Technical solutions and industrialised construction systems for advanced sustainable buildings

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ABSTRACT: At a time of severe market shrinkage, the spread of an approach to planning that is socially, economically and technologically sustainable, represents a culture of quality that is once more measurable, which makes it possible today to define innovative building models for the industrial and production chain.

The production of open industrialised building represents the most effective response to the need to recognise a reduction in building costs and times on site to ensure the environmental and economic sustainability of the intervention.

The concentration of effort and investment in processes and technologies aimed at a more rational energy use and exploitation of renewable energy sources (clean energy technologies) could act as a driving force for economic recovery by ensuring, at the same time, full agreement with energy and environmental constraints and international certification standards.

CCCabita - is an environment conscious constructive system that allows a coherent response, and a flexible one, to housing demand thanks to the potential for aggregating the residential blocks that define the different sizes of accommodation ensuring the adoption of the most innovative technical solutions and favouring the wider variability of the different housing models.

1 GENERAL INSTRUCTIONS

Today's open building systems express the best result of innovation and experimentation applied to the field of building production. These systems represent the result of a research path towards building technologies of rapid execution and high quality of the product with which to meet the needs of new forms of living, respond to economic demands dictated by the recession in the construction sector and introduce technical elements that are attentive to protecting the environment.

A more elaborate definition for industrialised construction means a change of thinking and practices to improve the production of construction to produce a high quality, customised built environment, through an integrated process, optimising standardisation, organisation, cost, value, mechanisation and automation.

Currently, there is a wide definition of Industrialised Building System that could be either the product or process: it is not necessarily restricting its scope to the final product which is a system but mainly involves the processes which lead to the production of the system and its construction application.

The International Council for Research and Innovation in Building and Construction (CIB) linked industrialisation with the use of mechanical power and tools, the use of a computerised steering system and tools, production in a continuous process, continuous improvement of efficiency, standardisation of products, prefabrication, rationalisation, modularisation and mass production.
From the perspective of construction, industrialisation is a part of a wider modernisation process through the development of modern methods of production and technology systems. Many industrialised construction technologies coexist with onsite work in hybrid construction and so demarcating what constitutes offsite practice is problematic.

The Industrialised Construction Systems should be seen as an innovation in construction. The innovation agenda has been promoted worldwide as an evolution of construction using new and innovative techniques rather than a revolution.

2 INDUSTRIALISED CONSTRUCTION SYSTEMS

2.1 Modern methods of production and technology systems

The design and executive model of an open constructive system is based on an “open building system” within which the various components and the many technologies available on the market (from vertical closures to small elements, to closures in plates or panels of dry-mounted wood, by industrialised baffles and precast reinforced concrete pillars, to the dry or wet internal partitions) are inserted into a matrix of reference that is the instrument for modular coordination, and verification of tolerance and compatibility between different technologies and components.

However, industrialisation means an industrial method employed with reference to mechanisation, standardisation and prefabrication. In the lack of a uniform definition and uncertainty regarding the context and boundaries of the Industrialised Building System many different terms are used to describe industrialised construction and prefabrication. The term is used interchangeably with other terms like offsite construction, prefabrication, offsite manufacturing, Modern Method of Construction, industrialised building and industrialised construction.

Present-day manufacturing processes adhere to current building culture as outlined and, in the form of new organic and systemic proposals, are reflected in a production of catalogue systems: in these it is possible to detect the integration of different technological solutions and determine their ability to meet, for each occasion, different project needs.

As part of the present-day logic at work in the construction market, the CCCabita project represents an innovative open industrialised building system, which was born from the experiences and synergies of a plurality of subjects grouped in a consortium, and having a dual purpose: on the one hand, the development and testing of models of sustainable social, private-public and student housing and, on the other, the promotion of the system with public and private clients.

The CCCabita project, promoted by the CCCabita Consortium, was awarded the Ecosustainability and Technological Innovation prize at the Social Housing Exhibition Awards at EIRE (Expo Italy Real Estate) 2010.

The CCCabita project has also been selected for an international competition for the formation of the list of projects for high-performance and low-cost residential buildings at Housingcontest 2011. The competition, sponsored by the City of Milan in collaboration with the Association of Architects of the Province of Milan and other associations from the sector, involves an intervention on social residential housing of approximately 5,000 sqm of GFA organised on five levels, following a typological and dimensional mix requested by the design for a total of 66 dwellings. The project illustrates the elevated characteristics of aggregative flexibility of the living units, adapting themselves to the urban context defined by the design integrating housing types and compositional schemes of great importance.

2.2 CCCabita - environment conscious constructive system

The CCCabita Consortium is formed from the integration of a set of cooperative businesses, in their capacity as partner manufacturers/producers, and a number of private parties that constitute the partners in the consortium.

Among the private parties are some of the leading companies in the domestic market representing the leading manufacturers/suppliers of industrialised system components; the different suppliers flank both the team of operators specialised in the fields of system
engineering and financial planning, as well as the academics and researchers directly involved in the design of the system.

Through this strategic organisation of the consortium, the various clients are always flanked throughout the entire process of implementation by expert consultants who - in relation to the different final uses, intervention programmes and specific programmatic needs - can suggest and model on a case-by-case basis execution time, performances, production and management costs of their projects.

The CCCabita system does not therefore represent a single project but, by virtue of the high level of industrialisation of the system - and organisation of the consortium - allows the realisation of a plurality of construction interventions: the intervention can then be calibrated by adopting the specific solutions in the catalogue provided within the wide range of technical solutions belonging to the construction system.

Partners and technical choices form the basis of the constructive simplicity of the system; the quality of materials and product certification are a guarantee of environmental sensitivity and of a particular attention to the life cycle of the building and its related operating and management costs.

The high performance of the materials used in the technical solutions of the system are the result of a certified and aware production cycle in which saving energy and reducing the environmental impact meet the “quality credits” of the environmental certification protocol LEED® from which the CCCabita system takes its inspiration.

The approach of the working group was therefore to adopt as a priority an operating instrument, of scientific validity, on the basis of which to evaluate the criteria of energy and environmental sustainability of the buildings even before knowing their future geographical location and environmental conditions.

2.3 The technical manual for the CCCabita system

The technical offer of the system is structured in a technical-regulatory and typological manual, a tool that expresses the wide architectural variability and technical specifications of the system. The manual is divided into three different sections: the technical legislation of reference of a number of municipal realities, typological legislation and a catalogue of technological knowledge of all of the technical components of the system.

The system manual offers itself therefore as a tool for the definition of the key quality criteria of the system and, in typological terms, for a complete compliance with national regulations.

The section on technical legislation brings together all the design standards and housing parameters encoded by the various laws and that form the basis on which was developed the technical variability and flexibility of the system.

Each alternative technique of the building system reflects and meets the entire body of legislation at present in force with regard to the following aspects: urban and typological planning, structural and antiseismic, plant, energy and fire safety.

Starting from the sample study of five cities (Rome, Florence, Bologna, Milan, Turin) standards have been defined of typological and dimensional architectural design, suggesting an approach to design that is flexible and easily applied throughout the entire national territory and, in part, internationally as well. Building regulations, technical regulations for the implementation of town plans, and regional laws are integrated and translated into a single project language that finds its validity in the system’s legal manual: a tool at the disposal of clients and planners for the definition of cubatures and surface areas achievable on the basis of the building potential available.

The section on typological legislation illustrates the means of aggregation of the dwellings that make up the individual living compartments, defining a mixed settlement that is flexible and compatible with the programmatic demands. The different combinations among the individual types of accommodation can have an effect on the morphology of the building all the way up to achieving the right mix of housing requested, as well as allowing more articulated building plant systems.

This objective of typological and morphological flexibility has been achieved by seeking a profound modularity and systematic nature in the structures and plant up to the definition of
“services module” and the “technical plate”: the latter is the basis on which is built both the flexibility of the housing units and plant network, and the modularity of the façades.

The typological plant is defined by the aggregation of elements generated by the three modular units - A, B, C - that make up the technical plate and which represent the geometric and spatial matrix on which is built the entire aggregative model of the settlement: the units compose and aggregate to form distinct configurations each time. The residential blocks confer, through their composition and aggregation, an extensive compositional freedom on the typological plant; they represent the synthesis of the search for modularity and flexibility of the system, disconnected and at the same time consistent with every technical, structural and plant choice.

The open system is not limited to the presentation of a single distribution solution, but expresses its potential in the combined compatibility of the multiple housing units: different sizes of accommodation appropriately verified in their technical and optimisation feasibility by the partners involved in the consortium.

The typological development of the system represents the outcome of a planning process that has involved and integrated the different partners through a continuous sharing of the different technical information from each member of the team; these activities have been followed by successive moments of verification and control of the stages of progress: a path of progressive approach to each solution - definitively validated - that represents the expression of the best design synthesis between the ideational/composition process and the know-how of the operators involved in the executive development of the system.

The specific rules of technical composition and verification are provided in the typological manual of the system, and it explains each distinct aggregative solution classified according to the main typological rules of line, balcony/riailing and gallery.

The typological-distributive plant is therefore based on research into different consolidated settlement patterns responding, through separate residential blocks, to the expectations of a diverse multiplicity of users, and following the logics in place in the demographic and compositional structure of the family groups (young couples, large families, student accommodation, students, single people, self-sufficient people with disabilities, the elderly).

The depth of the structure provides an early indicator of the quality and organisation of the system of routes and use of space. The choice of a slender building emphasises the efficiency of the housing model to guarantee double exposure and cross-ventilation, which is also supported by mechanical ventilation that operates on both extraction of used air as well as on indoor thermal balance and comfort.

The section is completed by a matrix summarising the significant metric data of the typologies examined and referring to the parameters explained in the technical regulations.

The catalogue of the technological system provides a more in-depth reading of the technological and constructive aspects. The technical catalogue integrates and collects all the technical and plant alternatives of the system and represents the analytical foundation for the construction of the technological matrix of the system.

The technical matrix sets out the potential relationships between the different technical solutions, while the constructive details solve the main critical points of the building (wall-coverings, wall-frames, wall-floor, overhangs, ground attachments) that are verified in their performance response from both an acoustic and thermal-hygroscopic point of view.

The detailed study of each separate system matrix obtained from the integration of the individual technical solutions is presented through a first overview that, according to the hierarchical articulation of the technological system in the appendix to the UNI 8290:1981 norm, represents its synthesis and defines its representation shown in the schedule of technical solutions.

In the schedule are described the individual technical solutions and performances offered by each technical element. Each of the identified solutions is characterised by the technical and dimensional details of the materials and products adopted, expressing, in effect, the potential of the project.

In this way all the solutions are comparable to each other without any technical choice determining a technical discrimination against any others.
The technical catalogue of the building system is a valuable tool that allows the recognition of the technological-performance efficacy of each alternative technique but it is through the study of the connections and building nodes that the final quality of the system is ensured.

The reading of the catalogue of the technological system is completed by the development of exemplificative schemes and constructive details deriving from the application of various technical solutions to each of the types of housing developed.

These schemes show some of the solutions that can be pursued through the CCCabita system to which are linked a number of planning suggestions referring to pilot projects that accompany the manual: the projects presented illustrate the architectural possibilities that are the result of the process of integration between planning choices under the typological-technological profile, of the sustainability and environmental compatibility of the accommodation itself.

Each of the pilot projects in the manual is accompanied by a financial project, a detailed analysis of the construction costs; a framework of economic comparison illustrates the same project carried out with traditional building techniques and its comparison with the different systemic solutions proposed. The analyses also highlight the calculation of gross leasable area and parameter values - defined by the price per surface - referring to the different configurations of the technological system.

The economic analysis is accompanied by a schedule of activities that illustrates the conveniences and peculiarities of the different systems over a period of time from the planning to the implementation phases during building.

3. INNOVATIVE AND TECHNICAL SOLUTIONS FOR OPEN INDUSTRIALISED BUILDING

3.1 Integration of technical solutions in the CCCabita construction system

The constructive integration promoted by the CCCabita Consortium is defined by the implementation of the housing model with construction systems that are innovative or derived from the hybridisation of these solutions with more traditional elements, combined in new sectors of industrial production.

The matrices of compatibility between the different technical solutions in the catalogue define the integration of a number of technological systems, each of which is assigned a specific identity number: the structural solutions, diversified by morphology, material and procedure for mounting/assembly on site, are the main factor for the determination of each system.

A first industrialised system is defined by a monolithic structure with supporting partitions in lightly reinforced cement conglomerate, built through insulated formworks in polystyrene (producer Nidyon-Consorzio Etruria); this solution is highly successful insofar as it allows the realisation of any typological configuration and helps to eliminate any thermal bridges for the benefit of the thermal-hygrometric performance of the building. The solution can be used for both closures and internal partitions.

A second system, with greater internal flexibility in the dwelling, is based on a precise structural system with multilevel pillars, precast beams in reinforced concrete and prestressed hollow core floors (producer APE). The hyperstatic system allows a considerable reduction in the time to completion and limits the presence of structural elements within the spans, favouring in this way a greater flexibility and aggregability of the separate living units.

This solution does not interfere with the closing solutions nor with the internal partitions which in this way can be realised with different solutions: external dry-mounted closures in OSB framed panels (producer Holzbau), or pre-assembled LCS modules (producer Diwem); dry-mounted internal partitions of variable thickness covered with plasterboard and gypsum fibre (thickness 125 mm, sound reduction index Rw=58 dB, thickness 215 mm, sound reduction index Rw=66 dB) (producer Saint Gobain); external walls made of masonry in vibrocompressed cement conglomerate with low environmental impact, with pre-and post-consumer recycled content of more than 40% (thickness 30 cm, sound reduction index > 57 dB) coated or multilayer (producer Vibrapac); interior walls in elements in vibrocompressed cement conglomerate of variable thickness if internal partitions in the dwelling (12 cm thick, sound reduction index > 45 dB) or partitions between different units (thickness 15 cm, sound reduction index > 47 dB).
A third system involves the construction of closures, floors and structural elements through multilayer bearing panels in totally dry-mounted cross-lam wood. The frame of the structure is made up of large linear elements that contribute to the elimination of thermal bridges, a considerable reduction of the thickness of the building envelope, and can cover an entire wall with a single element up to a maximum length equal to 20 m.

The walls and floors - both internal and covering - can be easily connected with standardised connecting elements offering both lightness and speed of assembly.

The constructive nodes are solved and developed in a definitive way in the design phase, reducing the risk of error during the engineering and implementation phase.

Figure 5. Flexibility of the technological offer.
The modularity of the opaque elements used goes with that of the three modules of glass closures; these last are made with high-performance energy frames and involve the most innovative systems of transparent enclosures. The exterior doors are made of thermal aluminium alloy profiles (producer Schuco) and insulating double glazing that can guarantee values of thermal transmittance \((U_{\text{glass}})\) of 1.1 \(\text{W/sqm k}\), solar factor \((\text{SF})\) of 55\% and noise reduction \(R_w\) of 42 dB. The windows are fitted with a prefabricated box for the housing of roller blinds made of a one-piece high density (35 kg/m\(^3\)) self-extinguishing expanded sintered polystyrene.

The attention to the aspects of an energy and thermo-hygrometric wellbeing nature within the environmental units is also reflected in the technical choices for the partition, such as the heated flooring in the interior and ceilings that ensure the achievement of LEED® credits thanks to the high percentage of recycled material contained and because it is easily renewable.

The plasterboard false ceilings (producer Saint Gobain), essential for the use of industrialised floors, provide for reduced thickness, respond effectively to the plant integrability and improve the acoustic quality of the building. In correspondence to the balconies and open spaces the false ceilings combat, through the insertion of insulation, the thermal differences with the outside.

### 3.2 Plant equipment

Since this is a modular design the plant equipment mentioned below refers to the plant plan for a building of 66 lodgings which involves the generation of hot and cold fluids and hot water from a central location. The generation system consists of a cycle-inversion heat pump with desuperheater is capable of recovering up to 25\% of the waste heat of the process. The energy obtained from the re-use of waste heat released by the machine integrates with the energy supplied by the thermal vacuum solar panels placed on the roof for the production of domestic hot water (DHW). This is stored in a thermal puffer of 6,000 liters, which allows for use even in bad weather conditions or in cases of high and simultaneous request by the users.

The photovoltaic system - which is also on the roof - provides 275 monocrystalline modules (producer Saint Gobain) for a total power of 66 kW peak to guarantee 1kW peak per dwelling.

The residences are also equipped with a system of centralised control and supervision for the recording of the consumption of electric power, heating/refrigeration for temperature control of the environments, and hot and cold water.

Heating/cooling inside the housing is of the radiant type supplied with fluid at 40/35 °C in winter and 18/21 °C in summer. The radiant panels are made with the “knuckles” system or the anchoring of polyethylene pipes of specially shaped plastic panel inside dry or wet screed. Below this panel there is provision for the insertion of a layer of insulate shaped in relation to the surrounding environment, as foreseen by the norm UNI EN 1264. The attachments for heating/cooling circuits in correspondence of the collector are provided with electrothermal actuators that allow the opening and closing of the circuit in relation to the incoming signal from the thermostats in the building, obtaining in this way a modulated ambient temperature. In each main room in fact there is a digital thermostat through which the user can adjust the temperature set-point.

Humidity control is ensured by a system of mechanical ventilation controlled with an integrated compressor which is much more efficient than traditional crossover flow recovery: the air drawn from outside, before being introduced into the environment is preheated (pre-cooled) thanks to the energy recovered from the expelled air through an active thermodynamic process in a circuit with a reversible heat pump. Thanks to this heat recovery from the expelled air, the ventilation system can autonomously satisfy the heat demand of a dwelling up to 5 °C of the ambient external air temperature. The air changes guaranteed, in agreement with UNI 10339:1995, are equal to 30 mc/ h/person.

The adjustment of the air conditioning is both environmental and climatic insofar as produced by means of thermostats within the dwellings and an external sensor connected to the thermal power plant.

The lighting of external lights (gardens and coverage) is controlled by programmable control switches; the lights in the stairwells are equipped with actuators controlled by infrared presence detectors favouring in this way a considerable saving in terms of energy consumption.
4 CONCLUSIONS

Industrial production has been practiced on a large scale since the Second World War but now industrialisation enables the construction industry to manage material and energy flows better. It not only creates new opportunities, it also forces the construction industry to adapt new practices, following open and closed prefab systems.

The new practices include: reduce, reuse and recycle resources; eliminate toxic substances from construction; apply life cycle economics in decision making; create a quality built environment.

Industrialized construction - offsite standardized manufacturing of building parts and even of whole buildings - has shown to contribute to the achievement of at least a large part of the objectives for the construction of advanced sustainable buildings.

Open industrialisation regards not only residential buildings, but is reached by all building sectors by making agreements about methodology, measurement systematics and connections.

In a design approach, technical principles, based on a dynamic open building systems and products, are developed, in order to separate the different building layers and to deconstruct building components.

Those projects are evaluated by users and other stakeholders. If necessary the generative design approach will be improved, the technical principles could be revised and dynamic solutions can be implemented in the system.

REFERENCES