# The environmental benefits of the Off-Site Manufacturing

S. Russo Ermolli
*Università degli Studi di Napoli Federico II, Naples, Italy*

ABSTRACT: The contemporary orientations in design activity, in production offer and in building techniques is by now distant from the idea that such issues have to pass through an industrialized management and rigidly serial of building elements. The panorama of technological options underlines the presence of innovative construction products and systems - such as volumetric units, panellised frames, structural insulated panels - functional to the rapidity of the cycle of production and reduced employment of resources, easily adaptable to the variability of contextual situations, to assemble with dry techniques and able to guarantee the satisfaction of specific technological and environmental requirements. The use of increased potentialities of design and production processes has contributed to the development of innovative products and systems potentially able to ensure high functional and design quality standards and to offer a wide range of environmental benefits especially in terms of speed of construction and waste reduction.

To face the theme of prefabrication within sustainable architecture involves the need to investigate a wide series of aspects that caused deep changes in the building process: the orientations of design activity and of production offer, the adoption of techniques and construction practices, the modalities of buildings management. Environmental issue has in fact assumed an important role in directing the strategic choices in construction sector both at commercial level, both at normative level, and through a progressive rethinking of architecture design and its construction phase.

The concept of prefabrication has assumed during the years a less rigid meaning in comparison to the hypotheses assumed in the period of its theoretical formulation: we assisted in fact to the passage from “heavy” and closed systems, to products and systems – result of processes of *light* production – functional to the rapidity of the cycle of production and to lesser employment of resources, easily adaptable to the variability of demands of the market and contextual situations, to assemble with dry techniques and able to guarantee the satisfaction of specific technological and environmental requisites. The use of the increased potentialities of design and productive processes allowed the passage from an economy of scale to a scope economy, contributing to the development of morphologically similar products, but with different dimensions and performances. Therefore not numerous samples of a same type of product but a number, varying on demand, of different products from the same typological class.

The diffusion of prefabricated products and systems in industrialized countries appears rather variable: if in Scandinavia in fact around 80% of new houses is realized *off-site*, in the United States – despite the promotional efforts of various government agencies – the market is strongly dominated by traditional building processes (Kieran & Kimberlake 2003). In Japan few great corporations control the prefabrication market, with companies like Toyota that, with


Figure 1. Steel-frame housing construction method by Toyota Home. The company is developing new products which meet "Next generation energy-saving standards" and has been taking measures to reduce CO2 emissions at both the occupation stage and the production stage. In the graph the results of waste reduction measures at construction sites of prefabricated houses and goals (Toyota).

sophisticated IT driven production and assembly plants, is capable of producing thousands of housing units per year (Bottom, Gann, Groàk & Meikle 1996). Different firms, using CAD/CAM manufacturing capabilities, *Enterprise Resource Planning* strategies and software, and advanced building simulation capabilities into manufacturing processes, can produce high quality, high performance building products at relatively low cost.

Especially in countries like United Kingdom, Sweden, Germany and Japan, in the last years numerous research projects were finalized to investigate the possibilities of development of standardized production and employment of prefabricated products and systems in housebuilding. The research projects involved manufacturing firms, research institutes, universities, designers and building contractors and allowed to individualize numerous consequential advantages from the employment of advanced systems of production and to delineate the future scenarios of the *Off-Site Manufacturing* (OSM).

From the sustainability point of view, the advantages from the use of prefabricated products and systems are in fact related to a greater control of quality in the production phase, less waste of material in factory and on site, higher speed in the construction phase. The consequences include the improvement of profitability and productivity for contractors, the increase of guarantees on product final quality for buyers and consumers, the reduction of resources employment and of general investments finalized to the building construction, less impact on the environment during on site works.

Figure 2. Structural timber housing system. Precision-engineered wall and floor panels are fixed together before the roof is lifted on to the top (Space4).

In fact, according to the scheme of environmental evaluation by the European Program EuroHouse (Long 1999), are considered, among the consequential benefits from the employment of prefabricated systems:
- from 30 to 60% in the reduction of times on site through a more efficient coordination of the different construction packages;
- the reduction of 50% of water quantity in comparison to a traditional construction;
- 50 reduction% of the quantity of material utilized and produced by excavations;
- wider use of recycled materials (like timber, steel, aluminum, etc.);
- up to 80% in the reduction of waste materials during on site works;
- up to 60% in the reduction of $CO_2$ emissions and of annual energy consumes during building life cycle;
- possible reutilization and reuse of prefabricated elements.

The raising of prefabrication is mainly addressed (even if interesting niches of production remain in commercial, hotel and industrial sector) to the diffusion of structural building systems in the housing market. This tendency departs from the consideration that it is necessary to use industrialized components able to answer quickly to the variability of demand, fitting without conflicts in the market of the traditional contractors. Building systems must be able of mutual integration and be conceived and coordinated to be assembled to create not a single house model but different solutions and typologies, realizing buildings that are not formally and technologically determined by its use. The issues connected to these strategic objectives are:
- the research for every component of the maximum dimensional and finishing variability;
- the research of the maximum speed of construction with the wider quantity of dry assembly procedures;
- the minimization of the number of components;

- the use of *lean* production processes to reduce the incidence of stocks and to increase the product quality;
- the development of assembly procedures independent from atmospheric conditions;
- the research of minimum weight;
- the facilitation of maintenance operations.

With such premises, one of the most interesting challenges for the diffusion of OSM in housing building process concerns the overtaking of cultural barriers connected to standardization and prefabrication issues. Among the different actors of the building process, users and designers result particularly damaged by the errors made during the long history of prefabrication: errors that, at different scale, can be recognized in the majority of housing experiences in different countries. The carelessness of contractors in comparison to design reasons, the general low quality of the buildings, the abrupt fall of building performance with inevitable investments for the maintenance – in many cases uncertain and transitory – have contributed during the years to the abandonment of housing prefabricated systems and to privilege building solutions mostly known and controllable. Particularly, users recognize buildings realized with the traditional technologies more in conformity with the applications of reliability, resistance and duration in comparison to the prefabricated building systems (Craig, Laing, Edge 2000). At general level can be said that a typical tendency is to introduce in the market, close to the basic constructive system, more and more articulated series of special elements, or in any case integrated, that completed the offer of traditional products and systems, preserving therefore the possibility to continue to use materials management on site consolidated in the building tradition.

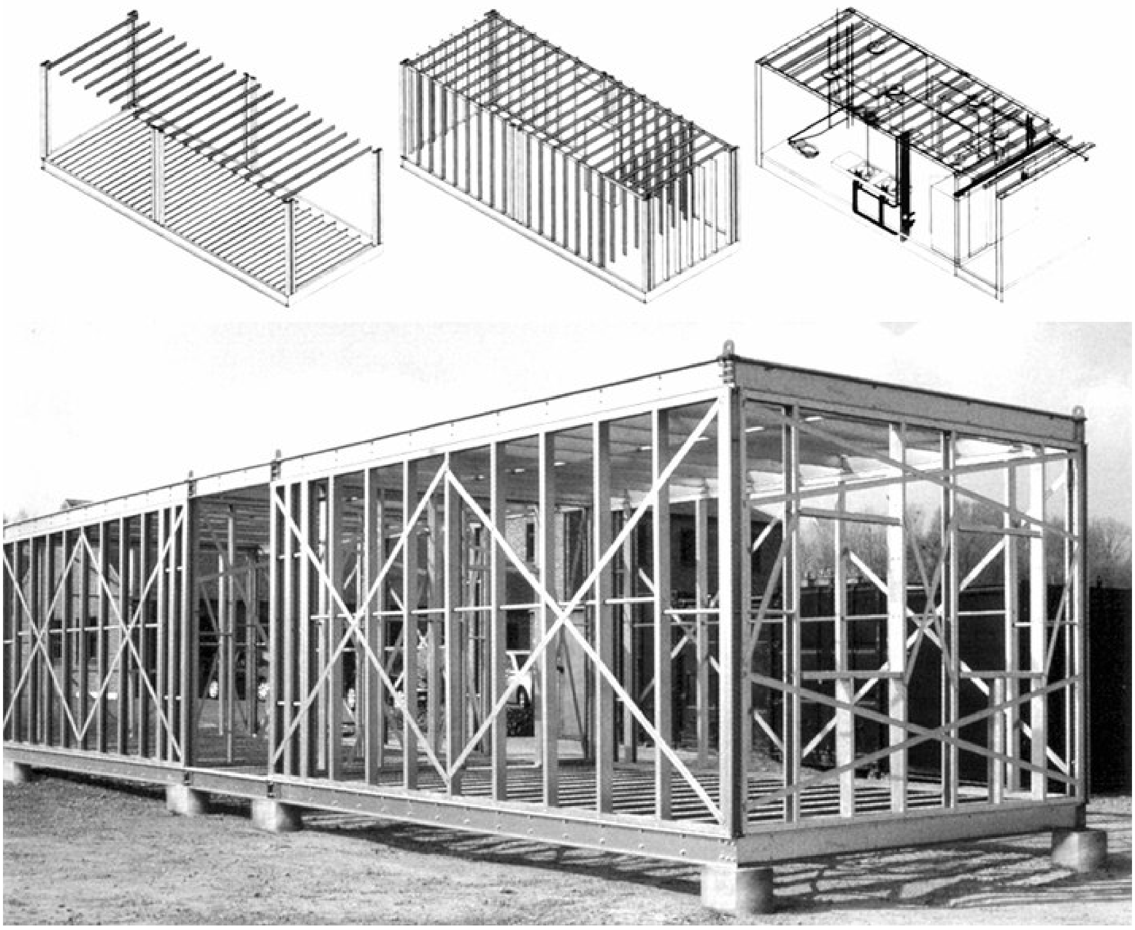

Figure 3. In Volumetric system the CFS braced units are completely prefabricated in the factory and can be delivered to site with all internal finishes, fixtures and fittings in place (Kingspan).

Not by chance some recent productive tendencies include not only the offer of building solutions with high level of prefabrication that can be completed with traditional materials and techniques, but also OSM systems like, for instance, monolithic brick panels that, thanks to its reassuring formal qualities, result particularly accepted by users.

In such point of view it is possible to individualize the tendency from public and private clients to ask for a wider use of OSM in housing interventions, both for building elements and for installation systems, supported by numerous research programs by manufacturing firms of materials and components, finalized to the improvement of the production processes and the increase of products performance. The prefabrication task of the last years can be seen in a series of housing realizations, some of which experimental, useful to verify formal and technological potentialities of the prefabricated systems (Arieff & Burkhart 2002; Birkbeck & Scoones 2005). Broadly publicized by the press in different countries, these realizations have seen the collaboration of users associations, local administrations, manufacturing industries, designers and contractors, succeeding to reach satisfactory results in commercial and design terms.

In the wide catalog of structural prefabricated systems available on the market result particularly interesting those with large scale elements, like façade panels, floor slabs, staircases, bathroom pods, etc., made in timber, steel or reinforced concrete. The trend to use large prefabricated elements sees the building manufactures proposing elements with high performances, low formal predetermination, light and dimensional flexibility, to assembly with easy operations. Such systems don't exclude besides the possibility to be completed with traditional techniques and materials, through an interesting process of contamination and integration of building solutions with different level of innovation.

The use of prefabricated structures allows besides to minimize waste production on site, that becomes the place where to assembly industrialized products and not a place where to *create* manufactured articles (with consequent extension of construction times, waste production and possible increase of errors).

As consequence of different researches and realizations of residential buildings in different countries, we assisted in the last years to a growing diffusion of structures conceived and designed to be realized with large dimension elements (panels or three-dimensional modules) created by the assemblage of horizontal and vertical elements. Vertical panels can be formed by a rigid closed cell insulation, as pressure injected CFC free polyurethane, incorporated among outer skins of aluminum, galvanized steel, concrete or Oriented Strand Board (like the *Structural Insulated Panel* - SIP), or from a frame of braced profiles in *Cold Formed Steel* (CFS), manufactured from roll formed galvanized steel strip with thickness between 1.2 to 2.4 mm. The use of steel seems to play a fundamental role in sustainability issue, particularly for the attributes shown in Table 1.

Table 1. Attributes of steel in sustainable construction (Widman 2005).

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|---|---|
| Usability | Steel construction is pre-fabricated in efficient factory processes with minimum use of resources, and enables long-span, high rise and flexible buildings |
| Speed | Steel structures are installed rapidly on site which reduces local disruption |
| Weight | Steel construction are light and therefore efficient on materials, energy, transports and emissions. The low weight also enables vertical extension and optional location |
| Waste | Steel construction is very material efficient, generating low amount of waste, and most of the waste is recycled |
| Performance | Steel is high performance, dimensionally accurate material, produced with modern computerized technology |
| Logistics | Steel structures are delivered to site “just in time” for nstallation and can be produced locally |
| Durability | Steel structures have long very design life and the high quality remains |
| Health | Steel construction is dry construction, low-emitting material, controlled and safe process and leads to high quality architecture |
| Recyclability | All steel can be recycled without quality losses and all steel has recycled content |
| Reusability | Steel buildings or components can be dismantled, upgraded, relocated or re-used |

Figure 4. Application in Malmo (Sweden) of almost fully equipped modules in light gauge steel framing mounted in a framing system with steel columns to form multi storey residential buildings. The system provides cost-effective, environmentally sustainable dwellings of good quality and with short production time (Open House System).

In such point of view CFS members – light, easily-handled and with a wide range of shapes and dimensions – can be combined as Panel construction, Volumetric or Semi-volumetric system (Trebilcock 1994; Gorgolewski, Grubb, Lawson 2001). In the Panel construction wall panels, floor cassettes and roof trusses are prefabricated in a factory and later assembled on site. In the Volumetric system units are completely prefabricated in the factory and delivered to site with all internal finishes, fixtures and fittings in place. Units are stacked side by side, or craned one above the other, to form a stable finished structure, using the form resistance of the "wagons" and the dimensional precision reached by productive processes. In the Semi-volumetric "hybrid" solution Panel and Volumetric systems are used together.

The three-dimensional units are generally employed for those parts of the building – as bathrooms and kitchens – that require long time of realization and skilled labour. The different members of the systems are lifted and assembled among them using dry connection systems to reach, according to the different systems, from three to five floor height. In the Volumetric solution the main installations systems are directly incorporated in the factory inside the panels: on site must be made only the necessary connection among the different modules. Therefore the construction proceeds rapidly and not only guarantees the reduction of realization times (calculated around 60%), but also of the service life energy (25%), in comparison to more conventional construction procedures (Widman 2004).

The systems can be completed with the integration of different materials, products and techniques, also not necessarily from industrial source. It’s possible in fact to realize on site some parts of the building – as the staircase-elevator tower – or to use dry assembly systems, as the different typologies of envelope with metal studwork substructure and external rainscreen.

The possibility to integrate the systems with different technologies is related with an aspect that makes reference to the recent innovations of the productive processes. The use of these systems doesn't condition in any way the architectonic outcome, thanks to possibilities offered in factories by versatile methods of production, able to vary on application some characteristics of the products, in times and costs comparable to those of series production. Through the use

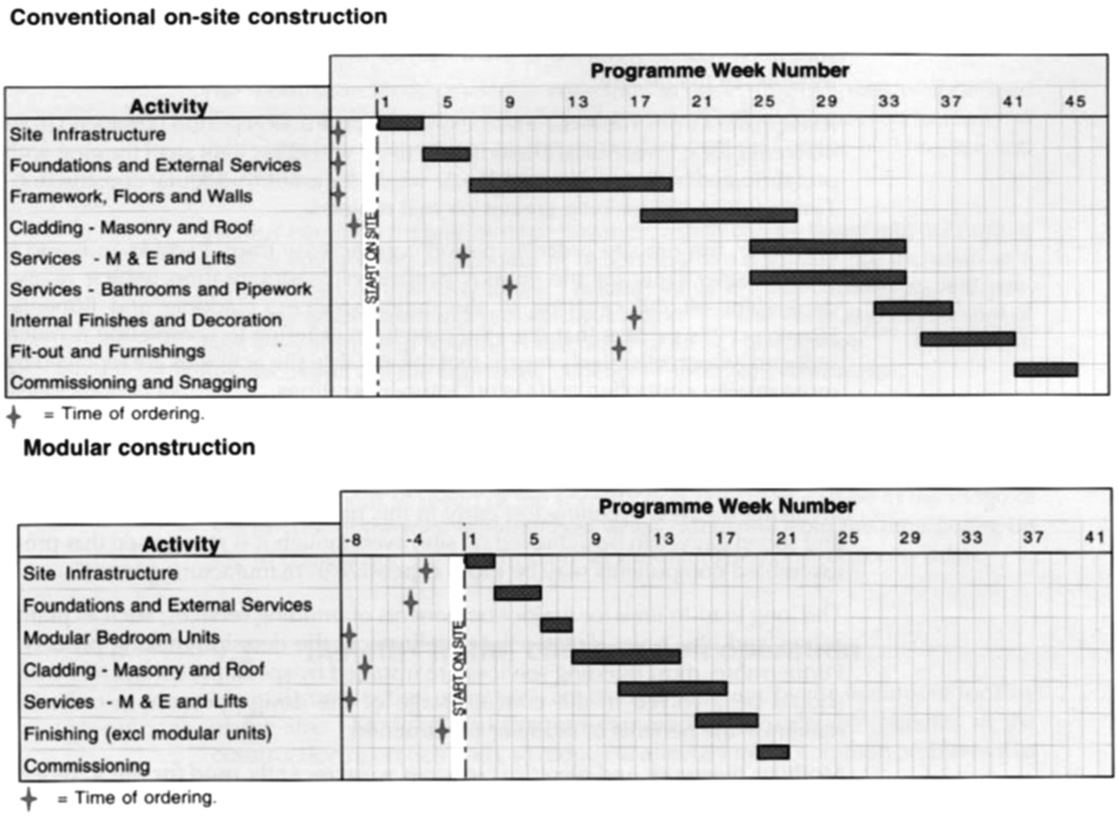


Figure 5. Comparison of procurement and construction process between on-site and modular construction for a typical medium-sized building (Gorgolewski, Grubb, Lawson 2001).

of light production models it is in fact possible to quickly modify the type of workmanship of the elements that compose the systems offering diversified configurations of the final product.

Even if the manufactures generally have the tendency to provide prefabricated elements with standard dimensions, in effect it is possible to produce numerous typologies of elements with notable borders of morphological, dimensional and technological variability.

The speed of construction, assured by the physical characteristics and by the assemblage modalities of the elements, permits also interventions in high density areas, minimizing the risks and the uneasiness on site and in neighboring zones, as for instance noise, dust, vibrations, etc. An aspect that influences in negative way the diffusion of the large element prefabricated systems is the equipment for the lifting. Usually habitants feel like an intrusion in their private life the use of big cranes and bulky lifting systems for building operations. Some contactors transport the prefabricated elements on trucks provided of small sized cranes to avoid the construction of fixed equipments and try to obviate the problem suspending the prefabricated members to the arms of the site equipments (generally excavators), using it as handling operator.

Building industry of prefabricated components tries therefore to orient itself toward a production in agreement with eco-compatibility issues, promoting the decrease of material and energy intensity of the production processes and reducing, at the same time, the use of non renewable resources. To such strategic finality are evident numerous points of contact between the innovative ways of industrial production and the sustainability goals. In fact, besides the design and the eco-compatible construction, it is important also to develop conditions of sustainability within the housing industrial production. In fact the investments of numerous manufacturers try to individualize the possibilities that industrial production offers for an advantageous relationship among environmental aspects and methodologies of improvement of production processes and products. Some modifications related to the structure of the

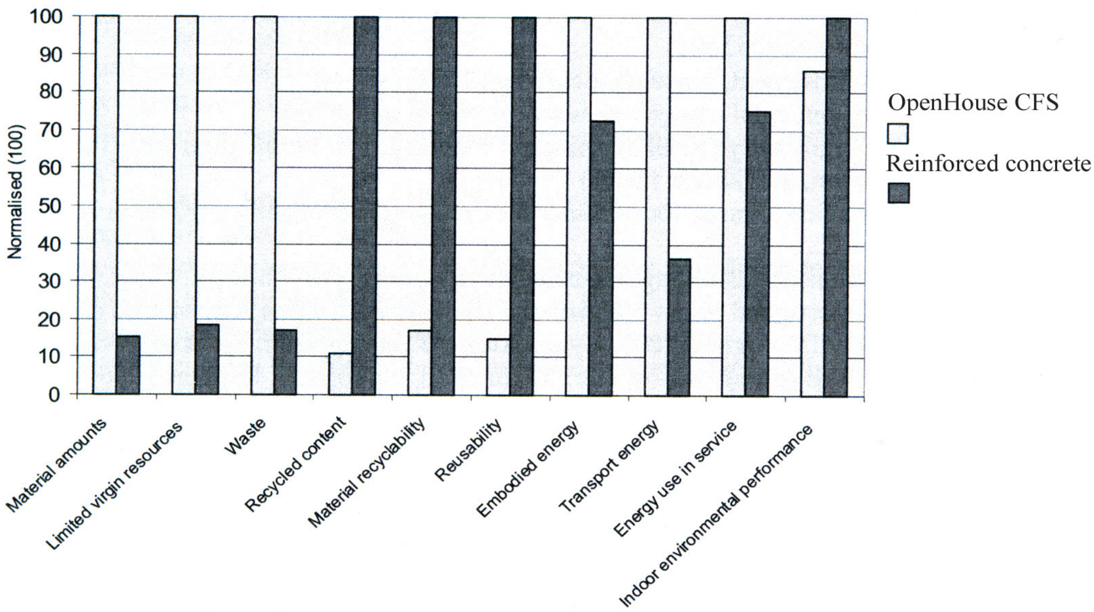


Figure 4. Normalised comparison of sustainability parameters between the Sweden OpenHouse CFS system and the national average reinforced concrete system (Widman 2004).

production, already in action in the building sector and finalized to the continuous improvement of the processes, can cooperate with the issues of the environment safeguard. Its new productive logics constitute a factor of connection with a wider environmental responsibility, converging toward processes of prefabrication finalized to a low impact in the use of resources, in the organization of the productive sequences and in the management of the products cycle.

Moving more of the construction process from the building site into the relative safety of factory conditions, where efficiency and control can be better managed, seems to have the potential to lead to significant sustainability improvements compared to traditional site-based construction, not only with technical benefits – that include increased speed of production, reduced levels of defects and waste, greater efficiency in the production process, and reduced impact on the environment – but also social benefits, like improvements in health and safety, more stable employment, investment in machinery and development of skills.

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