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WASTE RECOVERY FOR ENVIRONMENTAL PROTECTION

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Abstract: The purpose of the research carried out by the authors is represented by the use of waste, such as that from agriculture, from wastewater treatment plants (WWTP) and from the fiber glass industry in order to obtain construction materials (bricks). The authors, as part of a research project, designed and tested new recipes for making bricks, starting from a series of existing waste materials in significant quantities. By using different types of waste and re–introducing them into the economic circuit, a better protection of the environment is ensured in the current context of climate change.
Keywords: wastewater sludge, agricultural waste, brick, wastewater treatment

1. INTRODUCTION

Significant amounts of waste are generated by economic activity. Waste management raises many environmental problems and for this reason, researchers are looking for solutions for the subsequent recovery of waste in order to achieve the concept of circular economy (Loehr, R., 2013; Reno, J., 2015). In the framework of the research carried out by the authors, solutions were sought for the valorization of some wastes from agriculture (He, J., Kawasaki, S., Achal, V., 2020; Duque–Acevedo, M., Lancellotti, I., Andreola, F., et al, 2022; Magar, J., 2020), those from the purification of industrial wastewater (Świerczek, L., Cieślik, B. M., Konieczka, P., 2018; Shi, S., Xu, G., Yu, H., Zhang, Z., 2018; Gherghel, A., Teodosiu, C., De Gisi, S., 2019) and from constructions in order to make bricks. It was desired to obtain bricks used in non–structural constructions.

Agriculture is the provider of a large amount of waste from agricultural plants. Agricultural plants can ensure the valorization of stems, leaves, seed pods. The most significant residues from the agricultural sector are: wheat, oat, rye and rapeseed straw; sunflower stems; green or dry leaves from various trees, from sugar beet, sunflower, fodder beet; chaff of various cereals (barley, oats, wheat); different seed coatings: walnut, hazelnut, sunflower seed shells; corn cobs and cobs; tomatoes, potatoes, soybeans, beans, etc.; leftover clover, green or dry alfalfa; vine rope from cleaning the vineyard; branches from cleaning fruit trees, etc (Souza, A. B., Ferreira, H. S., Vilela, A. P., et. al., 2021; Gudainiyan, J., Kishore, K., 2023; Chinnu, S. N., Minnu, S. N., Bahurudeen, A., Senthilkumar, R., 2021; Mo, K. H., Thomas, B. S., Yap, S. P., Abutaha, F., Tan, C. G., 2020; Hafez, R. D. A., Tayeh, B. A., & Abd–Al Ftah, R. O., 2022; Hassan, A. M. S., Abdeen, A., Mohamed, A. S., Elboshy, B., 2022). One of the possible ways to recycle such agricultural waste is to use it in industrial and construction applications. Agricultural waste has become increasingly used in construction due to the improved characteristics of the material obtained, mainly in terms of thermal and acoustic insulation, lower costs and environmental protection by reducing the use of conventional raw materials. The use in the composition of construction materials of plant waste such as cereal straws, sunflower stems, represents a solution to reduce pollution. These raw materials are widely available, easily renewable and lead to lower final costs of construction materials. Also, the use of vegetable waste, such as that obtained from shredding corn cobs or sunflower stalks, leads, in addition to protecting the environment by reducing the use of conventional raw materials, to obtaining a finished material with improved thermal and sound insulation characteristics, far superior to those of the base material. Research has been identified using sunflower seed waste and, more specifically, its inedible husk as a possible alternative material for building materials.

2. MATERIALS AND METHODS

As part of the activity, various agricultural wastes were researched, tracking the influence of different composition percentages on the properties of the final product. The choice of agricultural waste as an addition to obtain building materials in the form of bricks aims to print as an effect:

- the production of ecological bricks for ecological constructions, in accordance with the Romanian environmental legislation in force (Law 211/2011 on the waste regime; Decicion no. 856 / 2002 on the record of waste management and for the approval of the list including waste, including hazardous waste; Order no. 95 of February 12, 2005 regarding the establishment of acceptance criteria and preliminary procedures for accepting waste for storage and the national list of waste accepted in each class of waste storage);
- heat–insulating properties;
- soundproofing properties;
- reduction of the carbon footprint;
- the positive impact of these plant construction materials on energy consumption in buildings in the three phases: construction, operation and demolition.

The choice of the suitable agricultural material for inclusion in the brick matrix was made taking into account the research carried out at the national and international level and taking into account the quantities of each class of agricultural waste, generated in Romania. It can be said that cereal straws are in first place in terms of distribution and accessibility. On the next places are the sunflower and corn crops.

- Cereal straw (wheat, barley, oats, rice). Straws, by their composition, are a very good thermal insulator if they are compacted and uniformed in the construction elements of the building and have a very long life if they are kept in good humidity conditions – below 25%. (Zhou, Y., Trabelsi, A., El Mankibi, M., 2022) The thermal conductivity of straws can reach very good values and varies according to several factors, such as: the construction system (how they are placed in the structure), density, humidity, fiber orientation (parallel or perpendicular to the heat flow).

Straws are a good acoustic insulator and their performance varies depending on their density and the degree of homogeneity in the building elements. Straws are natural fibers rich in silicates that can last for hundreds of years under favorable conditions of humidity, oxygen and temperature, conditions that can be easily ensured by good design, execution and maintenance of the building (Koh, C. H. A., Kraniotis, D., 2020). So straws have successfully passed the test of time. Straws are a permeable material to vapors and water in liquid state and therefore do not need special protection such as vapor barriers. In addition, straws are a natural material and do not contain chemical compounds or other substances that could affect the health of the occupants in the long term. Straw is a by–product in agriculture, and as a raw material for construction, it is available in abundance, taking into account the fact that straw can come from several crops: wheat, barley, oats, rice, etc. Romania grows an average of 2 million hectares of wheat annually, being among the top exporters in the European Union. For each hectare, 2–5 tons of wheat grains and 4 tons of straw are harvested. This means that annually in Romania there are approx. 8.4 million tons of wheat straw alone. Straw can be purchased in bales of various sizes and shapes at low cost. The impact on the environment is measured by the energy embodied in a building material, representing the total energy consumed for the manufacture and commissioning of the building material. A complementary quantity that measures the impact of a material/process on the environment is the carbon footprint, which measures the CO_2 emissions related to the energy embedded in the building material. Straw requires very little energy to be harvested, baled, transported and/or processed into various forms for construction: bales, ground and blown straw, etc. Straws have 126 times less embodied energy than glass wool and 47 times less than expanded polystyrene, per kg of material. Therefore, straws are a very good alternative for sustainable and energy efficient constructions. The only drawback of straw is that to be used in a classic construction in the form of bales, it requires intensive work on the site and generates a lot of dust. But thanks to the available technology, several constructive systems have appeared in which straws are used very efficiently, cleanly and without much effort.

- Sunflower stalks and corn cobs. In a study on the use of agricultural waste in the process of obtaining construction materials, namely sunflower stalks and corn cobs, it was found that: sunflower stems have somewhat higher densities and better results in terms of compression, resistance to breaking, splitting, modulus of elasticity and resistance to freeze–thaw than those with corn cobs; vegetable components lead to a decrease in concrete density, as their content increases, regardless of the vegetable raw material used, sunflower stalks or corn cobs; the compressive strength was reduced due to the use of vegetable waste; tensile strength – compositions with sunflower stalks lead to significantly higher values than those with corn cobs, due to the difference between the two types of waste; elasticity of concrete compositions: higher modulus of elasticity when using aggregates from sunflower stems for compositions with up to 35% vegetable matter and vice versa for replacement rates of mineral components higher than 35%; vegetable waste resulted in reduced resistance to repeated freeze–thaw cycles; thermal conductivity is similar for both types of vegetable waste (Binici, H., Aksogan, O., Dıncer, A., Luga, E., Eken, M., Isikaltun, O., 2020).

The advantages of using sunflower stalks and corn cobs in concrete compositions, in addition to their ecological and sustainable character, are the significant influence in reducing density and thermal conductivity. The three types of plant materials proposed to be used in this study were selected because they are locally produced, easily accessible and cheap: cereal straw, sunflower stalks or corn/maize cobs. The choice of the optimal variant of plant material for the introduction into the matrix of the composition of the bricks is made according to the preponderance of one of these plant materials (cereal straw, sunflower stalks or corn), in the geographical area. In Romania, cereal straws are in first place in terms of distribution and accessibility. On the next places are the sunflower and corn crops.

The materials chosen by the authors to be used in making brick recipes:

- mineral materials: cement, sand;
- mineral waste: wastewater treatment sludge.

For the development of the final recipes that were experimented, the following table compares the concentration values of each component, proposed in by the authors (%) compared to those proposed in the specialized literature (%).

Table 1. Concentration values of each component of the material used for bricks fabrication

Waste	Type	Proportion	
		Proposed by the authors [%]	Proposed by specialized literature [%]
Sewage treatment plant sludge	Solid, humidity <80%	30–60	5–55
Agricultural waste	Solid, shredded	5–30	20–80
Cement	Solid	10–20	55
Sand	Solid	15–30	30
Glass fiber	Shredded	2–5	4
Clay	Solid	–	5–15

3. RESULTS

Figures 1–4 show some of the bricks obtained using agricultural waste, sewage sludge and glass fiber waste. Table 2 shows some characteristics of the bricks obtained with recipe no. 1, using different types of agricultural waste. All bricks obtained (with different types of recipes, different proportions of the component materials) were analyzed according to the model presented in table 2.

Figure 1 – bricks made with corn cobs – recipe 1

Figure 2 – bricks made with corn cobs – recipe 2

Figure 3 – bricks made with sunflower residues – recipe 1

Figure 4 – bricks made with sunflower residues – recipe 2

Physico–chemical analyzes were carried out for bricks with the best impact behavior and physical appearance suitable for further use as building materials. For example, the physico–chemical characteristics of the brick obtained using recipe 1 – corn cobs are presented in table 3.

Table 4 shows the physico–chemical characteristics of the bricks obtained using recipe 1 – sunflower stems. As far as can be seen, all the values obtained as a result of the testing of the bricks fall within the legal limits, without any exceeding. The bricks are considered safe for use in non–structural construction. Before entering the experimentation process, the sludge resulting from the pretreatment station was analyzed from a physico–chemical point of view, in order to compare with the values of the physico–chemical parameters necessary to be met (non–hazardous waste according to Law 211/2011, HG 856 /2002 and Ord. 95/2005). In this sense, the physico–chemical analyzes were carried out according to the work standards in force and the results obtained also respect the maximum limits imposed for the various component materials.

Table 2. Characteristics of bricks using recipe 1

Type of agricultural waste	Mode of behavior of agricultural waste	Physical aspect of the brick	Impact resistance, after 7 days of drying
Wheat straw	Difficult to shred and incorporate into the mix	Gray appearance, the waste is unevenly distributed, there are cracks in the brick structure after drying.	At the simple mechanical impact cracks appear in the structure.
Corn stalks and corn cobs	Corn stalks are harder to shred because of the leaves. The corn cobs are crushed very well and incorporated evenly into the mixture. The option of using corn cobs was chosen.	Gray in appearance, the waste is evenly distributed throughout the brick structure if only corncobs are used.	At the simple mechanical impact no cracks appear in the structure.
Sunflower stems	Chop them up very well and incorporate them evenly into the mixture.	Gray in appearance, the waste is evenly distributed in the brick structure.	At the simple mechanical impact no cracks appear in the structure.

Table 3. Physico–chemical characteristics of the brick obtained in recipe 1 – corn cobs

Constituents	Amount in waste		The limit imposed by Law 211/2011, HG 856/2002 for non–hazardous waste [%]	The limit imposed by Law 211/2011, Order 95/2005 [mg/kg]	
	[mg/kg]	[%]		inert waste	non–hazardous waste
pH	7,68 unit pH		–	–	Minim 6,0
Inorganic substances	–	79,03	–	–	–
Organic substances	–	20,97	–	–	–
Total organic carbon	21200,0	2,12	< 5%	30000	50000
chloride	214,0	0,0214	< 5%	–	–
Tone	864	0,0864	< 5%	–	–
Phenol index	< 5,0	< 0,0005	< 3%	–	–
fluoride	< 10	< 0,001	< 3%	–	–
Metals			Total metals < 3%	–	–
arsenic	< 1,0	< 0,0001	Total metals < 3%	–	–
Cadmium	< 2,0	< 0,0002	Total metals < 3%	–	–
Total chrome	< 50	< 0,005	Total metals < 3%	–	–
Copper	< 5,0	< 0,0005	Total metals < 3%	–	–
Molybdenum	< 20	< 0,0002	Total metals < 3%	–	–
Mercury	< 0,01	< 0,000001	Total metals < 3%	–	–
Nickel	< 10	< 0,001	Total metals < 3%	–	–
Lead	< 20	< 0,002	Total metals < 3%	–	–
Zinc	< 20	< 0,002	Total metals < 3%	–	–

Table 4. Physico–chemical characteristics of the brick obtained in recipe 1 – sunflower stems

Constituents	Amount in waste		The limit imposed by Law 211/2011, HG 856/2002 for non–hazardous waste [%]	The limit imposed by Law 211/2011, Order 95/2005 [mg/kg]	
	[mg/kg]	[%]		inert waste	non–hazardous waste
pH	7,68 unit pH		–	–	Minim 6,0
Inorganic substances	–	79,12	–	–	–
Organic substances	–	20,88	–	–	–
Total organic carbon	20800,0	2,08	< 5%	30000	50000
chloride	264,0	0,0264	< 5%	–	–
Tone	972	0,0972	< 5%	–	–
Phenol index	< 5,0	< 0,0005	< 3%	–	–
fluoride	< 10	< 0,001	< 3%	–	–
Metals			Total metals < 3%	–	–
arsenic	< 1,0	< 0,0001	Total metals < 3%	–	–
Cadmium	< 2,0	< 0,0002	Total metals < 3%	–	–
Total chrome	< 50	< 0,005	Total metals < 3%	–	–
Copper	< 5,0	< 0,0005	Total metals < 3%	–	–
Molybdenum	< 20	< 0,002	Total metals < 3%	–	–
Mercury	< 0,01	< 0,000001	Total metals < 3%	–	–
Nickel	< 10	< 0,001	Total metals < 3%	–	–
Lead	< 20	< 0,002	Total metals < 3%	–	–
Zinc	< 20	< 0,002	Total metals < 3%	–	–

Table 4. The limits of variation of the different materials and waste that will enter the composition of the bricks

Recipe	Industrial sludge [%]	Agricultural waste [%]	Cement [%]	Sand [%]	Fiber glass [%]
The variation (%) of the components in the recipe	30–60	5–30	10–20	15–30	2–5

In total, the authors tested 5 recipes for the manufacture of bricks with different compositions. Table 5 shows the limits of variation. In this article, the results obtained only for recipe 1 are presented, because the best results were obtained for this recipe.

4. CONCLUSIONS

The choice of recipe variants was made taking into account the data from the specialized literature, the experience accumulated through the research carried out in other European projects regarding the recovery of industrial waste. Five recipes were developed for experiments on the 3 types of agricultural waste:

- wheat straw;
- sunflower stems;
- corn stalks and corn cobs.

Taking into account the following elements:

- ease of processing by shredding experienced agricultural waste;
- degree of inclusion, uniformity in the mixture, compatibility of components;
- the physical appearance of the bricks;
- the impact behavior of the bricks;
- the data from the specialized literature regarding the beneficial effects of agricultural waste on thermal conductivity, density, elasticity, were considered to be the best bricks obtained by recipes 1 and 2 made with agricultural waste from corn cobs and sunflower stalks.

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