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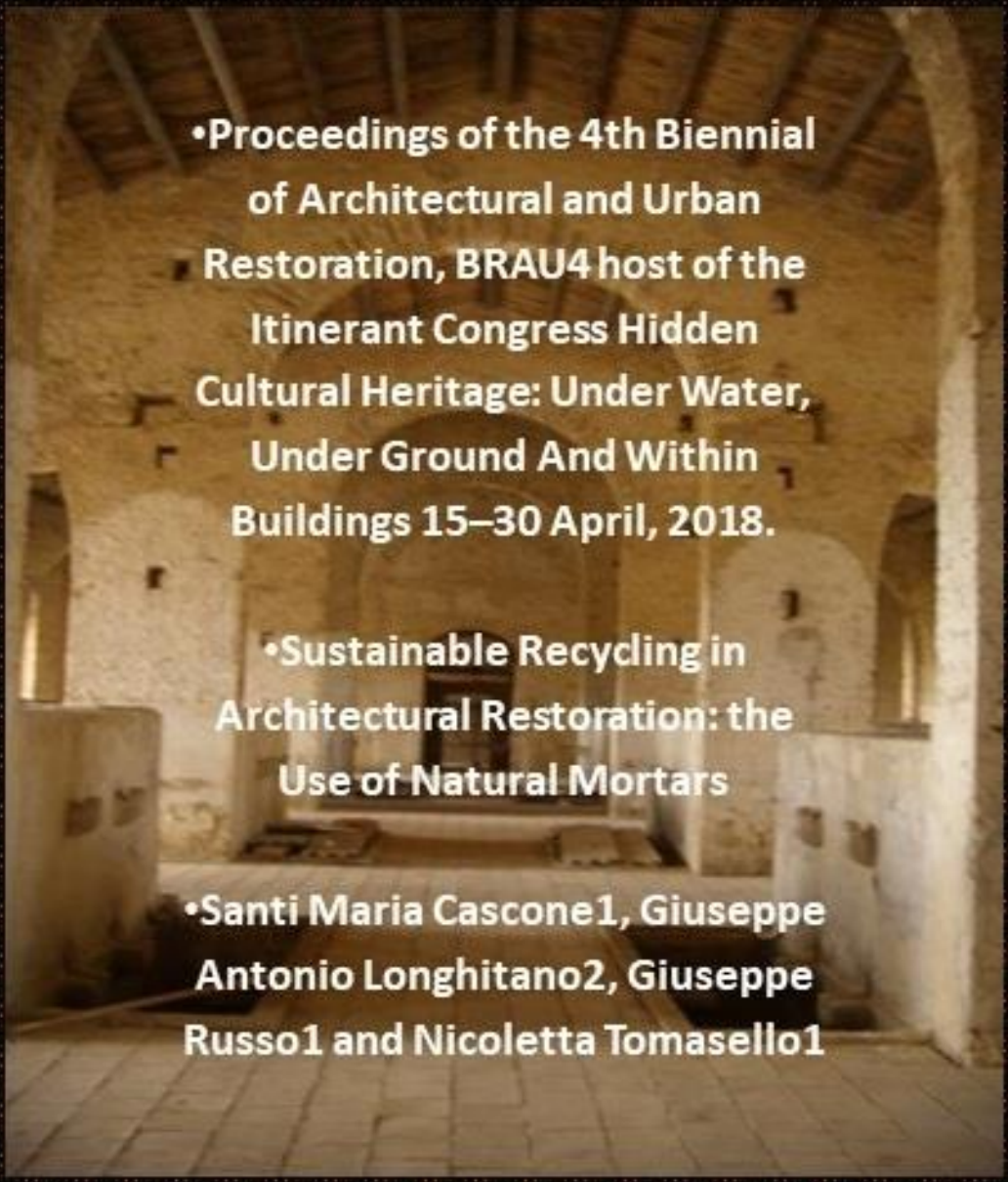

•Proceedings of the 4th Biennial of Architectural and Urban Restoration, BRAU4 host of the Itinerant Congress Hidden Cultural Heritage: Under Water, Under Ground And Within Buildings 15–30 April, 2018.

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Sustainable Recycling in Architectural Restoration: the Use of Natural Mortars

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Abstract

Architectural restoration can be considered strictly connected to the sustainable recycling process. Intervening on a historical building in a sustainable way involves the use of materials and technologies not too impactful, that minimize the building alterations caused by artificial products and the restoration impact on the environment, in line with the Life Cycle Assessment aims. The application of this concept can be identified in primary and secondary recycling activities, based on the reuse of building components. The use of a procedure based on the recycling of aggregates available on the building site in which they are produced concerns this topic. These materials, which have to be integrated with natural aggregates, are used for the formulation of natural mortars that will be used at the same restoration site. The application of this procedure leads to many advantages. The reuse of materials deriving from demolition for the mortar formulation helps to reduce the indiscriminate exploitation of natural inert aggregates and non-renewable raw materials, all in order to contain the disposal of waste in landfills and to limit the pollution produced by the heavy goods vehicles. Furthermore, this approach leads to the reduction of costs and environmental impact. By proceeding with a pre-programmed selective demolition of the materials to be reused, it is also possible to obtain products that, in the case of nonstructural components, provide performances comparable to those of the traditional ones. Finally, this methodology has a symbolic value, which can be associated with avoiding the loss of the “material identity” of the buildings, especially in the historical ones. This study aims to illustrate some examples of mortar formulation with recycled materials coming from demolitions and used as part of the mix. This mortar will be used for the restoration of the same buildings, which are in these cases historical building for museum use, civil buildings and religious buildings. Specifically, it will be illustrated the steps that lead from the identification of the material to be recycled to

its use in the natural mortars formulation, in order to achieve a sustainable restoration based on the use of components that, by reducing wastes and by recycling them, are “reprogrammed” for a new life cycle, thus ensuring the improvement of the collective well-being.

1 Introduction

The demolition and reconstruction processes are responsible for the production of considerable quantities of waste, which is in continuous increase and has considerable repercussions on the environment [1]. In particular, the construction sectors are among the largest producers of carbon polluting emissions [2]. In the European Union, the C&D (Construction and Demolition) sector leads to the formation of about 30% of the total waste generated [3], including materials such as bricks, cement, excavated earth, glass, plaster, wood and stone. Most of these materials are recyclable and can represent an alternative to the use of natural ones. This is shown by the many international certifications, such as the LEED➤ [4] which “rewards”, in the form of credits, the use of materials and construction products that contain a quantity of recycled material [5]. The advantages can be found in the reduction of the environmental impact [6] [7] and the consumption of resources [8] [9]. The reuse of building materials belongs to the field of primary recycling – a term used to identify the reuse of components of the building system such as tiles, bricks and wooden beams – and secondary recycling, a term used to identify the recycle of the construction material. The second case is the object of this study. The materials deriving from demolitions can be used as aggregates and this process, which ensure environmental sustainability, do not involve physical-chemical transformations but simply a volumetric reduction and a grain size reassortment, aimed to the production of new mortars.

2 The Natural Mortars

2.1 Definitions and uses

The mortar is a mixture composed by water, inert and/or hydraulic aggregates and a binder. The aggregates are traditionally sands, sometimes integrated with pozzolana of different origin, which have grain size curves characterised by different diameters. The binders generally consist of gypsum, aerial lime, aerial lime integrated with pozzolanic material and/or cocciopesto, natural hydraulic lime or hydraulic lime properly called Portland cement. The type of binder affects the hardening of the mixture, which occurs in contact with air for aerial lime (aerated mortar) and in contact with air or water for hydraulic lime (hydraulic mortar). If the used binder is composed by several elements (lime and gypsum, lime and cement, etc.), the mortar is called bastard. The mortar is generally adopted for many uses in the building. Indeed, it is spread on stones or bricks in the walls or it is used for the realization of plasters, as well as for the construction of subfloors. Some of the possible uses are included in the following case studies.

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In the case of historic buildings, the walls are often made with materials that are conform to the morphology of the places. The elements constituting the load-bearing walls of the building, such as stones and mortars, intrinsically define the quality of the building.

2.2 The mortar object of the study

The composition of the mortar should be carefully studied, since the mineralogical combination of the mixes, the volume ratio defined by the aggregates on the binder and the consequent mechanical characteristics of the mixtures define the quality, the expected durability and ease of application. However, the composition of the mortar does not affect only in structural terms, but also in colour rendering in the case of finishes. Mortars have aesthetic quality if their colours are not obtained by using colouring pigments, but through natural aggregates capably dosed. In the case of restoration of historic buildings, the realization of the mortar should be carried out respecting the existing ones. This principle allows both to avoid inconsistencies between the existing and the new material, and to preserve the historical identity of the building by saving its peculiarities. The knowledge and the relief of the morphological and structural typology of the stones and mortars of the existing building are of utmost importance. In this perspective, the characteristics of the existing masonry represent the starting point for the definition of the mortar composition to be used in the restoration. In order to follows the exposed aims, the object of this study is the mix formulation of natural mortar which includes recycled materials coming from the demolition activity of the same restoration site, which are used as “recycled aggregates”. The choice of using materials coming from the demolition is carried out firstly in order to obtain environmental advantages. In the Life Cycle Assessment1, limiting the use of heavy goods

vehicles for moving the material leads to a significant reduction of CO_2 emissions in the environment. Transport affects not only the supply phase of the materials, but also the phase of removal of the elements that, in this alternative, are reused and not defined as “wastes”. The choice to reuse the material coming from the demolitions, characteristic of the places and found on site, allows to preserve the historical identity of the building, that is “returned” to its context without altering its global appearance.

2.3 The material treatment and the mortar formulation

The recycling of the material to be reused in the mortars in object started - concretely in the case study concerning Nelson Castle and in the design phase for the other two case studies - with the partial demolition of the buildings components, with consequent generation of the so-called secondary raw materials2. In these case studies, secondary raw materials were the “regenerated” aggregates suitable to be used in new mixes aimed to the formulation of natural mortars that are, by choice, without additives.

1LCA is a method that evaluates the set of interactions that a product or service has with the environment, considering its entire life cycle that includes the phases of pre-production, production, distribution, use (or reuse and maintenance), recycling and final disposal. The LCA procedure is internationally standardized by ISO 14040 and 14044. 2The secondary raw materials consist of raw materials processing scraps or materials derived from waste recovery and recycling.

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The material coming from the demolition, worked through crushing systems, was initially subjected to a screening, which allowed a first subdivision based on dimension defining an over-screen and an under-screen. The residual material obtained from this first processing was therefore treated with a transportable hammer crusher. The obtained material was contextually submitted to a sieving operation, which allowed the division in dimensional range of 0-2 mm, 2-3 mm and 3-6 mm. About 10% of the material has been subtracted since it coincides with that which, according to the Fuller curve, is retained on 63-250 micrometres sieves. These parts should not be used because the harmful soluble parts could be concentrated in this fraction of micronized aggregates. In order to understand the mineralogical nature, the obtained material was subjected to an additional laboratory chemical analysis, which confirmed the absence of harmful substances. Furthermore, it was possible to identify the nature of the obtained aggregates, classifiable in three categories based on their characteristics:

❼ recycled with a gypsum base;

❼ recycled inert aggregates;

❼ recycled of hydraulically active aggregates.

In order to obtain the final mixes, these aggregates were integrated with natural materials such as:

❼ inert aggregates of crystalline calcium carbonate with different grain size;

❼ inert aggregates of basalt with different grain size;

❼ igneous and/or cocciopesto aggregates with different grain size;

❼ pozzolanic Gneiss aggregates with different grain size.

3 Case Studies

In the following case studies, the recycled aggregates used in the formulation of the mortar have been integrated with natural aggregates based on micronized cocciopesto that, proportioned to the hydrated lime calcium, is able to guarantee the naturalness of the formulated compounds. The used binders are therefore natural. The studied buildings undeniably have a monumental and historical value. Their presence is a demonstration of a past and is an identifying sign of the places. The restoration interventions related to each building have been advanced ensuring the preservation of the historical image and, at the same time, a high level of performance.

3.1 The church of “Santa Venera in Avola”

The Church of Santa Venera in Avola is located in Piazza del Teatro, inside the hexagonal area designed by Angelo Italia in 1693. It was founded in the 18th century, precisely between 1713 and 1715. The fa¸cade, in white cut stone, shows, in its three orders, the influences of the construction periods. This fac¸ade, enlivened by the presence of elements such as pillars, trabeations, capitals and niches, shows signs of reconstruction. The church

Figure 1: The church of “Santa Venera in Avola”.

has a Latin cross plan; eight Tuscan pillars that support cross-shaped vaults on the sides divide the three naves. The central nave is surmounted by a barrel vault, in which eight “nails” are grafted. From the beginning of the fifties of the last century, the central space of the Latin cross is surmounted by a semi-spherical dome in reinforced concrete that rests on a pre-existing masonry drum. Above the dome stands a lantern. Most of the remaining roofs consist of Sicilian tiles. With reference to the type of construction, recent studies have shown that, from the floor to a depth of 2.1 m, the foundation structures consist of a sack masonry made of roughly squared stones laid with mortar and scales of smaller stone. Below the foundation up to about -4.0 m, there is a sub-foundation consisting of limestone fragments in a silty matrix. The pillars are made of coarsely squared ashlars placed with lime mortar and stone flakes. Most of them have an external cut-stone facing of about 18-20 cm thick, laid out without significant mortar thicknesses. The composition of the mortar is of good quality lime, but the nature of the used mix is very poor. Regarding the roof, it is of a gabled wooden type with triangular trusses. The vaults of canes and gypsum of the central nave are supported by wooden ribs, while those of the lateral nave are real in conglomerate of scales and gypsum. At the end of the 80s of the last century, the roofs and the external plaster were restored.

The object of the present study is a consolidation and restoration intervention conducted because of the damage caused by the earthquake of December 13, 1990. The partial demolitions carried out to this end concerned the masonry, from which it was possible to recover about 22.590 kg of aggregates to be recycled, and the intrados and extrados of the dome, from which it was possible to recover about 560 kg of aggregates. The intervention also provided for the removal of external plasters, from which it was possible to recover about 9.500 kg of aggregates to be recycled, and of internal plasters, from which it was possible to recover about 71.770 kg of aggregates to be recycled. To the total of the demolished and removed product, equal to about 104.420 kg, the unworkable gypsum, equal to about 16.890 kg, and 10% of non-reusable material, equal to 8.753 kg, was subtracted. The quantity of aggregates that could be recycled is therefore approximately 78.780 kg. These aggregates were reused for the formulation of the mortar used for the consolidation of the masonry, for the reconstruction of the concrete cover of the dome and for the realization of paint and part of the plaster, both traditional and transpiring. The overall amount of natural aggregates deriving from the recovery of demolition material has been estimated to be about 60% of the total required for the execution of the intervention, therefore 100% higher than required by the law.

3.2 The Nelson's Castle

The Nelson's Castle, coinciding with the Abbey of Santa Maria of Maniace, is a building belonging to a complex located between the municipalities of Bronte and Maniace, in the province of Catania. Erected in its first conformation in the XXII century and abandoned after the earthquake of 1693, the complex - consisting of a church, a cloister, a cistern and a granary - was rebuilt and transformed into a residence by the admiral Horatio Nelson, who in 1799 received it as a gift from the king of Naples Ferdinando IV. Nelson's Castle was acquired in 1981 by the Municipality of Bronte from the heirs of admiral Horatio Nelson. The architectural complex, now composed of residential house, warehouses and courtyards - used as museums and containing archaeological finds - is enriched by a park that contains an outdoor museum of lava stone works. The complex presented some critical issues for which the restoration intervention in question was carried out. The building showed minor injuries such as deteriorated painting and water infiltrations, both of rising up in the walls and of infiltration in the coverage. Parts of the building were never built, such as architectural barriers and some coatings, while some balconies showed signs of deterioration. The paving of the outside courtyard, made with flints and lava stone bases that mark the path, was in a state of deterioration, as well as the pillars of reinforced concrete constituting the pergola and the fountain. In order to maintain the monumental value of Nelson's Castle, the restoration project included - in addition to maintenance works, completion of parts of the complex and reconstruction of parts of the external paving and the plants - further interventions. These consisted in the rebuilding of part of the damaged coatings, such as plasters and decorative paints, and in the creation of new plasters with anti-wet characteristics. Following the same steps illustrated in the case of the Church of Santa Venera in Avola, partial demolitions and removals have enabled the recovery of about 55.000 kg for the interventions related to the noble wing of the building and about 1.407.080 kg for the interventions related to the remaining part and to the external areas. The 10% of non-reusable material, equal to 146.208 kg, was subtracted from the total demolished and removed product, equal to about

1.462.080 kg. The quantity of aggregates that could have been recycled was therefore equal to about 1.315.870 kg. The recycled aggregates covered 60% of the material necessary to produce natural mortars needed for the restoration, therefore, even in this case, 100% higher than the value required by the law.

Figure 2: The Nelson's Castle.

3.3 The Municipal Palace of Salemi

The construction of the Municipal Palace of Salemi, facing the Piazza Dittatura, is presumably datable around the mid-eighteenth century. Compared to the original structure of the old building, consisting of two floors and a loggia adjacent to the square, the current

site has an extra floor and a rear unit, added in recent times and facing the Via Cosenza. The ancient fa¸cade has been completely restored and presents, to date, the styles of the Ionic, Doric and Corinthian orders. In relation to the distribution of the spaces, the indoors, consisting of the offices and the representative rooms, develop in all three elevations around the structure of the staircase. With reference to the type of construction, the surveys conducted before the restoration work object of the study have shown that the vertical supporting structures are made, in the first two elevations, in masonry of stones and mortar. The remaining elevation is composed of tufa blocks with a thickness of about 35 cm. The roof of the building overlooking the Piazza Dittatura and via Amendola is a terrace. The remaining part, facing via Cosenza, has temporary coverage. Regarding the composition, the stone covering used in the facades was made using “Campanella stone” (medium-grained biocalcarenes with a high fossil content), while the

Figure 3: The Municipal Palace of Salemi.

masonry blocks were made using tuffs of marsala, different from the first lithotype mainly due to the coarser particle size (coarse and macroporous biocalcarenite). Recently, part of the complex has been object of structural consolidation works. These interventions involved the consolidation of the vertical bearing structures. Other interventions, such as completion of coverage and consolidation of floors, were carried out. From the surveys conducted on the complex, it was found that the building was affected by numerous problems. The most relevant deteriorations found in the natural stone were the superficial patinas, the disintegration and the black crusts. The plasters showed a very advanced state of degradation, extended to most of the visible surface with swelling, detachment and surface deposit. Starting from the state of fact and from the analysis of the used materials previously described, the proposed intervention followed a specific approach to solve the different problems, taking into account the architectural-historical value of the building. In this case study, like in the others descripted before, one of the key points of the restoration was the use of natural mortar having, at the base, aggregates coming from partial demolitions and removals carried out on site. These interventions have allowed the recovery of about 995.800 kg of recyclable aggregates, to which 10% of non-reusable material, equal to 99.580 kg, was subtracted. The quantity of aggregates that could be recycled therefore amounted to around 896.220 kg. Overall, the natural aggregates deriving from the recovery of demolition material have been estimated to be about 41% of the total material disposed of, therefore 36% higher than required by the law.

Conclusion

Through the described case studies, it was possible to show the reuse of the material coming from the demolitions in the restoration site. The advantages deriving from the

illustrated methodology were primarily economic, since it was not necessary to conduct the material in landfill and its cost was significantly lower than a material used “from scratch”. Other benefits concerned the environment, as the environmental impact resulting from the processing of the material and its transport, has been considerably reduced. The value associated with the reuse of materials deriving from demolition was also symbolic, related to the preservation of the building identity. The Italian cultural heritage - which is the first in the ranking of countries for UNESCO cultural heritage [10] on the territory - is in fact subject to continuous conservation and restoration works. After these activities, buildings should not lose their peculiarities and their intrinsic values.

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