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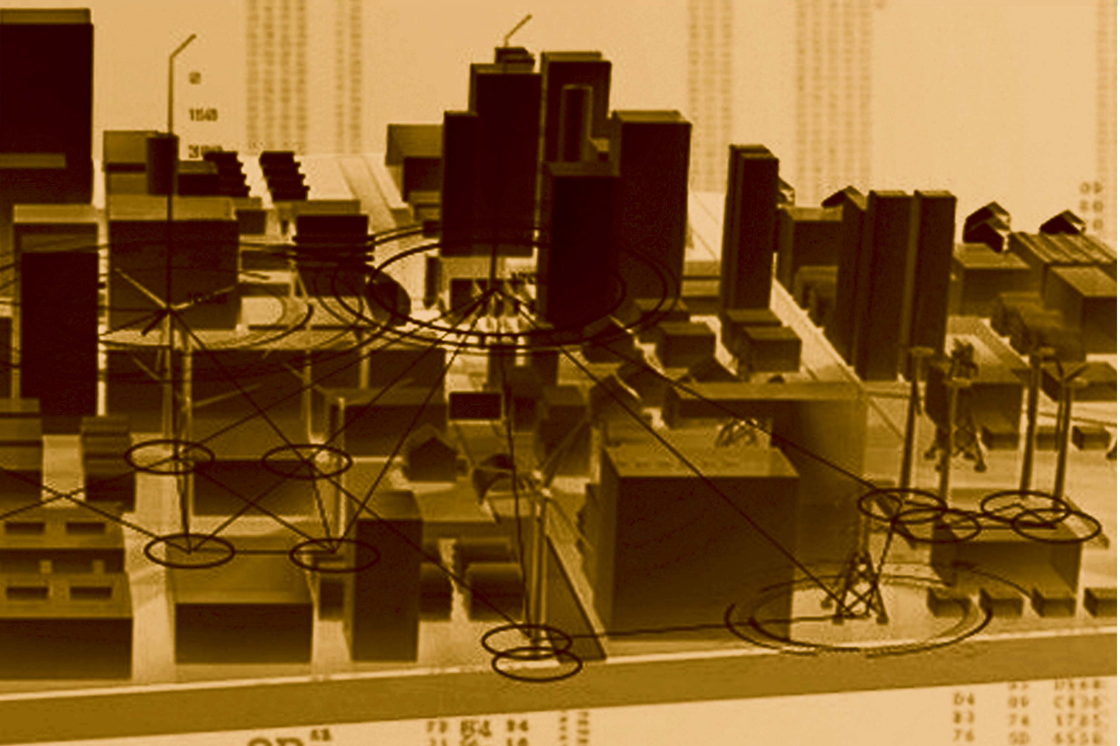

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2.17 INDUSTRIAL PRODUCTION, NEW TOOLS AND TECHNOLOGIES FOR DESIGN OF CUSTOM PREFAB HOUSING

Spartaco Paris, Roberto Bianchi*, Beatrice Jlenia Pesce**

Abstract

The paper investigates the relationship between the production of systems and components for prefabricated houses and the innovation of design tools. The goal is to understand the current limits and potentials of the available instruments of parametric modelling; it follows an operational path articulated in two parallel activities: an analysis carried out on recent case studies of industrialized houses and through an experimentation activity carried out on the field. The text focuses on BIM, which allows creating virtual models that simulate the construction, the use and the management over time.

Keywords: Mass customization, adaptability, reversibility, BIM, digitalization

Introduction

The paper investigates the relationship between the production of systems and components for prefabricated houses and the innovation of design tools.

This theme is part of a research developed within the Ph.D. in Planning, Design and Technology[1] and within the University research carried out at the University of Rome[2]. This ongoing study aims to understand the current limits and potentials of the instruments, available today, for parametric modelling; it follows an operational path articulated in two parallel activities: an analysis carried out on recent case studies of industrialized houses and through an experimental field research.

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1 "Industrial mass customization for temporary and reversible housing", Beatrice Jlenia Pesce, Tutor: Prof. Spartaco Paris, XXXI cycle, PhD in PDTA, Sapienza University of Rome.

2 "Advanced technologies and design criteria for systems and components in residential buildings retrofitting for building envelope" coordinated by Spartaco Paris.

One of the research fields of the Modern Movement has been to increase the adaptability of domestic space, stimulating many of the reflections and experiments in residential architecture by the main modern and contemporary architects (Schwartz-Clauss, 2002).

Today more than ever, the progressive overlapping of the working sphere with the private one, as well as the need to foster an increasingly flexible lifestyle, free and nomadic, has led to search, with ever greater commitment, housing solutions that can be freed from predefined layouts (Ábalos, 2012).

The adaptability of the domestic space has already reached in the past the most interesting results when it was pursued through industrialized construction systems. The current prefabricated systems, although starting from the standardization of the components, allow greater flexibility in the design phase and a consequent adaptability during the entire architecture life cycle.

Designing depending on the adaptability of a system, means dealing with the "time factor" of the project, time from which changes in uses and functions are achieved, but also spatial configurations. According to R. Krananenburg[3]:

> «A house designed for mobile, flexible living could be one which during its inhabitation might be moved from one place to another or be changed in its shape or structure – walls might fold, floors shift, staircases extend; lighting, colours and surface textures metamorphose. Parts of the house could leave the site or a part could be added or the whole building could leave the site and return, or the entire building could roll, float or fly to a different location» (Kronenburg, 2002).

The building systems that might support this sight of inhabit are usually customizable and use specific management and design tools. Nowadays the customer requires an increasing personalization of the "product" he needs.

In the 21st century, architecture would be a customizable "product": modular construction is no longer conditioned by mass production, repetition or uniformity. Today, in all industrial productions, mass customization[4] has almost completely replaced mass production. The latter depended on production rate to reach economic convenience; on the other hand, mass customization, thanks to a different production and management model, subverts this production rule, following a cultural model that puts the customer at the centre, as an active subject in designing and manufacturing. Companies like Dell or Nike succeeded also thanks to the ability to offer their customers high quality products with a high customization level, while maintaining a low cost. This has been possible by subdividing the product into smaller parts on which the consumer can make a choice. Through a careful management of suppliers, obtained through informatics control platforms, these companies can assemble the product, depending on the buyer desires, and send it in a reasonable time (Kieran, 2004).

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[3] "Modern Architecture and the Flexible dwelling", in *Living in Motion*, p. 21.

[4] Definable as "the production of high-quality components, adaptable to the individual choices of designers and consumers" (Hashemi et al., 2016).

Today, mass customization suggests a new way of design architecture and offers the tools to manage its complexity, due to the increasing level of mechanization. Each component is designed and verified by an interdisciplinary team that guarantees its reliability. The simulators and the virtual models also make it possible to control and to verify, in real time, the form, the performances and costs, thus allowing choices that are more conscious. The informatics tools make it possible to organize the complexity in both design and construction phases, managing time information, costs, assembly sequences, the geometry and the position of each component. Among these informatics tools there are the BIM[5]. This type of digital platforms allows creating virtual models that simulate the construction, the use and the management over time of the architecture. The simulation makes possible to divide the building in littlest and easily manageable parts that can also be designed or manufactured in another place, and shipped directly to the site for the final assembly. In these digital models the joints and angles are designed and studied as well as information regarding the constraints and performance of each component. The virtual model becomes a verification tool that makes the use of physical mock ups superfluous and allows solving the possible interferences between the architecture parts before the construction phase. With these processes, "doing' architecture can be raised through greater control of the project, raising quality standards and improving performance. Using BIM software, designers therefore have the opportunity to control, in addition to the single multidisciplinary contributions involved in the project, the entire design / production process, the constraints and the role of all "parts" which compose the construction. He can manage the design and assembly of each components "piece by piece", providing for their sequence of assembly and connection. One of the other potentials inherent in the use of a BIM software for architecture is the possibility, as it happens for other industries, to establish a direct connection with the world of research and experimental production, since it is possible to verify the functioning and performance of innovative components within the same virtual model.

A case study: *pop-up system*

In this context, a field research was carried out on a series of light and customizable building systems that can also be used for temporary housing.

The systems have been selected for their flexibility and adaptability. It was possible to study the *pop-up building system*, through virtual models managed with a BIM software, a period of study within the Italian design partner of the French pop-up house and, during the system upgrade, into the French factory.

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[5] Building Information Modeling, «acronym coined at the beginning of 2002 to describe together virtual design, building and Facility Management» (Osello, 2012).

The pop-up construction system belongs to the family of wooden frame systems. It was patented in 2015 by the Marseilles pop-up house as a highly insulated system, whose walls are made of expanded polystyrene panels (Eps), a low-density thermal insulation material. The polystyrene panels have uniformly flat surfaces on each side and are assembled together by means of microlamellar wood studs (Lvl), 30 mm thick, interposed adjacent to the Eps panels. The studs and panels have the same depth. They are connected to each other by means of screws 665 mm long, arranged along the whole height, which, crossing the entire thickness of the panel, avoid the deformation of the stud both transversely to its plane and at the moment. This arrangement of the connections allows the panel to collaborate statically against the lateral forces of the wind. The innovation compared to other similar construction systems, as specified in the patent application, lies in the extreme simplicity of the system, in the choice to use very light and handy construction elements, and in the collaboration of the insulating panels to the statics of the building. The same static and constructive solution employed for vertical bearing structures is also proposed for horizontal structures. The dry assembly of the building system, without the use of glues, facilitates the disassembly of each component, in view of reuse or recycling. The hyper-isolated structure makes passive houses and requires a careful bioclimatic design. Consistently to the site, the designers perform simulations of the solar path, adding, where necessary, overhangs brise soleil; the windows are usually placed aligned to the inner surface of the wall in order to exploit its thickness for shading. The building system is designed to adapt to all the French microclimates, but it can also be imported into the Italian climate context where the first pop-up buildings begin to be built.

250 buildings have already been built (in just over 3 years of commercialization), with good future sales previsions. The system, due to its micro-modularity, allows a good flexibility in design phase, guaranteeing a high degree of planimetric and volumetric customization. Now the constructive limits are in the maximum high development of two floors, in the maximum free light between two bearing walls of about eight meters and in maximum overhang.

These limitations, however, are irrelevant if we think that the market to which the company head towards is the one of isolated houses. What has established the success of this company, in addition to the quality of the architecture, is a careful management of the process. The company, which has a background in the IT sector, has focused both on the digitalization of design and configuration phase, developing a BIM application from the Sketch-up software, and on automating the construction process. The software is optimized for the management of that building system and allows controlling the costs and constructive implications of the design choices in real time. Starting from this application, the online configurator was developed, available to design partners, which makes the design and modelling phase immediate, considerably shortens communication times with the company and with the customer.

Once the project has been completed, the company calculates the structure and the energy performance and provides the certifications required by the French legislation[6]. In this phase, it is very important to acquire the climatic data on the prevailing winds because, since this is a light construction system, they imply an increase in the structure at the points of greatest stress.

The company follows the double channel of mass custom and semi-custom production: it is so possible to design a completely new house or to modify a pre-arranged housing model, starting from a dialogue between the user and the designer aimed at identifying customer needs.

The construction elements follow the modular logic of the system and come to the construction site ready for assembly, with a detailed design, a precise storage and installation plan[7]. A team that has been formed by the company then assembles the house. A single worker can easily transport and place each component. The speed in execution makes this system usable in emergency conditions. The production times for a single house are about 6 weeks, but the assembly time is about 10 days. The costs are competitive, even on the Italian market; however, it is necessary to activate a minimum production volume, equal to a surface of 70 square meters, so that the company obtains economic advantage. At the moment, therefore, small houses are not sold.

One of the strengths of the building system is the quality of the materials chosen on their low pollutant emissions into the air[8]. The company is constantly working to optimize connections and joints, to reduce the number of components and to minimize on site assembly operations. The design research within the company focuses on reducing maximum number of components produced by external subcontractors in order to manage the production phase as autonomously as possible, optimizing the times. Other customizable industrial production, tends to produce increasingly complex components and to reduce the number to shorten assembly operations. The pop-up case pursues this goal in the opposite way: simplifying the components, which are always monomaterial, thus favouring their reuse. During the experimentation phase, we developed, in collaboration with pop-up house Italian partner, the project of a 30 m^2. housing module that, when aggregating with another module, allows to reach a covered surface area of 70 m^2. In fact, the Italian market also requires very small modules that can be used as pavilions, dependences, or small offices. The idea was to design a more adaptable home, which could change over time, growing or decreasing, without causing excessive resource waste.

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6 The French certification rules do not match with the Italian ones, so it is necessary that the Italian partner verify the structural design calculations.

7 Each building is equipped with an assembly and disassembly booklet.

8 The Eps is neutral to smell, does not degrade the air quality of the spaces that delimits and prevents the formation of molds, it is also sealed behind the panels of Osb. The panels mounted in pop-up houses are free of formaldehyde and have E1 emission class, as well as the phenolic glue used in the micro-lamellar uprights.

The modules can be added to the existing one(s), using a spatial filter that becomes distribution and which is built by translating the overhanging roof above one of the entrances. Precisely to allow the free arrangement of the module depending on orientation or aggregation mode, each of the four sides has a window or a door that allows the modules to be connected in each direction.

Although the pop-up house has produced an innovative constructive system, focusing on the digitalization of the process and on the automation of production, there seems to be no complete reflection on how this innovation can influence new forms of living.

The small experimentation, starting from the technological and constructive assumptions developed within the pop-up system, proposes a solution that opens up to future scenarios in the field of residential constructions.

Conclusions

To date, we have seen a difficulty in updating the production chain, mainly used to conceiving the design and construction activities in a traditional way, and, at the same time, the need to increase the level of training - even within the company - of all the actors involved from the conception phase, to production up to construction.

Actually, a significant development element with a great potential is the possibility of providing a building system not only with an as-design model, but also with an as-built model, for managing operation and maintenance activities.

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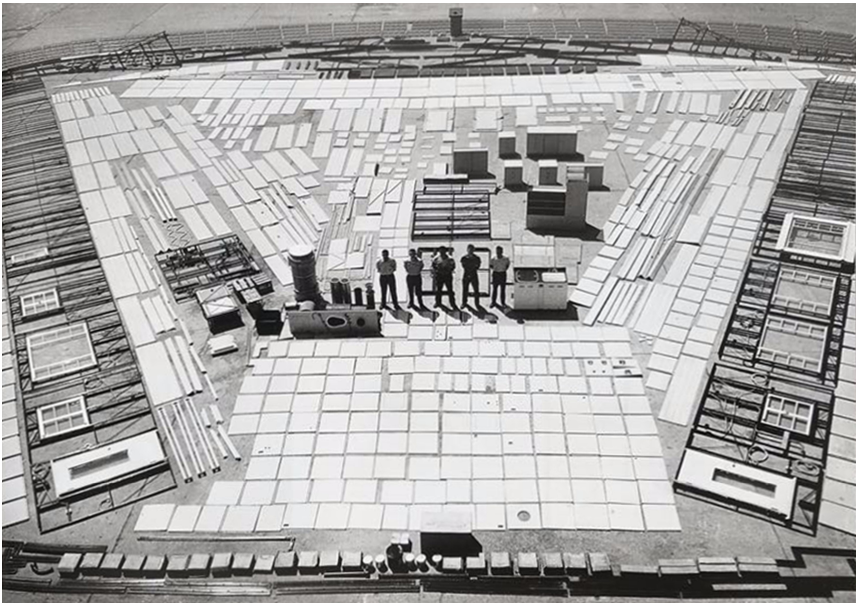

Fig. 1 - Lustron house. Columbus, Ohio, 1948-1950. Carl Strandlund.