Artificial Stone at the Beginning of the XX Century: Materials, Technologies, Decay Processes and Refurbishment

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ABSTRACT

At the beginning of the XX century, the building area has been characterized by a significant interest towards innovative materials and techniques, whose feasibility and durability the planners have been completely relied on. A specific example is given by building elements realized with "artificial stone". This "artificial stone" was a "new" but nonetheless "basic" material, that allowed replacement of natural stone that was more expensive to procure and also more difficult to obtain. This study provides an in depth analyses of the use of artificial stone for façade. Previous research has aided illustrating both the positive effects, as well some potential critical points of this material. Furthermore, knowing that these elements can undergo specific material and technological decay require practitioners having the requisite knowledge or technological "culture" pertinent to the refurbishment of artificial stone, without which often leads to unsuitable maintenance and repair work. Particularly, the analysis of materials and technologies employed for the building envelope have been developed. Starting from the scientific knowledge of elements and typologies and from the taxonomical identification of potential decay processes and macroscopic alteration forms, that these handiworks could undergo, the study aims at investigating the possibility to produce an artificial stone to repair or replace the damaged material with particular attention to its composition and durability and the compatibility between ancient and new materials.

KEYWORDS

Artificial stone, Decay, Materials, Replacement

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1 INTRODUCTION

Artificial stone is a building material that characterizes a large part of the architectural heritage built between the XIX and the XX centuries. The historical architectural value given to buildings rendered in artificial stone, seldom ascribed to the artificial stone as bearer of historical or technological value. As a consequence, one frequently has inadequate maintenance, refurbishment or restoration work that are typically oriented towards the replacement of elements rather than to their preservation.

The paper focuses on the definition of pathologies and decay processes for artificial stone used in the external façade of buildings in general, using the specific example of some Apulian buildings as a reference case. Hence the goal was to define suitable guidelines and operating criteria for maintenance and restoration of the artificial stone.

The study starts from the material-technical-technological evolution due to the introduction of a new material and to the development of a new technology within a process that took place, in great part, without the direct participation of academia, reconstructed also by the study of design patents lodged between 1870 and 1940 in Patent Office of the National Central Archive (of Italy) From the patent information, it is possible to draw extract information on mixtures and preparation techniques, and also defects and lack of performance that the new material demonstrated over time. Additionally, in certain instances the patent information provided empirically based diagnosis of the causes of defects or performance deficits and possible improvements in regard to both the selection of basic mix materials and the technology for maufacturing these products. The study made possible a direct comparison between mixtures and the manufacturing process through an analysis of appropriate case study of Apulia.

1.1 Artificial Stone Over Time

Research on the artificial stone manufacturing process has very ancient origins and represents a constant in the building history. Nevertheless, it is possible to outline a way characterized by testing and manufacturing aimed at obtaining materials that are both aesthetically like natural stone and guarantee of a greater durability for buildings.

Since Roman times, to obtain a stone that became hard when exposed to the air over time, a blend of one part crushed lime with two parts sand was used. Over the centuries, a good number of architects such as Bramante, Palladio and Bernini, have experimented with imitation stone with mixes that were basically based on lime.

During the Renaissance the use of plaster became common for covering building façades. Use of natural stone was limited to structures of civic or national importance, and as well to architectural decorations on these buildings. These elements were so limited that it was possible the low cost imitation by elements made out of common lime or water lime mortars. This employment is especially evident on the façades of residential buildings realized with ashlar stone: natural stone was used for the base of the façade whereas the upper part was realized using artificial stone and in an exact imitation of the course and pattern used for laying the natural stone in the base of the wall. During this period, rendering mixtures for artificial stone essentially included marble dust, lime and glue. [Cavallini & Chimenti, 1996]

There are several techniques developed in the XVIII and the XIX centuries to obtain a material that simulated cut stone. For example, mix of sand, hill and pigments applied on wood bases or plaster worked to simulate ashlars of stone, or cast iron worked for appearing as stone. Between the end of the XIX century and the first half of the XX century artificial stone has been achieved in large part due to the rapid growth of the use of Portland cement. The introduction of Portland cement, in the first decades of the XIX century and the consequent progress of the respective technologies made possible the production and the spreading of the new material with very low costs. The use of these techniques to produce artificial stone permitted replacement of natural stone, a more expensive product and one that was difficult to procure given the distance to quarries and the cost and expenses of quarrying stone.

European and North American manufacturing centres started to produce artificial stones by earthenware or cement (Pulham stone, Haddon stone) and several mixes of modified gypsum plasters and were patented as artificial marbles [Proudfoot, 1996]. The use of the artificial stone became increasingly widespread and a symbol of progress obtained in the new industrial society. New production processes, industrial management methods, artisan traditions all found in the artificial stone building sector are illustrative of the close alliance between art and industry in this period of industrial development.

The imitation of natural stone, moreover, does not only concern aesthetical issues such as the choice of colours, grain or texture, as it was during the Renaissance, but also performance related issues such as flow, shrinkage and curing. As such, one has the development of a new technology that involves different parts of the building, particularly the external façade and those related to brick or stone masonry.
The new material seems to very well meet the requirements of the architectural culture at that time, which was connected to eclecticism and Art Decò; such type of architecture was characterized by extremely "plastic" elements that are easily produced using a cementitious mixture placed in moulds.

This evolution leads to the use of this material beyond that which was first proposed to replace natural stone, and from the 1930's this product becomes an independent architectural subject, extensively used in the building industry and with shapes and element never before realized with natural stone.

1.2 Manufacturing and Patenting

First, we have some tests for the use of cement to simulate stone at the end of the XVIII century in France and England. The "Coade Stone" is one of the most widely used products first produced in England and used in European and American architecture until the end of the XIX century. However, from the second half of the XIX century, the largest number of patents is produced, in particular, those from America, England, France and Italy.

An early American patent, dating back to 1868, belongs to George A. Frear from Chicago for "Frear Stone", a mixture of natural cement and sand with the addition of a shellac solution to enhance the strength in the curing first phase. This method is used and copied extensively with some differences in the choice of materials and methods; whatever is used however, today the specific typology of decay is evident.

"Coignet concrete" or "Coignet Stone" as developed by the pioneer of cement use in France, Francois Coignet, has a French patent that uses the cement as binder. This patent, dated 1869 and 1870, makes use of Portland cement, water, lime and sand as raw materials to manufacture prefabricated cement elements. These are immediately modified in the US manufacturing process with a mixture of sand and Rosendale cement. Hence, in the 1870 American patent awarded to Coignet, this modified formulation is sold to an American, John C. Goodrich Jr., who founded the New York and Long Island Coignet Stone Company. This company manufactured the artificial stone for the Cleft Ridge Span in Prospect Park, Brooklyn, New York, and consdered to be one of the earliest known use of this type of architectures in the USA.

The patent of Frederick Ransome is one of the most widespread English patents, in which is used a mixture of sodium silicate and calcium chloride to obtain calcium silicate blocks, whereby the removal of sodium chloride produced from the process is completed by means of washing with water during the cure. But for a great number of formulations we have soon the use of Portland as binding, that is a more reliable and less expensive product.

First the experimentations and the success of the new material are focused on a cheap artificial stone as a substitute for more expensive and less available natural stone. Then the manufacturing doesn't aim anymore at an imitation of the natural stone from an aesthetic point of view, but also and above all in regard of performances.

As evidence we have a large number of patents of the different kinds of mixture brought onto the market between the XIX and the XX century. There, we can see an advanced research aimed at improving the physical-mechanical feature and at developing a new technology, in a process mainly based upon products whose definition is the result of experiences made in artisan way but with proto-industrial developing for production.

The goal of the study of patents registered between 1870 and 1940 in Italy is the historical, technical and technological knowledge of this material. The research was carried out by means of a critical review of patents that allowed cataloguing these in accordance with essential mixtures and with regard to the binder used.

For each one of this typology declared defects and probably causes has been identified, and then, for each defect, improvement strategies suggested with regard to the mixture form, as wells as to technique and manufacturing procedures.

In the first manufacturing phases of these materials, during the XIX century, the main required performances are design, durability, cheapness and easy fitting. As a consequence, the manufacturing aims to guarantee and to improve these requirements for the market.

The main used bindings are lime, Portland cement and Sorel cement. The latter is largely used by the best producers of that period like the Union Stone Company in Boston that adds sand or crushed stone to the hydrate cement in order to obtain a variety of artificial stone.

Since the end of the XIX century many patents declare some defects of products on sale and suggest adding some additives that improve their performances. In specimens with lime and sand, we can have frequently change of geometry and cracks in the final products. The reason of this is the type of lime, the additives used to make easier the cohesion between ingredients and the content of water in the mixture.

When the caustic lime is used, the most common aim is to obtain crystallized masses by adding sulphuric or sulphurous acid in the mixture. But this doesn't produce the expected results, because reactions with sulphuric acid are too quick and they don't allow a good combination between lime and gypsum.

On the opposite, the mixture containing sulphurous acid slows down the natural process of cohesion and it doesn't permit to arrive at a strong and firm level of cohesion. So this type of mixture is modified using water lime (Patent No. 52901- 28/08/1899 Kiefer) to replace the caustic lime, and the production process is helped adding sulphuric acid that in this situation acts at the right velocity.
With regard to the content of water, it cannot be checked with accuracy, because often the sand used is not completely anhydrous but it shows variable and not measurable quantity of water. Then the indication is to make row materials totally anhydrous, by means of centrifugation for example (Patent No. 53024 - 25/09/1899 Schwartz), and to add the right quantity of water just after carefully mixing.
Further described defects concern the poor compactness of mixture after setting that can cause fragility and strength below expectation.

To face up to this inconvenience we have many indications. Some patents suggest to obtain a better cohesion in the mixture increasing grain size assortment by fine milling of sand (Patent No. 74288 - 15/11/1904 Kwiatkowski), or in other case to let the lime slake at the same time of lime and sand milling and mixing.The slaking can happen in one or two subsequent steps. In the first case (Patent No. 72121 - 13/05/1904 Stoffler) the lime slaking is contemporary to the milling and the mixing of lime, sand and water. In the second case (Patent No. 74288 - 15/11/1904 Kwiatkowski) part of sand is milling with quicklime to obtain his partial slaking using the content of water of the sand. Then, the remaining sand is added with the water needed to end the slaking and to obtain the expected density.The success and the diffusion of the new material lead the manufacturing to correct the defects and to satisfy the increasing performance request. So, for example, a large number of additives are added at the main row material in order to obtain the same workability of stone, a good fire resistance, weatherproof, lightness and insulating capacity. It is suggest (Patent No. 71963 - 29/04/1904 Cordes) to add barium hydroxide or carbonate in the mixture of water, lime for cement and gypsum in order to manufacture an artificial stone that is workable with saw and chisel, light, with a good strength, fireproof, weatherproof, and insulating. Some shavings are put in the mixture in order to manufacture a quick and durable stone hardening, to help particles cohesion, and so to increase the strength of final mass wood. The use of coal ash guarantees a uniform distribution of wood shavings in the mass because the ash adheres to the shavings and prevents their floating into the mixture.In compounds with Sorel cement as binding agent it is often possible to have volume variations and cracks that make the artificial stone not much durable, sensitive to freeze-thaw cycles and to the presence of water. To obtain a better durability for the product with magnesia binding, the water absorption capacity, typical of Sorel cement is reduced, as well as the consequent variations of geometry and volume that cause cracks in the handmade, by adding phosphate of lime in the mixture (Patent No. 43116 - 22/03/1896 Preussner). The phosphate lime combined with the magnesia avoids the production of calcium chloride that is responsible for water absorption.To obtain a good strength to freeze-thaw cycles it is suggested (Patent No. 51473 - 20/04/1899 Ameloung) to add amorphous silica with inert like soil sand and sawing. In this way the additions react with cement to obtain magnesium silicate; the obtained stone is porous and it is necessary to use soluble glass or alkaline solution as a finishing surface.In compounds with Portland cement as binding it is often possible to assess vulnerability to atmospheric agents, to variation of temperature and to acid etchings. To improve the behaviour of the material it is suggested to insert many additives in the mixture like, for example, (Patent No. 69147 - 09/09/1903 Jurschina) a mixture of soda silicate and milled clay, that makes not alterable the traditional mix of Portland and sand or marble dust, after cooking at 1000-1400°C. In the same case, the Portland cement is totally replaced with the aim to increase the strength of the products. Substitutes are, for example, residual products of combustion of coal and of metal founding like the cast iron or the steel. These are milled and mixed with lime at a ratio of 83:17 or 66:34 (Patent No. 57293 - 15/10/1900 Martinelli).

Finally, there are many patents in which, a part of the binding typology, suggestions are given to improve specific features such as the impermeability, freeze-thaw cycles resistance, as well as fire resistance, atmospheric agents resistance and colour stability. Among the suggestions (Patent No. 71166 - 18/02/1904 Muller) there is the adding of vitriol, iron, copper or metal oxide in the mixture.

2 PATHOLOGIES AND DECAY PROCESSES

As it is clearly underlined within the patents, defects and pathologies are characteristic of artificial stone since the period of its greatest production. They are basically referred to some categories, shown in Table1.

They can be connected with the quality and the typology of the raw materials, as well as to the manufacturing techniques. Some pathologies have also been surveyed by an investigation on some samples of artificial stone buildings in Bari. In fact, in Bari, and more generally in Puglia, artificial stone was widespread, also due to the development of some firms, like Ditta Peluso and Ditta Ghilardi [Peluso, 1931], with national and international relevance.

Case studies were chosen according to some significant parameter, for instance functional destination (economic and popular building, middle class building, monumental building, public building) because it is connected to the different quality of materials; exposition to natural and anthropical agents (e.g. proximity to the sea or a town centre having high traffic levels); location of samples on the façade (base, column) and their interaction with close elements. Figure 1 shows the form used to catalogue to building survey information and from which an analysis was based for each case study that was conducted. As was evident from the critical analysis of the available patent information, the durability of artificial stone depends on several factors: the quality of materials, care in execution of the work, and from the degree of exposure to environmental agents casing deterioration. In some cases, the resistance of this product may be comparable or superior to natural stone. Nevertheless, the survey on some artificial stone samples shows a decaying process that relates to several casual effects.

First, the dirt depositing with the action of atmospheric and polluting agents, above all on the elements in relief as capitals, pilasters and trabeations, decorations and friezes, often subjected to break-up of mortars and erosion of surfaces. Then, the grain size composition, making the surface more or less rugged, significantly influences the capability of pathogenic agents to adhere to its surface, such as the incapability of materials, and particularly of binding, to resist to the breaking action of water.

Table 1. Pathologies verified during the period of greatest production

Binding Agent	Defect	Pathology	Causes
Lime	Loss of geometry	early strength to temperature variations early strength to moisture variations early strength to atmospheric agents	typology/quality of raw materials quantity of water content
	Cracking	early strength to temperature variations early strength to moisture variations early cohesion of particles	typology/quality of raw materials quantity of water content manufacturing process
	Fragility	early cohesion of particles	grain size variety inadequate typology/quality of raw materials manufacturing process
Sorel Cement	Variation of volume	high capacity of water absorption sensitivity to freeze-thaw cycles	typology of raw materials
	Cracking	high capacity of water absorption sensitivity to freeze-thaw cycles	typology of raw materials
Portland Cement	Variation of volume	early strength to temperature variations early strength to atmospheric agents	typology/quality of raw materials quantity of water content
	Cracking	early strength to atmospheric agents early strength to temperature variations sensitivity to freeze-thaw cycles	typology/quality of raw materials quantity of water content manufacturing process
	Superficial crumbling	early strength to temperature variations early strength to acid etchings early strength to atmospheric agents	typology/quality of raw materials quantity of water content

Variations of temperature and humidity cause a loss in dimensional stability and loss in mass of the stone; cracking is evident due to the expansion and the shrinkage that these stresses cause to building materials. With regard to the realisation of elements in artificial stone we have often too thick elements without any reinforcement or clamping elements. This condition produces the separation of parts that are more or less significant in relation with the grain size and the binding.

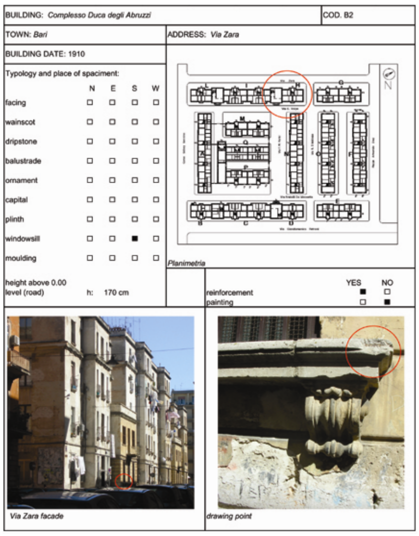

Figure 1. Specimen taken from a windowsill

Poor connections between adjacent elements made in factory and subsequently placed in work determine wide cracks, as well as scarce protection of clamping and clinging elements that causes their corrosion. Again the efficacy of protection depends to the quality of material forming the mixture that envelopes vulnerable parts by corrosion. Bad maintenance interventions, commonly performed during years: superficial treatments through covering paintings, often preceded by impregnation of the supports with irreversible fixatives, besides altering chromatic values of the material, compete to bait phenomenon of decay, even of notable entity. The start points of the described decay can be located in edges and relief parts, in surfaces of portions reinforced with metallic elements subjected to oxidation, in connections among different elements, in the zones of lifting and separation of following paintings, where deposit of particles and/or meteoric waters is possible.

Specimens were submitted to diffractometry and spectrographic tests to characterize the physical chemical petrographic. Results are not yet complete, however, no substantial differences in the composition of the mixtures are evident at this stage. Further tests are necessary to further understand the phenomena of decay of these materials

From an analysis of case studies and patents, and also with reference to a taxonomic systematization [De Tommasi & Fatiguso, 2005], a matrix of pathologies for artificial stone facades was defined that summarizes and classifies the main decay processes related to the mixture as provided in Table 2.

Table 2 - Pathologies for artificial stone facades summarizing the primary decay processes

DECAY		POINT OF CRISIS			CAUSES						PATHOLOGIES
A6	Crumbling	PI4	PI5	PI16	C3	C4	C5	C6	C8	C14	P1 P3 P4 P5 P6 P7
		PI2			C2						
A7	Detachment	PI7	PI8		C2	C9	C10				P1 P2 P3 P4 P5 P6 P7
		PI8	PI9		C10						
		PI1	PI4		C11	C12					
		PI11			C8	C14					
A8	Efflorescence	PI12			C15						P5 P6
A9	Erosion	PI4			C4	C16					P3 P4
A10	Exfoliation	PI1	PI4		C15						P3 P4 P6 P7
A11	Cracking	PI1	PI12		C8	C14					P1 P2 P3 P4 P5 P6
		PI1	PI2	PI10	C17						
		PI2			C2	C9	C19				
		PI13			C18						
A17	Swelling	PI1	PI2	PI12	C2	C11	C14	C19			P1 P3 P5 P6
A18	Presence of chips	PI1	PI2	PI12	C5	C12	C19				P1 P3 P7

POINT OF CRISIS
- PI1 Entire surfaces
- PI2 Steel reinforced surfaces
- PI4 Decorations
- PI5 Rough surfaces
- PI7 Arris
- PI8 Basements
- PI9 Passing zone
- PI10 Single parts
- PI11 Core-outside division surface
- PI12 Small thickness covering
- PI13 Connections between elements realized out of side
- PI16 Contact zone (different materials)

CAUSES
- C2 Corrosion of reinforcement
- C3 Air pollutions dregs
- C4 Rain action
- C5 Chemical etching
- C6 Washing away
- C8 Wrong mixture composition
- C9 Scarce protection of steel reinforcement
- C10 External mechanical stress
- C11 Large thickness without reinforcement
- C12 Different features of layers
- C14 Manufacturing mistakes
- C15 Moisture of bearing
- C16 Wind action
- C17 Shrinkage
- C18 Ineffectiveness of connection
- C19 Mechanical stress

PATHOLOGIES
- P1 early strength to temperature variations
- P2 early strength to moisture variations
- P3 early strength to atmospheric agents
- P4 early cohesion of particles
- P5 high capacity of water absorption
- P6 sensitivity to freeze-thaw cycles
- P7 early strength to acid etchings

3 CONCLUSIONS

The Second World War, as well as the definitive affirmation of a "modern" architectural and technical-technological culture in which the assumptions that favoured birth and diffusion of artificial stone don't find place anymore, decrees the end of the brief success season of such technologies. They quickly disappear with the men that produced them and with the knowledge mainly derived from their experience. As a consequence, actual lack of a "culture" of artificial stone is the cause of a frequent difficulty of action that leads to wrong maintenance and/or restoration interventions, or even worse, to the removal of such elements. According to what has been said, the research has to be oriented toward the definition of specific operational procedures for maintenance, refurbishment and integration of manufactured articles in the artificial stone.

A preventive phase of knowledge of building is fundamental therefore, referred to chemical-physical characterization of materials and their components, to measurement and survey of environmental parameters, to study of previous refurbishments and use conditions, to recognition and description of macroscopic alterations, to be followed by a phase of diagnostic of decay and individualization of relative causes. Such phase of knowledge, will be the object of further researches, must be structured in order to allow definition of types of intervention and operative guidelines.

Particularly it is necessary to define specific techniques and technological solutions for interventions, referred to both the integration and/or remaking of lacking parts and the maintenance of coverings of façade. For the former, research aims at the individualization of re-proposition modalities of technologies and original materials. For the latter the objective is the definition of typologies of intervention in relation to the required performances, of specific executive methodologies and of fittest materials for conservation of elements.

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