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Potentials and Perspectives of Off-Site Technologies for the Existing Building Heritage in Italy

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Abstract: New systems of industrial production with the innovative materials and technological evolved systems contribute to the increase of the construction quality of the finished product: from a single technical element to the whole building. The new perspectives of the industrialization process manufacturing, for the purpose of upgrading the energy efficiency, offer, in fact, a wide range of possibilities on the existing intervention with the purpose of the remedy for the low levels of performance and re-placing a product on the market which an increased value in the face of greater energy efficiency. The main factors that affect the feasibility and type of intervention are three: price, time of realization and payback times. In light of this, the building sector changes more and more quickly its nature: from on-site becomes off-site moving from the yard to the factory where, by binding to the manufacturing processes, implements the effectiveness of the construction industry and secures greater results in terms of energy retrofit. A change that affects industrial processes, products and construction sites increasingly oriented towards the aggregation of prefabricated or semi-prefabricated elements instead of on-field construction.

Key words: sustainability, energy retrofit, off-site construction, integrated solutions, redevelopment

1. Introduction

Most of the energy consumption in Italy is attributable to the civil use sector, having represented 39.3% of total consumption in 2015, exceeding the consumption deriving from the transport sector by 7.2% [1]; a significant figure accentuated by the remarkable consistency of the Italian housing stock: of over 12 million residential buildings [2], approximately 53.7% are over 40 years of age as they were built before 1970 and, therefore, before the issue of the energy efficiency standard and the anti-seismic standard [3]. There is also a further 31% to be considered built in the following twenty years (1971-1990) and 7.4% in the last decade of the 20th century so as to go to constitute a considerable stock of buildings that is more than 30 years old [4].

The interventions on the real estate, in terms of energy requalification, represent a sector in strong growth, given the increasing availability of buildings, in which all the operators of the construction process pour. On the one hand, innovation and on the other, the context that becomes increasingly wider if we consider the continuous comparison with the main emergencies affecting the whole planet: the rise in temperatures, the maximum concentration of carbon dioxide in the atmosphere and, above all, the non-renewability of resources. The interventions aimed at greater energy efficiency of buildings represent one of the many tools available to overcome these challenges also by virtue of the objective, now expiring, for Europe, according to the requirements of the European Directive 2010/31/EU [5].

By the Emergency Efficiency Report, from the Energy & Strategy Group of the Politecnico di Milano [6], in 2017 the overall total of investments made in Italy was equal to approximately 6.7 billion euro

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confirming the positive trend of the last 5 years which, by operators in the sector, seems to be confirmed also during the first half of 2018. The ranking of investments sees the Home & Building segment excel — with 65% of the total — affected by various solutions and technologies concerning the building: most of the investments are concentrated in heat pumps and cogeneration plants — 30% — but there is a good 16% growth as regards the interventions carried out on the envelope in terms of opaque and glass surfaces.

Considering new perspectives, surely, play a significant role the so-called Modern Methods of Construction, new building technologies, aimed especially at the upgrading of existing assets and to its transformation with renewed energy and environmental performance and sustainable cost time. A renewed range of products in which converge both materials and the shaped components for a better integration with the “built” technologies of existing buildings, controllable and manageable thanks also to the introduction of new methods of digital modelling as the BIM.

Innovation and sustainability, aimed at the redevelopment of the existing heritage, represent two key points on which to focus for an evolution of Architecture and its processes not only limited to the national but also European context: in fact the objectives defined by the EU 2020 ten-year strategy must continue to be a stimulus to research. The prevailing orientation is to develop ad hoc technical solutions that are increasingly customized in terms of product and standardized in terms of process: the goal is to have maximum yield with minimum waste.

2. Material and Methods

The construction technologies that use prefabricated components combine both the demands of the application and the performance requirements of the building itself. There are several experiences, both internationally and nationally, that have been able to combine performance efficiency — in terms of energy efficiency above all — with an economic sustainability of the intervention in relation to the reduction of on-site processing times. An example is the Dutch “Energiesprong” program, started in 2012, which provides for the redevelopment of over 100 thousand housing units to guarantee and take action to eliminate consumption over thirty years; thanks to the choices of the team commissioned by the Dutch Government, a large and diversified social housing stock was redeveloped with interventions on the envelope and on the systems in a very short time and with a significant reduction in consumption, reducing 40% of intervention costs in three years [7]. The same project was also presented in Italy in 2015, taking into consideration the possibility of intervening on the existing one through components made in the factory and “added” to the old structure [8].

There are many advantages of these technologies linked both to the installation in terms of times and operating phases and to the whole process that concerns them: design, production, construction site. The design phase, first of all, plays a fundamental role from the study of the raw material, with its parameterized physical and mechanical characteristics, to its digital model, allowing, from the beginning, to solve low-level construction nodes highly complex, reducing the risk of error during assembly time; the production phase, thanks to an evolution of industrial processes and the adoption of innovative instrumentation, allows, in a very short time, to have the finished product from the digital design; the construction phase represents the moment in which the components are assembled to support structure and between them, according to hierarchies, established during the design phase, which allow maximum performance in terms of geometry and mechanical characteristics and the collaboration between the elements [9]. Generally, metal and wooden components are used: while the first are already known in the building sector as support for internal partition elements as an internal addition to existing perimeter walls to support coatings, the latter are spreading rapidly, especially in the international market, both for new constructions and above for the recovery of the existing.

The wooden components constitute light structures essentially attributable to two different construction systems for the geometry of the elements used but in any case, combinable with each other: frame structures - beams and columns - and load-bearing elements - panels. The use of innovative materials, such as engineered woods, contributes considerably to reinforcing this distinction: precisely for the production process that the material undergoes - wood - it is possible to obtain higher performance both in terms of mechanical strength and durability of the material. Among the different types of engineered woods, we focus on those that have achieved remarkable performance from a structural point of view: the LVL (Laminated Veneer Lumber) and the CLT (Cross Laminated Timber) [10]. The LVL is the basis for the construction of beams and columns, while the CLT is the basis for the realization of load-bearing panels, also known as X-lam or Cross-lam panels. The LVL elements are made up of several “sheets” of wood, generally very thin with thicknesses around 3 mm, obtained directly from the trunks of the trees, through mechanized procedures that prevent the use of instruments in sequence, and subsequently glued between them. This type of technology is particularly used for the construction of unidirectional elements such as beams and columns, allowing to reach even very large spans up to 24-25 m.

The construction system with load-bearing wooden panels based on CLT technology is a system based on solid wood panels with 90° crossed and glued “sheets” of wood (minimum 3 layers), with very variable thickness and dimensions. whose geometric characteristics depend on the necessary structural dimensioning, the technologies of the manufacturing companies and functional requirement [11]. They can be made with different essences: fir, pine and larch are the most common as they have better strength and durability characteristics for the construction. This system can be used to build both walls and floors of multi-storey buildings, generally on a foundation consisting of a reinforced concrete base. To understand how far these technologies can be pushed, the Mjøstårnet building — also known as the Mjøsa Tower — in Brumunddal, Norway is below mentioning (Fig. 1). Finished to build in March 2019 has been defined, during the same year, as the wooden building highest in the world with its 84.5 m, a record made official by the Council on Tall Buildings and Urban Habitat [12]. Mjøstårnet has a combined area of approximately 11,300 square meters. The building has 18 floors comprising apartments, a hotel, offices, a restaurant, a panoramic terrace and common areas. The CLT was used to make the partitions of the lift and stairs, while beams and columns were made of LVL through connections with steel plates and bolts. Although the choice to build the stair-lift block with wooden load-bearing elements can be considered innovative, there was the compromise of use of reinforced concrete for the flat deck of the last seven floors to increase the mass of the building to reduce the swing due to the wind [13].

The use of wood, in all its evolutions, can be considered a sustainable choice in terms of speed of execution and in terms of energy retrofit [14], but precisely for its very qualities, it can be considered a valid ally for interventions on the existing, in recent years, also in Italy.

The use of wood for the structural and energy requalification of existing buildings offers several advantages: lightness, versatility, resistance, good performance during earthquake and from an energy point of view. Furthermore, to have access to tax incentives, it makes it that constructive wood solutions are also choices to make elevations or extensions building in very fast time.

The most widespread technology used is based on X-lam panels, the choice of which is dictated by the lightness of the material, which weighs to a lesser extent on the pre-existing structures, and by the speed of construction which allows to reduce the phases of building site. Another advantage is linked to the reduction of the impact on the environment: careful and scrupulous design minimizes the use of materials on site, transport and the production of waste. Residential and public-receptive buildings are increasingly seeing the use of these technologies: the need often derives from the possibilities that may exist on the increase in surface area or cubic capacity allowed by regional laws and, before these, by national laws. These are interventions that, although of limited size, weigh on existing structures - often in reinforced concrete that can be 60 years old and beyond — for which optimal performances are foreseen in terms of integration with existing technologies and energy improvement. As an example, we can consider the intervention carried out in Carole, in the province of Venice, at the "Hemingway Village" (Fig. 2): an expansion of three floors above the two existing buildings already characterized by three floors above ground. The tourist buildings have exploited the residual building capacity of the area and the bonuses of the Municipal House Plan which have allowed to increase the 30% of the existing useful surface and also to access important tax breaks. The technology used, X-lam panels, has been used to avoid overloading the existing structure too much and has had the additional effect of making an improvement in terms of energy retrofit and living comfort for the entire building. The duration of the construction site, of only 6 months, was less than the established time scheduled with the additional advantage for the activity to reopen to the public immediately after closing for the winter season. The up-extension work began in November 2010 with the removal of the existing roof and the preparation of the reinforced concrete curbs for the laying of the bearing structures in X-Lam panels.

Fig. 1 Mjøstårnet, Burmunddal, Norway, 2019 (from: http://buildingcue.it).

Fig. 2 Hemingway Village, Carole (VE), Italy. From: http://grandellihouse.it.

The wooden structures, inclusive of slabs walls and roof, were completed in January 2011. The realization of the interior with plants, false walls, doors, floors and finishes is in contemporary external casing was performed to coat with closure of the yard and inauguration May 2011. The existing apartments on the 3rd floor have been transformed and raised into duplex apartments, taking advantage of the entire 4th floor, in order to optimize the heights and create a clear division between the living area, on the lower level, and the sleeping area , on the upper level. The 5th and 6th floors, on the other hand, are characterized by one-room, two-room and three-room apartments in order to offer a different range of housing types. The internal distribution has also been revised according to the accessibility of the new floors, made by extending the current stairwell made of reinforced concrete. It should be emphasized how the use of X-lam technology has allowed the use of other construction technologies to support the improvement of energy performance such as external insulation with finish with heat-insulating varnishes, to increase yields energy of the building, and the installation of wooden windows and finally it allowed to maintain the external image of the building without altering the original typological characteristics [15]. The use of wood in general, and X-lam panels in particular, is becoming a custom especially for interventions, which are limited in invasive nature, to be carried out quickly; the technical process begins with a correct design of the elements to be used as well as the connections between them and the existing structure — the critical points — continues with the realization of the elements in the factory and continues on the construction site with a double action: the preparation of the support, freed and cleaned of all that does not belong to the system of structural elements and the "assembly" of the elements in X-lam, with the appropriate connection systems. The procedure, thus standardized, could also be extended to larger buildings of the single-family house, as shown by the project of the accommodation facility in Venice, but could even go beyond the addition to the existing intervention to take the form of integration with the existing. Let's think, for example, of the possibilities that could exist if, by redeveloping an entire building from the 70s-80s, the most common in Italy, all external infill elements could be replaced with X-lam panels: the intervention would certainly reduce construction time, with substantial savings on all the costs deriving from it, and it would certainly increase the energy performance of the building. Just a consideration: an average transmittance value obtainable by external insulation with rock wool panels on the perimeter brick wall is around 0.30 W/m^{2}K, while, using the same type of insulation — wool panels of rock — but on an X-lam support, a transmittance value of around 0.18 W/m^{2}K could be obtained; a considerable reduction, normally obtainable only with a high thickness of insulating materials and all the disadvantages that this entails.

3. Results and Discussion

The use of wood in general, and X-lam panels in particular, is becoming a custom especially for interventions, which are limited in invasive nature, to be carried out quickly; the technical process begins with a correct design of the elements to be used as well as the connections between them and the existing structure — the critical points — continues with the realization of the elements in the factory and continues on the construction site with a double action: the preparation of the support, freed and cleaned of all that does not belong to the system of structural elements and the "assembly" of the elements in X-lam, with the appropriate connection systems. The procedure, thus standardized, could also be extended to larger buildings of the single-family house, as shown by the project of the accommodation facility in Venice, but could even go beyond the addition to the existing intervention to take the form of integration with the existing. Let's think, for example, of the possibilities that could exist if, by redeveloping an entire building from the 70s-80s, the most common in Italy, all external infill elements could be replaced with X-lam panels: the intervention would certainly reduce construction time, with substantial savings on all the costs deriving from it, and it would certainly increase the energy performance of the building. Just a consideration: an average transmittance value obtainable by external insulation with rock wool panels on the perimeter brick wall is around 0.30 W/m^2K, while, using the same type of insulation — wool panels of rock — but on an X-lam support, a transmittance value of around 0.18 W/m^2 could be obtained; a considerable reduction, normally obtainable only with a high thickness of insulating materials and all the disadvantages that this entails. The complexity of the theme of technical and management thermal requalification is well known, but the contents of these interventions are still rather cumbersome and uncertain thanks to a wide range of solutions accompanied by a lack of awareness of their potential due to the absence of a systematization of existing technologies. The variability of the raw material on which to intervene — the existing heritage — assumes a fundamental role in the evaluation of the type of intervention and this is often made conditional to a slowdown in the initiation of the interventions themselves. It is essential for the entire sector and for all operators entire the sector to acquire greater confidence in new construction technologies that can be acquired through greater knowledge and awareness in order to operate with renewed technical efficiency. Producing more efficiently, reducing time and development costs: these objectives do not should only be signs without foundation, but all the buildings sector with its operators should focus on the emerging technologies of manufacture directed from digital infrastructure to combine production series and variety of goods produced. New parameters for assessing the feasibility of the interventions therefore come into play: the reliability of the assets, the traceability of the components, the programmable maintenance, as well as the containment of energy costs with a view to retrofitting the existing one. The off-site construction is not a specific technology, but rather a set of experiments which covers all the technologies available in all operational areas of construction and above can converge in reuse and in the existing retraining. The innovation lies in using knowledge already developed in some industrial sectors to turn it to more precise and targeted purposes to give a concrete answer to a question that is continuously updated and compared with environmental sustainability targets to be achieved. From the status of art, business networks and production chains, specialized in research and application of technologies for sustainable construction aimed at and interventions on the existing could be enhanced for their intelligent management; it really could lead to integration with advanced technological systems such as smart living technologies: a concrete support to architectural practice which is able to offer solutions that will answer to the needs of the client, responding, at the same time, in an exhaustive way to the challenges of the green economy.

4. Conclusions

The negative decline of the last ten years in Italy, mainly due to the drop in new buildings, has led to the reformulation of the list of priorities in the construction sector: in particular the reuse of public and private assets, housing and infrastructure has become central, while, more and more, the realization of new interventions has assumed a marginal role. If the strategies and the way forward for a recovery of the sector, for the near future, appear to be substantially shared, the path leading to a lasting development of the sector is less outlined. It could be possible to identify interventions applicable to the building heritage in a transversal direction to increase well-being and comfort but at the same time reduce costs and times of the intervention: interventions that cannot be scheduled by the intended use of the buildings and building typology but for integration with existing construction technologies by evaluating their implementation with HI-dom support systems. The real innovation lies both in the introduction of new materials with variable performance, selectable and controllable thanks to physical-chemical alterations and, above all, in the use of new laying and assembly techniques while resorting to traditional materials exploiting their physical characteristics, as we have seen in the case of wood, in relation to the renewable nature of the raw material and the sustainability of the production processes. Within the same matter the answers can be found for a new economy based on the awareness that the technologies and knowledge available are no longer enough to solve the current needs of sustainability [16]. Innovation, competitiveness and sustainability, aimed at redeveloping the existing heritage, represent three key points on which to continue to focus in order to definitively overcome the persistent gaps in the existing heritage.

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