BARCODE HOUSING SYSTEM: OPEN CONSTRUCTION SYSTEMS APPLIED TO INDUSTRIALLY PRODUCED HOUSING

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ABSTRACT

BARCODE HOUSING SYSTEM is a research project developed over the last four years with the support of the Spanish National R+D+I plan. The goal of the project is to create an ICT (Information and Communication Technology) environment which supports the design and construction of flexible and adaptable housing through industrial processes.

We have developed a computer-supported design and construction system to design housing buildings which can be materialized in multiple forms through the use of different building systems and components. The system supports the participation of the different agents –architects, manufacturers and dwellers– along the design and construction process in both synchronous and asynchronous ways.

A rule-based generative system creates the housing units automatically. These are later assembled in housing blocks or towers. Building components are described in an on-line catalogue from which they are retrieved to create a building model. Manufacturers can insert their products in the catalogue, architects can select the components to be used in the building (façade, structure), and dwellers can customize the housing units by choosing partitions, and equipment (kitchen, bathroom). This way, for a given housing block different combinations of building components can be evaluated before it is executed.

In this paper, we describe the characteristics of the ICT environment, as well as the principles of the construction system, including structure, exterior and interior envelopes, and building services. Furthermore, the different ways in which the information system can guide the technical team in decision-making throughout the design process are outlined.

1.- Introduction

The substitution of a conventional building practice –often mistakenly called traditional– by an industrialized system is taking place in a slow, yet irreversible way. Within the limited scope of the subsystem sector, however, industrialization has gained more ground. Nowadays, open industrialization takes place as a spontaneous form of open building –limited to some subsystems and to light construction– lacking a well defined base of relations. As a matter of fact, we have evolved towards an industrialization of an open nature in which a limited compatibility between components exists. This evolution, from conventional to industrialized building, has not occurred suddenly but has been the result of a long development process driven by technological developments.

An industrialized building system is a set of elements –which make up the complete building or a part of it– that are so rigorously inter-related[1] that the ensemble can be considered a finished and interdependent unity. The elements are industrially produced and the constructive process is also controlled industrially. It is important to understand that the system is not a "material" entity –as would be the case with a building component system– but rather, it should be understood as a set of relations between the building parts which influence both the design and the assembly process.

A building system is open when it is formed by a set of components of similar characteristics that can be combined with others in different ways, through previously established types of connections. Paradoxically, this kind of "open" system leads to a technocratic model that is barely compatible with the characteristics of the building components market. Experience has shown that an open system –understood as the highest expression of universal assembly– is a utopia.

Nevertheless, open construction systems are still valid conceptual models which might enable us to increase the level of industrialization in the building sector in the future. However, to make open systems successful, a maximum flow of relations between component parts that do not have a similar origin must be reached[2]. The openness of building systems is necessary in order to optimize the capacity of product assembly coming from different manufacturers and the information exchange between the participants in a design and building process, at both a national and international level. This requires a coordinated development of subsystems and components produced by the specialized construction industries.

Open building encompasses a diversity of issues, from design to construction: feasibility of a particular design to be built in a variety of ways, competition between existing systems and products and diversity of alternative construction and assembly processes. Once a building has been built, open system facilitates the possibility of future changes of use, the exchange of modules and subsystems as well as the recycling or reusability of building components.

A realistic application of the principles of the open system contemplates the use of semi-finished products and components that can be compatible, although they were not initially designed to be so. We could define this approach as an integrated components assembly. Accordingly, a set of semi-finished products and components sufficiently compatible would provide sufficient diversity to satisfy a reasonable demand of architectural and technical variety. In a context in which there is no place for a unique and dominant building system, this model based on compatible parts can facilitate the technological development and innovation of the building industry.

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[1] According to Lessing [1], industrialized construction is "an integrated manufacturing and construction process with well-planned organization for efficient management, preparations and control over resources used, activities and results, supported by the use of highly developed components." In this notion of industrialization the emphasis is placed more on the processes than on the products. According to Monjo [2], rather than speaking of "industrial production of buildings" it would be more appropriate to speak of "industrial process to execute buildings", a process which embraces the industrial production of building components, a rationalized and efficient building as well as the industrialized production of spatial units

[2] As Bernard [3]. has contented, the feasibility of open system does not necessarily rely on dimensional coordination and assembly rules that ensure a universal compatibility of components. Rather, its feasibility would be based on the discovery of new relations between industrially built components –following market laws based on competition between companies– and the complete building, thus ensuring that the diverse sequence of components comply with certain basic compatibility criteria (geometric, mechanical, physical and chemical).

There is a possibility that components coming from diverse industrial production processes –including those coming from other manufacturing sectors– fabricated by different companies, make up a construction system encompassing the entire production cycle of the building and its industrial organization from the very beginning. These open systems can promote a renewal of building forms, materials and processes in the construction sector, as well as fostering the transfer of solutions which have been previously validated in other subsectors such as, for example, the metallic, wooden and prefabricated concrete industries. Due to its technological versatility, light industrialized construction appear to be a promising way to achieve the necessary adaptation of a diversity of programs and building types that characterize housing construction.

To sum up, open systems have been implemented without having previously laid out the necessary theoretical bases. As a result, what we have today is an intensive use of parts industrially produced in large or reduced series lacking clearly defined rules of interdependence as well as other sort of relations inherent to the industrialized constructive systems. BARCODE HOUSING SYSTEM tries to compensate for the limitations of the open system model by establishing some bases that facilitate the integration of building components along the design and construction processes. The rules of assembly are derived both from the abstract principles which makes the base of the system (spatial configuration, modularity) as well as from the specific requirements derived from the building (material and section of structural elements, dimensions of ducts and pipes) and spatial components (minimum dimensions of rooms, adjacency constraints).

2.- Interrelated working environments

BARCODE HOUSING SYSTEM consists of interwoven working spaces where different actors (architects, developers, manufacturers, occupants) can participate in a synchronous and asynchronous manner throughout the whole process of design and construction of collective housing projects.

The work spaces and their functionalities are the following:

- *PROJECT DEVELOPMENT*. In this working space, developers, architects and building managers specify site properties (area, size), number and type of housing units, building and planning regulations (building volumes and height), and environmental conditions (climate, orientation). Alternative solutions of buildings (massing, location) can then be explored for the given site conditions and brief.
- *HOUSING UNIT LAYOUTS*. In this space, architects select a set of units that will be used later in the generation of a building. The units have been generated by the system in batch processing, and are stored in the system database. The selection becomes a “discovery” process as the architect finds the housing layouts while navigating through the space of solutions which the system has generated in previous project developments. In the case of an adequate layout not being found from the existing solutions, the architect can request from the generative system to create alternative layouts that conform to the desired criteria (surface, number of rooms, number of bathrooms, open or close kitchen,...). The new solutions are stored in the database, thus enhancing the previously existing pool of solutions.

- *HOUSING UNIT CONFIGURATION*. Occupants describe their housing program (family members, usage of spaces, lifestyles…) working with user-friendly interfaces that represent housing units and layout in a graphic language that can be understood by lay people (schematic plans, photographs depicting activities in spaces, bubble diagrams). The system returns the housing units that suit to the criteria defined by the users and they select those that find more adequate to their needs. Then, the selected units are used in the generative process that creates the housing block. Once the housing units have been assembled, there is a process by which occupants and architects collaborate using a 3d environment to define the arrangement of a living unit (finishing, partitions, and furniture).
- *HOUSING UNITS ASSEMBLY*. In this environment, the architect defines the design criteria for the assembly of living units, for instance: degree of compactness of the housing block; degree of optimization of building services; minimum distances to access cores (staircases, elevators); material of the structural skeleton, and so on. Once the design values are set, a generative process creates the solutions that satisfy these criteria.
- *BUILDING COMPONENTS CATALOGUE.* A XML-based product modeling catalogue enables manufacturers to introduce descriptions of their products which will be then selected by the team in charge of the project development. Based on this selection, the future occupant chooses the components (doors, windows, partitions) and inserts them in the 3d representation of a dwelling.

This structure of autonomous and interrelated workspaces supports open and non-linear design and construction processes. In order to interact with the system, it is not necessary to proceed along the working spaces in a linear fashion. Rather, the only prerequisite is to start the Project Development works space, where the characteristics of the program are described (site, brief) and users are registered. All other spaces can be activated later at any moment during the project lifecycle. In this way, the system can support non-linear design and construction processes by exploiting, as Kalay [4] has argued, the potential of ICT technologies to transform established design and construction processes. For example, the system can support the creation of a network of small interconnected companies collaborating in the construction process [5].

The workflow through the workspaces can start at different points and at different times (fig. 1). For instance, a work flow could start in a traditional manner by defining a site and a programme and then following with the design and the construction of the building. But it could also start differently, for example, by defining building components from different manufacturers in a catalogue. However, use of the system is not limited to the construction of a building. It can be employed, for example, to investigate appropriate forms of dwelling for a particular area based on the descriptions of the housing units generated by prospective inhabitants. All of these processes can start at different moments, even though they are part of the same design and construction project. Furthermore, outcomes from a particular project – catalogue of housing units and blocks, building components catalogue– can be reused in later projects. In this way, with this open system it is possible to support different organization models to carry out a project development[3].

[3] According to Pérez Arroyo [6] the organizational models can be summarized as follows:

- Traditional model. A developer commissions a project to the architect, which is then built by the contractor.

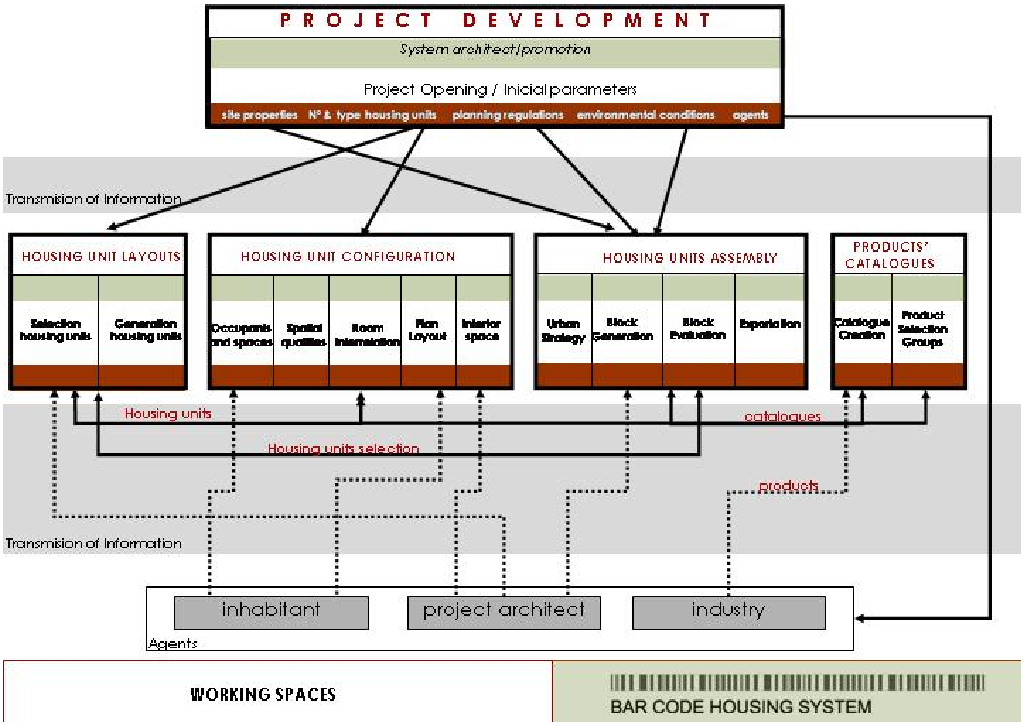

Figure 1. Structure of the working environments.

3.- System structure

The system is structured in three levels (fig. 2). At the lowest level there are the specific conditions and components that will be used in the housing design and construction, for instance, the orientation of the site, the building components, or the material to be used in the structure. The intermediate level is made up of the subsystems: spatial, structure, building services and envelope. At the top level, the system regulates the relations between subsystems, by setting up the rules by which elements from different subsystems can interact with each other.

- Evolved traditional model. Developer and architect working as a team require from the contractor the adoption of specific building systems or components.
- Programs model. A developer owns a building system which can be adapted to the particular conditions of site and program.
- Technical-based model. A developer declines any responsibility and delegates it on the technical teams.
- Case-based model. A developer applies solutions previously elaborated by a contractor and its technical team.

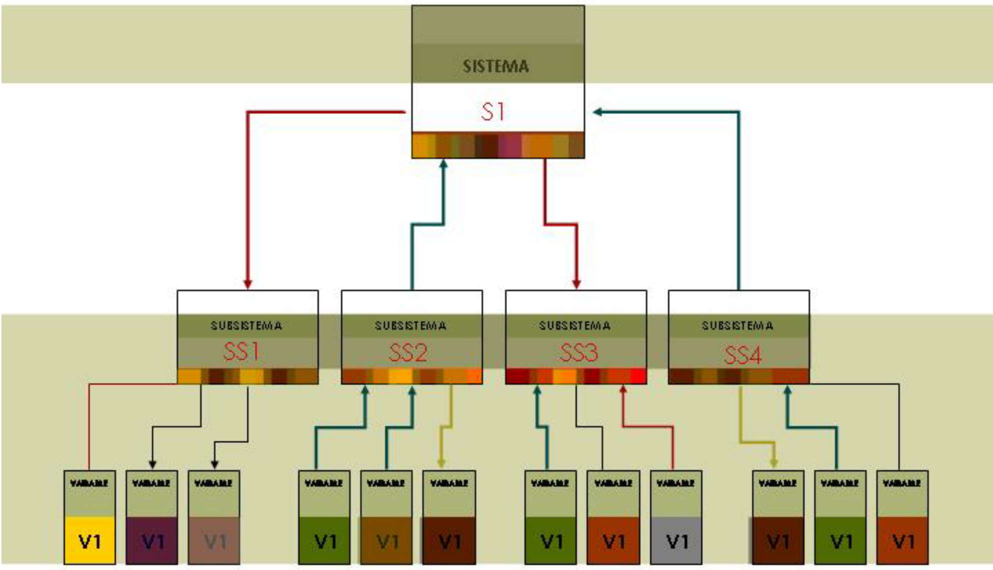

Figure 2. Structure of the system.

At outset, a clear separation exists between generic principles (grid and dimensions, spaces and components, rules of assembly, compatibility rules) and their application using components of a particular subsystem. This separation guarantees the versatility and adaptability of the housing produced by the system enabling a design to be materialized in various forms using multiple combinations of building components according to the principles of open building.

The generic principles of the system are based on:

- a *spatial structure* resulting from the aggregation of horizontal and vertical bars, whose intersection brings about the minimum spatial unit *-a cell-* from which rooms are generated.
- a separation between *spaces and space-delimiting* objects. Spaces are autonomous entities in which objects are placed (e.g. a column, a piece of equipment).
- an underlying *modular grid* which controls the position of both spaces and objects.
- a *dimensional coordination*, which regulates the position of elements on the grid and their maximum displacement with regard to the grid points.
- a set of *assembly rules,* called *"connectors"*, that guarantees the compatibility between components of the different subsystems (structures, building services, space layout).

These generic principles have been established in two ways: as aprioristic conditions that precede the design of the different subsystems, and as derivations of the conditions that a subsystem might impose. The spatial organization in bars and cells is a principle of the first type, while "connectors" would be an example of the second.

3.1.- Spatial structure

Housing units are based on a spatial structure made of horizontal stripes placed over a modular grid (fig. 3). A similar division of floor plans in stripes was already considered by Habraken in his seminal work [7]. Vertically, the floor space is divided into bars which also adhere to the module of the grid. Maximum and minimum dimensions are established for each of the stripes. For instance, the intermediate areas Z2 and Z4 can vary from 2.4 to 3.6 meters. These thresholds guarantee that rooms placed within these zones have the adequate dimensions. This is an example of the way in which a priori principles (e.g. a spatial structure made up of bands and stripes) and conditions imposed by a subsystem (e.g. Spatial Layout) become interwoven.

At the intersection of a horizontal stripe and a vertical bar lies a cell, the minimum spatial unit with a function. Some of the attributes of a cell (function, maximum and minimum dimensions) are determined by its location within the structure of horizontal stripes and vertical bars. For example, cells located in zone 2 have the function of living room or kitchen, and their depth is proportional to the depth of the housing unit.

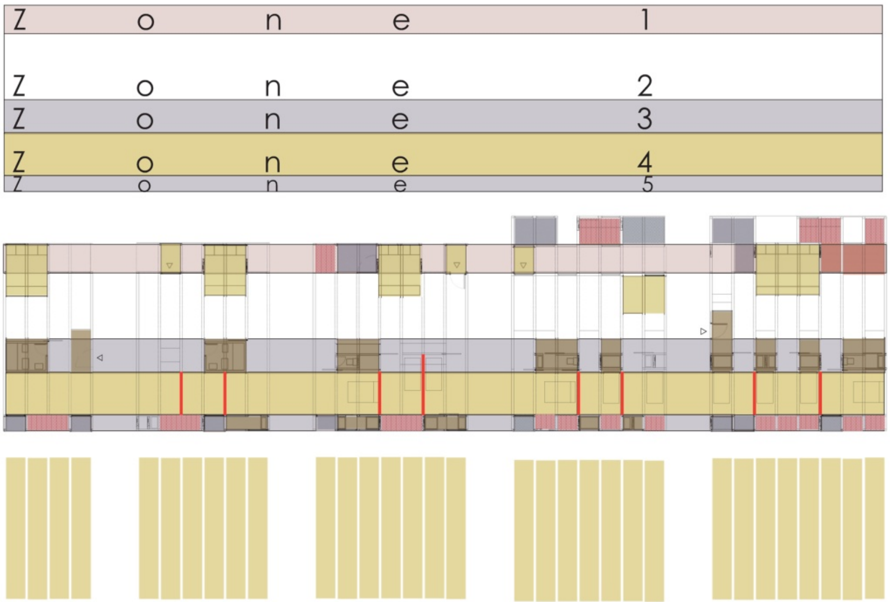

Figure 3. Spatial structure underlying the housing units

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Cells can be of two kinds: *serving* (those that contain a building service, like kitchen or bathroom) which are located on the Z1, Z3, and Z5 areas, and *served* (those without any servitude) placed on the Z2 and Z4 areas. Rooms are the result of joining the cells within a zone. A group of cells makes a room with a specific function and appropriate dimensions (bathroom, kitchen, bedrooms).

This spatial structure allows the generation of dwellings to be placed within a linear block or tower, with combined access from staircases and walkways (fig. 4). It can be thought of as a “support” structure in the sense that it qualifies space in order to ensure that the placement of a dwelling unit within a given volumetric envelope will comply with the functional requirements imposed by the structure, circulation and building services.

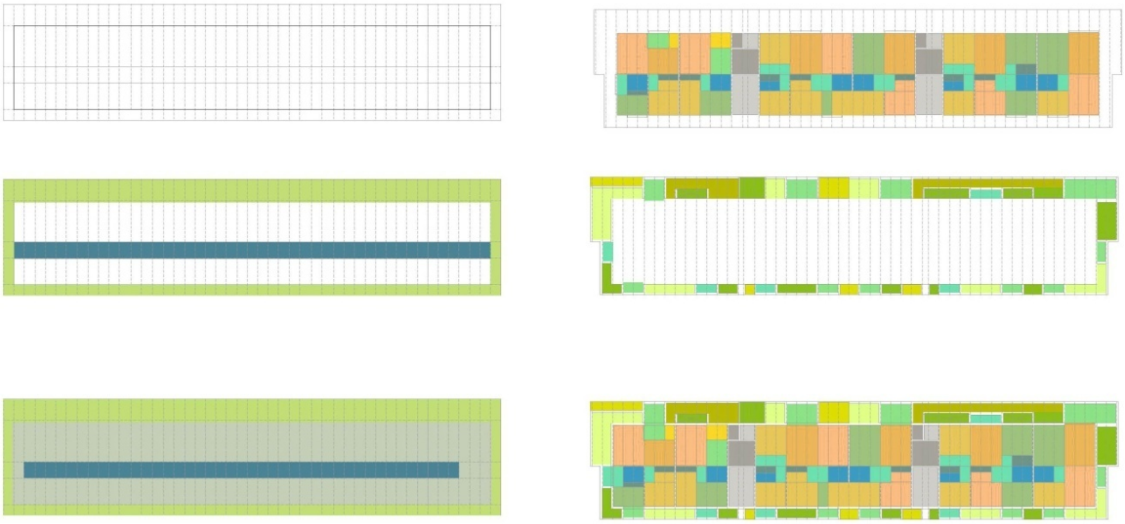

Figure 4. Dwellings placed in a linear block

3.2.- Assembly rules

To achieve *flexibility in creation* a non-deterministic method is applied: a grid of "connectors" is implemented and mechanisms of validation and qualification are executed by the system during the process of generation of the floor-plans and housing buildings (fig. 5). A connector is an element of a subsystem which embodies certain methods that regulate its interactions with the elements of other subsystems. Those methods are the result of the inter-relationships between subsystems. For example, in the process of generation a "connector" column could be invalidated because of a conflict with the Spatial Layout or Building Services subsystems. For instance a column connector is placed on the middle of a room. If a column connector is invalidated a structural validation of the remaining connectors is executed. The resulting grid of connectors is a "generic" solution of the structure. There is no specific element assigned yet to connectors, but they have been validated against the catalog of structural elements selected for the project, ensuring that there is at least one specific solution. Then, further manipulation is needed to optimize the structure, for instance, directing the generation process towards a regular distribution of columns and beams.

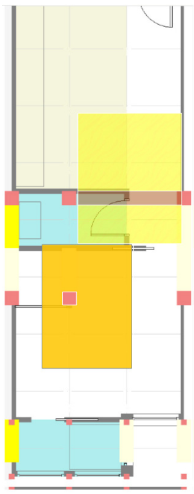

Figure 5. Connectors placed on a floor plan layout

When specific elements are selected for connectors, a process of dimensional coordination is applied. The insertion point of a column is a corner of a connector. From this point the different types of columns sections are placed. A structural grid is laid out and each intersection represents an insertion point. For instance, the longitudinal axis for the central frame is on the edges of Z3 and the structural elements are placed inside the zone. However, to guarantee that there is space for the finishing of the column an offset is calculated from the characteristics of the wall finishing material and applied to the grid (fig. 6).

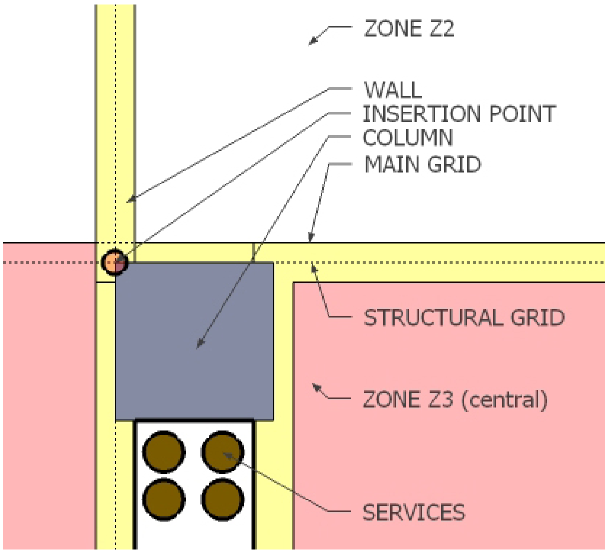

Figure 6. Relationships between subsystems within a connector

4.- Subsystems

At the top level, the system operates with abstract elements such as grids, modules, and rules that guarantee the proper assembly of components belonging to different subsystems. At this level there are no columns or ducts, only "elements" and "relationships" modelled as "connectors". At the subsystem level, however, the system recognizes the specifications of the building and spatial components, that is to say, their dimensions and placement constraints within the support structure.

The communication between subsystems takes place at the top (e.g. system) level. For instance, the relationship between a column and a duct is sorted out at the top level by checking that both elements can be put together. This way, the position of a column in the floor-plan is determined by the underlying grid as well as by the relationships with ducts and pipes which have been previously formalized at the top level.

Theoretically, there are no limitations for the number and nature of the different subsystems. In the current implementation the subsystems are four: space layout, structure, building services and envelopes.

4.1.- Subsystem Space Layout

The Spatial Layout subsystem consists of the components and rules to generate the floor plan layouts and the housing buildings (blocks, towers) resulting from the aggregation of housing units.

The goal of the design criteria adopted for this subsystem is to achieve maximum flexibility in the arrangement of rooms inside a dwelling as well as in the aggregation of units in the building.

In order to generate a floor plan, cells placed at the bands and stripes of the spatial grid are grouped into rooms which in turn are assembled to create a dwelling. A generative procedure controls that the aggregation of cells gives rise to meaningful rooms (with appropriate dimensions and functions). Likewise, the procedure ensures that a group of rooms brings about a functional dwelling by checking the constraints and the adjacency rules. Through the multiple combinations and interrelations of rooms, the system is able to produce floor plan layouts which respond to a diversity of functional requirements.

Spaces resulting from the aggregation of cells are characterized as ‘server’ or ‘served’. The ‘server spaces’ are static, since they are linked to the supplies and structural building’s system. Typically, these are the spaces to allocated kitchens and bathrooms. The ‘served spaces’ have a more adaptable character: they can have various forms and dimensions and they can hold different functions. These spaces are generated within the Z2 and Z4 areas and even after they are built, their boundaries can be easily modified by means of mobile partitions modulated according to the underlying spatial grid.

The floor plans that result from the application of the generative processes can have a width of between 3.6 and 10.2 m. and a depth of between 8 and 12 meters (fig. 7). For the smaller 8-meter high housing unit, it is possible to do away with the central area. In spite of the manifold variations in plan, all the layouts share a common “genetic” code: the underlying spatial structure, plus the generative rules. The procedure generates the plans in a batch mode and stores them in the system database. At the time of writing, over 10.000 different floor plans had been generated.

Figure 7. Housing layouts sharing the same spatial structure

Housing units created by the BARCODE system are characterized by different kinds of flexibility: multiple layouts can be created for a given area (flexibility in creation); a given housing layout can be transformed by changing the partitions (flexibility in usage); and a built flat can expand or reduced its area by adding or giving away vertical bands (flexibility in transformation). The three kinds of flexibility are interwoven and rely on the same principle of spatial ordering based on horizontal stripes and vertical bars. In this way, each housing unit can be configured differently –either during the creation or the use to adapt itself to different user's necessities.

The generative process to create the housing building starts with a selection of dwellings previously generated by the system (fig. 8). Architects and future occupants can participate in the process of selecting the appropriate dwellings for a particular project development using the *HOUSING UNIT LAYOUT* and *HOUSING UNIT CONFIGURATION* environments respectively. To initiate the generative process it is necessary to define the volumetric envelope, the density of occupation of the volume, and the type of access (staircases and/or walkways).

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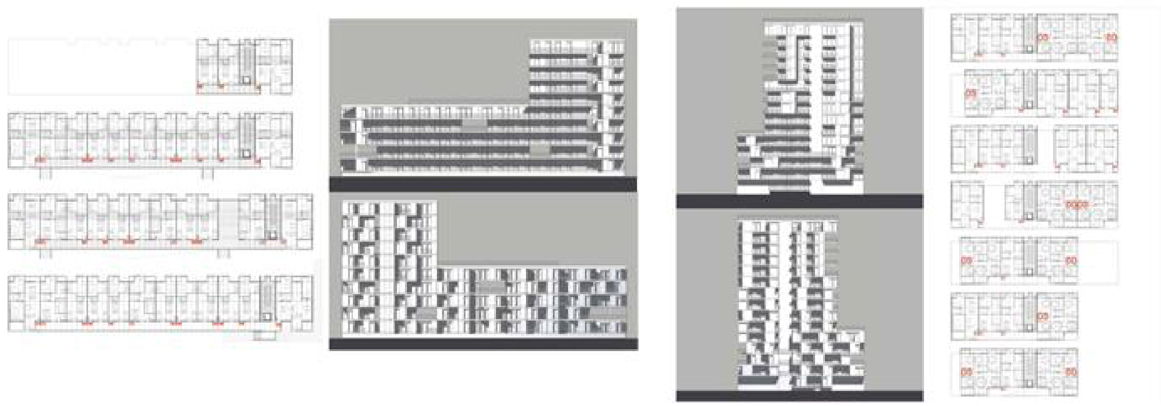

Figure 8. Housing blocks and towers generated by the system

4.2.- Subsystem Structure

The subsystem encompasses the structural elements (excluding the foundations) and the procedures to determine their positioning and pre-dimensioning.

The subsystem structure has been designed to comply with the following design criteria:

- Flexibility: Explore different materials and layouts for the structure during all the process of creation.
- Compatibility with other subsystems: Explore the relationships with each other without prioritize any subsystem or letting the user to establish priorities during process.
- Rationality and Parameterization: Define a structure of variables and relationships to make logical decision that can be implemented by software.
- Modularity: Use industrialized or predesigned products to create different structures coordinating its dimensions with each other and the different subsystems.
- Validation: define method of calculations to verify the structure in a pre-dimensioning manner, and ensure that the final structure calculated by a

professional would not differ substantially from the structure suggested by the system.
- Universality: include the widest range of industrialized elements.

The structural type is composed of longitudinal frames made up of columns and beams, shear walls and rigid slabs (fig. 9).

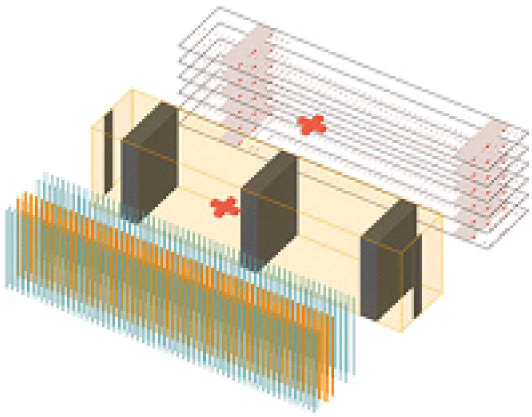

Figure 9. Structural model

In order to come up with a structural pre-dimensioning method, shear walls to resist horizontal forces are located in the circulation cores. This way, the nodes of columns and beams can work as articulations. There are three main reasons that justify this approach:

- Articulated nodes are easy to construct while satisfactory continuous-monolithic unions are difficult to find in industrialized systems
- Much more complex analysis and calculations would be needed if monolithic unions are considered, something that is outside the scope of this investigation.
- Pre-dimensioned frames can be optimized in the final calculation with specific software, if monolithic unions are possible. Those changes should not be significant for a pre-design process.

Structural elements are not flexible elements in a building. Therefore, they should be bond to elements or zones with low flexibility like circulation cores, service zones, façades and ducts. Shear walls are placed in the circulation cores envelop, and structural frames can be aligned to three service horizontal zones (Z1, Z3 and Z5).

The main frames are placed along the two façades and columns are integrated in the facades. Because of this, the frame elements have a maximum width of 15 cm. and the beams span between 1 or 2 modules (1.2 to 2.4 m). When the depth of the block is large enough to accommodate a central service zone (Z3) an additional line of frames can be placed in the central part of the building. The columns of these frames can have a width of up to 40 cm, and the separation between columns depends on the loading capacity of the beams (maximum height of 50 cm.) and optimization process (e.g. choosing between homogeneous distributions or efficient sections of columns and beams). Slabs can span from 2 to 8 modules (2.4 m. to 9.6 m.) length, with a maximum thickness of 30 cm. They are made up of separated pieces whose width can be 1 o 2 modules (1.20 m. or 2.40 m.) depending on the material chosen (pre-stressed concrete, steel-reinforced deck, wood)

4.3.- Subsystem Building Services

This subsystem encompasses the supply (water, electricity, telecommunications) and evacuation (waste water, air, fumes) services of the building.

Building services have been thought of as an open system rather than being confined to specific rooms [8]. The aims of the design criteria adopted for this subsystem are:

- Accessibility, to facilitate the maintenance of the equipment
- Flexibility, to enable the layout of services in multiples ways
- Integration, to guarantee the proper relation with elements from other subsystems (e.g. columns)

The distribution of services is similar to the one being used in hotel buildings, with a horizontal distribution of services located in a gallery located at the base of the building or in the underground from which ducts and pipes run upwards through vertical conducts where all services are gathered (fig. 10). With this distribution it is not necessary to have communal areas to allocate devices to control energy building consumption, so that measuring can take place at each individual dwelling, or even for each appliance in the household.

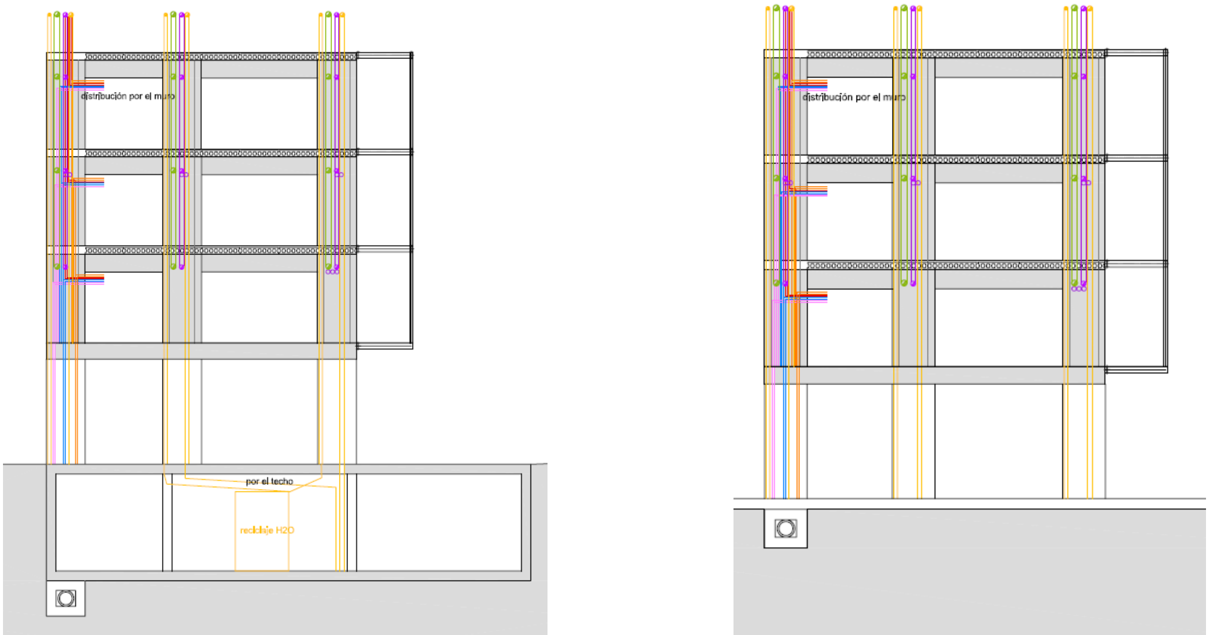

Figure 10. Distribution of the building services in a horizontal gallery connected to vertical ducts.

The flexible nature of the system demands two kinds of flexibility: at the project stage, it is necessary to have the maximum combination of rooms in the dwelling and units in the building; at the operational stage, when the building is in use and dwellings are occupied, it is necessary to facilitate the changes that the dwelling can undergo over time. To facilitate the first kind of flexibility, vertical ducts are foreseen to allocate the different services. As for the second kind of flexibility, the multiple access points to the services makes it possible to change the size and location of equipped rooms (kitchens, bathrooms) over time, and even change the boundaries of the dwelling thanks to the individualized consumption metering.

The building services have been planned in close connection with the other subsystems, space layout, structure and envelope.

The spatial configuration based on 1.2 meter wide vertical bars and the horizontal bands determines the positioning of the ducts that allocate building utilities. According to this spatial structure, service wells can be placed at each of the horizontal bands (fig. 11). The wells are dimensioned as to allocate all ducts (supplies, exhausts, sewage pipes). The dimension of the well takes into account the module of the spatial grid as well as the dimensioning of the pillars. The largest dimension (120 cm.) corresponds to the width of a water closet. This is also the dimension of the Z1, Z3 and Z5 zones. The shortest dimension (40 cm.) corresponds to the maximum dimension of the standard pillar. The inner dimension of the service well is the result of taking away the dimension of the pillar.

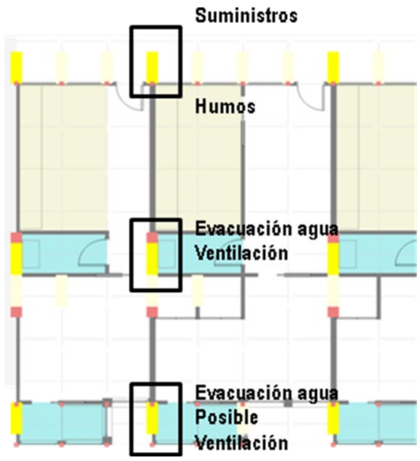

Figure 11. Location of service wells in the zones.

The insertion of service wells in the building floor plan takes place during the generative process. It is then when the system decides whether to use the service wells initially arranged at regular intervals over the spatial grid. The possibility that a service well runs through the whole building depends of the degree of flexibility assigned at the beginning of the process. A high level of flexibility means that a service well can be used or not by dwellings in a certain floor plan; a low level of flexibility means that at each building floor plan there is a dwelling connected to the well.

Both service wells and columns are fixed elements in a building. It seems quite logical to put them together to make up a single compound element as it is the case with technical walls or with structural elements containing an inner space to contained ducts and pipes. The solution we have adopted maintains the logical link between building services and structural elements while keeping each element physically separated.

Building services located at the building facades are integrated within the outer envelopes. Supplies coming from the vertical wells enter the served rooms (kitchens, bathrooms) through openings made in the façade elements.

4.4.- Subsystem Envelope

The subsystem Envelope encompasses the inner and outer surfaces that surround the interior space and the building respectively.

This is the design criteria for the elements making up the envelopes:

- A light façade composed of three layers: exterior, core and interior. The outer cladding is made with light plates of different materials: clay, fiber cement, metal, stoneware, synthetic composites and others (fig. 12). An air chamber is created between this cladding and the façade core which is made of a steel frame covered by an exterior layer, cement board resistant to water. In between the steel profiles, there is an acoustical and thermal insulation (i.e. a board of mineral wood). The interior layer is made of two sheets of plaster board.

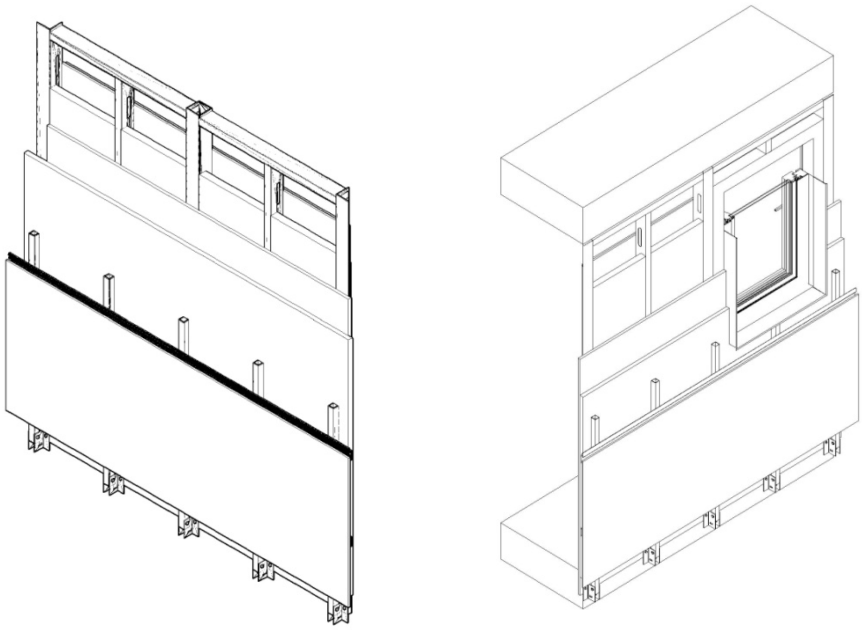

Figure 12. Layers composing the light façade.

- Windows and exterior doors are a mixed product made up of timber and aluminum. Windows are composed of two sheets of glass separated by an air space. Sun protection screens are placed inside the windows.

- The flat roof is built with a built-up system which provides a good thermal behaviour and an excellent maintenance. It can be easily fixed in case of leakage. This system allows the use of roof as a green roof and facilitates the placement of photovoltaic plates.

- Internal divisions and ceilings are built with plaster boards and light steel profiles. Acoustic insulation of the internal divisions is achieved by placing a mineral fiber board inside. The different degree of flexibility of internal divisions has been considered in order to choose the different kinds of partitions. Plaster boards are used as permanent divisions, while sliding timber panels are used to enable multiple space configurations on a daily bases.

A spatial grid of 1.20 m. regulates the relationships between the façade and the structural elements. Columns can occupy the grid points at will and their form and dimensions can vary (depending on the height of the building, the material of the structure, the dimension of the cantilevers). Façade elements, on the other hand, occupy all grid cells and their form and dimensions are more homogeneous than those of the structural elements.

Inner partitions also adhere to the 1.20 m. grid. Most of the industrialized products used to create the partitions can adapt to this modular dimension. A variety of partitions, with different materials, thickness and performance level, can be used to make the fixed and mobile divisions.

For each zone that makes up the spatial structure of the system, a specific type of partition is assigned (fig. 13). Thus, in the serving zones (Z1, Z3 and Z5), where the less flexible spaces are located, required fixed partitions while the intermediate zones (Z2, Z4) which allocate the most flexible spaces, require mobile and dismountable divisions.

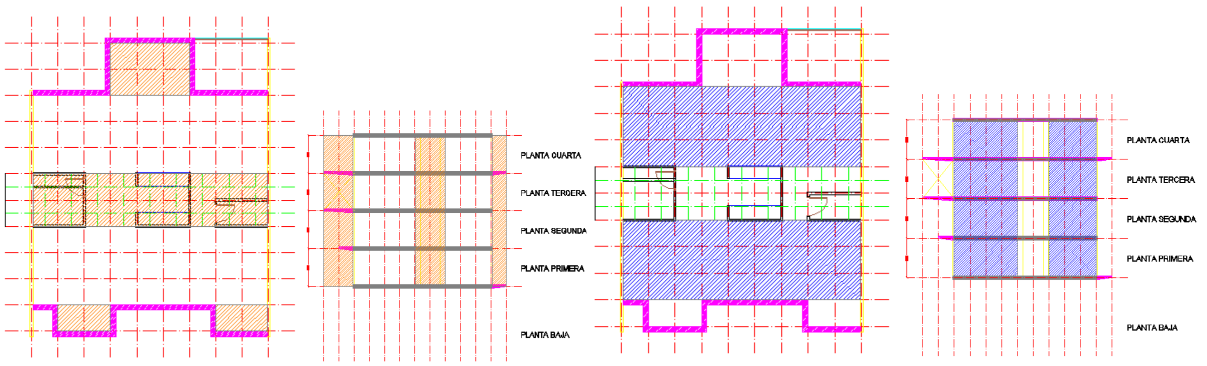

Figure 13. Zones and partitions.

Four different kinds of partitions have been defined in relationship with the degree of transformability of a space over time:

- Fixed elements, to be used in those spaces which are likely to remain unchanged over the building's lifetime (e.g. bathrooms, dwelling divisions).
- Dismountable elements, to be used in spaces which can vary on a middle term basis (e.g. bedrooms)
- Mobile elements, used to separate spaces that can often change, even on a daily basis (e.g. a separation between a working area and a bedroom)
- Doors and cupboards, auxiliary elements to be used as mobile partitions (e.g. sliding doors) or as space filtering elements (e.g. a shelf)

Because the positioning of the partitions is regulated by the grid and the by Space Layout subsystem, it is possible to easily transform the spatial configuration of the dwelling with these flexible partitions (fig. 14).

Figure 14. Transformations of the spatial layout through the partitions.

5.- Conclusions

In this project, we have integrated automatic design procedures with open building principles in order to rationalize the design and construction processes. This integration is based on an inclusive approach, encompassing design principles and rules controlled by the system which facilitate the application of open building principles by guaranteeing the applicability of a diversity of building components and subsystems at the project level. Design and construction processes can be carried out in a non-linear fashion, using the working environments that make up the system. These environments enable the participation of different actors throughout the design and construction process. In conclusion, BARCODE HOUSING SYSTEM provides a comprehensive model which can contribute to positively transform existing working processes in the building industry.

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