Bella residential complex*. Mar Menor, 1964-66



11a



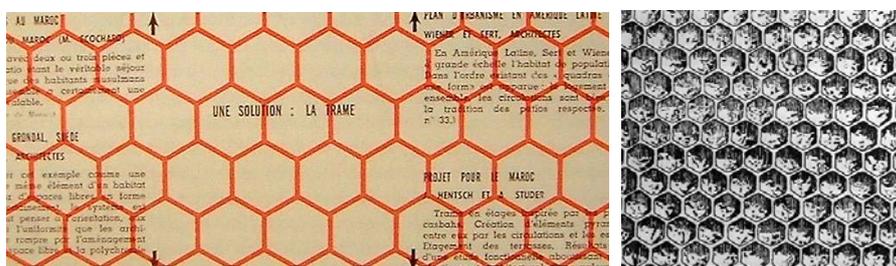
11b

Source: 11a. AVERMAETE, T., *Another modern. The post-war architecture and urbanism of Candilis, Josic, Woods*. Rotterdam, Nai Publisher, 2005. / 11b. MARTÍNEZ, C., PEMJEAN, R., *Alejandro de la Sota. Cuatro agrupaciones de vivienda: Mar Menor-Santander-Calle Valázquez-Alcudia*. Demarcación de Toledo, COACM, 2007.

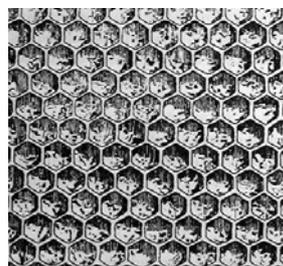
Universal order and accident, systematization and flexibility, abstraction and concretion are the complementary qualities found in the 'grid and type' duality coined by Candilis, Josic and Woods. It is not by chance that they used a hexagonal pattern as a background to their slogan. This pattern of growth, shown in red, happens to be one of the most intelligent methods of reproducing cellular structures, and is present in nature and in the internal configuration of many compounds (fig. 12).

Hexagonal patterns are found in many strategic places in nature. The structure of honeycomb, basalt formations, snowflakes and even the method of reproduction of some viruses is evidence that the geometrical unit best suited to annexation is the hexagon. This is because a hexagon comes closest to occupying the minimum perimeter of the circumference of a cell, while doing so in such a way that each cell's sides are in complete contact with those of its neighbor – thus wasting neither space nor material (fig. 12a, 12b, 12c).

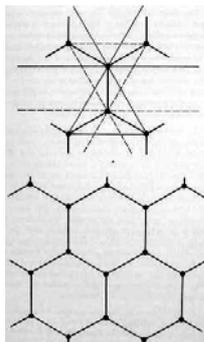
Figure 12. **Hexagonal pattern in nature and architecture: 12a. CANDILIS, JOSIC, WOODS. Fragments of Gamma-Gride panels, 1953. / 12b. Hexagons: honeycomb. / 12c. Graphite atoms. Internal structure. / 12d. Obra Sindical del Hogar. 916 Granada, 1962. / 12e. A. van EYCK, Previ neighborhood. Lima, 1966. / 12f. I. CHINCHILLA. Eco de montaña (Mountain Echo) residential fabric, 2007**



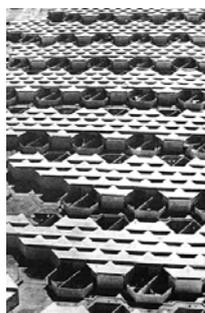
12a



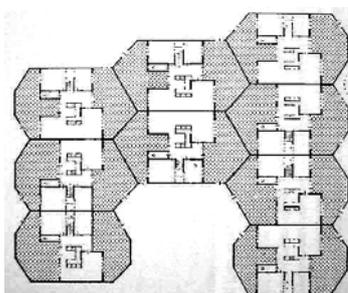
12b



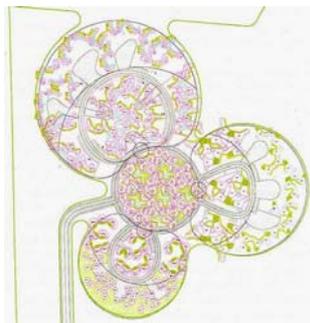
12c



12d



12e



12f



Source: 12a. AVERMAETE, T., *Another modern. The post-war architecture and urbanism of Candilis, Josic, Woods*. Rotterdam, Nai Publishers, 2005. / 12b. THOMSON, D'A., *Sobre el crecimiento y la forma*. Madrid, Cambridge University Press, 2003. / 12c. KEPES, G., (ed.), *Module, proportion, symmetry, rhythm*. New York, George Braziller, 1966. / 12d. BOLDÚ, E., *El tot i les parts: la casa com objecte industrial*. Tesis doctoral. Universitat de Barcelona, 2001. Inédito. / 12e. LIGTELIJN, V. (ed.), *Aldo van Eyck. Works*. Berlin, Birkhauser, 1999. / 12f. Arquitectos, 181. Madrid, CSCAE, 2007.

In the mid-1950s, a number of projects based entirely upon hexagons were designed and built. In the field of dwelling units, one of the examples of the most radical application of this geometry was the set of 916 dwellings developed in Granada by the *Obra Sindical del Hogar* (Union Organization for Housing). An entire neighborhood was built along just such a geometrical grid and based on the equilateral triangles that make up each of the hexagons: this included the urban plan, the courtyard-houses, the rooms, the structural system and each of the prefabricated pieces used in the building system (fig. 12d).<sup>13</sup>

Another architect who used geometries based on the hexagon in some of his proposals was Aldo van Eyck. Both in his Open Air School and in a children's playground in Amsterdam, he combined hexagonal prisms of different heights and dimensions. And, in the self-built dwellings in the Previ neighborhood of Lima, the inhabitable, two-storey volumes are inserted in the center of oblong hexagonal parcels, such that two courtyards are left open at either end; this guarantees that each house receives cross-ventilation (fig. 12e).

In more recent years, Spanish architect Izaskun Chinchilla organized one of her designs for Las Dehesillas-Espartalia around a hexagonal grid. At the central crown of the residential fabric, the dwellings were organized around a hexagonal perimeter that was open to a courtyard, and are linked in a sort of chain, which randomly opens up larger natural spaces (fig. 12f). Unlike the operation undertaken by *Obra Sindical del Hogar*, here one finds respect for the autochthonous landscape, a proliferation of gardens, the incorporation of the concept of neighborliness and the inclusion of public spaces for open-air commercial activities. All of these hark back to the ways of life and folk culture of a country that misunderstood industrial progress and waves of migration and has seen its own residential developments lose the values that characterized its architecture and made it inhabitable; furthermore, this design allows for a high level of savings with regards to energy and resource consumption.

## 6. Expandable spatial structures

At roughly the same time that Team X was making its proposals and shortly after the theoretical studies of Candilis, Josic and Woods, architects such as Louis I. Kahn, Moshe Safdie, Kenzo Tange, Kiyonori Kikutake and Kisho Kurokawa began to incorporate infinitely repeatable cell-elements in their buildings. These then gave rise to modular wholes that lacked any hierarchy. The resulting forms were isotropic, some were adaptable to different media, and their spatial potential went beyond planimetric expansion.

In these projects, the cells are structured by strict internal rules governing growth and addition, which are delineated along three-dimensional networks than can be extended without limits to make a potentially infinite field made up on modules of equal value. Manfredo Tafuri was critical of these processes; he stated that they utilize architecture as an empirical material, by delegating some of the decisions in the design process to chance and transforming the results into "an uncontrollable adventure". And Christian Norberg-Schulze warned that in systems that combine order – conceived of as a continuous infrastructure – with freedom – understood as a

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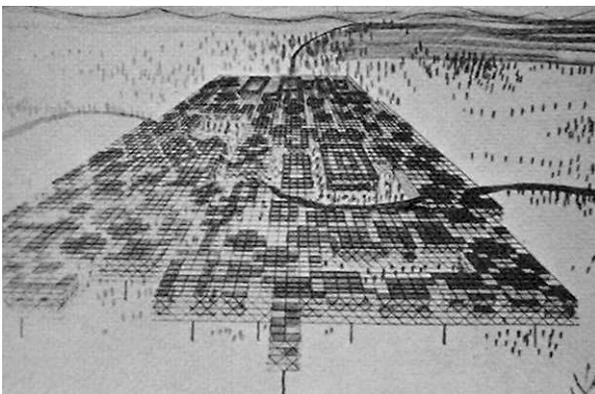
<sup>13</sup> BOLDÚ, E., *El tot i les parts: la casa com objecte industrial*, pp. 141-149

variable filling – buildings can be transformed into mere repetitions of singular elements. They thus lose spatial identity, and as a result end up devoid of orientation and reference points.<sup>14</sup>

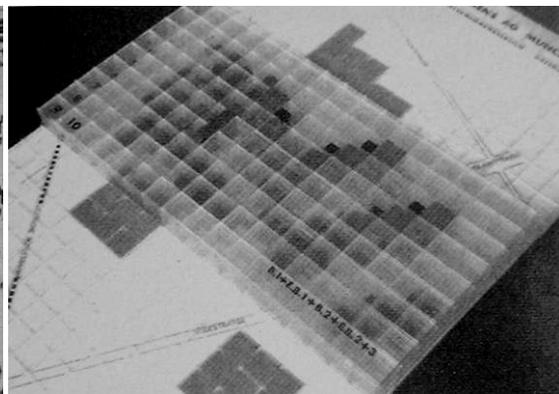
One of the pioneers in this “uncontrollable adventure” was Hungarian architect Yona Friedman, who, between 1956 and 1957, developed the concept of ‘scientific’ architecture. He established a universal system for developing all of his designs, in which the concept of structure was fixed and the modules – whether they were dwellings, facilities or public spaces – were grafted as satellite-cells to a general framework. This fixed spatial structure consisted of a three-dimensional mesh elevated atop *pilotis*, which was inserted ‘on tiptoes’ into the rural or urban environment beneath it (fig. 13a). Inside the mesh, fixed and mobile elements cohabited in keeping with the system’s geometric rules and the requirements of habitability.<sup>15</sup>

Van der Broek and Bakema also developed a special methodology for modulated growth, in which volumes were generated by the simple relationships that arose from superimposing and juxtaposing modules on a pre-established spatial framework. In their studies, the working system was as important as the design itself, as it was the former and not the latter that defined the final shape. Van der Borek and Bakema’s designs inserted multi-colored three-dimensional elements into a mesh of methacrylate strips whose transparency allowed one to visualize the changing order of one’s decisions throughout (fig. 13b). Once the program had been established, the methacrylate framework would disappear and the building would be left over as the ‘remains’ of the process: a mere consequence of the laws imposed by the system.

Figure 13. **Expandable spatial structures: 13a. Y. FRIEDMAN, Spatial infrastructure, mobile architecture, 1956-57. / 13b. VAN DER BROEK & BAKEMA, Spatial mode**



13a



13b

Source: Arquitectura COAM, 345. Madrid, 2006

During the same time period, Spanish architect Rafael Leoz designed several proposals for associating elements based on the geometry of bodies and their strength of form. Working from

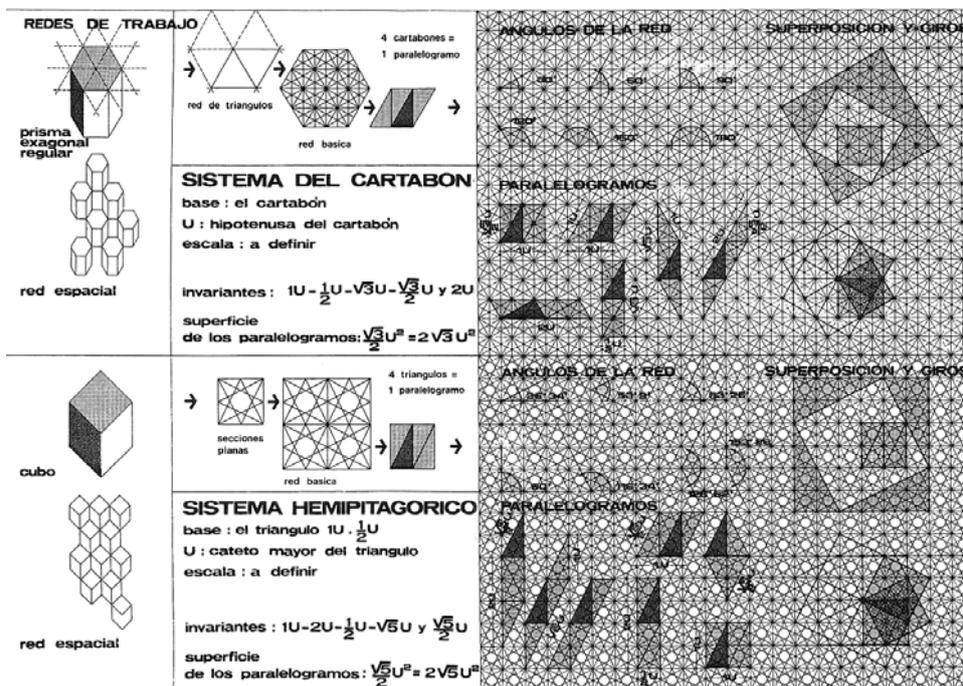
<sup>14</sup> TAFURI, M., *La esfera y el laberinto*, pp. 446. NORBERG-SCHULZE, Ch., *Los principios de la arquitectura moderna*, pp. 47-53

<sup>15</sup> DE FUSCO, R., *Historia de la arquitectura contemporánea*. Vol. II, pp. 496-497

two-dimensional spatial grids, Leoz built ceramic pieces, sculptures and buildings by reproducing simple or combined figures in all the varying combinations allowed by the underlying mesh framework. Symmetry, turning, translation and rotation, that is, the four geometrical methods for reproducing units, are implicit in Leoz's systems and are valid in any discipline (fig. 14). With the mentality of a Renaissance artist, Leoz designed his 'work networks' so that they could be used to generate any composition based on simple geometric entities.<sup>16</sup> Though they exhibit their own particular characteristics, 'mat-buildings' should also be mentioned in any genealogy of expandable growth. The term 'mat', first used in an architectural context by Candilis, Josic and Woods and explicitly conceptualized by Alison Smithson in a 1974 article on proposals by Team X,<sup>17</sup> adds textile properties to its system in addition to a three-dimensional mesh.

In 'mat-buildings', compositional structure is based on one more grids that yield a non-hierarchical isotropic mesh into which one fits solids and voids. Dwelling units are combined with other complex frameworks that link built pieces with courtyards, thoroughways and green spaces. Examples cited by Alison Smithson include his 1957-58 design for Berlin-Hauptstadt; Candilis, Josic and Woods' proposal for the 1963 Frankfurt Urban Plan contest, and their Free University of Berlin, which was finalized in 1974; and Le Corbusier's 1964 design for the Venice Hospital.

Figure 14. RAFAEL LEOZ, Working networks. Cartabon system



Source: MOYA BLANCO, L., *Rafael Leoz*. Madrid, Ministerio de Educación y Ciencia, 1978.

<sup>16</sup> For further information on Rafael Leoz, see:  
MOYA BLANCO, L., *Rafael Leoz*, 1978  
LEOZ, R., *Redes y ritmos espaciales*, 1969

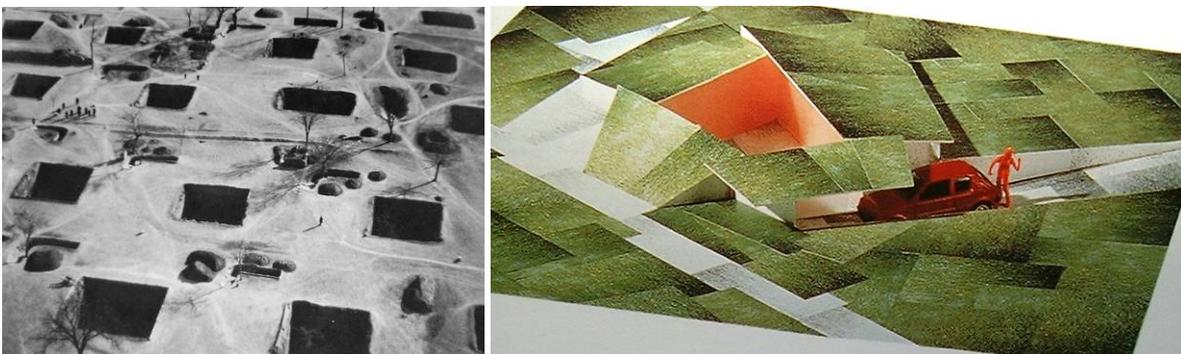
<sup>17</sup> SMITHSON, A., *Mat-buildings: how to recognise and read it*, pp. 573-590

In 'mat-buildings', unlike Egon Eiermann's *Teppichhaussiedlungen*, voids are not identified as simple courtyards, but instead form an inseparable part of the system. Air is trapped in the interior of the building, as is a lawn – in the case of the Free University of Berlin – or water, in the case of the Venice Hospital. In these designs, unlike more object-focused projects, it is not units that contrast against a background, but rather the background itself that enters into the inside of the system.

From this perspective, any design would be considered a 'mat-building' if it started off as a solid surface from which compact masses were subtracted so as to facilitate the ventilation and illumination of living units. Thus, proposals for underground dwellings that feature a geometric structure that both regulates the creation of dwellings and the subtraction of material would be included in this category.

In such cases, the integration of the habitat and landscape tends to be much greater. Houses, the voids that serve them, access and vertical connections, building materials, vegetation and the land upon which one operates all form part of the same strategy. Such would be the historical case of the underground houses in Honan, China (fig. 15a), or that of more contemporary projects such as T. Lacoste and A. Robain's 1991 entry to the European 2 contest for housing in Dunkirk, or the 'puzzle houses' designed by Jacob and MacFarlane in 1997 (fig. 15b).

Figure 15. **Underground houses as infinite matbuildings: 15a. Subterranean dwellings. Honan, China. / 15b. JAKOB & McFARLANE. Puzzle houses, 1997**



15a

15b

Source: 15a. RUDOFISKY, B., *Architecture Without Architects*. Albuquerque, University of New Mexico Press, 1964.  
15b. *Quaderns d'Arquitectura i Urbanisme*, 220, Barcelona, COAC, 1997.

## 7. Interwoven frameworks

Unidirectional, bidirectional and spatial guidelines can support more complex layers of program when they are used to generate new combinations of repeated forms. If the existing repetitions have been produced on a plane or in space without deformation of the basic forms – by means

of interwoven frameworks in a way similar to the generation of a fabric and with mechanisms similar to those used in 'mat-buildings'- the linkage between the shapes and their linking systems is more sophisticated.

In interwoven frameworks, the lines that arise between units cross back and forth over one another and create a network that can be progressively enriched by adding new forms and new links to the system. Thus, when faced with the horizontal stratification of most architectural designs, these interwoven networks pair spaces and elements both in plan and section, which allows for visible diagonals and crossing paths that incorporate new sequences of events. Likewise, by exploring the geometric periodicities implicit in these mechanisms one can open the field so as to transition gradually from generic space to concrete detail within the hierarchy of forms.

It was Islamic artisans who were the great explorers of the gradual periodicities achieved by linking formal elements and a panoply of interlacing lines. Because of the ornamental –and structural– requirements of their architecture, and due to a strong cultural emphasis on mathematics and geometry, these artists refined a method of enriching the mechanisms by which shapes and lines were linked together.<sup>18</sup> These systems, which were not limited to graphic and sculptural ornamentation on walls and ceilings, were also used on furniture, ceramics, lattices and ironwork. Furthermore, they were able to articulate a wide palette of geometric and naturalistic motifs that achieved a high degree of complexity and virtuosity (fig. 16a).

Throughout history, other artists and architects have shown their interest in interwoven patterns and the various applications thereof. Indeed, Gothic tracery, as well as many other forms of stone or woodwork used to decorate churches and cathedrals, is indebted to these systems. During the Renaissance, both Leonardo da Vinci and Albrecht Dürer drew images that bore witness to their fascination and curiosity regarding how continuous patterns would unfold.<sup>19</sup>

Famous 20<sup>th</sup> century schools of art and architecture –such as the Bauhaus or the Ulm School– utilized mechanisms similar to medieval Islamic interwoven patterns and Gothic tracery as the basis for ingenious designs of a great beauty and plasticity (fig. 16b). To get his students to practice composing formal systems in space, for example, Joseph Albers would use a ductile material, such as paper, to produce infinitely repeatable constructions based on practically identical fragments.

The implicit pedagogy in these exercises and the message underlying them stems from professors such as Gui Bonsiepe at the Ulm School and the Bauhaus's Gunta Stölz, who compared the creative process behind creating any handcrafted or architectural object with the act of crafting a fabric.<sup>20</sup>

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<sup>18</sup> GOMBRICH, E., *El sentido del orden*, pp. 63-94

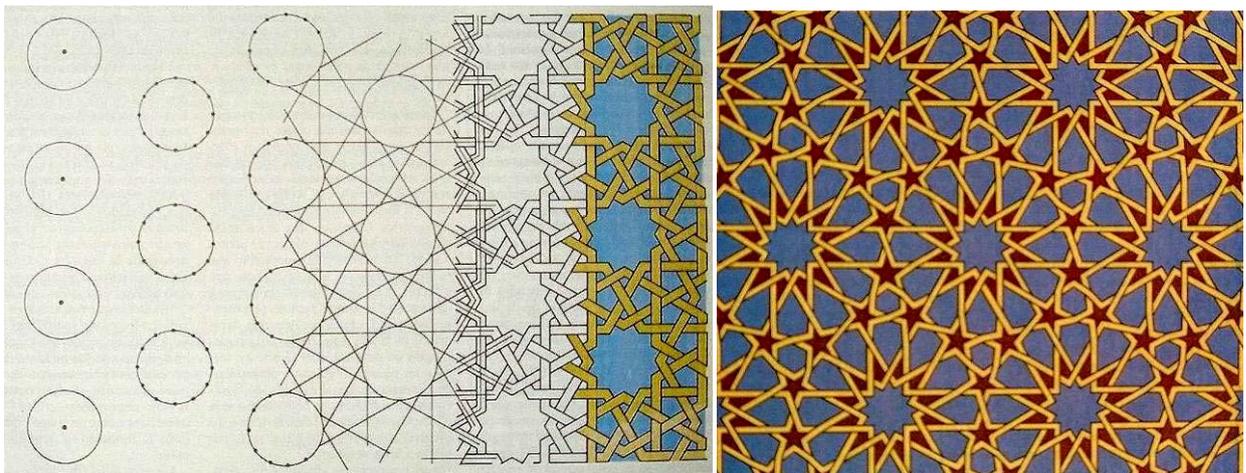
<sup>19</sup> In a series of drawings entitled 'La academia de Leonardo da Vinci', the Milanese artist demonstrate his skill not only in the analysis of Islamic examples, but also in the resolution of new problems that have arisen in interweaving patterns. See: PEDRETTI, C., *Leonardo architetto*, pp. 296-303

<sup>20</sup> Gui Bonsiepe affirmed that "how convenient it would be if the design of a product – and that is the creation of a form – were as easy as braiding the strands of a rope!" See: BONSIEPE, G., *Arabescos de racionalidad. Notas sobre la metodología del diseño*, pp. 147

By following these analogies further, one can identify mechanisms similar to interwoven patterns in a number of the designs for iterative dwelling units. If one extrapolates the patterns of Islamic artisanship to architecture, one can imagine the lines that link these shapes as ways of accessing habitable spaces; floral or geometric motifs can be understood as the nuclei of vertical connections and the remaining forms can be seen as buildings and courtyards. Thus, one is left with an iterative dwelling fabric that is developed at varying levels. Between 1980 and 1982, in an area of New Delhi, architect Raj Reval designed a spatial system for designing expandable residential construction patterns in which pedestrian connections would be made on different levels. Likewise, he used roofs and intermediate zones as public spaces. This led to raised streets, which in turn gave rise to an interwoven network similar to interlaced patterns (fig. 16e). Yona Friedman also designed a number of spatial cities in which an interwoven pattern was used to conceptually represent the complexity of the system (fig. 16c). And, in 2002, the firm AAMM designed a group of single-family courtyard-dwellings in Torrelodones, Madrid, in which one can discern mechanisms of connection between the units that are very similar to those used in spatial fabrics (fig. 16d).

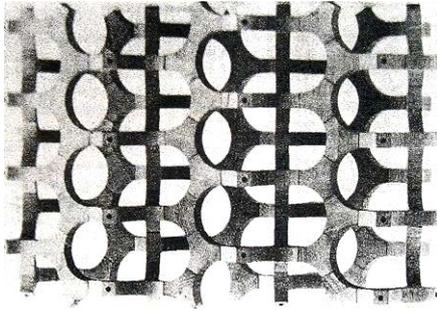
This method of interweaving empty and occupied spaces in three dimensions typifies autochthonous architecture in Northern Africa and in places where climate, topography and lifestyles have required it. The kasbahs, for instance, are paradigmatic examples in which different levels of pathways and streets necessitated by the need for natural lighting and cooling have favored a circulatory network which moves not only people, but also air, water and light; this is analogous to the ornamental systems used by these cultures to decorate their furniture, ironwork, lattices and tiles (fig. 16f).

Figure 16. **Interwoven frameworks in architecture and art: 16a. Construction of an Islamic interwoven pattern and another islamic interwoven pattern. / 16b. Exercise: Ulm School. / 16c. Y. FRIEDMAN, Interwoven spatial city, 2006. / 16d. AAMM, Residences in Torrelodones, 2002. / 16e. RAJ REVAL, Asian Games Village in New Delhi, 1980-82. / 16f. Casbah. Ventilation study**

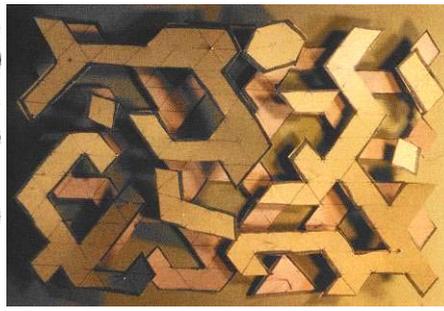


16a

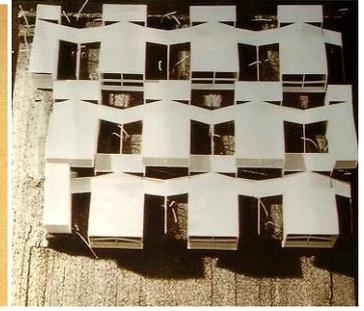
Gunta Stölz, compared the art of weaving with building: “Weaving is building; it is creating structured figures based on disorganized threads.” See: FIEDLER, J., FEIERABEND, P., (ed.), *Bauhaus*, pp. 351



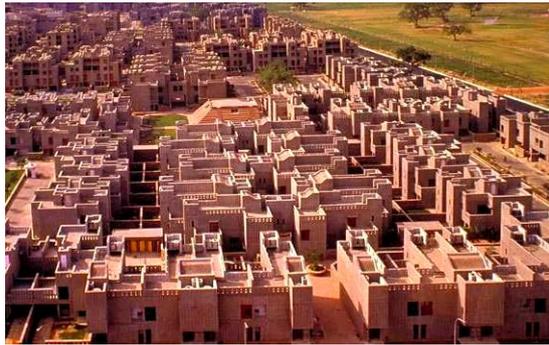
16b



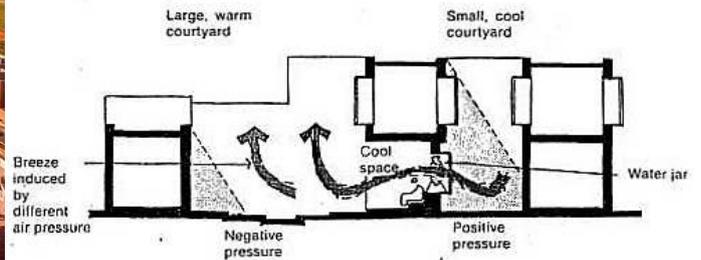
16c



16d



16e



16f

Source: 16a. Investigación y Ciencia. Versión española de Scientific American. Agosto, 1988. / 16b. FRIEDMAN, Y., *Pro Domo*. Barcelona, Actar, 2006. / 16c. Arquitectura COAM, 326, Madrid, 2001. / 16d. BONSIPEPE, G., *La crisis del objeto*. 0 Monografías, 1, 2001. / 16e: [http://www.greatbuildings.com/architects/Raj\\_Rawal.html](http://www.greatbuildings.com/architects/Raj_Rawal.html)

Iterative systems based on interwoven networks also offer the advantage of flexibility, and are thus more easily adapted to irregular terrain. The pieces that are typically molded to changes are usually transitional spaces, such as porches, courtyards and wrought iron gates, so the resulting distortion does not affect the capacity or the geometry of the dwelling spaces. Other parts of the system that facilitate this flexibility and even favor formal changes are the elements of vertical communication, as they are able to absorb – thanks to their changing section and their heights – the morphological differences that arise from the limits imposed from outside the system.

## 8. Corollary

The examples illustrating this essay are taken from different periods in history, and it is the formalization of objects and the mechanisms used to compose them that allows one to establish paths that go beyond strict sequences in time. Nevertheless, it is evident that a great number of these designs arose during the 1950s, 60s and 70s, which were precisely when scientific and technological advances began to pick up speed and shed light on important insights into the formal structures of matter and the universe. These advances established a new context in which architects reexamined how they could investigate form, and parted ways with some of the premises of Functional Rationalism.

These years were also marked by the hatching of new philosophical and scientific currents that examined the concept of 'structure' as a generator of internal order. In architecture, the term 'structure' is not solely used to refer to the system that stabilizes a building, but is also a synonym of organization, complexity and order, and is taken as a starting point for formal configuration. For Louis I. Kahn, form should be shaped based on internal 'pre-forms', as though this would deliver vital impulse that would allow for the expansion of a morphology that would in turn stem from the internal needs of the design.<sup>21</sup> Likewise, W. Tatarkiewicz highlighted the authenticity of structural forms to distinguish them from happenstance ones. According to Tatarkiewicz, the morphological significance of the term 'structure' is such that it defines those forms that are configured by internal forces: those whose appearance responds to some authentic condition coming from within.<sup>22</sup>

Structure, in the reproduction of dwelling units, permits a system of open design and also defines its intrinsic potential for growth, by establishing the rules that should guide the entire evolutionary process. Still, in these sorts of operations, the term 'structure' should also posit a design system that incorporates time and change; a system that allows for mutation and adaptability both to the realities of construction and to the requirements of climate, functionality, society, organization and culture of wherever the system is to be inserted.

Along these lines, it is not by chance that many such architectural designs are not just morphologically but also conceptually similar to natural mechanisms of growth, as those are what best match the term 'structure'. Both nature and the internal order of compounds follow processes of configuration that respond first and foremost to internal necessities while still being able to change and adapt to the environment in which they unfold.

## 9. Conclusion

The open systems that recent years have seen in the field of low-density housing are typified by the ability to reproduce ad infinitum one or more typologies of alternating built and open spaces. They are non-hierarchical, and are generally isotropic and egalitarian operations, which lay their trust in mechanisms of reproduction based on the implicit design of units, and can be used over time to allow for the further growth of the whole. While architects – with the help of computers – establish the rules of the game, the materialization of the system lies in the hands of the users themselves or whoever executes the system in the future.

One can find operations that are similar to these contemporary projects in some of the Utopian proposals of the masters of the Modernist movement, who were keen to enhance hygiene and were evidently influenced by the zeitgeist of admiring the qualities of seriation and Mechanism. Their most direct heirs, in the second half of the 20<sup>th</sup> century, built entire neighborhoods inspired by these Utopian proposals for iterative horizontal cities, which were modified to meet local conditions of climate, topography, materials and culture.

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<sup>21</sup> "En la preforma descansa más energía que en nada que pueda venir después". Cited in: NORBERG-SCHULZE, Ch., *Louis I. Kahn, idea e imagen*, pp. 95

<sup>22</sup> TATARKIEWICZ, W., *Historia de seis ideas*, pp. 253-262

The generic rules of the game that regulate iterative construction processes, whether they are imposed by architects or they arise anonymously, are analogous to the structures that underlie natural and scientific processes, as well as to the mechanisms of generation used in other disciplines of art and artisanship. They all share a geometric abstraction implied by their units, and mechanisms for reproduction based on the isometric movements – reflection, symmetry, translation and rotation – which were first codified in the 18<sup>th</sup> and 19<sup>th</sup> centuries as tools for reproducing patterns. They all also incorporate the term ‘structure’, which is not solely understood as something underpinning the operation but also as something that generates form in and of itself and as a mechanism of mutation and adaptability to the environment.

Based on geometric movements in planes and space, one can visualize a series of sets of families of architectural systems that –by relying on guidelines established by lines, networks, meshes or interweaving– can extend and interweave to give rise to a series of habitable elements, courtyards, throughways, open spaces and greenswards. These then yield –not just in modern times but throughout history– open, iterative systems that reconcile time and space, the natural and artificial, newness and tradition, utopia and reality: the eternal problems of human habitability.

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