

Design and Visualisation Strategies in Parametric Building Components

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ABSTRACT: New digital programming and fabrication techniques enable the development of parametric building components. These processes use a repertoire of working methods that differ from those commonly used in building projects. This paper presents five examples of parametric design and digital manufacturing carried out in Latin America, reviewing the graphic tools used in relation to the architectural design process, in order to clarify the characteristics and possibilities of these technologies. Particular project resources identified are; presentation of global parameters, modular programming, production drawings and assembly instructions. All serve to complement the conventional building design, to provide massive but variable manufacturing solutions. These new technological procedures require to be normalizing in order to integrate properly into architectural design and construction.

KEYWORDS: Parametric Design, Digital Manufacturing, Mass-customization, Architectural Design, Visualization.

INTRODUCTION

The recently developed parametric design and digital manufacturing technologies allow the manufacture of particularly complex building elements, with a wide variety of shapes, materials and uses. These new technologies provide the opportunity to create works of architecture with sophisticated pieces, encouraging the design of different elements with a similar design and execution procedure. Parametric building components can have diverse geometric configurations and applications, while still maintaining an operational relationship and flexible production strategies. Thus, a way of working is developed that differs from that of conventional architectural design which normally seeks a unique formal solution to erect in a specific location. In contrast, the following examples using new programming and manufacturing techniques utilize variable shapes and varied materials with numerous fabrication and installation options.

In order to visualize and realize these different possibilities, the development of parametric building components employs different graphic tasks and techniques to those traditionally used in architectural projects. Geometric programming systems and manufacturing and assembly plans can be seen in the experiences using variable digitally manufactured elements, new graphic tools that broaden the repertoire of resources used in the conventional work of architecture. Such design and visualization processes and techniques must be identified and regulated in order to foster appropriate and effective use in the building process. This paper reviews some experiences, acknowledging the graphic resources used and their working conditions with a view to normalizing these methods and techniques in order to integrate them appropriately into the design building process.

1.0. PARAMETRIC DESIGN AND DIGITAL MANUFACTURING TECHNOLOGIES.

Two independent but mutually supporting technologies are usually combined in the production of variable building components: parametric design and digital manufacturing. Both are emerging technologies with products or equipment still under development and used in different fields. Parametric design refers to digital systems (software) that enable geometric programming, and by other hand digital manufacturing involves machines (hardware) that produce physical elements based on numerical data. Digital manufacturing equipment can be produce designs developed by parametric systems or by regular drawings or written instructions. In turn, shapes generated through parametric software can be realized with conventional manufacturing processes. In other words, both technologies can be used separately, and also combining their capabilities.

Parametric design is a concept emerged from the origins of computer graphics, and present in almost every vector-based design or CAD program, through the interactive manipulation of numerical modification of geometry. In some design systems it has been implemented more expressly through written modifications,

and also recently in utilities with textual or graphic programming, such as Generative Components (for MicroStation), Digital Project (from CATIA) and Grasshopper (in Rhinoceros). Parametric design has mainly been used in the field of architecture to refine complex structures or roofing systems, as well as in temporary installations and some large-scale production systems (Meredith, 2006; Madyour et al, 2009, Woodbury, 2010, Garcia and Jofre, 2011).

Digital manufacturing has also emerged out of the metalworking industry and consists in diverse equipment that mould or sculpt a material with CNC (computer numeric control) using a variety of different machine sizes and processes (Seely, 2004). Like knife cutting for card or vinyl, laser cutters for wood or plastic and lathes and milling machines to elaborate timber, polyurethane or non-ferrous metal blocks. As well as worktops to cut and or shape composite panels, water jet cutters for metal plates or robotic arms to sand or join elements, also integrated into centralized manufacturing. Besides 3D printers to create small-scale volumetric models by consolidating liquids, particles or gases, and even large-scale parts by contour crafting. This equipment is been used in the construction industry to produce components such as metallic pillars and beams, tiles, panels and furniture, as well as to create experimental models or prototypes (Kieran and Timberlake, 2004; Stacey, 2004; Gramazio and Kohler, 2008).

2.0. EXPERIENCES WITH PARAMETRIC BUILDING COMPONENTS

In recent years we have conducted several academic experiments in Latin America, creating variable building elements through parametric design and digital manufacturing, with the support of several partners, collaborators and companies, in academic researches and industrial agreements.

2.1. Pixel-Wall

This development is a design and fabrication system to build flexible partitions made of interlocking rectangular pieces, named "pixel-wall" (Bruscatto and Garcia, 2010). The system was carried out as university research in the period 2009-2010, and has included CAD designs and digital 3D modelling, parametric programming, structural analysis, elaboration of a dozens of physical prototypes and until now five full-size constructions up to 10 metres long and 2 to 4 metres high in different materials manufactured with laser or CNC cutters. The pieces can develop straight or curved longitudinal configurations as well as domed structures, for spatial divisions or decoration. Wooden boards and plastic sheets have been used for pieces, with some metallic connectors to improve resistance, but giving in all cases a fast procedure of assembly and also re-assembly of different configurations with the same pieces. The development has received sponsorship from three different companies, was twice awarded funding from government entrepreneurship schemes and is currently being run as a start-up company.

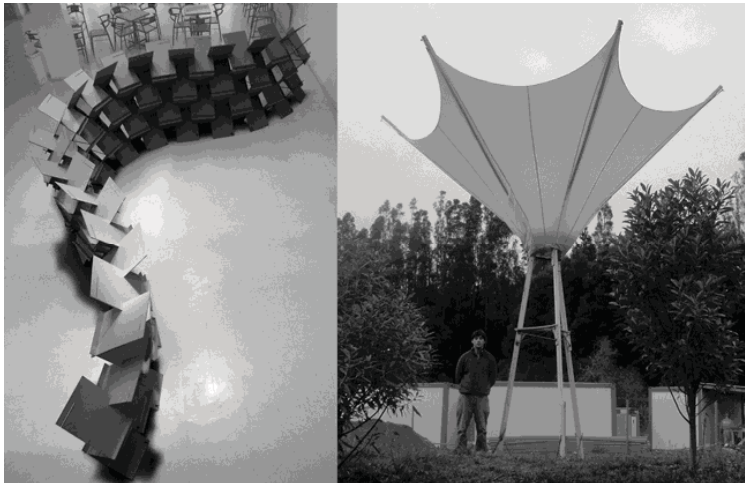


Figure 1. Installations of Pixel-Wall and Tulips (Author, 2010, 2011).

2.2. Tulips

Another design and manufacturing procedure has been developed for a fabric roofing module with variable hexagonal frame and triangular central support made with timber bars with CNC-manufactured connecting

nodes (García; 2012). The system was developed over the 2011-2012 period, mainly during an intensive multidisciplinary seminar and also ensuing architecture and civil engineering degree projects. The design looks to have different layouts of roof and support according geographic or functional conditions of the place, as well as diverse arrangements of modules for varied uses. The development has involved CAD design and 3D digital modeling, parametric programming, structural and climate analysis, a number of scale prototypes and two 9x9m and 6m high units, made with regular fabric and wooden pieces. It has received funding from companies and institutions and is now being developed independently by the students previously involved.

2.3. G-House

This experience aimed to develop an incremental housing system for warm climates called “Generative House”, made with double compressed timber panels (García and Turkienicz, 2010). It was developed as an international cooperation project between Chile and Brazil in 2010 for massive low-cost housing, with support from companies, research agencies and undergraduate and postgraduate students. Urban-scale programming and parametric definition were used to elaborate a generative design of different layouts and arrangements, numerous scale models and about a hundred CNC components were made and two full-size module constructions 6m by 4m in plan and 3.5m high were exhibited in industrial trade fairs. These prototypes involved around thirty panels in one-week manufacturing process, more diverse tests of execution, with an assembly of a couple of hours each time.

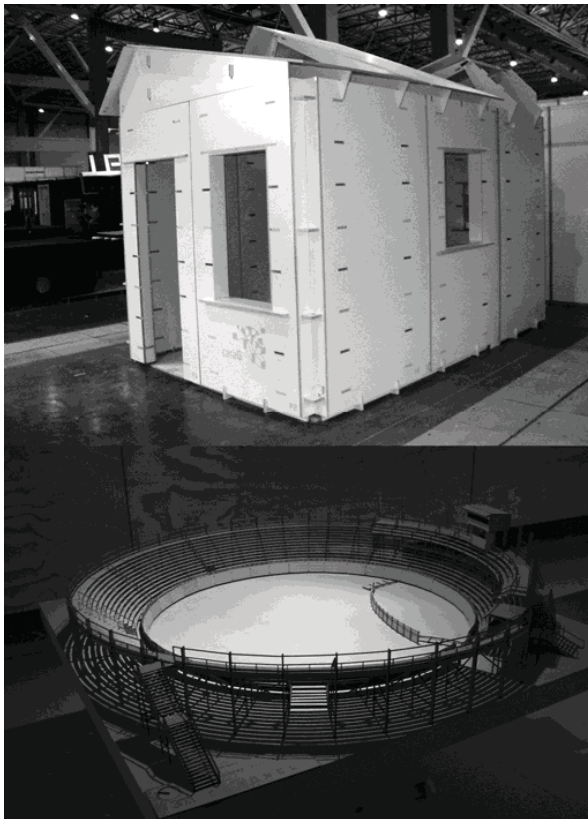


Figure 2. Prototypes of G-House and model of Medialuna (Author 2010, 2009).

2.4. Medialunas

This work was targeted to a prefabricated design for a traditional rural rodeo stadiums (called “medialunas” by the shape as half-moon of the central yard), composed of steel sheeting elements combining stands, booths and corrals in a variable system (García et al., 2009). The design was developed in a semester-based studio in 2009 with architecture students and collaboration from local institutions, in order to develop a prefabricated system for diverse layouts. The project included CAD design, geometric programming, plans

for laser-cut manufacture and six scale models. Each of them had different conditions and assembly with around two hundreds of pieces of twenty similar shapes, so they can change configurations and well as to enlarge the initial stadium.

2.5. Eco-slabs

A research to get sheeting optimized through structural topology for mezzanine floors in buildings was conducted. These plates are planned with a curved base created with prefabricated molds that reduce the material used by 50%, in turn reducing the building's environmental footprint, so they were called "eco-slabs" (García and Otárola, 2012). These elements were developed in a university research project between 2011 and 2012 as part of several civil engineering degree projects. The work has included numerous structural analyses, digital models, parametric visualizations and constructions and scaled down prototypes in polystyrene, timber and concrete constructed with CNC milling machines. Industrial development is ongoing with financial support from companies and institutions.

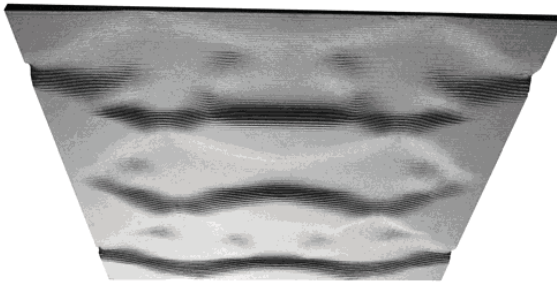


Figure 3. Model of Eco-slab (Author, 2012).

3.0. GRAPHIC PROCESSES AND TECHNIQUES

In those case studies developed in parametric building components, the following procedures appear according to the sequential stages of the architectural project:

3.1. Design conception.

In parametric and digital manufacturing experiences the graphic means used in the initial design phases are not clearly expressed (as also occurs with traditional processes). Certain physical conditions or geometric relationships are proposed in order to define the general shape of each element, as well as some features of likely uses, but mainly the development and even assembly details are usually described. The general volume or specific parts of the design are occasionally sketched by hand, precise performance, spatial or size criteria may be indicated and sometimes a natural or functional design allegory is identified. Rarely is any characteristic of the site or functional organization expressed at this stage, both aspects that frequently condition conventional architecture projects. Actions pointing towards a developing shape predominate (these are usually called "generative" or "evolutionary" processes) without predefining any set result. It is almost as if the design emerges without any explicit intervention from the designer, although the process established determines the possible results. This is an integral and interactive activity guided by only very general requirements and conditions.

In this sense, a more explicit and detailed description of the initial geometric conditions is proposed, for example, general or modular sizes, performance values and construction features (cost, time execution, etc.), all of which can be interpreted as global parameters (Lyon and García, 2011). In this way the form-generating processes can be defined with greater precision and permit creativity and effectiveness. Some typical aspects of any architectural project, such as the site survey or list of interior spatial requirements and distributions are notably absent since the designs developed are usually sited in non-specific locations and for diverse activities. However, some form of global sizing and definition of use criteria (climatic, operative and time-based) as well as certain specific operating conditions, ranges of sun protection, structural resistance, price, etc. can be determined and integrated into the design procedures. Indeed, such aspects are valuable tools in structuring the developing process. Intentions of aesthetic expression are also relevant and these tend to motivate processes and provide special working conditions, seeking to lend meaning to the design. In this way clear goals can be set with which to assess the resulting form of the project.

This description requires the graphic visualization of certain formal global conditions, numeric or conceptual expression of other aspects with relevant (minimum and maximum expected) values or points of reference. Consensus is reached over expected conditions, based on eventual use patterns and needs, probably requiring some methods of industrial production or from the building market, while partly using conventional methods of architectural project design. Schematic views of the general volume and specifications are obtained as well as some degree of analysis regarding manufacture and mass production.

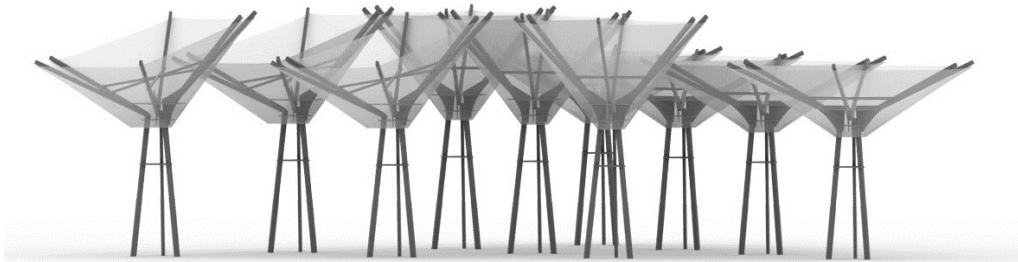


Figure 4. Design Concept of Tulips (Author, 2010).

3.2. Project Development.

There are considerable differences in the resources used in these experiences in the process of working out the design. In contrast to predominance of the orthogonal views normally used in the traditional architectural design, works with parametric design and digital manufacturing shows written or graphic programming that generates diverse geometries displayed in three-dimensional representations. The programming consists of an ordered list of instructions written in a code or graphic sequence that indicates geometric actions and conditions. This list is implemented into a digital system that interprets it and presents the results on other additional screens. Conditions or connections affecting the generated shapes can be modified, thus creating various different versions of the designs and these in turn can be visualized in different ways. Usually instructions or graphic components collect external information from other analysis or are able to send data to the processing or visualization systems or to the manufacturing equipment, carrying out additional steps to generate further information about the geometric form. An example would be to generate sections through the design at appropriate intervals according to the material used, thus optimizing materials.

The growing development of these programming experiences has generated controversy regarding the establishment of modules or structures to organize and generalize use (Barrios, 2006; Davis et al, 2011). This involves determining segments of programming that carry out a series of actions that can be independently handled, intervened in or reused. Such a measure facilitates input data recognition and the resulting information. This would be useful since programming is usually carried out by a specialist in an interactive process that generates a labyrinth of instructions difficult even for other specialists to follow, thus reducing the possibilities of creating new or broader versions of any design. Programmers are increasingly sharing parts of their data input processes in order to facilitate design development. In this context, these new technologies would benefit from a degree of standardization, although such a task would surely require an institution-led process of normalization.

Three-dimensional visualization of the geometries by means of digital representations generated by the same or another design program are used to complement the process, using diverse forms of visual expression or even creating additional static or animated presentations. An approach that permits simultaneous display of multiple possibilities of form or animation of the digital model in a generative process is advantageous. At the manufacturing stage, the diverse forms of the project elements should be identified and displayed in order to enable better design management since the process generates a large number of independent pieces, some very similar to each other (in contrast to conventional design which works with general views or written specifications). To this end, lists, alphanumeric coding and graphic tables are drawn up displaying the different types and sizes of elements in order to resolve and process physical production. Occasionally, the digital models developed are used to demonstrate dimensioning and relationships between the building components since some are connected to each other or their length is determined by the general design and in this way intersections and distancing can be reviewed. (Mechanical or BIM software can detect this automatically but this technology is not usually linked in with parametric

programming). This instance also serves to update general design dimensions or construction details when necessary. Component sizing in comparison to final building scale is also reviewed as well as equipment types and materials, and even costs involved, generally leading to adjustments in individual pieces in the graphic tables or coding lists.

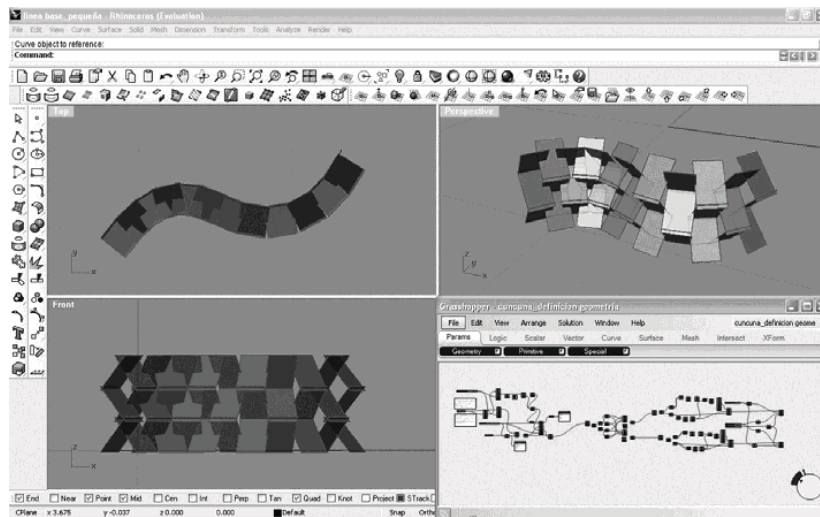


Figure 5. Programming of Pixel-Wall (Author, 2010).

3.3. Execution

Two kinds of graphic document are used to complement general construction drawings in the physical manufacture of the design with digital equipment. These are the production drawings and the graphic assembly instructions. Both are common in other manufacturing sectors but are not normally used in architecture projects (except perhaps in large-scale buildings).

The production plans are needed to elaborate the different components in the digital manufacturing and their nature depends on the specific machine used (although a number of general formats exist). In other words they are created as part of the production process or the designers already know which kind of equipment they will use. Nevertheless, the nature of these plans can vary considerably since the project duration and materials used may still be uncertain, making it impossible to determine costs or the processes involved. This equipment traditionally uses “G code” programming language but many now operate with DWG format drawings or alternatively printer controls can be installed that permit the use of any design programme. It is only important that the representation that is created contains an adequate description for the manufacturing process, while excluding all irrelevant information.

The final representation can be based on conventional drawings or data from the parametric programming but the graphics file must be made suitable for manufacture. This means eliminating all graphic elements that will not become physically manifest (such as measurements, labeling and projected views) leaving only sectional profiles and remove areas. Sizing depends on the proportions and dimensions of the material to be used (sheeting or block, or correctly speaking, the “working surface” of the machine on the material, according to the point of origin or processing surface) which may need modifying if a scale model is to be made. The component or model must be adequately laid out or distributed upon this working surface or volume in order to guide the manufacturing process and make the best use of the material while reducing work times. In fact, specific programs are able to analyze the layout of flat shapes or volumetric forms in order to minimize waste. However, some manufacturing processes either require a set distance between pieces or specify fixing positions, as well as particular arrangements or marks for handling. Some processes even create printed lists or copies of the plans to aid production in the case of a large range of elements. The aforementioned component lists or coding require careful management since some manufacturing processes produce each piece separately or in a different order to that required by the designer. Some machines can register the code number onto the component itself or a label may be attached. Likewise, packing and dispatching of components requires control procedures.

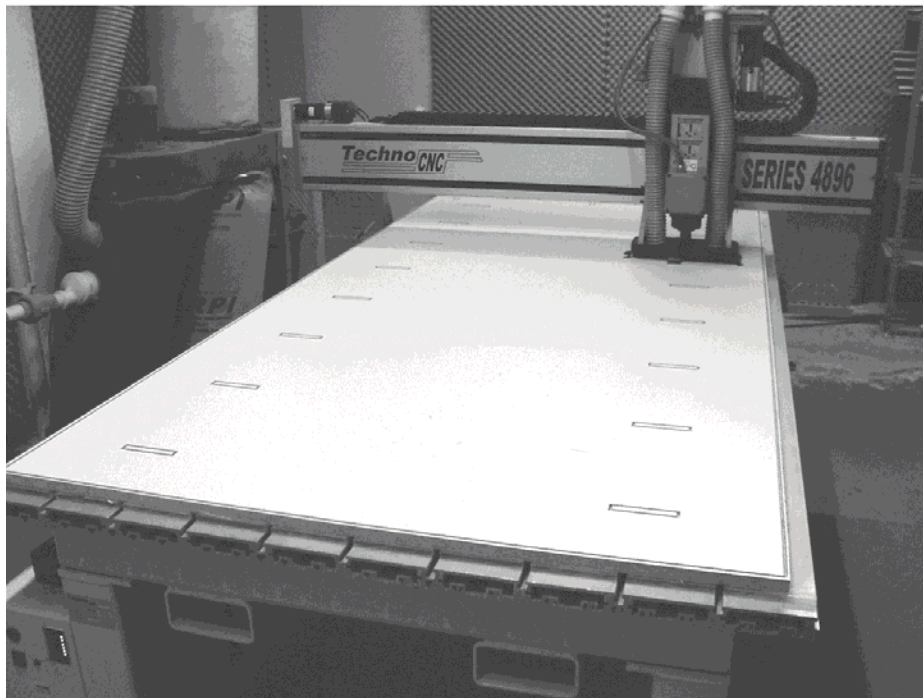
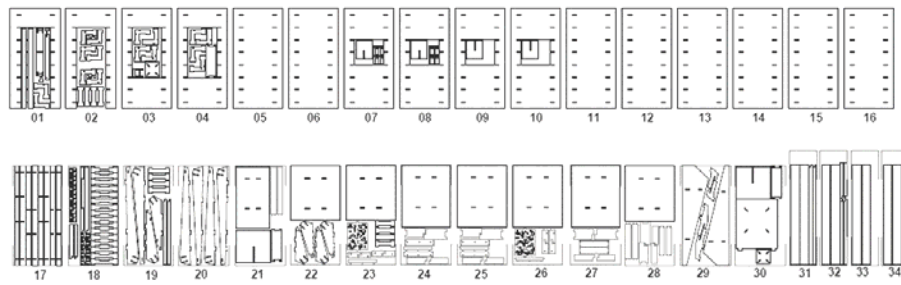


Figure 6. Production Drawings and Manufacturing of Panels for G-House (Author, 2010).

Subsequently, assembly plans are required. Although configurations are usually improvised in the case of the earlier trials with few components, as the size and diversity of elements increases along with a greater complexity of connecting details and component sequences this process must involve adequate planning. Sometimes transport, storage or handling aspects require specific instructions. In really large-scale and complex designs physical scale models are usually made with the sole purpose of determining the most efficient assembly process or partial mock-ups or ground plan configuration trials are carried out before final construction on-site. In cases where the designers will not carry out the final construction themselves the assembly process must be fully and carefully detailed (as in the case of furniture assembly). In this situation assembly plans are usually drawn up using isometric sequences with step-by-step instructions (and suitably labeled components) and a drawing of the completed design. Construction requirements are also specified (number of people, tools, connecting pieces and time scale) as well as site requirements (space, ground area, etc.) or recommendations regarding weather conditions. As digital models are available, animated sequences are frequently used to describe the assembly process. Stop-motion videos may also be made using models or test pieces in the component workshop (with a fixed position camera taking consecutive shots at each of the different assembly stages) and these often prove to be the clearest way to explain the assembly process.

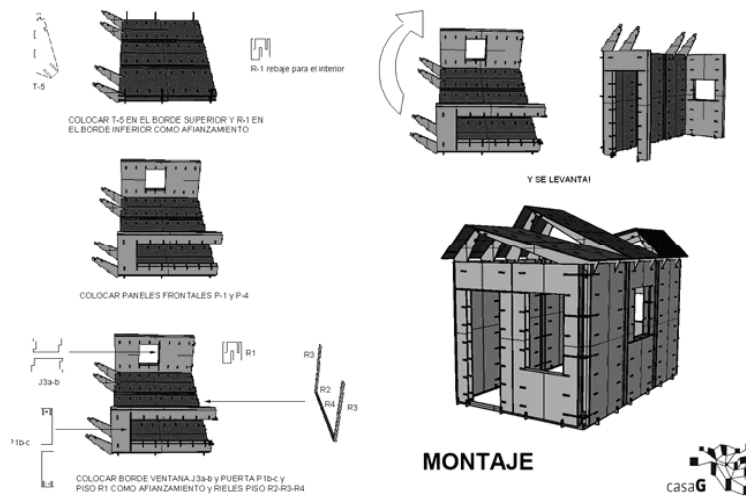


Figure 7. Assembly Instructions for G-House (Author, 2010)

CONCLUSION

The above experiences in parametric design and digital manufacturing reveal the use of specific graphic resources in the production of building components that serve to complement usual design techniques. More specifically, these involve the visualization of global aims, geometric programming, manufacturing plans and assembly instructions, all of which must be normalized to regularize their use. In this way, the repertoire of development and construction strategies of works of architecture can be broadened.

Parametric design and manufacturing are still applied in small experiences and elements. The use of these techniques in larger scale projects requires not only the training and availability of equipment, but also to understand and manage the massive customization of designs. Building process is traditionally oriented to unique result, so these tools can suggest more possibilities for the specific work as well as other applications. Introduction of these procedures can motivate practitioners and patrons to apply these capabilities for diverse building needs.

Besides, this variety of design resources allows clearer representation of project conditions, definition of form and physical concretion. It reveals geometric and constructive characteristics that offer diverse functional and aesthetic possibilities. One significant characteristic of these technologies has been the electronic linking of information (the so-called “digital chain”) into the process of project, design definition and final construction, thus expressing the aspects involved and their specific relationships more clearly, providing a platform for collaborative work and a diversity of solutions and uses. However, a higher degree of technical knowledge is undoubtedly involved, making more demands on the preparation and infrastructure, for teaching, design and production. These design activities must be integrated into current possibilities but also presents a challenge to traditional architectural processes.

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