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INNOVATION IN THE BRICK INDUSTRY
A COGNITIVE FRAMEWORK

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Abstract

In Italy, the ANDIL Observatory (2017) has quantified an annual production of bricks of less than 5 million tons: a slight growth forecast for the coming years makes it possible to identify possible evolutionary paths in the production sector. The contribution presents a critical reflection about innovation in the brick production sector, identifying the most recent and interesting solutions in terms of productive, product and process innovation. These solutions have enabled this material to respond efficiently to a increasingly stringent regulatory framework and to meet contemporary formal and market needs.

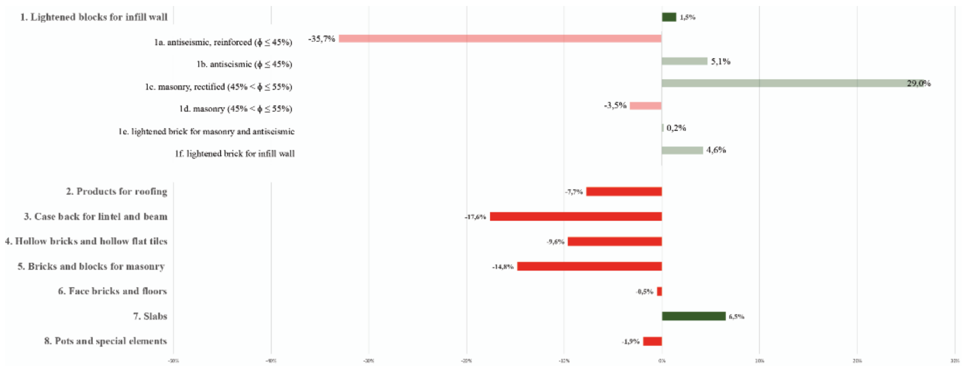
Keywords

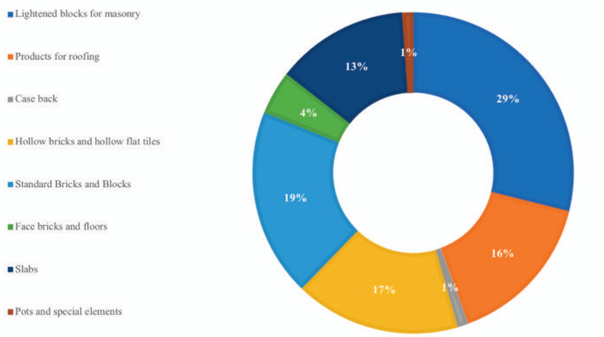
brick industry, innovation, recycling, robotics, augmented reality

It has always been necessary to invest in development and innovation of the construction sector, specifically in the field of brick production, because of its centrality in the Italian economic system. In 2016, investments in the construction sector represented 9.6% of GDP uses and 46.7% of gross fixed investments of the country (Rugiero et alii, 2018). A recent mapping of great transformations of the Italian construction sector, in the last ten years, describes an overall recessive picture up to 2013 and a slight recovery from 2015. This recovery is due to more favorable conditions for exports, to domestic consumptions and to the growth of employment levels (Rugiero et alii, 2018). From 2017 it is reported a slight increase, equal to 0.3%, mainly attributable to the expenses incurred for extraordinary maintenance of public and private works[1]. In term of employment, in 2017, the entire construction sector employed approximately 1,514,000 workers, which means 4.4% of Italian workers; despite the increase in the demand for high-tech interventions, due to the energy impact, the seismic retrofit and safety assessment of the existing buildings, the workers in the construction sector are concentrated in the less qualified works and the more usurious ones and also the most exposed ones to the lengthening of working days (De Angelis, 2018). In 2017[2] the industries that deal with the production of bricks correspond to around 2,000 units and their medium-small size has contributed to determining, over the years, the contraction of investments in research and innovation (Baratta, 2014).

This data permits to highlight that could be in the inverse relationship between employment and working hours a reason for inefficiency in the building sector. Inefficiency that could be solved with mechanisms of innovation. The construction sector is, in general, a low technological sector and the lesser contribution of innovation is in the brick production sector, i.e. 4% (Rugiero et alii, 2018). The deficit in technological innovation is joined by negative data on the production of bricks, as reported in the ANDIL[3]. Observatory: in 2017, the annual production was less than 5 million tons, a certainly negative amount also because it confirms a production decrease originating from 2007 (ANDIL, 2017).

Although this decrease, the production has been accompanied by an increase in the use of the plants, equal to about 43% (ANDIL, 2017), due to the need to reorganize the concentration of production. Moreover, in the analysis of the performance of individual products, compared to 2016, there has been an increase both in production and in the use of lighter blocks for infill walls, load-bearing walls, load-bearing walls in seismic areas and, among the latter, of rectified blocks (+ 29%; Fig. 1). The data analysis of brick production by type shows that over 50% of the products requested by the market is equally divided between traditional products (perforated and hollow tiles) and products with higher performance requirements (lightened clay blocks); the facing bricks, although they do not represent a high production percentage, are however





Figg. 1, 2 - Manufacture variation of brick products 2016-2017; Production of brick products expressed as a percentage (credits: ANDIL 2017).

growing (Fig. 2). The slight annual growth, between 1 and 2%, expected up to 2022 (ANDIL, 2017), makes it possible to identify possible further lines of innovation in the brick production sector.

The characteristics of product innovation in the brick industry – The innovation originates from new scientific knowledge or from needs to be covered (Sinopoli, 2002a). In the framework of recent innovations in the field of bricks, the ones that Nicola Sinopoli called 'invisible innovation' are prevalent. These are innovations that provide non-fundamental but important performances, that constitute a response to new legal requirements, and that are 'functional', it means developed as a natural evolution of products or processes for performance improvement. Always Sinopoli said that the innovation that works is the one which does not change the practice too much, but simplifies the use: in essence, an incremental innovation. Furthermore, the legislation as 'innovation accelerator' (Sinopoli, 2002a) continues to impose increasingly stringent requirements regarding the environment, energy and safety, with the consequence that some past innovations in ceramic materials, e.g. lightened clay block and rectified bricks, have become products of common use. It is desirable that this will happen with insulated clay brick, especially in a context where the use of building products is mainly poured into the existing redevelopment market and where, by 2020, the transposition of European directives should impose interventions of energy efficiency on around 3% of public and private building assets.

From this perspective, certainly desirable are functional innovations of products and components that consider the character of brick as an 'open system' able to fit and to be continuously applicable into any new or existing building, as defined by Guido Nardi (1980), also due to regulations about performance and use. Another noteworthy aspect is the ambition of process efficiency in the new millennium: it is certainly different than in the last century for two reasons. The concept of efficiency understood as the outcome of an industrialization process capable of producing in short times large quantities of products have already been reached and this productivity and repetitiveness is no longer necessary in a downsized market. Rather, efficiency must be sought in other features of the process and no longer in the quantity of the product produced. Innovation must find traces in the production, use and disposal phases because the technological performance of a product is now evaluated over its entire life cycle to meet the most advanced requirements of project, process and resources circularity. This is the essential direction of making and producing today.

The historical evolution of brick products – The history of brick production is among the oldest: the first processes of cooking and systematic production of bricks date back to the Babylon of the second millennium BC, that means that we can consider these building products among the first industrialized products. Cooking and molding represent the first form of evolution of the material aimed at improving the performance aspects of hardness and durability, in addition to those of installation. The Romans are certainly responsible for the development of employment techniques; they use raw bricks for the elevation structures of the houses, up to the 1st century BC as described by Vitruvius. With the transition from the republican age to imperial Rome, and, in particular, in the Augustan age (1st century AD), the spread of baked bricks would expand. The Romans were originally responsible for the use of bricks for the roofing, and subsequently the use of the same elements for the walling structures: it is probable, in fact, that the size of the Roman brick, flat and of thickness, might be consequence of this transfer of use from roof element to masonry one. Also, to the Romans we owe the first functional innovations: the first one of engravings the grooves on the raw brick to make the bipedales easily divisible on site and to obtain triangular modules for the realization of the curtains of the opus taestaceum; the second one the use of waste or recovery bricks for cocciopesto floors, the opus signinum (Acocella, 2016).

The Byzantine culture guaranteed continuity in the use of the material, improving its cooking techniques, the mixtures and experimenting its use for the construction of dome-shaped structures; with the Romanesque culture in our territory, the brick returns to be used massively as a visible face. Many of the architectures that characterize the following centuries such as the Tower of the Palazzo Comunale in Siena (1338-1348), the dome of Santa Maria del Fiore in Florence (1420-1436) up to the Oratory of the Filippini by Borromini in Rome (1637-1667) show how the technical culture of brick continued with experimentations and excellent achievements, the lasts accompanied, over the centuries, by the definition of the rules of use during the 16th to the 18th century thanks to Palladio, Guarini and Gallacini and in the nineteenth century, among many, with de Rondelet, Claudel, Vicat and San Bertolo (Quarneti, 2018).

In the twentieth century, bricks are widely used, their diffusion are such that they are recognized in numerous architectures of the Masters of the Modern Movement, as in the works of Alvar Aalto, an example of «the impartiality of Modern Architecture towards this material» (Lederer, 2014, p. 52). The 20th century architecture is also a place of experimentation of the integrated use between brick and other materials and of the aesthetic quality of the products. Since the mid-1900s, innovations in the brick production sector have focused on improving industrialization, production and assembly techniques and about pre-assembly products (Conti, 2002).

The direction of innovation in recent decades – The conditions that have supported the tools of innovation in the production and research sector have been both the public support policies for innovation and, since the 1980s, the creation of the National Association of Brick Industrialists (ANDIL) which «began implementing a strategic operation of associative synergies way back in the Eighties, at both research and marketing level, thanks also to the creation of informal networks between universities and research institutes, at the disposal of manufacturers for both research and its results and for communication and training» (Baratta, 2014, p. 55). As it happens for all the other productive sectors, the innovative capacity of the brick derives from its characteristics of workability and pliability (Conti, 2002) and because of the need to protect our Planet, the brick sector requires continuous improvement for the reduction of environmental impacts in the life cycle, despite the fact that the more general direction has for some time been aimed at improving products in view of their life cycle (Carbonaro et alii, 2018).

An excursus of the innovations of the last decades of the last century shows that in the Seventies the production techniques are improved, in the Eighties productions become industrialized also for ancestral elements such as crafted soft brick and in the Nineties innovation focuses on the production of pre-assembled systems and solutions that can be assembled in a dry building site (Conti, 2002). At the turn of the millennium, the use of bricks is therefore tested in the latter two areas: the major exponent of this activity is the Renzo Piano Building Workshop which, in many architectures of that period, from the IRCAM of Paris to the warehouses of the port of Genoa, passing through the residential complexes of Rue de Meaux always in Paris and the Cité Internationale of Lyon, up to the experiments of the Banca Popolare di Lodi, the buildings of Potsdamer Platz in Berlin and the skyscrapers of the Sole 24 ore in Milan, of the New York Times in New York and St. Giles in London (Fig. 3), led to the innovative use of traditional products and the definition of new brick products (Piferi, 2016).

Other innovations, from the beginning of the millennium to the present, achieve a certain performance direction that derives from the need to adapt products not only to existing rules, but also to the trend that the legislation pursues. These innovations result in having determined the set of requirements that a ‘new system’, be it a new product or a new way of assembling existing products, must fulfil. Sinopoli (2002a) argues that innovating in a given sector means creating an object (a basic material, a semi-finished product, a component, a piece of equipment, a technique, a process, but also a procedure, an organizational model, a service) that is different in everything or in part respect to the objects of which one has experienced. The recent innovations in the sector reflect

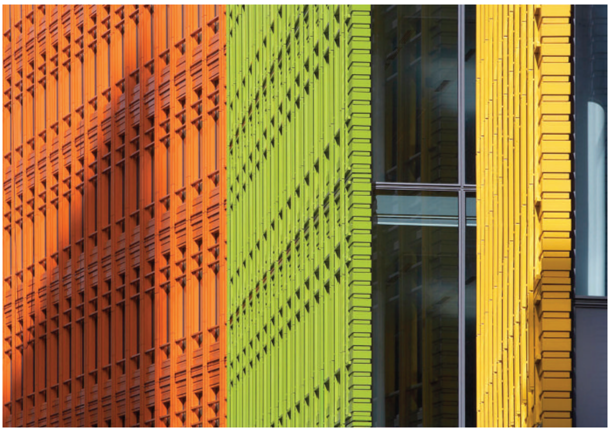
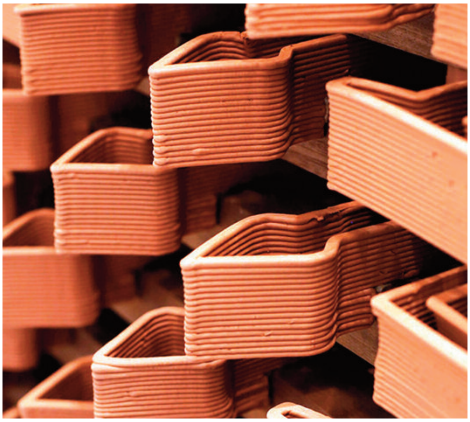


Fig. 3 - Renzo Piano Building Workshop, St. Giles*, London 2010: the ceramic envelope (credit: www.archdaily.com).*

the drivers of innovation identified by Nicola Sinopoli (2002b) at the beginning of the 21st century: safety, sustainability and hardship[4]. Among the many possible classifications, innovations in the brick production sector therefore lend themselves to being read in terms of productive innovations, concentrated above all on the raw material, product innovations, which have led to new components, and process innovations, which led to new techniques and work on site.

Productive innovation – Productive innovation has a functional nature, driven by the fulfilment of economic and technological requirements such as, in particular, energy and environmental ones. Innovations that have encouraged the development of tools for the use and recycling of waste derive from environmental innovation drivers, which move beyond the principles of sustainability to those of the circular economy. Furthermore, the current legislation, which since 2017 has made compulsory the use of recovered and recycled materials in public works[5], aims to encourage, the re-use of waste in their original functions and the recovery aimed at obtaining raw material. From this point of view, the introduction of material waste for the production of bricks is made possible by the production cycle of clayey materials because the mixture is very heterogeneous by its nature and suitable to incorporate substances such as waste, even in significant percentages coming from other work cycles (Rubbonello et alii, 2009).

In this context, there are some products on the market which, in compliance with the regulatory requirements, include a content of dry recycled material of at least 10% on the weight of the product and have an environmental product declaration (EPD) as required by the technical rules. In the same field, some researches have been developed, including those aimed at integrating textile waste into the mixture such as polyester fibres, developed by the Polytechnic of Turin in collaboration with companies in the tex-



Figg. 4, 5 - Ceramic Constellation Pavilion Hong Kong University + Plasma Studio: 3D printing of bricks (credits: inhabitat.com).

tile and construction sector. These researches have shown that textile waste can be effective by improving the value of thermal conductivity without compromising mechanical performance (Montacchini et alii, 2019)[6]. Other researches are aimed at introducing additives into the production cycle of bricks from waste materials such as glass from cathode tubes (Rigo, 2012). On the other hand, some experiments to use residues deriving from the waste combustion, from which fly and heavy ash are obtained, are more consolidated; the legislation identifies, in addition to other sectors of the construction industry, also for bricks, the possibility of recovery activities of the ashes (Novelli et alii, 2007). Another way is that traced by the numerous possibilities of adding the mixture of clay. Recent research shows the results of the possible addition of the mixture with three ecological materials: the date palm fibres, olive waste and straw. These experiments are carried out by adding different fractions of volume of the materials in the mixture and are part of the numerous studies on the behavior and properties of clay reinforced by the fibres of ecological materials (Lamrani et alii, 2019).

The direction of innovation aimed at optimizing the life cycle and the use of bricks as a second raw material is already in place: the use of brick waste is studied as a fine aggregate in concretes and mortars, as well as raw material or addition for the production of recyclable concretes (Cheng, 2016). However, there are still some difficulties due to the variations present in the components of the different wastes: the different quantity of silicates and aluminium oxides greatly influences the pozzolanic activity determining a mixture with discrepant characteristics. Furthermore, the policies regarding the classification of construction and demolition waste are not yet sufficiently rigorous and the advantages on the recycling cost, compared to the direct use of other additives, are not evident. Despite the environmental policies can create strong incentives for recycling (Horckmans et alii, 2019).

Finally, a relevant process innovation is the realization of brick products through 3D printing. Every single element is printed in a single shape or dimension through a robotic technology that allows to configure different shapes and density of mixture for different clay elements, adding a precious versatility to the design process (Figg. 4, 5). The most innovative robotic technologies, including those being tested at Hong Kong University, proceed with printing times of approximately 2 minutes per element, before firing at 1,025 °C (Jewell, 2017).

Product innovation – Among the product innovations, those aimed at improving the thermal performance of brick products are essentially represented by two solutions: the first one relates to the pre-assembly of thermal insulation panels to the product, in a sort of stratified block (Fig. 6); the second one concerning the filling with diffused insulation the hollows present in the product destined to the realization of walls, masonry and slab floors (Fig. 7). In both cases, the choice of the insulation to be used is determined by the need of a compatibility with brick, fire-resistant (class A1), durable, breathable and environmentally friendly. The blocks with diffused insulation represent the evolution

Figg. 6, 7 - Stratified brick block; Insulated brick block (credits: www.teknoring.com; www.danesilaterizi.it).

Figg. 8, 9 - Next page. *Onion (Chaktranon & Chaiamnuay),* Brick a brac*, Thailandia (credits: www.laterizio.it).*

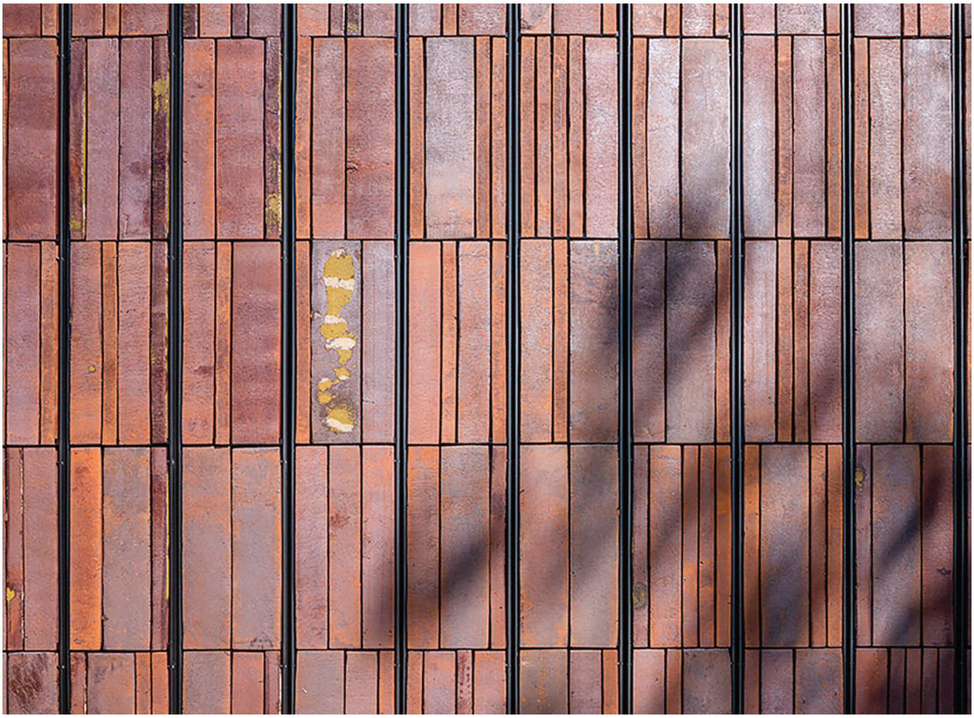
of the brick in terms of design of the finished elements (interlocking blocks, block with thin partitions and staggered partitions), of the geometry (rectified, half lap joint) and matching with other materials such as perlite and rock wool (Baratta et alii, 2018a). The recent project of the block-plaster, result of a research led by the Polytechnic of Turin, realizes a brick envelope system with high environmental sustainability, both in terms of performance in use and in terms of embodied energy in the materials and components (Carbonaro et alii, 2018): the new of this system is both the design of two blocks of brick (one heavy and one light) optimized for requirements and compatibility of use in the wall layering, and the integral project of the whole system itself.

In addition to the researches that pursue the improvement of energy and environmental performance, there are many that, often including environmental requirements improvement, implement the fire performance and mechanical resistance of brick products. The blocks with diffused insulation for reinforced masonry, for example, are an easy diffusion innovation because they combine the thermal properties of the brick with diffused insulation with the mechanical performance of the reinforced masonry building system, generating a technological system that is efficient from a structural and thermal point of view, but also with positive acoustic and fire behavior. This solution offers the possibility of acquiring with a single product the increasingly stringent regulations of the national context in terms of seismic safety, fire protection[7] and energy saving (Baratta et alii, 2018).

Other studies propose innovative solutions with reference to the shape of the product (Figg. 8, 9), perhaps with an approach that maintains solid roots in the past and the reference to the product in use, going beyond the use of the traditional component to favor the constitution of multi-layer products (El Wardi et alii, 2019).

Some forms of innovation concern the aesthetics of the product, which has always aimed at enhancing the quality of the brick as a covering material through colorimetric

and finishing variants (Fig. 10). For example, for the shells of some architectures soft bricks have been developed without sand on the surface, so as to produce an element characterized by sharp edges and with greater prominence of the colour of the clay. This involves the execution, in the manufacturing process, of the disarm of the bricks during the forming with the use of beech filings instead of the sand, because the filings, thanks to its vegetable origin, burn during the cooking and leave a smoother surface and brighter colour (Desiderio, 2013). It is clear that in this operation, productive innovation and product innovation coexist.



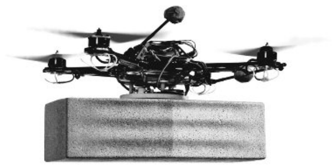


Fig. 10 - Kjaer & Richter, Extension of the Museum of Ceramic Art*, Clay (DK) 2015: envelope in brick tiles with variegated colours (credit: www.laterizio.it).*

Figg. 11, 12 - Realization of a brick panel through a robotic arm; Laying a brick through drones (credits: www.gramaziokohler.com).

Process innovation – Process innovations mainly concern the transmission of information and the installation phase. With regard to the first area, a strategic step towards optimizing the building process is represented by the rationalization of information flows that link the phases and the actors involved, favouring transparency and interoperability. This was one of the main objectives of INNOVance, a research project funded by the Ministry of Economic Development (Di Giuseppe et alii, 2016), aimed at creating the first national database for construction sector: the close collaboration of 16 partners, among which universities, manufacturers associations, builders, research centers and software houses, has made possible to create a system that can store, update and transmit all the information of the sector in a clear, standardized and interoperable way thanks to a single data collector. Moreover, even brick manufacturers have begun to convey the technical information of systems and products through Augmented Reality, with a positive response from the actors involved in the design and execution phase: the designers can, through the association of technical information on each design drawing, defining in detail the requirements and specifications of the selected products for construction; the companies present on building site, by scanning the parts of the design documents and drawings, can identify exactly which products to use and how; the Construction Manager, responsible for the qualitative and quantitative acceptance of the materials, can also check in real time the correspondence of the products to the design and standard indications (Magarò et alii, 2019).

The innovations that refer to the installation phase have been generated with the aim of simplifying the site and reducing the risks and improving the quality of the finished work. In this sense, innovation turned towards the use of automation tools: software, Computer Numerical Control machines and robotics. The use of these tools appears to be aimed at reducing the gaps between the industrial and artisan worlds and the generation of new forms of 'hybrid' craftsmanship. The mechanisms for automation and robotics can intervene both in production and in construction sites and these same mechanisms are able to condition the process right from the ideational phase, contributing to redefining the morphology of the building, structural and non-construction components, allowing for creating elements with increasingly complex geometries in terms of size and morphology, which can be articulated, irregular and curved (Ferrari, 2019).

Fabio Gramazio and Matthias Kohler of ETH Zurich have experimented the use of a robotic arm to lay the bricks of the envelope of the Gantenbein winery in Fläsch (Bonwetsh, 2006) according to a design whose complexity was such that if it had been made by hand workers it would have required much more time and certainly less precision in laying (Fig. 11). Further, they, together with Raffaello D'Andrea, have experimented the use of drones for the laying of bricks: with the Flight Assembled Architecture project, the drones were used to lay bricks in positions identified by a georeferencing system of the environment. The procedure is simple and fast: using a suction cup, the drones hook the neatly positioned element onto a plane and transport it to the position envisaged by the project (Fig. 12). The project is still in an experimental phase but the expectations and potential are enormous. This realization is illustrative of how much innovation in construction is not born only from the need to give exhaustive answers to the users' needs, but can put into question the organization itself of the project and of the construction site. In other words, innovation can combine functional and organizational needs and acts together or separately on the product and the process (Sinopoli, 2002a).

Conclusions – In the last decade, the evolution and innovation of product in the sector have been limited to the achievement of results aimed at confirming the positions already acquired, on technical solutions and already consolidated products and to 'defend', rather than investing in innovation (Baratta, 2014). The future in terms of production depends, on one hand, from the functional innovation that follows from the market success of new generation products, capable of guaranteeing excellent mechanical and thermal performance (Baratta et alii, 2018b) due for the increasingly stringent regulatory constraints both in terms of seismic and energy requirements; on other hand, from the possibility of renewing linguistic reasons, albeit in the overall decrease of production, which would derive from the capacity of this material to create assonances with the built context and with the landscape. This is because technological innovation in brick products certainly has a continuity with the past, especially for the figurative value of the material.

The possible directions of innovation certainly involve the pursuit of products and processes with high performance requirements and the development of systems that target the construction and disposal phase of the product to extend the qualities of sustainability and safety beyond the production phase, defining competitive products in the project circularity. It is certainly in the complexity of integrated management of the various requirements that productive, product and process innovation can be achieved.

NOTES

1) The growth of investments for the renovation of the existing building stock is certainly influenced by post-earthquake reconstruction actions and by policies aimed at favouring energy efficiency.
2) As in Rugiero et alii (2018) data based on AIDA, Computerized Analysis of Italian Companies for the period from 2007 to 2015 with a reference database of about 200 thousand companies; manufacturing companies are considered separately by companies involved in mining and support for the extraction of materials.
3) ANDIL – National Association of Brick Industrialists.
4) Intended as a discomfort and disadvantage condition that drives innovation to reach a comfort condition.
5) DM 11 October 2017 about Environmental Minimum Criteria (CAM).
6) The research project is developed by the group of the Department of Architecture and Design, Politecnico of Turin (P.I. Elena Montacchini and Silvia Tedesco).
7) In the case of the use of blocks with diffused insulation in polystyrene spheres with the addition of graphite, the self-extinguishing characteristics of the material solution reduce the overheating of the polystyrene avoiding its sublimation: blocks of reinforced masonry with 40 cm of thickness with this type of diffused insulation succeed to guarantee a value of REI 240 (Baratta et alii, 2018b).

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