Integrated Design and Production.
Decision-making Tools for Optimal
Industrialization of Housing
Construction

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ABSTRACT
The paper proposes a series of decision-making tools to find solutions for
the issues concerning industrialization of housing construction by helping
industry professionals – designers, developers and builders – from the very
earliest design phases, via:
- The preparation of a series of standardized rational solutions
  for different housing formulas
- The organization of product catalogues covering market
  assemblies and components
- The development of IT tools for industrialized housing
  construction that would include the above formulas and
  catalogue, and facilitate their use by design architects and
  engineers without forfeiting freedom of design.
- Appropriate training for workers participating in housing
  construction

KEYWORDS
Industrialization, Rationalization, Sustainability, Housing Construction,
Decision-making Tools.

1.1 BACKGROUND
Some of the most representative facts and figures in connection with the
present status of industrialized housing in Spain are:
Housing is a primary necessity.
Housing accounts for a substantial portion of building construction (>80%), with production amounting to over 700,000 units yearly. Today's construction systems and procedures can be regarded to be obsolete and inefficient. They have remained essentially unchanged in the last 50 years, with a low level of “rationalization” and a high percentage of “in situ” work.

Most “in situ” construction techniques deployed in housing are based on the use of an abundant supply of generally low-skilled labour (“crafts without craftsmen”). One outcome is the need for frequent demolition and rebuilding of newly finished units of work, with all that entails in terms of rubble, technological impoverishment of the industry, large numbers of building failures and inevitably higher costs. According to the latest figures, over 15% of construction costs is devoted to correcting on-site errors.

At present, nearly every block of flats is a prototype in which the initial design takes insufficient account of the construction system to be used. This leads to work-site adaptations not necessarily suitable for the building, whose implementation detracts from overall efficiency. The result is that new production and control techniques in place in other industrial processes have not been instituted in housing construction, reducing the quality, efficiency and, in short, the sustainability of the process as a whole.

In this vein, the specific issues that may be cited in support of the need for a change in the present approach include:

a. **High prices**, that in turn depend on a number of factors, namely:
   - *High construction costs*, due to an excessive reliance on “in situ” labour-intensive work resulting in relatively long turnaround times.
   - *Construction errors* that necessitate repeat work in many units, as well as a substantial amount of correction work prior to final product delivery.
   - *Pathological processes* in the first five years of use, and the concomitant additional cost.

b. **Low quality** leading to excessively high maintenance costs, normally due to:
   - *Poorly suited designs* from the standpoints of the general approach *(preliminary design)*, hampering construction rationalization and sustainability both.
     - technical specifications *(final working construction design)*, leading to improvised worksite decisions and changes and hindering quality control of the various units of work.
   - *Poor quality construction*, for several reasons:
     - poorly trained workers,
     - overly large number of units of work erected on site,
     - insufficient emphasis on quality control.

c. **Scant operational and sustainable rationalization** of housing, with no particular emphasis on:
   - *Energy savings*, for the failure to envisage bioclimatic and co-
generation (CHP) solutions in the design
- *Domotics* for all building services as a whole, without which the use of bioclimatic energy saving systems is particularly difficult.

d. Difficulties encountered to design housing at least partially based on (industrialized) “assembly” techniques for greater overall efficiency in building production.

Essentially, then, the situation is characterized by:
1 *Ingrained traditional housing construction techniques*, which hinder the change in professional (both designer and builder) mindsets and habits required to adapt to new techniques and procedures.
2 *A need for a new focus in design and construction* to rationalize the various phases involved (design, materials, construction and maintenance) and benefit from the advantages of the industrial approach.

### 1.2 OBJECTIVES

In light of the foregoing, a need has been identified to define and design the tools required to reach two basic objectives:
- *To optimize housing production.*
- *To maximize sustainability in housing production and use.*

Moreover, account must be taken in this context of the pressing need to integrate housing design and construction in a single process to ensure smooth and efficient industrialization.

#### 1.2.1 Optimization of housing production and maintenance

This requires viewing housing construction as a global process covering everything from building design and final construction to maintenance throughout its service life, including items such as energy consumption in keeping with the intended use and the manufacture of materials and components for framing as well as building services.

Such optimization can be achieved through the deployment of a series of decision-making tools:
- **Design rationalization of housing solutions** (at the expense of their possible uniqueness), which calls for specific analysis in both stages:
  - *Preliminary design* to optimize operability and facilitate industrialized building, establishing the necessary design guidelines for what might be called a “design for rational buildingt” as well as a “design for sustainable habitation”:
  - *Final construction design*, defining the technical specifications and conditions for such industrialization.

- **Coordination and classification of market products and**
techniques to attain:
  o Ready adaptability of their mechanical and geometric properties to rationalized design (modular coordination and attachability).
  o Possible inclusion in the industrialized housing construction process, via one of the following two formulas:
    • Closed schemes, involving the use of specific designs and components.
    • Open schemes, with component and technique interchangeability for coordinated designs.

- **Design of an IT tool for:**
  o Entry and updating of the various rationalized designs of the housing solutions obtained.
  o Entry and updating of the market products and techniques obtained.
  o Interactive use of the tool by the different actors participating in the process, to seek industrialized solutions for real-life situations:
    • Designers, in particular, for their project designs.
    • Developers, to optimize buildings.
    • Material manufacturers, to specify product qualities and geometries.
    • Builders, to rationalize construction.
    • Tenants, to optimize use and maintenance.

This tool, in short, would be an integrated computer-aided design system to facilitate the tasks of the players involved in the housing design and construction process (designers, engineers, builders, suppliers, public authorities, tenants) and further interaction among them. This in turn entails the development of computer software that "improves" (automates and optimizes) normal design and construction tasks in the framework of existing practice, and the implementation of measures to begin to upgrade such practice through the resourceful use of information and communication technologies. Other aims include the integration of design and construction processes and the incorporation of bioclimatic solutions.

1.2.2 Maximum sustainability in housing production and use

A series of goals would have to be defined as a corollary to the design tools specified in the preceding item. These goals include:

- **Improved efficiency of construction techniques and procedures** (materials, components, workmanship), which entails rationalization of the entire process, to achieve:
  o a high degree of industrialization,
- **shortened overall construction times**,  
  - lower total costs as a result of time savings.
  - **Improved quality of the final product and durability of its components**, to lower building use and maintenance expenses.
  - **Reduced maintenance needs**, in all respects:
    - Reduction of energy consumption by using, among others, bioclimatic design solutions, natural energy collectors, low energy generators and so forth.
    - Reduction of replacement and repair needs thanks to higher quality materials and components with longer durability.
  - **Improved housing operability** while ensuring effective environmental control in interiors through, among others, automated operating controls (home automation) that cover all aspects of habitability.

All the foregoing should culminate in the erection of one or several “demo” buildings to verify both the feasibility of industrialization as a system for rationalizing housing construction - with lower costs and enhanced quality - and the utility of the IT design and management tools described to reach this aim. Any such building should also stand as an example of sustainable industrialized construction, in which particular attention is lent to aspects such as energy consumption during construction and resource consumption once the building is in use.

### 1.3 INVISIO, A UNIQUE STRATEGIC RESEARCH PROJECT

A unique strategic project (INVISIO), subsidized by the Spanish Ministry of Education and Science, is underway in Spain to reach these aims and develop the above design and management tools. The project addresses the following lines of R&D that in turn cover the decision-making tools to be obtained:

#### 1.3.1 Analysis of the status quo

The real needs of the various stakeholders will be analyzed: consumers, developers, designers, manufacturers and builders, along with the most representative software developed in recent years for rational housing design and industrialization. In a nutshell, the analysis will cover any prior developments on which to base housing production rationalization and sustainability, and the integration of “ICTs” to improve housing design and construction.

Among other measures, a nation-wide design competition will be held to gather ideas for the rationalization and industrialization of housing construction.
1.3.2 Rationalized housing solution typology

The typology of the many housing projects presently underway in both public and private developments in Spain should be analyzed to establish any corrections or variations required to rationalize preliminary design and facilitate production procedures, efficiency and sustainability. The result, drawing as far as possible from the ideas obtained in the nationwide competition, would be a series of “standard preliminary designs” to attain the objectives specified and build a database that could be used with the housing design software discussed below to generate a catalogue. This would be preceded by a sociological survey to gain a fuller understanding of the different types of basic family units, ranging from unipersonal to plurifamily dwellings; their variation over time and impact on housing design and operability would be analyzed, along with the possibility of dimensional adaptations throughout household life cycles.

1.3.3 Definition of sustainable housing solutions

This activity pursues a sustainable approach to building design and would enlist the participation of all the actors involved, addressing the two basic components of sustainability, namely:

- **Production process efficiency**, which involves the low-energy manufacture of materials and components in which raw material and pollution levels are likewise low; and the use of more efficient construction techniques, rationalizing operations to deploy less labour.
- **Simple maintenance** to ensure material and component durability, convenient replacement and possible “de-construction” without polluting the environment.

In addition, the basic conditions for geometric and operational coordination of the various environmental control facilities and units will be established, and heating and AC units will be designed for low-cost or recyclable fuel readily used in standard housing units. A basic analysis of the life cycle of the solutions proposed will also be conducted. A “laboratory dwelling” will be built to experiment with and improve the elements defined, ensure their proper operation and determine the ease with which they can be incorporated into the building process.

1.3.4 Sustainable operability and home automation

This activity, which supplements the measures set out in the preceding item, seeks to ensure the sustainable operability of industrialized housing through improved operational use. This in turn entails the implementation of readily available and easy-to-use home automation systems for normal residential functions, as well as to maximize the benefits of energy
savings systems through so-called “home platforms”.
To this end, a survey will be conducted of the various digital home automation products on the European market (personal and household devices, network technologies, interconnection architectures and standards, micro-servers, terminals and sensors and so forth), followed by the generation of new designs or adaptations to ensure ease of production and greater suitability for industrialized housing construction. Moreover, these products will be included as a database in the computer-aided housing design and management software discussed below.
The various devices will be tested in project “laboratories” to ensure the proper operation of the elements defined and determine how readily they can be incorporated into the building process. Their operability will also be confirmed and they will be improved as appropriate.

1.3.5 Analysis and definition of the optimum characteristics of construction products and techniques
If the objectives sought are to be realistic, a system must be established for integrating present and possible future systems and products on the domestic and European markets. This will ensure the existence of elements and components usable with the computer-aided design software to be developed and the effective operation of the system under open scheme industrialization conditions with “buy and plug” solutions. The above will involve, firstly, a study of both the precedents for and definition of certain basic criteria for incorporating systems in open scheme industrialization building, determining the respective dimensional and modular standards. Subsequently, an exhaustive analysis will be conducted of products with some degree of prefabrication (standardized mass production) that can be incorporated into final housing units. The analysis will focus on dimensional coordination of the design typologies defined in 3.2, along with an in-depth review of systems for joining and attaching the different construction components. All of the foregoing refers to components and techniques for framing as well as building facilities and services.
The results could then be applied to define the most appropriate physical-chemical and geometric properties for the construction products and techniques to be included in a “catalogue of industrializable parts and components” that would serve as a design tool; any such catalogue would have to be usable with computer-aided design software intended to facilitate the task of manufacturers, designers, developers, builders and tenants in the development of sustainable and industrializable housing construction.

1.3.6 Automatic solutions for erecting work units on site

The possible avenues considered for process industrialization also include the automation of construction activities as an in-plant and on-site management tool. In this regard, the following are analyzed:

- **Management** of each of the possible activities to be automated, i.e.,
  - component manufacture,
  - operation logistics,
  - shipping and job site placement, and
  - construction unit use and maintenance.

- **Automated job site placement** of the materials and elements for each unit, which in turn requires,
  - worker assistance,
  - industrial tools (construction machinery) and
  - comprehensive robotization of these activities.

The above arrangements seek to minimize the need for labour in construction operations with the dual aim of enhancing product quality and improving operational safety.

The robots will be tested in the “laboratory dwelling” mentioned above.

1.3.7 Industrialized solutions to enhance energy savings in housing

The objective is to define the solutions best adapted to industrialized processes as design tools, based on existing low energy solutions for housing use and maintenance. In this regard, the analysis will cover all solutions that seek a minimum environmental impact and the use of CHP from passive bioclimatic framing to the most active mechanical systems. In other words, the object of this study will be energy savings systems in which lower energy demand is a natural outcome of bioclimatic housing design; this, in turn, should be envisaged in the design of the various construction components as part of what might be termed “energy efficient” industrialized housing.

To this end, optimum solutions for bioclimatic architecture in industrialized housing are under study and specific designs under
development for the manufacture and installation of inter-attachable components on enclosures (facades and roofs) to maximize energy savings in building environmental control. Once defined, these components should be tested in the laboratory dwelling. In addition, standard bioclimatic solutions will be designed as a reference and a series of pilot trials will be run to verify performance in different climates.

1.3.8 Interactive software

The intention is to study and develop IT software able to help designers define and shape space into possible architectural solutions for housing within the limits determined by the project typology established in the preceding items. The software would be especially geared to accommodate industrialized market components or rationalized traditional techniques and sustainable solutions as well as home automation systems. Such software would constitute a decision-making tool for designers, whose preliminary designs would be drafted from a series of iterations showing possible geometries and spatial relations that could be successively selected to establish the final solution. The ultimate design should cover all the systems involved, from basic structure through HVAC, including facade and roof enclosures and interior finishes, as well as energy efficiency and home automation solutions. The computer program should also include a function to develop the final construction design, bearing in mind: compulsory European, domestic and regional legislation; the construction solutions accepted in the preceding items; structural engineering and interior environmental control; construction drawings; job and technical specifications; and highly detailed bills of quantities for the solution put forward. It should likewise be a management tool for all the other actors involved, including developers and tenants to define types and programmes of needs, material manufacturers to improve product design, and builders to rationalize and industrialize construction processes.

1.3.9 Housing prototypes

To complete the study and ensure its viability, prototypes must be developed to fine-tune preliminary and construction design procedures and guarantee the operability and sustainability of the construction solutions chosen. In addition to verifying the practical functionality of the software tool designed and its results, such prototypes should serve to analyze the actual viability of the industrialization processes involved in the assembly phase, including what might be termed the partial industrialization of construction processes to rationalize certain activities. Two possibly
simultaneous options would be considered throughout: the maximum use of precast/prefabricated units comprising certified components with high quality finishes, and the rationalization of traditional techniques and systems to limit the amount of on-site erection work involving the enlistment of unskilled labour, including automatic solutions for existing work units as mentioned in 3.6. This should be supplemented with the establishment of strict production quality controls and the possible institution of methods for verifying performance.

At least two types of buildings would be erected for verification, namely blocks of flats and single family homes.

1.4 CONCLUSIONS

The final outcome pursued with this research project is to obtain a series of “design and decision-making tools” for the construction process as a whole to industrialize all the various phases involved in housing production: design, manufacture, construction and maintenance. More specifically, these tools include:

- **Design and production specifications** for construction components to be used in industrialized systems, including inter-element attachment solutions.
- **Database of commercial products and components** that can be used in open and mixed scheme industrialized housing design.
- **Construction solutions for sustainability and energy efficiency** in industrializable housing.
- **Home automation systems** to improve the operability of industrializable housing.
- **Robot systems for “in situ” construction activities** using automated machinery.
- **Software for computer-aided design and management** in industrializable housing construction.