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ENHANCING SUSTAINABILITY OF RESIDENTIAL BUILDINGS USING QUARRY STONE WASTE AS A BUILDING MATERIAL

The intensive construction industry drives a demand for use of waste stone as a sustainable construction material. This is result of the goals to decrease the intensity of use of the available natural resources and to increase in utilization of stone waste from quarries. This paper delves with the utilization of waste from the marble mine in the Gjurovo locality near Prilep for construction purposes. Geotechnical testing was carried out on the quarry waste and the possibilities for its use as a construction material were examined. Then, a residential building at a distance of 40 km from the quarry is considered as a case study. Two alternatives were compared for the building: the first one by using conventional construction materials and the second one by utilising stone waste from the quarry. The costs of items where it is possible to use waste stone were compared. The study shows that the costs for earthworks can be reduced by 58%; concrete works by 5%; floors by 25% and facades by 24%. It is calculated that the construction costs for 1 m^2 of the building can be reduced by 6%, compared to the alternative with the conventional materials. The study promises that there are many opportunities for the use of quarry waste as a building material. The use of quarry waste reduces construction costs, which benefits the circular economy and all aspects of sustainable development. The paper also discusses some of the limitations of using quarry waste that should be considered in any project.

Keywords: sustainability, residential buildings, quarry stone waste, cost reduction, circular economy

1. INTRODUCTION

The intensive construction of residential buildings increases the need to use natural stone as a sustainable building material, which leads to a reduction in its available quantities in nature. On the other hand, it also increases the amount of waste generated during the process of extracting and shaping stone, as well as the energy embodied in the products obtained by its use.

Regardless of the method used for natural stone extraction, during the cutting and shaping of the blocks into a final product, approximately 20-30 % of the volume/weight of each unit is lost [1]. The waste generated is not only solid waste, but there is also slurry waste which is mainly obtained from the technological process of obtaining the required final product. In practice, If not used for other purposes, space for planned disposal is provided for this waste. The amount of such waste is constantly increasing and has a negative impact on the environment, human health and other aspects of sustainable development [2]. Instead of its disposal, it is of global interest to find sustainable solutions for its application.

The use of quarry waste, both solid and slurry, for application in new products is not a novelty. This material can be used in construction and other industries as a resource for obtaining various products [3, 4]. The solid stone waste can be used as floor/wall tiles with irregular or regular shape or as a buffer, the marble flour (white powdered limestone) can be used in tile glue, the marble powder can be used to prepare glass-polyester composites etc. [5]. This will not reduce only the permanent destruction of natural stone deposits, but it will also reduce the CO_2 emissions from the stone extraction and shaping processes [6]. From that point of view, when the material is from a local quarry, it has an additional advantage in the reduction of transport distances and costs. Furthermore, this approach stimulates the local economy in sustainable manner. The end result is an improvement of the products sustainability and if it is a construction material, it also contributes to the sustainability of the buildings. However, despite numerous conducted researches to use the marble quarry waste as a construction material or for production of new products, there are few studies focused on the economic aspect of its use, especially on the impact on building construction cost. Therefore, the aim of this paper is to investigate the possibilities of using marble quarry waste as a local construction material and assess its impact on the sustainability and total costs of the building construction.

2. LITERATURE REVIEW

A review of published research and reports regarding structural applications of marble and granite powder quarry waste is given in [5]. It was observed that using that waste positively affects the physical and mechanical properties of the concrete. At the same time, construction costs are reduced by a certain amount. These findings are confirmed by other studies. They have proven that in the construction industry, solid coarse and fine waste, not only from quarries but also from the demolition and deconstruction of buildings (concrete, metal, bricks, etc.), can be used for the preparation of concrete, as coarse and fine aggregate, for partial replacement of cement and for other purposes [1, 7-10].

Kore et al. present a review on sustainable utilization of marble waste for concrete preparation [7]. They concluded that there was no negative impact on the properties of concrete or mortar by replacing cement with marble powder by 10%. Furthermore, that combination of marble waste and fly ash as a binder was found to be more beneficial than just using marble waste for replacement of Ordinary Portland Cement (OPC). According to the authors, marble waste can be used to replace fine and coarse aggregate in the range of 50% and 75%.

The research of *Qamer et al*. [8] presents the results of the mechanical and long-term properties of concrete using dimensional stone from marble waste as a component for concrete. The results, compared with the properties of conventional concrete, showed that coarse and fine aggregates can be replaced with marble waste in large quantities. A mixture of marble powder waste and fly ash was proposed for binder, rather than simply replacing it with Portland cement. Furthermore, the study [11] focuses on the dried waste marble powder used for partial replacement of cement in concrete. The authors developed mathematical models based on statistical methods and experimental results. They proposed guidelines for the use of marble powder as a partial replacement of cement in concrete.

Another research by *Mangi et al. was* focused on usage of waste of marble and ceramic tiles for partial replacement of aggregate and binder [9]. It was found that concrete made using such waste is durable and strong. *Patil et al.* used waste marble sand to replace the 1-2 mm size aggregates in concrete [12]. The strength of their concrete was higher compared to conventional concrete.

The study [13] focuses on mortar production using waste marble powder as a partial replacement for cement. The authors concluded that mortar with the proper use of waste marble powder as a filler is a low-cost material and is beneficial for both the environment and the stone industry. In this regard, it was noted in [14] that the dimensional stability and durability of mortar could be improved by replacing the mortar paste with waste marble powder.

The usage of fine waste marble powder in pozzolanic concrete to increase the sustainability of the concrete is presented in [15]. The cost-efficiency analysis showed that embodied CO_2 emissions can be reduced by using silica fume binder and waste marble powder in concrete. In addition, the physical properties of the concrete are improved, and the reduction in the disposal of marble waste provides economic qualifications and environmental benefits. A similar study was presented in [16], where marble powder was used for partial replacement of cement in concrete. According to the results of the compressive strength test, it was identified that a decrease in compressive strength was observed with an increase in the content of marble powder in the test specimens.

Regarding cement, the study [17] focused on the density, porosity and mechanical properties of a new class of inorganic polymer cements made with local marble waste powders. The results of the research showed that the cements have a low carbon footprint and can be used as low-density, low-temperature binders for sustainable construction. Granite quarry powder was used in the research presented in [18]. The results of the research showed that replacing cement with 10% or 20% granite quarry powder was not detrimental to the durability of the product.

The use of marble powder for the production of bricks for exterior and interior walls is presented in [3]. It has been found that waste marble powder can replace 5–30% of the clay, resulting in polished elements that have good construction performance and are more sustainable than conventional ones. Another solution for the use of marble and granite waste (fragments and powder) is to produce artificial marble. By using crushed fragments as a load, powder as a filler and adding polyester resin, the materials can be mixed and then compacted [19]. This product is economical and has mechanical and physical properties that are satisfactory for its use as a building material in structural and bearing members.

Therefore, it can be concluded that there are numerous studies on the use of mine waste from marble and granite, but they are focused mainly on the physical characteristics of the products where they are used. There are a small number of studies that focus on the combination of sustainability and economy aspects of the use of quarry waste as a building material in structures, which is explored in this paper.

3. MATERIALS AND METHODS

A residential building is selected as a case study to investigate the opportunities of using a quarry waste from local quarry as a construction material. The building is located in the city of Prilep, Macedonia, 40 km away from the quarry in question. The first analysed alternative for the building is construction with conventional materials, for which a bill of quantities and cost estimation are available [20]. As a second alternative analysed, a bill of quantities and costs is prepared for the items where it is possible to replace the conventional material with construction material prepared from quarry waste of the required quality. The comparison of the two alternatives is focused on the construction costs and associated sustainability.

3.1 PROPERTIES OF THE WASTE FROM QUARRY GJUROVO

For the quarry Gjurovo, Figure 1, near the city of Prilep, waste rock samples were tested.

Figure 1. Waste stone from quarry Gjurovo, near the city of Prilep

The aim of the tests was to determine the physical, mechanical and mineralogical-petrographic characteristics of the stone and to assess the suitability of the material for its application in construction as a building material. There is waste material in the quarry that cannot be processed in production. In addition, about 40 m^3 of dry sludge is produced per month. The marble sludge or powder in the production itself (cutting the finished product from marble tiles using water) is collected in the marble sludge purifier.

3.1.1 Physical and mechanical properties of the waste stone

By examining the physical and mechanical properties of the waste stone, results were obtained for the following parameters [21]:

- Compressive strength in a dry state;
- Compressive strength of water-saturated samples;
- Water absorption;
- Bulk density with pores and cavities;
- Bulk density without pores and cavities;
- Bulk density coefficient;
- Porosity, frost resistance.
- Obtained results and respective test MKS standards are presented in Table 1.

Table 1. Results for physical and mechanical properties

No	Property	Test standard according to MKS	Symbol	Symbol	Values	Quality Requirements: CON/MKS B.B2.009 BNS/MKS U.E9.021/028 RC/MKS U.E9.028
1.	Compressive strength in a dry state	B.B8.012	MPa	σ_{pmin}	129,50	CON/min. (80; 160) BNS/min. (140) RC/min. (120, 140; 160) Pad/min (100; 120)
				σ_{pmax}	160,80	
				σ_{pmed}	142,80	
2.	Compressive strength of water-saturated samples	B.B8.012	MPa	σ_{pmin}	121,40	CON/min.(64; 128) BNS/n.(100)
				σ_{pmax}	154,10	
				σ_{pmed}	135,80	
3.	Compressive strength after 25 freeze-thaw cycles	B.B8.012	MPa	σ_{pmin}	115,80	Max. 25 % lower compressive strength than standards
				σ_{pmax}	152,60	
				σ_{pmed}	128,00	
4.	Water absorption	B.B8.010	%	U	0,18	CON/max.(1.0) RC/max.(0.75; 1.0) Pad/max. (1,0)
5.	Abrasion resistance	B.B8.015	cm^3/ 50 cm^2	A_b	19,0	CON/max.(35.0) RC/max. (12.0, 18.0; 35.0)
6.	Bulk density with pores and cavities	B.B8.032	kg/m^3	γ_r	2720	(2000 - 3000) kg/m^3
7.	Bulk density without pores and cavities	B.B8.032	kg/m^3	γ_z	2760	(2000 - 3000) kg/m^3
8.	Density	B.B8.032	%	G	98,6	/
9.	Porosity	B.B8.032	%	P	1,4	/
10.	Persistence of frost action	B.B8.001	Damages and losses / % /	M	No damage and little mass loss of 0,2 %	CON/max. (5.0) RC/max. (5.0) Pad/ max. (10.0; 12.0)

3.1.2 Mineralogical-petrographic analysis

The mineralogical-petrographic analysis was carried out on the samples, which were macroscopically and microscopically examined and described. The microscopic examination was carried out with a polarized optical microscope with transmitted light.

Macroscopic description: The sample is a light grey rock that is compact, solid, and has a microcrystalline structure and a massive texture. When treated with cold dilute of hydrochloric acid (HCl), it reacts violently, indicating a calcite composition. The sample shows thin calcite veins and cracks, rarely filled with limonite.

Microscopic description: The microscopic examination of the petrographic preparation determined that the rock is characterized by a microcrystalline structure and has a granular texture. The rock is characterized by a mono-mineral composition, i.e. almost completely composed of calcite. Very small amounts of quartz and very rare limonite have been found. The calcite crystals are very small and generally occur in allotriomorphic form with sizes up to about 100 pm (Figure 2). Calcite veins with a thickness varying from 2-5 mm are often present. Larger crystalline calcite are within the veins, which reach a size of about 2 mm. A very small presence of quartz has been determined, which appears without any particular regularity in the form of irregular, rounded crystals with a size of 50-100 pm. The very rare presence of micro cracks has also been noted, which are filled with a small amount of tiny brownish-reddish limonite grains.

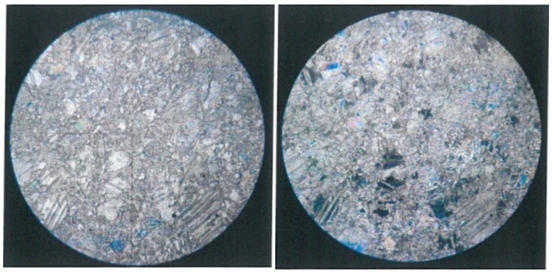

Figure 2. Micro-crystalline calcite, II nicoli (left), X nicoli (right)

3.1.3 Possibilities for application of quarry stone waste

According to the legal regulations in Macedonia, there are no restrictions on the application of waste from quarries as a construction material, as long as it meets the requirements determined by the relevant MKS standards. Furthermore, according to the determined physical and mechanical properties, as well as the mineralogical-petrographic analysis of the examined stone from the quarry, the material is suitable for use for construction purposes, i.e. as building material. The properties of the stone are in accordance with the stone quality requirements given in the relevant Macedonian standards (MKS standards). In addition to obtaining plates and elements/products with different dimensions and shapes, the remaining waste rock can be used as aggregate for concrete, asphalt, mortar, concrete blocks, buffer, for floors, partial replacement of cement, as a raw material for production of glue for tiles and for other construction purposes, after adequate research. In concrete, according to the tests, marble stone waste could be used in two cases: as a replacement for the aggregate and as a partial replacement for the cement.

3.2 DESIGN OF THE BUILDING WITH CONVENTIONAL MATERIALS

The designed building is for collective housing - apartments building, Figure 3, with reinforced concrete (RC) structural system with the following characteristics:

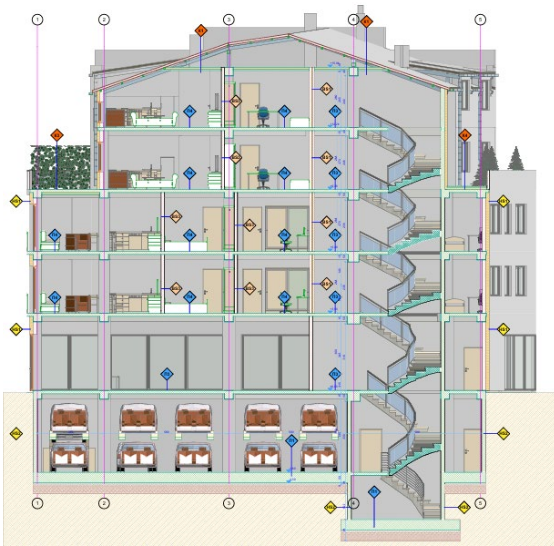

Figure 3. Cross-section of the building

- Number of floors is 6;
- Area of the construction plot is A=548 m^2;
- Gross area under the building is A=327.14 m^2;
- Total net area A=1470.51 m^2;
- The walls in the levels below the terrain elevation are designed as RC walls and RC stair core;
- The external walls are made of lightweight blocks with d=16cm, with a thermal insulation of expanded polystyrene;
- The floors are finished depending on the purpose: granite tiles for the business premises, stairs, entrance hall and hallway, floors in the garages are made of concrete, ceramic tiles are provided for the bathrooms and terraces, while laminate flooring is

provided in the apartments. For the ground floor – interlock pavers (behaton) are designed;

- The roofing is designed with sandwich roof panels with a slope of 15% and 35% placed on a steel roof structure. Solar roof panels are designed in one part of the roof;
- The exterior doors and windows are provided with PVC profiles, except on the ground floor where a glass facade with aluminium profiles is provided.

4. RESULTS AND DISCUSSION

A bill of quantities and costs was available for the building alternative with conventional materials, presented in [20]. Then, for the same building, an alternative design was prepared, where, for the items where it was possible, conventional materials were replaced with materials prepared by using stone waste from quarry. The calculations were made for use of the waste stone in earthworks, concrete works, floors, walls, and facade works. Respecting the law, the price of this local material was determined by the concessionaire of the quarry.

By comparing the costs for the two alternatives, the following reductions of the costs are calculated (Table 2):

- For earthworks - backfilling under the foundation slab and pavements, costs were reduced by 58%.
- For the preparation of concrete, the replacement was made for the following aggregates: 205 kg/m^3 for the 2nd fraction of 4-8 mm, 372 kg/m^3 for the 3rd fraction of 8-16 mm and 588 kg/m^3 for the 4th fraction of 16-32 mm, or 1135 kg aggregate in total for one cubic meter of concrete. After transporting the aggregate from the quarry, the concrete mixture can be done by mixer. The installation of the concrete can be perform with pump, with wooden formwork positions. The concrete works for the building were reduced by 5%.
- In floors and walls, a cost reduction was made by replacing ceramic tiles with marble tiles, partially using marble powder for glue. The costs were reduced by 25%.
- In facade works – the quarry stone waste was used as a partial replacement of the aggregate and for the glue. The costs were reduced by 24%.

The comparison of the variants proves that by using quarry waste as a construction material, the total costs of building construction are reduced by 6% (Table 2).

Table 2. Costs reduction when using waste marble stone

	Earthworks	Concrete	Floors and walls	Facade	Per 1 m^2 built-up area of the building
Costs reduction	58.00 %	5.00 %	25.00 %	24.00%	6 %

The results presented in Table 2show that the use of local waste stone material, which is of the required quality, reduces the costs of building construction. However, the results obtained confirm the results of other researchers who emphasize that the use of quarry waste in a certain amount fulfils the needed properties as a building material, reduces material costs, stimulates the local economy, social development, and is favourable for the environment and sustainable development in general [5, 22, 23].

5. CONCLUSIONS

Urbanization is characterized by the intensive construction of residential buildings. It contributes to improving people's living standards, but causes an increased demand for resources and raw materials for construction. Therefore, limited natural resources are being depleted and environmental pollution is increasing. On the other hand, quarry stone waste is a global problem due to the large quantities produced daily and due to its degradation and possible negative overall effects on the environment and human health. Therefore, the need to use it for other purposes is in the interest of sustainable development. Furthermore, the concrete produced by using marble waste is eco-friendly and economical construction material due to the low cost of the marble stone waste.

Using stone waste with required quality from a local quarry is a sustainable practice. This contributes to ensuring good use of natural resources and minimal environmental impact, which is in favour to the sustainability of the buildings.

An additional benefit is that the use of local materials reduces their carbon footprint trough reducing transportation distances, allowing the necessary building materials to be available "just in time". The increased use of local waste quarry materials would positively impact the number of jobs, primarily at the local level. It stimulates the local economy, contributes to environmental protection and raises awareness among employees about the importance of sustainable development and many other positive aspects of economic, social and environmental sustainability. The results of this research can be used as experience for further research.

The limitation of the research is that it isfocused on one case study - the use of waste from the Gjurovo quarry for construction of residential building. For further research, it is proposed to increase the number of analysed buildings, combine quarry waste products with other materials, compare the results with analyses for other types of buildings and structures (geotechnical, hydrotechnical), etc.

REFERENCES

[1] Vashi, J., Daftardar, A. (2024),"Sustainable concrete with optimum use of waste marble powder", in Proceedings of International Conference on Advancements in Construction Materials (ICACM2023), India, July. 2024, Vol. 3146, No. 1, 020004.

[2] Polydorou, T., Kyriakides, N., Neocleous, K., Hadjimitsis, D. (2022), "Handbook of Sustainable Concrete and Industrial Waste Management, 14 - Use of quarry waste in concrete and cementitious mortars", Woodhead Publishing, pp. 289-304.

[3] Suffian, M., Ullah, S., Ostrowski, K. A., Ahmad, A., Zia, A., Wieczorek, K., Awan, A. A. (2021), "An experimental and empirical study on the use of waste marble powder in construction material," Materials, Vol. 14, No. 14, 3829.

[4] Tazzini, A., Gambino, F., Dino, G. A., Casale, M. (2024), "Managing Marble Quarry Waste: Opportunities and Challenges for Circular Economy Implementation", Sustainability, Vol. 16, No. 7, 3056.

[5] Nayak, S. K., Satapathy, A., Mantry, S. (2022), "Use of waste marble and granite dust in structural applications: A review," Journal of Building Engineering, Vol. 46, 103742.

[6] Zhang, X., Yin, J., Li, F. (2023), "Research on the reduction of carbon emissions in buildings by specifying low-carbon concrete mixes in China," Proceedings on Engineering Sciences, Vol. 17, No. 4, pp. 655-666.

[7] Kore, S. D., Vyas, A. K.,Kabeer K. I., S. A. (2020), "A brief review on sustainable utilisation of marble waste in concrete," International Journal of Sustainable Engineering, Vol. 13, No. 4, pp. 264-279.

[8] Qamer, M., Rafique, M. A., Billah, M. B., Usman, M., Haider, W., Ashraf, A., Shad, M. A., Ibrahim, M. (2022), "A comprehensive review on the use of marble waste in concrete," International Journal of Advance Industrial Engineering, Vol.10, No.3, pp. 37-44.

[9] Mangi, S. A., Raza, M. S., Khahro, S. H., Qureshi, A. S., Kumar, R. (2022), "Recycling of ceramic tiles waste and marble waste in sustainable production of concrete: a review, " Environmental Science and Pollution Research, Vol. 29, pp. 18311–18332.

[10] Berdoudi, S., ElharrachH. B., Hebhoub, H. (2017), "Valorization and recycling of quarries waste as an addition in cement," IstrazivanjaiprojektovanjazaPrivredu, Vol. 15, No. 2, pp. 122-127.

[11] Singh, M., Srivastava, A., Bhunia, D. (2019), "Analytical and experimental investigations on using waste marble powder in concrete," Journal of Materials in Civil Engineering, Vol. 31, No. 4, 04019011.

[12] Patil, A., Pillai, A. A., Nair, A. P. (2022), "Use of waste marble sand in concrete, "International Research Journal of Engineering and Technology (IRJET), Vol. 9, No. 7, pp. 2614-2618.

[13] Benjeddou, O., Alyousef, R., Mohammadhosseini, H., Soussi, C., Khadimallah, M. A. Alabduljabbar, H., Tahir, M. M. (2020), "Utilisation of waste marble powder as low-cost cementing materials in the production of mortar", Journal of Building Engineering, Vol. 32, 101642.

[14] Li, L. G., Huang, Z. H., Tan, Y. P., Kwan, A. K. H., Liu, F. (2018), "Use of marble dust as paste replacement for recycling waste and improving durability and dimensional stability of mortar," Construction and Building Materials, Vol. 166, pp. 423-432.

[15] Ince, C., Hamza, A., Derogar, S., Ball, R. J. (2020), "Utilisation of waste marble dust for improved durability and cost efficiency of pozzolanic concrete," Journal of Cleaner Production, Vol. 270, 122213.

[16] Khan, K., Ahmad, W., Amin, M. N., Ahmad, A., Nazar, S., Alabdullah, A. A., Arab, A. M. A.(2022), "Exploring the use of waste marble powder in concrete and predicting its strength with different advanced algorithms", Materials,. Vol. 15, No.12, 4108.

[17] Kamseu, E., Akono, A. T., Rosa, R., Mariani, A., Leonelli, C. (2022), "Valorization of marble

powder wastes using rice husk ash to yield enhanced-performance inorganic polymer cements: Phase evolution, microstructure, and micromechanics analyses," Cleaner Engineering and Technology, Vol. 8, 100461.

[18] Medina, G., Sáezdel Bosque, I. F., Frías, M., Sánchez de Rojas, M. I., Medina, C. (2018), "Durability of new recycled granite quarry dust-bearing cements," Construction and Building Materials, Vol. 187, pp. 414-425.

[19] Attia, H. A., Farghaly, M. G., Saleh, A. M., Khalek, M. A. A. (2024), "For sustainability and a green environment: artificial marble granite as a value-added product from marble and granite waste residue", Journal of Al-Azhar University Engineering Sector, Vol. 19, pp. 254 - 268.

[20] Basic design of a residential building, Designers: Geniko - Prilep, Investor Mermer Imperial – Prilep, tech. No. 129/2022.

[21] Test report: Physical - mechanical properties and mineralogical - petrographic analyses of rock stone, AGI 09/21-1724, 2021 (in Macedonian).

[22] Singh, M., Choudhary, K., Srivastava, A., Sangwan, K. S., Bhunia, D. (2017), "A study on environmental and economic impacts of using waste marble powder in concrete," Journal of Building Engineering, Vol. 13, pp. 87-95.

[23] Parekh, R., Norford, L., Hughes, J. (2024), "Sustainable multi-story building design utilizing recycled marble and ceramic waste," World Journal of Advanced Research and Reviews, Vol. 23, No. 3, pp. 2879–2883.