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Shot-Earth for an Eco-friendly and Human-Comfortable Construction Industry

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This book is dedicated to the Pittet family, entrepreneurs of a small Swiss construction company, pioneer and expert in the Shot-Earth technology.

Preface

The sustainability of buildings is a strategic theme due to its relevant social, economic and cultural implications, and it represents a fundamental topic in several current research programs. In this context, the use of excavated soil can represent a promising solution among green building materials with low environmental impact. This material is usually treated as a waste to be disposed in special landfills. Nonetheless, soil is one of the oldest construction materials and it is still used today to construct buildings, mostly with traditional techniques like the “rammed earth”. The excavated soil can be used for both structural and non-structural applications, using directly the soil resulting from excavation in the site where the construction will be realized. An innovative type of excavated earth-based construction material, named Shot-Earth, consisting of a mixture of excavated soil, aggregate, binder and water, is being developed. More precisely, the mixture of Shot-Earth is based on a low content of water (with a maximum content of 3% by weight in the dried mixture) and cement (its maximum content is about 12% by volume for certain types of structural applications), generally in the proportions of 7 parts of soil, 7 parts of sand and 2 parts of cement by volume. Other types of binders such as hydraulic lime, geopolymers and multi-composite cements can be used successfully, and, in some specific applications, the binder could be also omitted. The mixture employs aggregates, that may come from sieving the excavation natural material or from recycling processes, such as in the case of aggregates deriving from the demolition and grinding of bricks and ceramic materials, or also from inerting processes of industrial or organic wastes, with great beneficial effects in terms of environments preserving and cost reduction. The mixture used in the Shot-Earth technology has a cost 30% lower than that of the conventional cement-based materials. A saving in disposal of excavation ground at the beginning of the work is also accomplished.

The technique for laying Shot-Earth consists in the application of the mixture by spray on a support (that serves as formwork) with or without reinforcements, using a pressure pipe. Such a peculiar technique allows to quickly realize a variety of structural systems even with complex geometry (vaults, shells, tunnel coatings, underground tanks, waterproofing of walls for landfills and waste storages, slope stabilization). This laying technique is characterised by a rapid application, since it does not require any further compacting operation of mass by vibration, due to the pneumatic action taking place during the spray phase. Since the mixture is very dry, a remarkable self-supporting capacity immediately after placing is obtained. A key feature of Shot-Earth is that it can be used alone (as aforementioned described) or as a part of a technology to realize high energy-efficient buildings. Buildings made with Shot-Earth technology are in fact characterized by high living comfort due to the excellent thermo-hygrometric behaviour of this new material. In particular, the high thermal resistance makes it possible to create walls and panels with considerable insulating capacity. Moreover, by inserting bio-based aggregates such as hemp shives in a mixture completely free of cement (usually a mixture of slacked lime and gypsum), high-performance insulating layers can be created on the surfaces of existing buildings, simply by spraying these mixtures. This innovative application can improve the capacity of a building to auto-regulate its interior heat and humidity, increasing indoor environment quality and energy performance and reducing building gas emissions.

This book is dedicated to the innovative and very promising technology of Shot-Earth. It illustrates the main findings obtained in the FIRS2019-00245 research project, funded by the Italian Ministry of Research (MUR), by three research units belonging to University of Modena and Reggio Emilia, University of Parma and University of Perugia. To date, there is a lack of precise information on at least three crucial aspects of this new technology: (i) Initially, it is necessary to define the optimal characteristics of raw materials and mixtures (mix design, granulometric distribution of aggregates, characterization of clays, chemical analysis of excavated soil and leaching tests) to realize handworks with precise physical and mechanical performances (for instance, in terms of thermal inertia, acoustic insulation, breathability, steam permeability, shrinkage, creep, compressive strength, fracture toughness, ductility and the performance features of adhesion to the support). It is in fact essential to improve these properties in order to promote and spread Shot-Earth technology in the construction industry area. (ii) It is necessary to optimize the casting (spray or self-compacting casting in formworks) according to the peculiarities and the expected standards of the structure to be carried out. Specifically, the process of Shot-Earth laying is affected by the pressure of the air flow which supplies the nozzle, the type of nozzle and the direction of the spray. As a matter of fact, by properly setting the pressure of the air flow and the direction of the spray, it will be possible to reduce the presence and the size of the voids inside the cast and to optimise their distribution, thus obtaining final products with different levels of porosity and density. (iii) The use of innovative materials and sophisticated construction techniques in the field of construction industry determines the need to know in-depth the behaviour of structure in terms of resistance, durability, functionality and living comfort, through an in-depth monitoring activity. It is important to highlight that this activity is increasingly widespread even in the context of existing buildings, above all of a monumental and historical nature. In particular, the structural monitoring must verify that the work built is able to withstand applied stresses over time (both static and dynamic). Analogously, multi-physics monitoring allows to evaluate the thermo-energetic and acoustic efficiency of the work. Both structural and multiphysical monitoring are usually carried out using a network of sensors, suitably arranged on the structure, data acquisition systems and software for processing. The modern technologies available today exploit the conductive nano/micro-fillers, dispersed within the material, as distributed sensors (smart monitoring). Such fillers (made by carbon or metal) may be added to the matrix of composite materials, modifying their electrical conductivity, in order to measure deformations, temperature and humidity over time. Thus, after the functionalization/integration of these smart systems, the structural effectiveness and thermo-energy-acoustic efficiency/comfort of products/buildings obtained from the use of Shot-Earth technology, after the aforementioned optimization processes, have to be appropriately quantified.

The main purpose of this book is to illustrate the technological innovation in the use of a new green material and the adoption of related eco-compatible technologies. Theoretical, numerical and experimental investigations were carried out, helping to deepen the knowledge of a conglomerate based on green materials and to spread a less invasive technology than traditional cement-based conglomerates. Furthermore, by varying the mix design, the Shot-Earth can also be applied in the context of preservation of monumental and cultural heritage, where the use of materials compatible with those originally employed in the construction of historical buildings is often prescribed. The Shot-Earth is designed for the construction of sustainable buildings, which represent an emerging and strategic sector of the global economy, with direct implications in terms of development of new entrepreneurial realities. To this end, the current book can be useful for drafting up guidelines on the use of Shot-Earth aimed at companies and designers to spread the know-how on earth-based conglomerate technologies.

The current book consists of nine selected contributing articles. The main results obtained individually from these works are presented below.

As above mentioned, the excavated soil is often the largest construction waste and its disposal is costly and problematic. For this reason, there is a growing interest in using the excavated soil right on site. In the contribution [1] a new type of earth-based building material is presented. This new material is based on the shotcrete technology and has been named Shot-Earth. A mix of stabilized soil, aggregates and water is consolidated by high speed projection, rather than by mechanical compaction. An experimental program was therefore carried out to evaluate the main mechanical parameters, such as compressive strength, Young modulus, Poisson ratio, shear modulus and tensile strength. This first characterization of the mechanical properties of Shot-Earth material has shown the great potential of this innovative and eco-friendly building material.

A procedure to highlight as the characteristics and percentage of the components influence the elastic and plastic behaviour of the composite has been proposed in [2]. For this purpose, x-rays micro computed tomography (micro-CT) was initially used to investigate the effective composition of the Shot-Earth materials. Then, through image processing techniques, a numerical homogenization procedure has been applied to derive the main elastic mechanical properties.

An analytical approach is presented in [3] to evaluate the linear elastic properties of Shot-Earth materials according to the mechanical characteristics of a specific soil.

The methodology, which is based on a multistep Mori-Tanaka scheme, aims at providing the mechanical properties needed in the design phases, in an easy manner, before the realization of a building in a specific site. Each step of the analytical approach is validated by means of the experimental results accomplished through a wide campaign.

The composite nature of Shot-Earth allows for the integration of fibers and fillers for adding or enhancing the performance of the matrix. The article [4] presents the experimental tests carried out on smart-earth samples, produced by use of carbon microfibers, with various dimensions, from small ones at laboratory scale to real-scale structural elements. Tests on small samples were carried out to identify the optimal composite material. Large-scale tests on a four-meter span vault, realized by the use of high-speed carbon-doped earth-concrete, demonstrated the ability of the material to combine mechanical properties with monitoring capabilities.

The built environment is responsible for global greenhouse gas emissions. New business models require value-chain decarbonization, capable of facilitating the energy transition. In this perspective, the contribute [5] evaluates the sustainability potential of an earth-based lightened mortar under development. Three samples with distinct water and earth contents combined with alternative stabilization binders were compared to a classic mortar selected as a benchmark. Earth-based materials are shown to be one of the most versatile low-carbon embedded building materials.

The Shot-Earth material can provide good energy efficiency and environmental comfort, thanks to its inertia and hygroscopicity. Article [6] analyses the thermo-acoustic performances of the Shot-Earth materials and of the Smart-Earth materials obtained with the addition of different amounts of fibers for structural health monitoring. In addition to these composites, suitable for structural applications, a natural fibers-functionalized mix was also developed and tested as an innovative plaster for outdoor applications. Each component's most critical thermal acoustic and hygroscopic performance was evaluated at a small scale and in the field to identify their potential in building applications.

A set of rules is set out in the contribute [7], to help professionals use Shot-Earth as a material for the design of load-bearing structures. This last article introduces the research that led to the development of a particular Shot-Earth, called "772", conceived as a structural material for compressed and bended structural elements. Mechanical responses of the structural elements obtained from the failure tests confirm that the rules and codes usually employed to dimension RC structural elements are also suitable for design load-bearing Shot-Earth structures.

Conversion of construction wastes into performant building materials is an efficient method to decarbonate the construction industry and preserve natural resources. As discussed in [8], this is the case of Shot-Earth materials, which represent a new class of sustainable construction material. This last contribution illustrates some criteria to facilitate the adoption of Shot-Earth in the construction market. In conclusion, the Shot-Earth technology represent a strategic solution to increase the valorisation rate of the construction waste, ensure more sustainability in construction and increase the economic revenues of all firms involved in the construction process.

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