Assembling sustainable ideas: the construction process of the proposal SMLsystem at the solar Decathlon Europe 2012.

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Abstract

The innovation of the construction process in SMLsystem lies in an evolution of the way of thinking the sustainable architecture. The key is that SMLsystem proposal is not constructed but is assembled. This way, it is designed with prefabricated and industrialized elements which allow themselves to connect as in a plug and play process in order to reduce the risks and save time and costs consequently. About that, the study and design of the junction has been another interesting issue to solve the assembly of the modules, focusing on factors like the isolation and the rainwater always present. In addition this proposal shows a new way in the use of wood as a structural material, as a building enclosure and as a dynamic system of solar protection, all of them as a result of the combination of various premises inherent to the concept of the project like the respect for the environment, recycling or sustainability and, of course, with an absolute integration with the architectural design. This way, the complete development of SMLsystem has had the capacity of defining a global project which reflects the primal ideas: design, sustainability, modularity, flexibility and prefabrication.

Keywords: sustainability; prefabrication; wood construction; assembly design; Solar Decathlon Europe.

1. Introduction

Society demand of sustainable architecture in terms of energy, that came from the oil crisis of 1973, was a true reflection of a need for change of awareness in how to address energy savings issues and concerning, of course, to architecture.

The development of theories about sustainability and bioclimatic architecture that appeared since then and which are so fashionable today, are one of the main references in the architect Olgyay. A pioneer in the study of treatment of bioclimatic architecture from concepts, he determined in [1] how to address the issue of sustainability of the building differentiating from the pre-existing relationship with the place in which it is located and, on the other hand, the sustainability of the architectural element itself. That means the building conceived as an expression of the results obtained from previous studies of both climate and technological solutions adopted. This allows to establish the possibilities of relationship with the environment, the materialization of this relationship, and the control and regulation of energy exchange between people and the building itself, i.e., the relationship between form and volume, skin and enclosure and between interior and environmental quality, respectively.

Technological development and current needs make possible to apply, test and develop Victor Olgyay studies (later picked up and advanced by Givoni in [2]) in research projects currently being realized in the field of self-sufficient architecture.

Any architecture to be identified as bioclimatic (also called “energy efficient buildings”, or “green building”) must have, as a condition of departure, a design in consonance with the climate in which it operates and with the people who will inhabit in order to be healthy with them and consume as less as possible resources. That design also must combine passive and active resources in order to get an optimal building design and an efficient control of the indoor climate [3]. Therefore, natural resources should be optimized constructively to obtain the best indoor environment, minimizing or, if possible, eliminating the use of mechanical technology. In fact, according to Professor Javier Neila González in [4]:*"The most effective measures, the ones which may represent the higher contribution, cost nothing, since they are the logical result of the use of design and construction elements"*.

Both the evolution of the technique and technology make easier a previous approach to comfort conditions. Through simulations from architectural design and the certified properties of materials or building methods used and their organization, can be undertaken potential design and constructive mistakes in order to make proper corrections to improve the efficiency of the building without having to construct it. Thus the building realized will respond to optimized comfort conditions.

Despite not providing accurate results, the use of current computer tools does allow to know globally the building behavior and its impact on indoor environmental quality, based on the order of arrangement of the materials and their technical characteristics. Consequently, as in many other occasions throughout the history of architecture, specialization leads to the emergence of new fields in research and experimentation (in this case applied to sustainable development). A clear example of this can be found in the homes for the Stuttgart international exhibition (*Weissenhofsiedlung*) promoted by the *Deutsche Werkbund* in the summer of 1927. Disassociating the relationship between loading system and formal aesthetics of the building, Le Corbusier began a personal research in the field of the enclosure as a fully autonomous and independent element of the structure, which meant a break with classical composition relating building, structure and shape, and twisted on the concept of the construction process. According to Le Corbusier in [5], *modern materials* made possible to reduce the thickness of heavy structural walls and re-compose them in walls with thinner specialized layers, more efficient and independent from the structure.

Despite this research of Le Corbusier, years before were already introduced concepts as assembled architecture, prefabrication or serial production at the Universal Exhibitions, which showed both the evolution of the industry and the research advances in building construction. One of the most famous examples is the Crystal Palace by Paxton [6] in 1851, who managed a comprehensive solution through standardization of elements, its dimensional coordination, its prefabrication and its assembly process optimization. It allowed to build 72,000 m^2 just in four months[7]. Shortly after in 1854, were developed examples applied at the housing field like the famous working class neighborhood *"le Dolfus"* nearby Mulhouse [8].

In the same line of research and expertise but using technology and current building systems, the proposals of the international competition Solar Decathlon Europe are an opportunity for the future development of sustainable and self-sufficient architecture. The proposal SMLsystem of the CEU Valencia Team for Solar Decathlon Europe 2012 takes on the challenge of combining the concepts of industrialization, prefabrication and flexibility through researching a sustainable building, drawing on the experience acquired in the 2010 edition with the proposal SMLhouse [9].

2. The SMLsystem proposal

SMLsystem (Fig. 1) is a clear reflection of that development that attempts to *"... satisfy the needs of the present without compromising the ability of future generations to satisfy their own needs"* [10].

The design of the proposal arises from the concept of housing as a personalized solution to user needs. Furthermore, the housing configuration is proposed as a system, generating multiple dwelling solutions through the choice by catalog of prefabricated components which are later assembled (Fig. 2).

The idea to generate a catalog reprises the final objective of standardization of the elements to provide an overall forecast that improves the result of the work. This concept was already developed in the beginnings by the manufacturers of industrial and agricultural machinery of the nineteenth century. In fact, in this period appeared the first leaflets with elements for dwellings like the ones by Charles Young and Company in 1885 [11]. Years later appeared various attempts of prefabricated dwelling like the famous Dymaxion House by Richard Buckminster Fuller in 1929 or other local examples like the *Modul-Arch system* by GO-DB architects [12].

Learning from these examples, the catalog developed in our proposal requires simplifying the number of elements to maximize their possible combinations in the most flexible way. Thus, the main components that make up the SMLsystem are a base module and prefabricated indoor boxes that form the wet cores.

To achieve the objectives of the system, the construction design of SMLsystem focuses on the ease of manufacturing of its components, as well as optimization of times and assembly processes.

3. The structural base module

Unlike in a conventional process, the beginning of the design phase starts with the understanding of all the constraints arisen by the implementation of housing, both projective and construction of facilities, and by the optimization in every moment of the execution. Therefore the first strategy proposed for the self-sufficient SMLsystem house is to optimize the number of necessary modules for the construction of the maximum area allowed at the competition. This way, SMLsystem decreases the number of the elements used in the 2010 prototype, and increases their size.

The overall dimensions chosen, take as a basis the module of 0.30 m, since the most of the construction materials such as panels or boards are made on the base of this measure, thereby obtaining for the compliance of the program a base module of 7.20 m long, 3.60 m wide and 3.00 m high (Fig. 3). That generates as a main inconvenience the need to use special transport for transfer by its width, but on the opposite of this problem, otherwise easily affordable, are the benefits of time and optimizing the assembly.

Among those, the greatest virtue is the drastic reduction in the number of singular points in this type of construction, among which the most important is the joint between modules. In the SMLhouse of the 2010 edition, there were six modules, with their respective five joints, that during the successive assembly and disassembly became one of the weaknesses of previous prototype.

Therefore, for the 2012 proposal, this point was to be solved in detail, starting from the reduction of the number of joints, thereby decreasing the number of modules to three. In addition, the reduction of the number of modules directly decreases the number of trucks needed to transport and also the use of aids such as cranes and hoists, improving the sustainability of the proposal since it generates less CO2 on the overall calculation of the construction process.

Another fundamental premise to the entire proposal is the complete execution made by prefabricated or postformed materials and the subsequent dry assembly, being timber the predominant material. This concept results in a cost and time reduction. On the other side the intention of this construction design was to avoid the appearance of fissures, as during the lifting and handling for the module assembly we foresaw the appearance of possible deformations.

Regarding the first of the basic components, the structural module is fully materialized in spruce (*Picea Abies L.*) cross laminated timber (CLT) of visible quality. The horizontal structure consists of cover panels made of cross laminated timber CLT 60 L3s, supported on L-shaped pillars and floor panels made of cross laminated timber (CLT) 120 L3s. As it is shown, panels are used as a component of an integral prefabrication [13]. The vertical structure consists of four L cross laminated wood pillars (CLT) C3s (210 mm wing and 100 mm wide) transversely braced with beams, cross laminated wood also (CLT) C3s with required buttonholes for dry assembly with screws (Fig. 4).

The characteristic arrangement of the supports is motivated by a market viability study as a result of the system flexibility (being this another of the points of departure). The grouping of several modules could generate the confluence of four supports at one point, with the consequent architectural problems that generates the perceptual break of the space. The L-shape and the distance to the edge of the slabs make the joint of four modules materialize only one support that ensures spatial continuity and configure an element perceived as light, the opposite of what would be a *macro* support (Fig. 5).

The raw materials used to manufacture the wooden structure and its features are:

- Cross Laminated Timber: the species used for the manufacture of the wooden structure is *Picea abies* according to [14]. Strength class C24.

- Preventive-protective treatment of wood: the surface of CLT panels is sanded and classified according to [15]. CLT panels are not treated in the factory.

-Metal elements: the iron work is steel S275JR type according to [16] and the screws is in line with [17].

The manufacture of the structure is made according to [18, 19].

The environment for the structure is considered indoor, because the moisture content in the materials is related to a temperature of 20°C ± 2°C and a relative humidity that may exceed 65% only a few weeks a year. Consequently, the assigned service class is 1 and, therefore, the rust protection of metallic elements to be applied according to [20] is not required for metal plates and bolts.

The fire resistance of structural members is set in 30 minutes (R 30) according to [21]. The size of the structure against fire is executed according to the method of the *effective section* and the method of *reduced strength and stiffness*, based on methods described in [22] which enable the absence of protection against fire by oversizing the structural elements taking into account its speed of carbonization (0.7 mm/minute for cross laminated *P. abies* timber).

4. The enclosure

The constructive setting of the enclosure layers (Fig. 6) is designed taking into consideration the assembly and disassembly processes that will undergo during its lifetime. The only element that changes across the enclosure is the finishing material. In the end walls is glass (corresponding to the photovoltaic panels located in east and west) and the rest is wood Framiré (the choice of Framiré wood for the finishing exterior façade responds both to design justification of chromatic unity of the house, as for its characteristics of providing outdoor durability without having to apply any further treatment or maintenance).

Thus, from the outside towards the inside occur photovoltaic panels with all its mechanisms and facilities or Famiré timber in shaped vertical slats, fixed in both cases by a substructure made of wooden battens 40x30 mm, allowing to accommodate a 4 cm ventilated chamber.

This substructure is mechanically fixed to the cross laminated timber board in the formation of the end wall main support, provided between them a breathable and waterproof sheet type Tyvek of Dupont, which protects the structural board and the enclosure. On the inside there is placed a 12 cm width thermal insulation of mineral wool and a steam barrier.

Finally, the substructure is executed with a lightweight plasterboard double panel with specific acoustic properties, screwed to a grid of galvanized steel stanchions and transoms (Fig. 6).

Research in this "energy sandwich" in the case of the PV end wall is taken to limit being designed as an entirely prefabricated enclosure, in one piece. This allows to eliminate the problem of assembly for minor pieces in building site, increases safety during construction and reduces production costs without losing the quality of the enclosure.

Therefore, the main objective of enclosure is to achieve flexible constructive solution which allows immediate future extensions or reductions of the housing without significant increase in resources and, above all, without having to vary its construction. In the case of the end wall, in addition to its great contribution due to its energy capacity, its design is made from sustainable criteria of removable facade, that is, a unique piece that can be completely separated from the dwelling in order to enlarge or reduce it quickly and efficiently. It becomes therefore a freestanding, energy, sustainable and efficient end wall, of which only additional charge will be to dismantle and reconnect to the new base module housing built for expansion (Fig. 7).

The evaluation of the thermal transmittance in the worst enclosure (corresponding to photovoltaic façade) is 0.3 W/m2 K. Considering the worst month for the generation of condensation, a simulated evaluation for Valencia in February shows that there are no condensation on the inner layers (Fig. 8). Even on the PV panel glass, possible condensation that would be generated in the month of February would be prevented by the air flows generated in the innertube. Regarding to this, photovoltaic solar panels of the enclosure are CIGS technology, which increases the efficiency of the system with a significant reduction in energy consumption and used material compared to other solar catchment technologies (up to two-thirds reduction in both). Concerning the size of the panels, is a result of studying the modulation of the other facade elements and the premise of ease of assembly and maintenance during its useful life.

5. The cover

The design and construction of the solution used in the deck responds to two issues: the intrinsic waterproofing, insulation and sealing and the support for the installation of photovoltaic and thermal collection. Furthermore it should allow passage to perform tasks in the maintenance and adjustment of installations and especially during these works it should not be damaged the waterproof layer and be avoided any anchoring or drilling of this layer to assure the proper operation and lifetime useful.

Regarding the constructive solution, it is used a not passable flat roof solution formed by the following layers arranged in order from the inside to the outside (Fig.9):

-Structural floor boards formed of cross laminated timber 60 mm thick (60-L3s CLT)

-Steam-barrier

-Thermal-isolating of mineral wool 12 cm thickness

-Geotextile sheet

-Double layer waterproofing sheet composed of a liquid polyurethane membrane with polyester reinforcement.

The sink arrangement is made so that downpipes can be placed inside the ventilated façade innertube, allowing their easy maintenance and eliminating the drainage system into the housing (Fig.10).

The second cover, with only the support function for the photovoltaic and thermal installation, besides the secure walkways, is executed by placing a timber substructure resting on the main beams of the module. This substructure is designed as another independent prefabricated element which is linked to the structural module. With this, the double deck creates a gap that can accommodate sunscreen lattices when folded (Fig. 11).

6. The joint between modules

Perhaps the most controversial point of a building by aggregation modules lies in the resolution of the joint between them. Its importance is such that it should be able to solve the continuity of thermal and acoustic insulation, waterproofing and architectural definition both interior and exterior. It also should allow to release and extract the slings to lift each module for transport and placement on its intended location.

The constructive solution to the joint assembly of modules includes the simplification as a premise of implementation. The use of the timber structure, basically allowed the solution adopted because it simplified the machining operations carried out in the workshop phase and avoided possible thermal problems which would have appeared using other structural materials.

In the side face of the floor and roof slabs there is a neoprene band sealing the joint between the different modules. As an alternative to lifting costly solutions, in that perimeter are practiced some grooves that solve the step of slings (Fig.12) and can be fitted to and removed during assembly and disassembly process without complications. This time the sustainability of the solution lies in the simplicity of its idea and ease of execution, despite having planned at the structural calculation the module behavior during handling of the structure.

When the modules are placed in the final position, just remains sealing the gasket to avoid thermal bridges and ensure the tightness of the perimeter. The thermal-acoustic solution is made by placing mineral wool panels on the perimeter of the joint previously sealed with neoprene bands (Fig.13). Here we distinguish two different solutions. On the floor and walls, the mineral wool is placed directly on the support (slab or enclosure) coating with wooden seen boards in the inner finish. The quality of the wood is another of the variables that user can choose according to his budget, becoming a factor of economic sustainability.

On the deck, the inner finish solution is as above (thus identifies the continuity of the board with the same material and the same solution) (Fig. 14). However, this time the thermal-acoustic isolation is placed on the top surface of the floor, encouraging constructive coherence of covering solution.

In this case, mineral wool panels are disposed on a steam barrier foil to prevent condensations on the lower surface of the slab. The waterproofing system is solved by the provision over the isolation of a continuous lacquered sheet channel overlapping under the beams of the substructure for installations. The encounter in standing seam of the two modules ensures the tightness of the solution, fostering constructive coherence of the covering solution (Fig. 15).

7. The lattice

The lattice is a complex system composed primarily of horizontal and vertical Oregon pine slats with section 50 mm x 150 mm. Each module contains its own lattices attached to the short endwalls and it is transported folded and just is unfolded after housing assembly, depending upon the needs or tastes of the user. So this system does not increase both transportation costs and execution time. Among the strips are placed pins and stainless steel ironwork which ensures equidistance and overall stability. In addition, vertical blinds incorporate a system of bolts that allow the rotation to regulate their position (Fig. 16).

Furthermore, this system let adjust the orientation of slat vertical blinds so that, depending on the season, the user can decide the position for sun protection or allow its passage as a sieve (Fig.17).

8. Conclusions

The decomposition of sustainable phenomenon in various fields, that is, specialization in each of sustainability parameters, is the way followed in the development of constructive development of SMLsystem, from bioclimatic design, use of materials and efficient building systems, fast assembly and disassembly, prefabrication and industrialization and optimization of the capture and use of solar energy. This allows to evolve bioclimatic design, technology and innovation in construction technology and improves the overall architectural design.

The main constructive innovation in SMLsystem is the change in the concept of building. SMLsystem is not built, but is assembled. Its design from industrialized and prefabricated components allows connection by easy and quick construction processes. Everything is based on an analogy to "plug and play" of computer components, from the joints between modules to the own connection of installations. Such optimization in construction technology reduces both the time of commissioning work as personal risks arising from any construction process. The construction design under these premises allowed to assemble SMLsystem within few hours, getting to be the house that used less mounting time in the Solar Decathlon Europe 2012.

Therefore, rather than *construction*, should speak about *SMLsystem assembly sustainable ideas*. As should be the case with everything that is designed, each project decisions are associated with a number of constructive reasons and their solutions. Without that they dilute the original ideas of the project, SMLSystem has developed a continuous work, with ability to define a comprehensive and constructive proposal that reflects the main points of departure: sustainability, modularity, flexibility and prefabrication.

It should be explained that the prefab system designed and built for the competition is based on a series of assumptions extrapolated from different case studies done throughout history such as the paradigmatic Packaged House [23] (1941-1952) of Konrad Wachsmann and Walter Gropius (the detailed study of standardized joints between panels) and other highly relevant examples listed in [24] as the Yankee Portables (1942) by Marcel Breuer (the easy expansion from a basic module), the system Moduli 225 (1969-1971) by Kristian Gullichsen and Juhani Pallasmaa (the foundation system adjustable for height and the possibility of multiple spatial combinations from a single module) and even more actual cases as the System3 (2007-2008) by Oskar Leo Kaufmann and Albert Ruf (the idea of rectangular modules of detached house with potential for aggregation block , in which completely prefabricated units of bathroom, kitchen and facilities are inserted) .

The nature of the experimental prototype SMLsystem joined to its own construction conditions (real model built entirely by students) makes that much of the construction technology employed cannot be contrasted with previous similar examples because of the obvious differences between the built prototype and an identical but built with skilled labor. In addition, its original character only allowed to extract actual data from its efficient behavior during the contest i.e., when the prototype was completely built and put into operation for the first time. Regarding assembly systems designed and explained in the article, it should be said that its simplicity of design facilitated the placing and allowed to construct without much difficulty.

All these factors demonstrate the scientific value of the building constructed as a research method. In this sense, SMLsystem is a continuation of the research started with the prototype SMLhouse of the SDE 2010 edition and is, at once, a starting point to advance the research initiated in the field of sustainable prefab architecture. The progression in this research is conditioned to approach new challenges aimed at optimizing each building development processes. There are three main aspects that should focus the development of research: reducing the overall weight of the prototype, the improvement in integration of facilities and the improvement in building systems "plug and play". These three challenges are leading the way for future research that could be opened to improve the overall building solution of the prototype.

Regarding the first aspect, the research should focus on reducing both the thickness of the structure and the enclosure. On one hand, using new sustainable and high strength materials; even might be possible to analyze the use of other wood structural solution, replacing the solid section cross-laminated solution for other mixed or partially hollow structural sections. And on the other hand, using a restudy of the geometry of the prototype to link the formal result to structural criteria based on the technical characteristics of the material, i.e., generating folded geometries with thin elements that should give structural rigidity to the parts which were more slender and which might suffer buckling.

About the integration of facilities, the main objective which should be proposed would be getting a solution which concentrates them on an insertable unit within the base module in the same way that the bathroom and kitchen modules are inserted. In this research would be necessary to perform a preliminary analysis of the required facilities, taking into account the different possibilities of aggregation modules to determine the maximum dimensions of the integrable module. In this case, moreover, we should consider the construction of fixed elements in the technical areas of the module (such as technical floors), so they would be ready to connect with the prefabricated module of facilities.

In addition, these study connections between fixed facilities and prefab units would also be part of the third aspect that may arise for future research: the "plug and play" systems. In this way, it would be essential the analysis of the "lean construction" method as a system that integrates research project and constructive development considering all intermediate processes that may take place, with the primary objective of improving the overall construction of the prototype, both in economic terms and in safety, reliability and quality aspects. An additional way of this third aspect would be the research on the optimization in the amount of prefab elements that could be carried in a single truck to be assembled on site. This approach would try “to manage and improve construction processes with minimum cost and maximum value by considering customer needs” [25].

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References

[1] Victor Olgyay, Architecture and Climate: Bioclimatic Design Manual for Architects and Planners (Spanish edition), Ed. Gustavo Gili, Barcelona (1998) ISBN 84-252-1488-2.

[2] Givoni, Baruch, Man, Climate and Architecture, Elsevier Science Architectural Series, (1969) ISBN 444-20039-8.

[3] Yingxin Zhu, Borong Lin, Sustainable housing and urban construction in China, Energy and Buildings 36 (2004) 1287–1297.

[4] Neila González, F. Javier, Arquitectura bioclimática en un entorno sostenible, Editorial Munilla-Lería, Madrid (2004).

[5] Le Corbusier. "L’Espirit nouveau”, Lecture given at the Sorbonne on June 12, 1924, the Grouped'Etudes et scientifiques philosophiques, and repeated on November 10, 1924 in the Ordre del'Etoile d'Orient, Almanachd'Architecture Moderne, Paris (1925).

[6] Crystal Palace, Hyde Park, 1851, Joseph Paxton and Fox & Henderson engineers.

[7] Krampton, Kenneth, Historia crítica de la arquitectura moderna, Gustavo Gili, Barcelona (1991), p. 34.

[8] Gravagnuolo, Benedetto, Historia del urbanismo en Europa 1750-1960, Ediciones Akal Arquitectura, Madrid (1998).

[9] AA.VV., Prototipo de vivienda solar prefabricada, SMLhouse, General de ediciones de Arquitectura, Valencia (2012), ISBN 978-84-939845-0-2.

[10] Informe Bruntland, “Nuestro futuro común”, Comisión Mundial Para el Medio Ambiente y el Desarrollo de la ONU (1987).

[11] Aguilar, Inmaculada, Arquitectura Industrial, concepto, método y fuentes, Ed. Museo de Etnología de la Diputación de Valencia, Valencia (1998).

[12] Palomares, Maite; Llopis, Verónica, GO-DB, Un fragmento en la historia de la prefabricación. 6th National Congress on Construction History, Ed. Instituto Juan de Herrera, Madrid (2009).

[13] Rodríguez Nevado, Miguel Ángel, Diseño estructural en madera: una aproximación en imágenes al estado del arte europeo a finales del siglo XX, Aitim, Madrid (1999).

[14] DIN 4074 / UNE EN 338 Structural Wood.

[15] DIN EN 13 017, Table 1, Classification by surface appearance.

[16] UNE EN 10025.

[17] DIN 931-934, Specifically, the nuts and washers follow DIN 934 and DIN 126 respectively.

[18] UNE-EN-386, Glulam timber / Specifications and Manufacturing Requirements.

[19] Standard DIN 1052, Wood Construction.

[20] ISO 2081.

[21] CTE, Basic Document Safety in Case of Fire DB-SI6.

[22] Eurocode 5, EN-1995-1-2.

[23] Herbert, Gilber, The Dream of the Factory-Made House. Walter Gropius and Konrad Wachsmann, The Massachusetts Institute of Technology (1984), ISBN 0-262-08140-7.

[24] Bergdoll, Barry; Christensen, Peter, Home delivery. Fabricating the modern dwelling, The Museum of Modern Art, New York (2008).

[25] Koskela, L.; Howell, G.; Ballard, G.; Tommelein, I., Foundations of Lean Construction, Elsevier (2002). ISBN 0750651490.

FIGURES

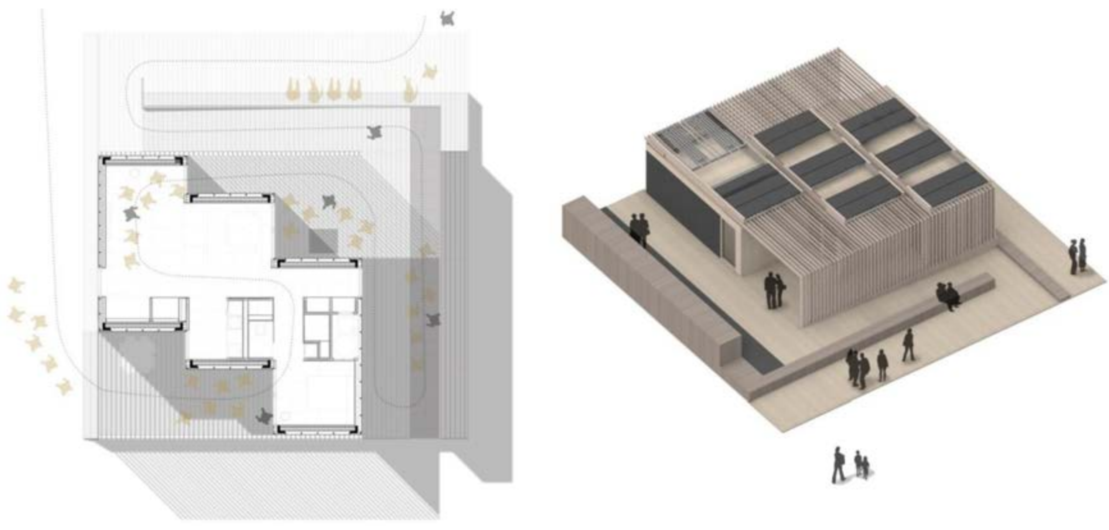

Fig. 1. Plan and overview of the SMLsystem proposal from University CEU Cardenal Herrera.

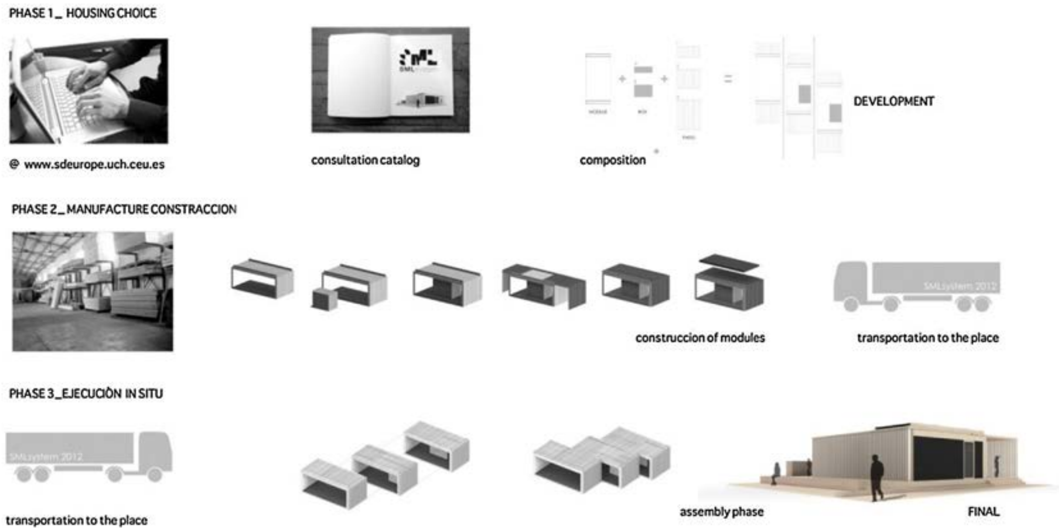

Fig. 2. Evolution of the design process, configuration and definition of the system.

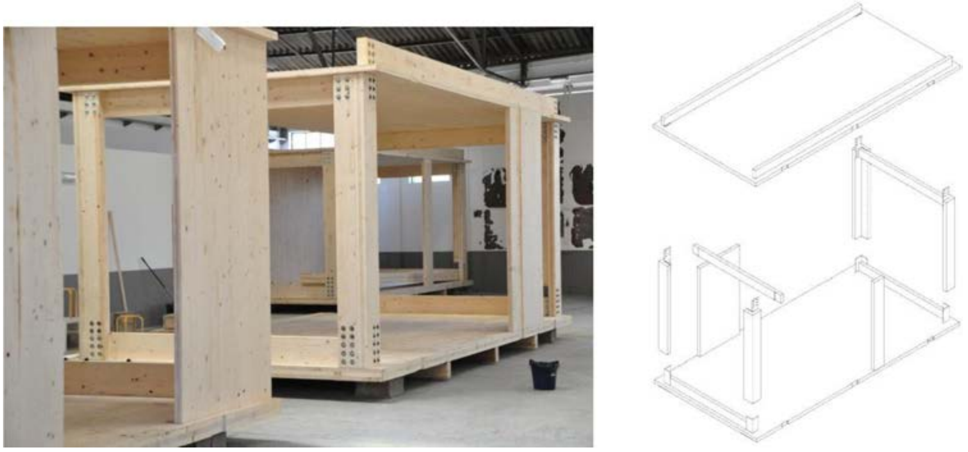

Fig. 3. Structural base module.

Fig. 4. Junction detail of the L-shaped support with the roof and the cross binding.

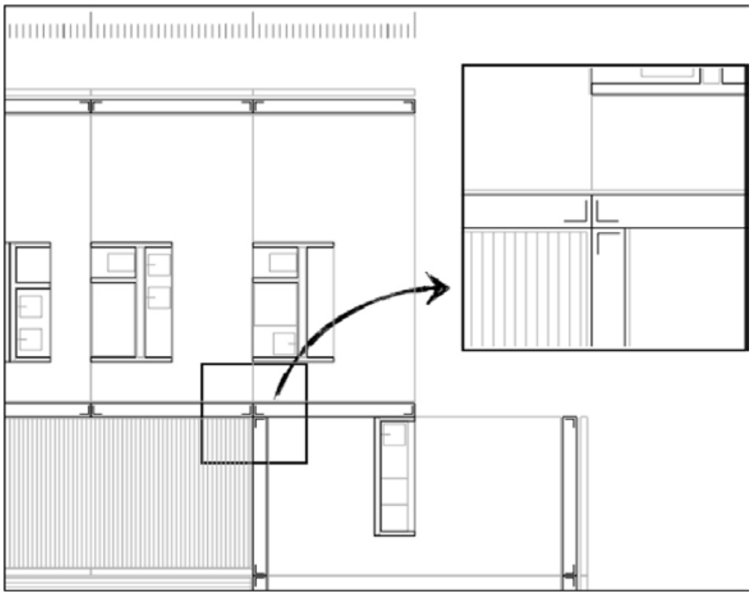

Fig. 5. Corner joint of several supports.

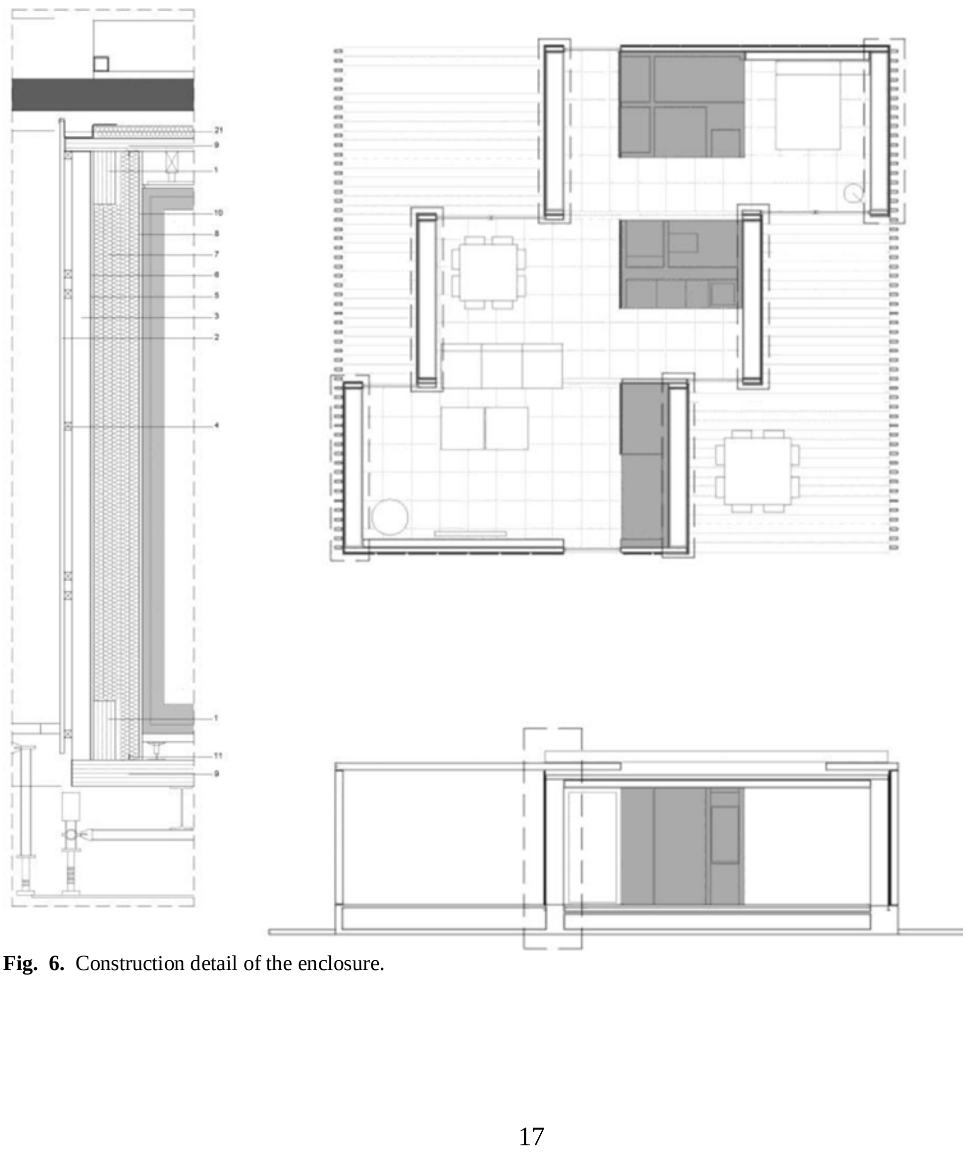

Fig. 6. Construction detail of the enclosure.

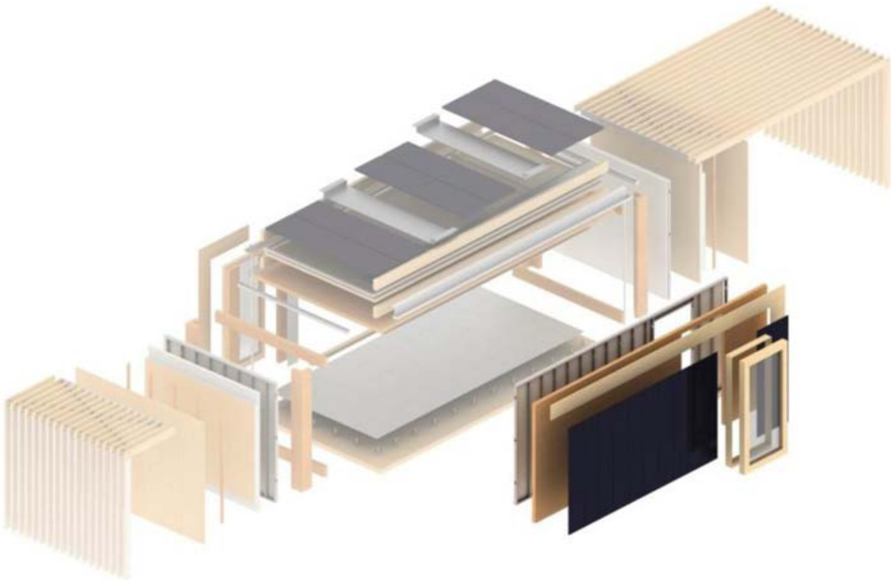

Fig. 7. Decomposition of the enclosure in the end wall.

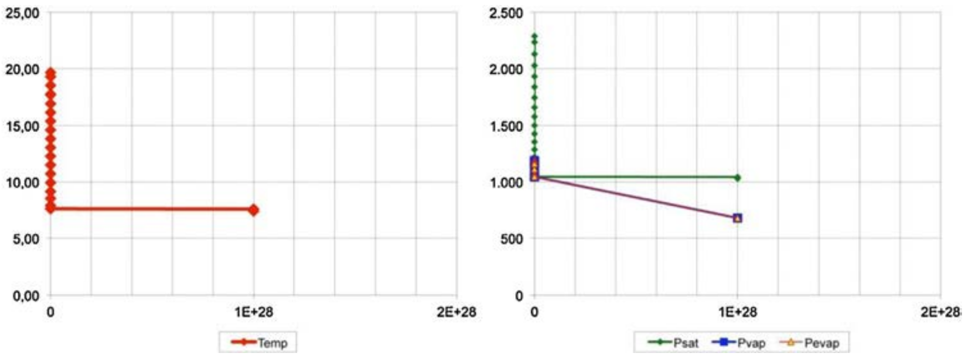

Fig. 8. Checking interstitial condensation in Valencia for February.

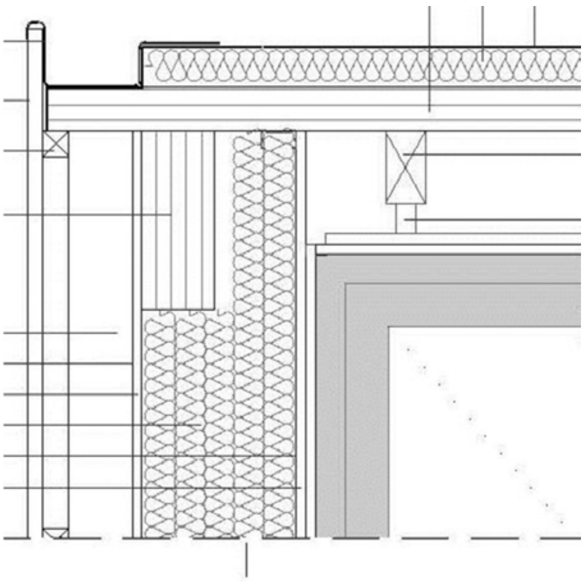

Fig. 9. Constructive detail of the cover layers.

Fig. 10. Arrangement of downpipes in the innertube of the enclosure.

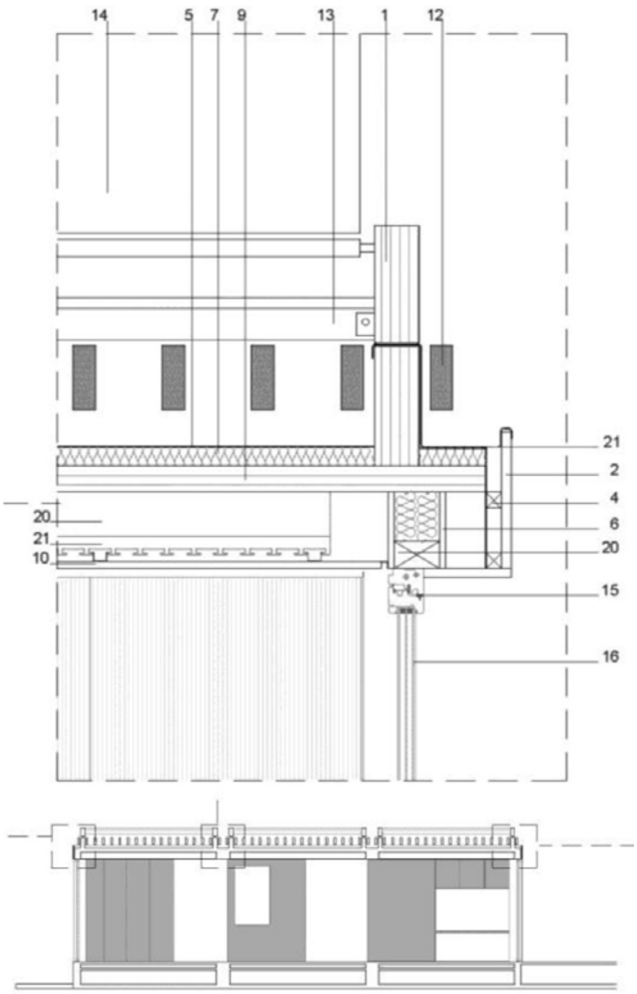

Fig. 11. Double deck.

Fig. 12. Groove in joint between modules.

Fig. 13. Neoprene band on the bottom seal.

Fig. 14. Inner solution for the joint.

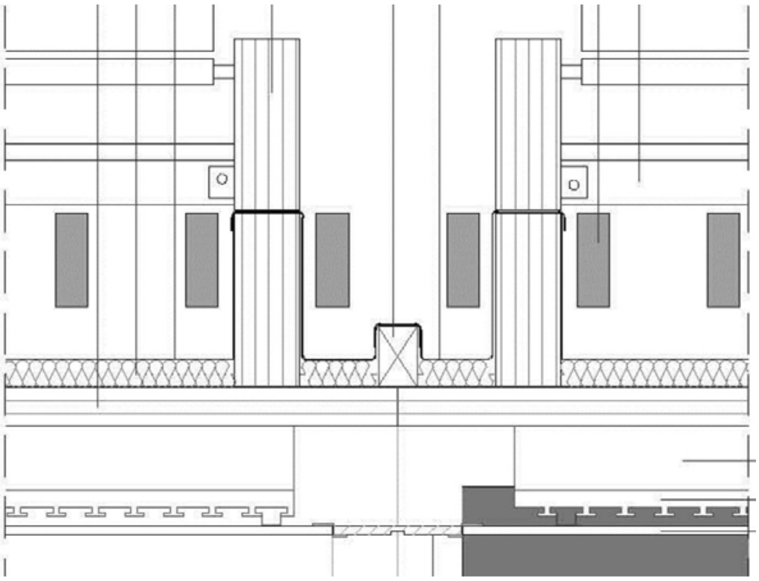

Fig. 15. Detail of lacquered steel plate at the join between modules.

Fig. 16. Ironwork system for the lattice.

Fig. 17. Possible orientations of vertical slats.