ECOGEODIDACTIC RESOURCE – A CIRCULAR PATH FOR NATURAL STONE WASTES - DIDACTIC INTEREST, ECONOMIC POTENTIAL AND SAFETY ASSESSMENT PROPOSAL

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Summary: *This research project integrates Sustainable Development Goals (SDGs), specifically Quality Education (SDG4) and Responsible Consumption and Production (SDG12), and involves Education Sciences, Geosciences, and (Eco)Design. The project aims to create an ecogeodidactic resource that includes both physical and theoretical components, pedagogical strategies, and teacher training, while incorporating inputs from children and the educational community. The methodologies of action-research and cocreation have been adopted, focusing specifically on Environmental Education for Sustainability within the Geosciences (mineral resources and geological heritage). The project seeks to revalue stone waste from slab processing, by developing a high-value by-product. During the pilot phase, stone pieces ("geoelements") were selected for interaction with preschool children, and a prototype was created to be installed in a kindergarten to monitor its impact. This resulted in a validation framework, that allowed for the discussion of the geodidactic interest, and the economic potential of this Project, as well as the definition of the initial guidelines for assessing their safety.*

Key words: *Environmental Education for Sustainability, Natural Stone Circular Economy, Preschool Ecogeodidactic resource, "Geoelements" validation framework.*

1. Introduction and Objectives of the Pilot Project

Environmental Education for Sustainability (EES) is a critical field that aims to equip individuals and communities with the knowledge, skills, and attitudes necessary to address environmental challenges and promote sustainability practices (Mazza, 2021). Education institutions, particularly preschools, play a pivotal role in EES also by integrating the 2030 SDGs (UN, 2015) into their curricula. This helps teachers, children, and educational community develop a critical awareness of complex global environmental issues (Hakiki & Saputra, 2024). Despite the big challenge in implementing EES effectively, there is a recognized need for more integrated approaches that connect education and environmental efforts with local community-level sustainability initiatives (Tuazon et al., 2024). Recent studies highlight the lack of didactic resources and insufficient teacher training (Tuazon et al., 2024), despite the significant opportunities to enhance EES through innovative teaching methods and community engagement (Walid & Luetz, 2018).

This work arises from the recognition of these gaps and opportunities, associating them with the pressing need for geoscience literacy (NASA, 1986 cit. Paz & Vasconcelos, 2025) and promoting a deeper understanding of the Geosphere, its mineral resources, and heritage stones (Ehling *et al*., 2024). As argued by *Camphire et collaborators (2022*), knowledge about the lifecycle of mineral resources (including natural stones) encourages recycling, reuse, and revaluation of materials, reducing waste and conserving natural resources, as intended by both SDG4 and SDG12 (Bond, 2018).

The same purposes may be inferred from the EES National Reference to Preschool Education (Câmara et al., 2018), increasing the relevance and, in a way, the urgency to develop a project with these considerations.

The specific case that embodies this research aims to integrate a productive and industrial entity, such as is Mercado da Pedra, in Portugal. Specifically, it focuses on the natural stone waste from the slab cutting process, which will constitute the "*geoelements*" – the physical component of the didactic resource. These *geoelements* should present the most diverse global origins, different lithotypes, petrography, sizes and shapes.

A first prototype of the ecogeodidactic resource was developed and installed in a kindergarten (Fig. 1). This pilot phase, was monitored with the following purposes:

i. To characterize children's preferences during the exploration and manipulation of *geoelements*

ii. Calculate the production costs and economic relevance of using waste as high added-value by-products.

iii. Determine the susceptibility classes of the *geoelements* when handled by children, for a preliminary definition of the safety requirements.

2. Material and Methods

This research used a mixed methods approach to assess the effectiveness of an ecogeodidactic installation (EES resource). It was a pilot phase of a larger action-research investigation, which is still ongoing. The next step will involve cocreation cycles that benefited from the results of this pilot phase.

This pilot took place in a *kindergarten, (Fig. 1A) in a rural* area in northwest Portugal, with an installation set up in the outdoor playground. The installation included a support roundtable with 59 stone pieces, referred to as *geoelements.* Of these, 34 are removable (Fig. 1B) and 25 are fixed, glued to the support roundtable.

Geoelements correspond to the processing waste or remnants that would typically be discarded after stone slabs transformation. To be selected and become a feasible *geoelement, the pieces* often require cuts to reduce size and smooth the edges.

The installation was exposed to children's interaction (Fig. 1C) for six months, after which the *geoelements* were collected for observation, characterization, and classification (Fig. 1D). During the interaction period, the children's level of interaction with the *geoelements* was recorded weekly (10 min/week) in logbooks.

Twenty children participated in this study: 12 boys and 8 girls, aged between 3 and 6 years old; one educator, and three education assistants.

3. Results and discussion

A referential framework was established based on the characterisation of the *geoelements* and the logbooks records. The framework includes 59 rows (each *geoelement*) and 33 columns, grouped into six groups of reference descriptors:

1. Codification (prototype series, *geoelement* ID and abbreviation of the commercial name).
2. Size and Shape (width, length/diameter, geometric shape, thickness, weight, perimeter, and area).
3. Geological Properties [reference mineral or predominant mineral in the *geoelement*, hardness class of the predominant mineral, brightness, petrographic texture, porosity and density Raw material [commercial name and colour,

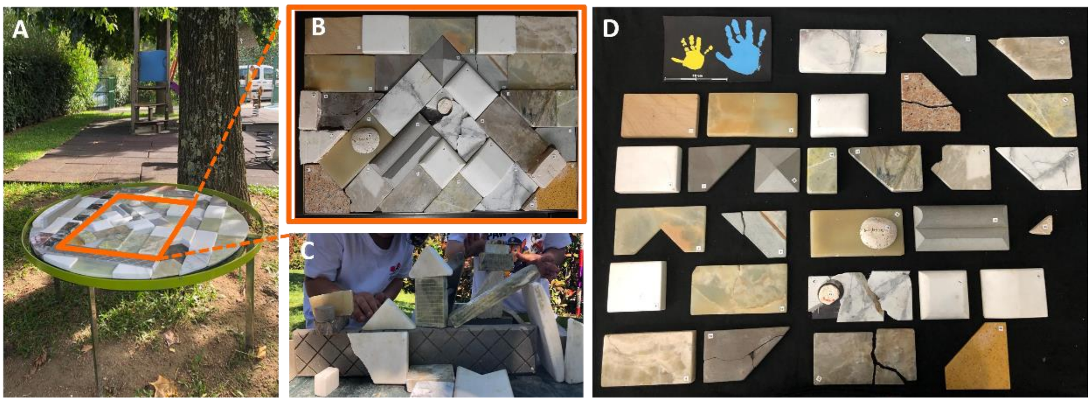

Fig. 1. The pilot project installation: A – Roundtable structure located in the outdoor Kindergarten; B - Removable geoelements in predetermined positions; C - Children interaction; D - Sampling of geoelements for evaluation after the interaction period.

reinforcement mesh type (on the back), percentage of resin on the surface (abacus count % area), surface finish and edge type].

4. Industrial and Market [natural stone cost on the market (€/m^2), cutting service cost (X€/m linear), edge finishing time (min/m), proportional finishing time/ stone hardness, finishing service cost (X€/m^2), total production cost (cutting service + finishing service), cost of by-product (cutting of size reduction + edge finishing), cost if ordered product (raw material cost + production cost] (X is a company-specific parameter)

5. Scales of Susceptibility (mechanical and geochemical), classified from 0 to 4 based on critical features recognized in the *geoelements*.

Relevant descriptors of the framework were selected, and their data distribution is shown in Fig. 2. The production costs of the *geoelements* as a by-product compared to the cost of the same *geoelement* as an ordered product show significant differences. The average production values of by-products are around five times less than values of the product ordered (Fig.2A). This highlights the economic potential of this approach. These results reinforce what Bond (2018) argue regarding the importance of lifecycle of natural stones its reuse and revaluation, reducing waste and conserving natural resources, as intended by both SDG4 and SDG12.

From a didactic point of view, some size parameters (Fig. 2B) should be considered to improve the children's interaction with geoelements. The *geoelements'* weight and area have asymmetrical and overly wide distributions, suggesting the existence of a critical size.

The didactic interest is related to the size of the *geoelement* and the size of the child's hand, as reported in the logbook (excerpt dated April 08, 2024):

> "… and from this first interaction, it was clear that some of the pieces were very large, heavy, unsuited to the small hands of 3-year-olds (…)."

To determine a critical size, the *geoelements'* size distribution was compared with the logbook records related to the size of the children's hands (Fig. 2C). The range between 9 and 12 cm seems to be the children's preference. It was also observed that some *geoelements* far exceed this value in their length.

Analysing the logbooks records according to the framework descriptors, the importance of the *geoelements'* size was recognized, along with susceptibility, especially the mechanical susceptibility.

Intrinsic aspects of the *geoelements*, such as colour, texture and brightness were also highlighted, compared with finishing, surface and edges, which are less frequently mentioned.

From the description of the geoelements (Fig. 1D) it is clear that there is a concern about the susceptibility, mainly the mechanical, as reported during the interaction period.

The expeditious classification of each *geoelement*, using a standardized scale of observations (Tab.1), highlighted the need to evaluate the safety of this didactic resource, considering the specificities of natural stone resources. These results emphasize the need for more integrated approaches that connect education and environmental efforts (*Tuazon, et al, 2024*) and promote geoscience literacy (NASA, 1986 cit. Paz & Vasconcelos, 2025).

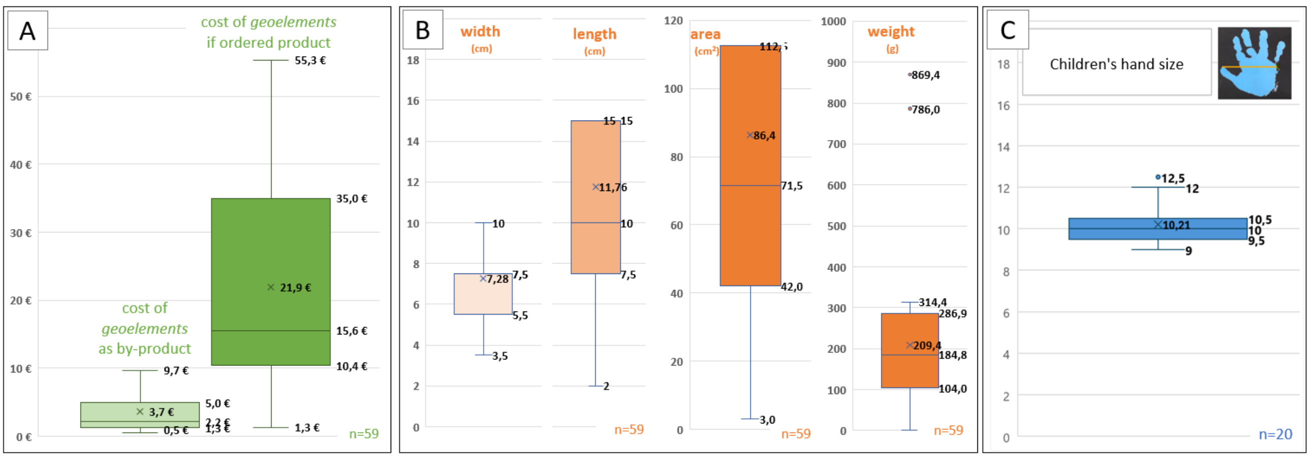

Fig. 2. Boxplots from the framework data and the logbooks records: A - industrial parameters of the geoelements production; B – Dimensional distribution of the geoelements; C – Children's hands sizes involved in the study (measured from the top of the thumb to the base of the pinky finger).

For equivalent objects and installations, the applicable standards are the *EU Toy Safety Directive - EN 71 Testing* (2019), accompanied in Portugal by the Technical Committee IPQ/CT 122 – Toys and Childcare items. The *EN 71* directive defines safety requirements related to aspects such as mechanical and physical properties, flammability, and chemical composition.

4. Conclusions

The referential descriptors framework and the analysis of the logbooks records proved to be a promising methodology for validating the selection of natural stone waste, as *geoelements,* to integrate an ecogeodidactic resource. Furthermore, this approach highlighted the didactic interest and the economic potential of this type of stone waste, as a by-product.

The data collection instrument – the framework with the six descriptors – proved to be a good reference for analysing the feasibility of the *geoelements*, with significant didactic value. The six descriptors' groups were shown to be relevant in the context of pre-school education within the scope of EES.

Table 1. Scales of susceptibility (expeditious classification).

SCALE	SUSCEPTIBILITY CLASSES	
	MECHANICAL	GEOCHEMICAL
0	Does not scratch or break	Does not alter the polish
1	Scratch	Loses polish/brightness
2	Breaks the edge	Oxidation marks
3	Breaks in one section	Marks of deep oxidation and biocolonization
4	Breaks into several sections	Neoformation (with efflorescences)

Cross-referencing with other data collection instruments, such as the researcher's logbook, reinforced and clarified children's selection of *geoelements: preference smaller, shiny and stackable, that could be handled, even broken*.

The ecogeoditactic resource could be considered a pedagogical innovation within the scope of EES, as it promotes intentional learning in children about mineral resources, stone heritage, circularity, and sustainability.

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