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Editorial

Sustainability in Geotechnics through the Use of Environmentally Friendly Materials

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1. Introduction

The reduction in the exploitation of non-renewable natural resources is nowadays widely recognized as a pressing need for a more sustainable society. Moreover, the increase in waste valorization and reuse of waste materials are undoubtedly important steps forward for environmental sustainability. Geotechnical design being part of typical civil engineering projects can play a major role in the sustainability of the built environment. Thus, a Special Issue was proposed focused on the use of environmentally friendly materials in geotechnical solutions, highlighting the relevance of geotechnics to reduce our carbon footprint. Their main purpose to collect and publish original research papers pointing out the use of sustainable materials in geotechnics has been achieved, through the great interest of the research community and a high number of submissions. This editorial summarizes the papers published during the 2020–2021 biennium, highlighting their main conclusions.

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2. Overview of the Special Issue

One of the biggest challenges facing civil engineers is the design and construction of sustainable structures and infrastructures. Geotechnical engineering, as a branch of civil engineering, can significantly contribute to sustainable development in the construction industry, implementing environmentally friendly and cost-effective solutions. The Special Issue "Sustainability in Geotechnics through the Use of Environmentally Friendly Materials" aims to highlight the ability of geotechnical engineering to contribute to a more sustainable society, through the use of materials and techniques with a smaller environmental footprint. The huge potential of this contribution is clear in the diversity of topics covered by the twenty-three papers published in this issue.

Several papers proposed sustainable ground improvement techniques [1–7] and soil reinforcement with alternative materials such as recycled polypropylene fibers [8], recycled tire-derived aggregates [9], recycled polyethylene terephthalate strips [10] or polypropylene waste strips [11].

The use of recycled materials replacing the soils or natural quarry materials in geotechnical works was presented by various researchers [12–16]. Sustainable solutions using geosynthetics to prevent soil contamination [17,18], to treat the sludge generated in different industries and avoid ground contamination [19] and to reinforce alternative filling materials [12,16,20] are also discussed in the Special Issue.

Low-carbon solutions for the stabilization of contaminated soils [21,22] and bioengineering techniques to prevent soil erosion [23] are put forward as relevant contributions to the planet's sustainability.

The relevance and topicality of the theme raised the attention and interest of researchers from different countries around the world. Ninety-one researchers from sixteen different countries contributed to this Special Issue (Figures 1 and 2). Based on the first author's institution, the greatest number of papers came from Brazil (seven papers), followed by India with three contributions. Australia, China, Portugal and Thailand contributed two papers each and Germany, Korea, Pakistan, Turkey and USA contributed one paper (Figure 1).

Twelve papers arose from collaborations among researchers from different countries. Figure 2 presents the countries of origin of the ninety-one authors (excluding authors with more than one contribution). In addition to the eleven countries identified in Figure 1, there are also contributions from Canada, Ireland, Japan, Saudi Arabia and Vietnam. As with the number of contributions, the greatest number of authors come from Brazil, followed by China (Figure 2).

The following section summarizes the different contributions with emphasis on the most relevant findings, following the order of their publication.

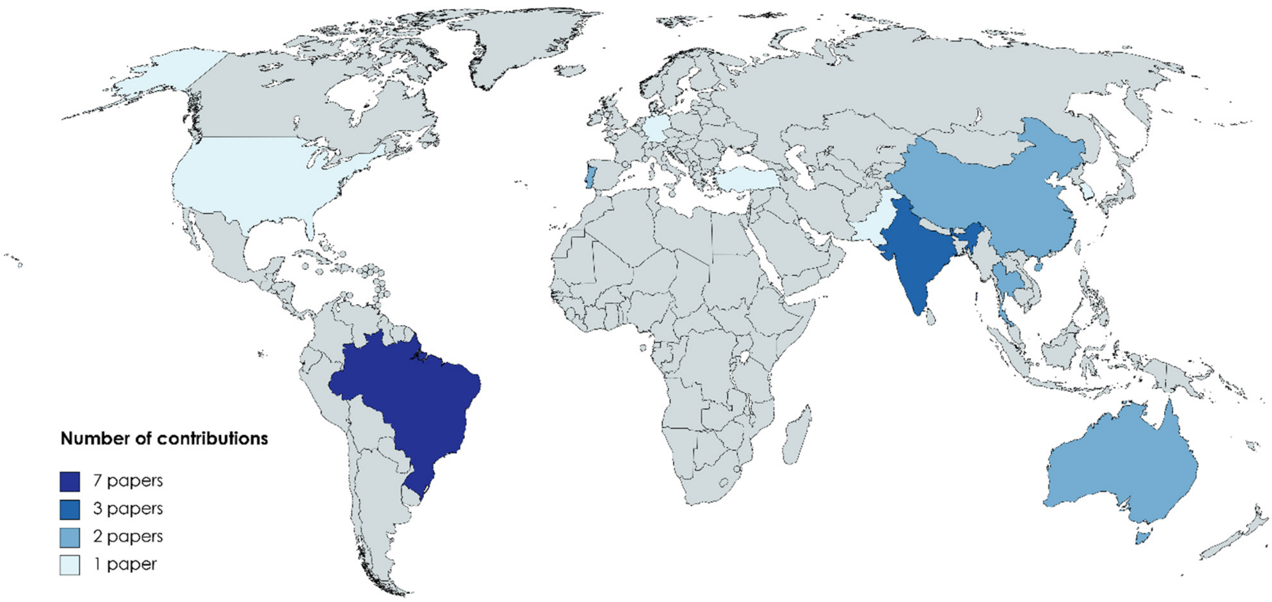

Figure 1. Number of contributions per country (based on first author affiliation).

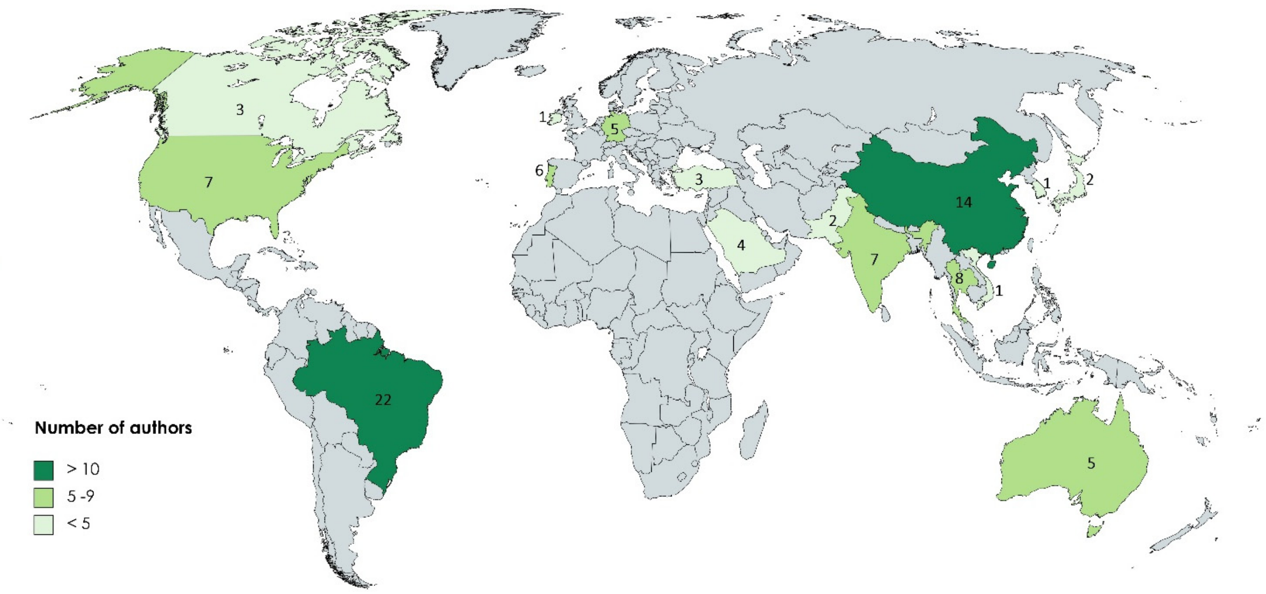

Figure 2. Number of authors from different countries (excluding authors with more than one contribution).

3. Highlights of the Contributions

A laboratory study on a low-carbon cementitious material known as limestone-calcined clay cement (LC^3) for the potential stabilization/solidification of zinc (Zn) and lead (Pb) contaminated soils is presented by Reddy et al. [21]. The authors found that the addition of the LC^3 binder at 8% can improve the compressive strength up to three times compared to untreated Zn- and Pb-contaminated soils. After a 14-day curing period, the pH transformation of acidic to alkaline nature allowed the adsorption of heavy metals in forming various insoluble metal hydroxides. This work shows that limestone-calcined clay cement is a green and sustainable remediation of Zn- and Pb-contaminated soils and the treated soil can be used as a safe and environmentally friendly construction material.

Vieira et al. [16] discuss the pullout behaviour of geogrids embedded in recycled construction and demolition materials, with emphasis on the effects of the specimen's size and pullout displacement rates. The results have shown that the pullout resistance of the geogrids increases with the specimen size and imposed displacement rate. The pullout interaction coefficient, one of the essential parameters in the design of geosynthetic-reinforced structures, exceeded the values typically assumed in the absence of test data (0.5–0.7), which allows us to conclude that the usual practices for conventional backfill materials (soils) are still applicable. The results of this study support the feasibility of using fine-grain recycled construction and demolition materials in the construction of geogrid-reinforced embankments, with obvious benefits in terms of environmental protection and sustainability [16].

The durability of a deposited marine clay treated with cement, copper slag, and hydrated lime was studied in a laboratory by Hanafi et al. [1]. Alternative ground improvement techniques, such as the one presented in this paper, reduce cement usage, and in addition, using waste material, such as copper slag, enables safe disposal of those materials. The authors claim that all proposed mixes resulted in the reduction of embodied energy and CO_2 emission.

Ma et al. [2] study the feasibility of using soda residue to produce an alternative material for geotechnical engineering applications. The preparation method of this material in the field is proposed and the mechanical properties for different mixing proportions with fly ash, sand and rubble are investigated. The authors concluded that the subgrade bearing capacity and deformation modulus of this alternative material are higher than those currently recorded with clays and sands.

The addition of lime and/or gypsum to enhance the geotechnical properties of two different types of fly ashes and a multi-criteria decision-making approach to assist practicing engineers in selecting the appropriate mixture for specific civil engineering applications are presented by Moghal et al. [3].

Moghal et al. [22] evaluate the efficacy of enzymatically induced calcite precipitation in the retention of heavy metal in soils. Soils contaminated with cadmium (Cd), nickel (Ni), and lead (Pb) were treated with three types of enzyme solutions. Based on their results, the authors claim that the enzyme-induced calcite precipitation can be an effective alternative in the remediation of soils contaminated with heavy metal ions.

Vianna et al. [23] explore different types of bioengineering techniques as environmentally friendly systems to prevent superficial erosion processes in soil slopes. The efficiency of these techniques was evaluated through high-quality images taken from periodical visits conducted over several months, processed with a computer code. The authors concluded that most of the solutions revealed a deficiency in vegetation establishment and were sensitive to climatological conditions, which has been conditioned by the low fertility and medium acidity of the soil.

Concerning the sustainable treatment of sludge produced in different industries, Aparicio-Ardila et al. [19] present a laboratory study and a statistical analysis on geotextile tube technology used for dewatering of sludge generated at a water treatment plant. The viability of using nonwoven geotextile, a material with better filtration characteristics than the commonly used woven geotextiles, was also studied by [19]. The authors propose to recirculate inside the geotextile tube the effluent collected at the beginning of the dewatering process so that it can be filtered more efficiently and therefore improve its quality. Under the same test conditions, the dewatering performance was better in the bags produced with nonwoven geotextile when compared to those manufactured with woven geotextiles (commonly used).

Lavoie et al. [18] evaluate the performance of two high-density polyethylene (HDPE) geomembranes used, for several years, in a sewage treatment aeration pond and in a municipal landfill leachate pond. The experimental study shows that these geomembranes perform adequately for environmental protection.

Almeida et al. [20] deal with the mechanical damage under repeated loading induced by incinerator bottom ash on three nonwoven geotextiles. The authors concluded that the damage provoked by the incinerator bottom ash on the short-term mechanical behaviour of the geotextiles tends to be lower than the damage induced by the natural aggregates used in their study, which represents good prospects for the use of these alternative materials in contact with geotextiles.

The mechanical properties of compacted lateritic soils reinforced with polypropylene (PP) waste strips cut from recycled plastic packing are discussed by Marçal et al. [11]. Among the many findings of their study, it is worth mentioning that the use of PP waste strips as reinforcements of lateritic soils led to an increase of the unified compressive strength and contributed to the change in soil failure from a brittle to a ductile mode.

Silveira et al. [10] evaluate the effect of recycled polyethylene terephthalate (PET) strips on the mechanical properties of cement-treated lateritic sandy soil. Based on their experimental study the authors concluded the inclusion of recycled PET strips in cement-treated soil can provide a sustainable alternative material with higher strength and ductility.

Safdar et al. [4] report the results of monotonic triaxial drained compression tests performed on sand-cement-fiber mixtures and propose various equations to evaluate the shear modulus and mobilized stress curves at small-strain levels. Their study aims to study the viability of utilizing tsunami waste as ground improvement materials to build sustainable geotechnical infrastructures. The authors claim this research related to increase in stiffness parameters due to the combined effect of cement and fiber additives might be useful for the practicing engineers in the construction of economical and sustainable geotechnical infrastructures.

Using a framework that incorporates resource consumption, environmental and socio-economic concerns, Samuel et al. [5] evaluate the sustainability benefits of a metakaolin-based geopolymer treatment for an expansive soil, when compared with a lime treatment method. Their study shows that the proposed geopolymer, primarily due to metakaolin source material, is a more sustainable alternative to the conventional lime treatment for soil stabilization. In short, the geopolymers can be viable additives or co-additives for the chemical stabilization of problematic expansive soils.

Park [17] evaluates experimental and numerically the permeability characteristics of a geotextile–polynorbornene liner at different oil pollutant contact times and pressure heads. This study confirms the impermeability of the geotextile–polynorbornene liner against oil pollutants and its potential as a solution to prevent pollutant diffusion.

Deng et al. [6] analyze the energy consumption and carbon emissions of Microbial Induced Carbonate Precipitation (MICP), used to strengthen soils and other materials, through the Life Cycle Assessment (LCA) method. The authors found that the current MICP application process consumes less non-renewable resources but has a greater environmental impact. The major environmental impact of MICP techniques is the production of smoke and ash, with other secondary impacts such as global warming, photochemical ozone creation, acidification and eutrophication [6].

A large database of soil/tire-derived aggregates (TDA) compaction tests assembled from the literature was used by Soltani et al. [9] to model the compaction characteristics (optimum moisture content and maximum dry unit weight) of fine-grained soils blended with sand-sized recycled TDA. According to the authors, the proposed empirical models offer a practical procedure towards predicting the compaction characteristics of the soil–TDA blends and can be used for preliminary design assessments and soil–TDA optimization studies.

Udomchai et al. [15] evaluate the interface shear strength between reclaimed asphalt pavement (RAP) and kenaf geogrids (produced with natural kenaf fibers), and assess their viability as environmentally friendly base course materials. A generalized equation was proposed for predicting the interface shear strength, which can be used in the analysis and design of related geotechnical projects including pavement projects, mechanically stabilized earth (MSE) wall design, embankment reinforcement construction and foundation design [15].

Lin et al. [14] analyze the feasibility of utilizing recycled aluminum salt slag (RASS) as a sustainable geomaterial through a comprehensive laboratory test program, focused on geotechnical and environmental engineering tests. Their study has shown that RASS has geotechnical characteristics suitable for their usage as pavement subbase material in road construction and does not pose any environmental and health issues. However, the authors point out that the quality of this aluminum industrial by-product is dependent on the machinery used and manufacturing techniques.

Sukmak et al. [7] examine the feasibility of using garnet residues (GR) as a replacement material in soft clay (SC) prior to cement stabilization, combined with tire-derived aggregates (TDA), to produce an alternative subgrade material. The authors found that GR replacement reduces the specific surface and particle contacts of the SC-GR blends. High amounts of GR led to the reduction in the unconfined compressive strength due to its high water absorption, resulting in insufficient water for cement hydration. Due to the low adhesion property of TDA, unconfined compressive strength and stiffness of cement-stabilized SC-GR reduce with the increase in TDA content. The cement–TDA-stabilized SC–GR at SC:GR of 90:10, cement content of 2% and TDA content of 2% is suggested by [7] as a sustainable subgrade material.

Schwerdt et al. [13] investigate the feasibility of using alternative materials, such as blast furnace slag (BFS), electric furnace slag (EFS), track ballast (TB), and recycled concrete (RC) as filling material in the construction of geogrid-reinforced structures. The laboratory characterization of the materials and a pilot application are presented. From the geotechnical point of view, these alternative materials revealed similar or even better behaviour than natural materials such as gravel. The results of the chemical tests show that only electric furnace slag and track ballast are qualified to be used without restrictions.

The effect of recycled polypropylene (PP) fibers on the shear strength–dilation behaviour of compacted lateritic soils is discussed by Silveira et al. [8]. The authors found that the PP fibers improved the shear strength behaviour of both lateritic soils studied and the shear stress–dilatancy behaviour is affected by the inclusions in the soil mix.

Palmeira et al. [12] present a review on the use of wastes, such as wasted tires, construction and demolition wastes and plastic bottles, as alternative construction materials in geotechnical and geoenvironmental works, giving particular emphasis to their combination with geosynthetics. The authors point out that, despite the benefits to the environment in reusing wastes in geotechnical engineering, it is important to have in mind that some of these wastes will degrade over time or can contain substances that may cause ground contamination. A careful evaluation of such aspects must be carried out before using wastes as construction materials in geotechnical and geoenvironmental works. In this context and when required, geosynthetics such as geomembranes and geocomposite clay liners, if properly specified, can provide efficient barriers for such contaminants [12].

4. Final Remarks

The principle of sustainable development was defined in the report "Our Common Future", also known as the "Brundtland Report", published in 1987 by the United Nations Brundtland Commission, as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [24]. Such a clear, seemingly simple and logical definition of sustainability should be part of everyone's principles and of the different sectors of activity. Due to the huge impact that the construction sector has on the environment, both regarding the consumption of natural resources and energy, and the large volumes of waste produced, this industry has been called upon to change its practices. It is therefore fundamental that researchers and engineers are increasingly encouraged to find solutions that meet sustainable development goals. This Special Issue was intended to bring together different contributions for greater sustainability in geotechnical engineering.

This Special Issue includes several contributions but there is still plenty of room for new contributions on sustainability in geotechnics. For this reason, the issue has been turned into a topical collection and new contributions will continue to be accepted.

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