Recycling and reuse of chosen kinds of waste materials in a building industry

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Abstract. The article describes the current state of knowledge and practice in Poland concerning recycling as a method of reuse of chosen groups of waste materials in building industry. The recycling of building scraps is imposed by environmental, economic and technological premises. The issue of usage of sewage residues is becoming a problem of ever-growing gravity as the presence of the increasing number of pernicious contaminants makes their utilization for agricultural purposes more and more limited. The strategies of using waste materials on Polish building sites were analyzed. The analysis of predispositions to salvage for a group of traditional materials, such as: timber, steel, building debris, insulation materials, plastics, and on the example of new materials, such as: artificial light aggregates made by appropriate mixing of siliceous aggregates, glass refuses and sewage residues in order to obtain a commodity which is apt for economic usage also was made in the article.

The issue of recycling of waste materials originating from building operations will be presented in the context of the binding home and EU legal regulations. It was proved that the level of recycling of building wastes in Poland is considerably different from one which is achieved in the solid market economies, both in quantity and in assortment. The method of neutralization of building refuses in connection with special waste materials, which are sewage sludge that is presented in the article may be one of the alternative solutions to the problem of recycling of these wastes not only on the Polish scale.

1. Characteristics of recycling of building wastes

A building site is a place of origin of different reuses and their significant part is building waste. According to the communiqué of the Commission of the European Parliament of July 1, 2014 [1], building waste is a refuse of building processes, repairs or disassembly of building objects. This definition is identical to the understanding of a building waste as stated in the decree of the Minister of Environment on a catalogue of refuses [2], according to which building wastes are wastes from the group 17, i.e. "wastes originating from building, repairs and disassembly of building objects and road infrastructure (including ground and earth from polluted areas "). The mentioned decree assigns them codes from 17 01 to 17 09 including the subgroups of various wastes – from concrete, glass, plastics, wood, asphalts and tar products, metal scrap, metal alloy, soil and ground, insulation and structural materials, also these containing asbestos, gypsum, mercury, PCB, up to the wastes containing dangerous substances. In the case of the earth being excavated, it is considered as building waste when this earth or rock ruble not obtained in deepening processes is removed (or moved) as a result of investment work and there is no administrative decision or project documentation which determine conditions and ways of their usage.

The Parliamentary act on refuses [3] defines recycling as the process of salvage during which
refuses undergo a renewed processing to obtain materials or substances in order to use them in their original or similar applications. In the process of recycling the result of waste processing during production procedure is a defined product. According to [4, 5], in the years of 2004-2006 the total recycling of building and disassembly wastes in Poland amounted to 28.3%, whereas in other countries stood at in: the Netherlands 98.1%, Denmark 94.9%, Germany 86.3%. In the Netherlands and Germany there were recycled mainly concrete, bricks, pavement flags and asphalt, whereas in Poland the most often recycled materials are earth, wood, glass, metals, plastics and gypsum. The materials recycled in the years 2005-2006 as counted generally in tons per an inhabitant in Poland amounted to 0.13 t/person, and in the case of building waste - 0.01 t/person (0.1%), whereas in the Netherlands the total amount of recycling stood at 1.55 t /person, and in the case of building waste 1.14 ton/ person (74%) [5].

2. Recycling of building wastes vs. sustainable building trade
Recycling of building wastes, usage of materials with a long period of durability and limitation of usage of building materials which pollute the environment are the basic recommendations of the strategy of sustainable building trade and an element in the sustainable development.

The sustainable building trade was indicated by the European Commission in “The initiative of pioneer materials in Europe” [6] as one of the six markets of innovative potential, which fosters competitive ability and creation of new work places in European economy.

According to the general Directive on wastes [7 ], which is a basic legal regulation of the EU in the field of waste management, the intention of the EU is creation of “recycling society”, whose aim will be “an avoidance of producing wastes and using wastes as resources”. This aim requires not only promoting good practices and solutions in this sphere which are used in the countries of solid market economy, but also introducing the system of incentives fostering: the use of recycled materials in a concrete building projects, the selective collection of wastes and expansion of the indispensable technological infrastructure.

The criteria of the sustainable building trade were introduced to the requirements of the condition of the CE labeling of building materials. Since July 1, 2013 the Directive 305/2011 [8] is in force in Poland, which replaced the directive on building products. The new directive introduced a new basic requirement concerning sustainable use of natural resources as a result of recycling, of durability of buildings and usage of eco-friendly and re-processed materials.

3. The legal bases of building wastes management in Poland
The management of wastes of different origin, in which of building wastes is regulated by the Parliamentary act of Dec. 14 , 2012 on wastes [3] and the executive regulations to it. The act of wastes constitutes a transposition of successive EU directives concerning wastes, among them the Directive of the European parliament and Council 2008/98/WE of Nov. Gospodarowanie odpadami 19, 2008 "on wastes, repealing some previous directives [7]. The notion of wastes management means collecting, transport and processing of wastes (salvage and neutralization among them) and supervision of these activities, together with activities carried out by the sellers and brokers in wastes turnover.

In accordance with art. 3 of the Parliamentary act on wastes [3], the notion of waste comprises each substance or object, which will be sold by the owner voluntarily or compulsory. The common feature is this, that it is a product which is a result of economic activity or of man’s functioning that is useless and burdensome to the environment.

According to art. 18 of the Parliamentary act on wastes [3], the most appropriate approach to the problem of wastes management is prevention of their production and limitation of their amount. The second recommended solution is preparation of a material which as a waste is fit for recycling or another salvage process. In the case of impossibility of technological salvage or of economic unprofitability of a such activity, the last recommended solution is neutralization of a waste by e.g. its storage or burning.

The state of wastes management in Poland is a subject to periodical controls through the introduction of Poland-wide Plans of Wastes Management. The first Plan was launched in 2010 and comprised the years of 2010-2012. The amendment of the mentioned document entitled "The Upgrade of Poland-wide Plan of Wastes Management for the Year of 2014", has not been introduced
by a resolution so far [9]. Each group of wastes is analyzed individually both in the Plan and its upgrade. In the case of building wastes, the following problems were determined:

- the wastes are not collected selectively,
- the collection of wastes does not include all producers,
- there is too high percentage of wastes which are neutralized through dumping or storage in relations to the existing capacity of recycling plants.

4. The duties of producers and owners of building wastes

The Parliamentary act on wastes [3], in art. 27 describes the general scheme of handling building wastes by their owners and producers. A building contractor, because of their activity connected with production of wastes which undergo on a building site an introductory processing and change of characteristics, is an original waste producer. The owner, however, may be at the same time a waste producer, but they do not have to be. A waste owner is a subject, who has the proprietary right to the land where the wastes are stored.

According to art. 27 of the Parliamentary act on wastes [3], a producer (a building contractor) is obliged for activities connected with management of wastes produced in the building trade. A contractor or an owner while giving over the wastes to the next owner transfers to them the duty of wastes management, but it does not pertain to the subject offering the service of transporting wastes between the successive owners (responsibility for the wastes lies then on the producer till the time of taking them over by the next owner). In the context of waste circulation and the methods of handling it, a special attention should be paid to the role of “the intermediary in wastes turnover”, understood as a party which organizes processing of wastes on behalf of other parties, however they do not need to take the wastes in physical possession. According to art. 27 of the Parliamentary act on wastes [20], the wastes seller and the turnover intermediary do not bear the responsibility for the management of wastes, they are not the owners of wastes – thus the role of an intermediary is often reduced to the transport of wastes from the producer to the owner.

The party which handles wastes should have an appropriate permit to carry out such activity, but the mode of their conduct should be characterized by the conformity with the principles of wastes economy, of environment protection and of local development plan. The priority should be salvage of wastes, and in the case of a lack of such possibility, their neutralization. Giving over the wastes to their owner, the producer – a contractor of building work should get a chart of taking the wastes over. It is a document confirming neutralization and stating that the responsibility of wastes management lies now on a consecutive owner.

Both the original producer and the wastes owner are obliged to cover the expenses of wastes management [3]. A special kind of building wastes constitute those which can be given over to individuals for utilizing them for their own needs. Such cases are regulated by the Decree of the Ministry of Environment of Oct. 10, 2015 on the list of wastes, which individual people or organizations that are entrepreneurs can re-utilize for their own needs and on the methods of their salvage [10].

In the case of managing debris or other wastes by the contractor, the contractor is obliged to submit a written statement confirming the method of their usage, but the range of his/her professional activity takes into account such possibility.

The main aim of wastes management – prevention of their production, is the basis for different strategies of the management of production, which focuses on an appropriate strategy of material delivery management and on decreasing of amounts of wastes. The strategy of so-called “lean management” in an enterprise is based on the concept of jettison of the excessive ballast, i.e. the activities which are not directly connected to production, with the care of avoiding squander. It assumes creation of simple organizational structures and elimination of additional activities through giving them over to other firms (e.g., marketing services, assessment of products quality, etc.). The strategy proposes so-called “lean production”, aiming at producing the sufficient amount of materials while using the minimal amount of means of production – devices, workers, materials. The main principles of the concept is avoidance of wastage through continuous rationalization of production in terms of cost saving and focusing on clients expectations. The basis of the strategy comprises also an appropriate flow of materials – the sense of production lies in clients order, and the effect is optimization of production [11, 12, 13].
The system of wastes management on a building site, because of their diversity as well as the requirement of specialist knowledge on their partition, is a difficult task. The system should be based on the analysis of wastes composition, on the coordination of their partition, establishment of proper zones of their segregation on inner recycling stations, on supplying appropriate containers by a specialist firm, and on transporting the wastes out of the building site in order to handle them properly (the schedule of the disposal should be fixed at the end of a working day to avoid disturbances on the building site.) The exemplary first building work done with the application of this system of wastes management was that of Stena Recycling w Business Garden Poznań, assuming among others 75% of raw materials salvage and lowering the investment costs by limiting production of wastes and re-usage some of them, as well as appropriate work safety conditions (collecting wastes in appropriate containers, which were emptied in time, eliminating the problem of overfilled containers and carelessly thrown wastes on the building site). Stena Recycling firm estimates that the savings from the proper wastes management on a building site of the area of ca. 20 thous. m$^2$ can amount to 200-500 thous. złoty [14].

5. Characteristics of predisposition for salvage and recycling of chosen building and special wastes

According to [9] in 2011 as much as 8236.9 thous. Mg building wastes was produced, in the successive years the amount of wastes decreased considerably: and in 2012 stood at 5756.2 thous. Mg and in 2013 5741.6 thous. Mg (Tabele 1). Such considerable differences resulted from the realization of large building investments connected with the organization of EURO 2012 Championship.

| Number and name of wastes sub | The mass of building waste in thous. [Mg] produced in years 2011-2013 |
|-------------------------------|--------------------------------------------------------------------------------|
| 17 01 - Building materials and elements wastes, road infrastructure wastes (concrete, bricks, ceramics) | 679,1  481,9  608,6 |
| 17 02 - Wooden, glass and plastic wastes | 15,7  16,0  23,1 |
| 17 03 - Asphalt, tars and tar products wastes | 24,5  14,7  67,0 |
| 17 04 - Metal refuses and metal scraps, alloys | 635,7  568,8  545,5 |
| 17 05 - Soil and earth, in which these excavated during | 6859,4  4349,3  4475,5 |
| 17 06 - Insulation materials and structural materials containing asbestos | 5,8  4,4  2,8 |
| 17 08 - Structural materials containing gypsum | 0,1  0,0  0,0 |
| 17 09 - Other building, repair and disassembly wastes | 16,6  321,1  19,1 |
| Total | 8236,9  5756,2  5741,6 |

According to the general directive on wastes [7], up to the year of 2020 as much as 70% of the mass of the building wastes in Poland is to be a subject to salvage. In accordance with this fact, the ever-increasing attention is paid to the intensification of undertakings connected with the usage of material wastes in their total or partly.

Table 2 shows the data concerning the salvage of building wastes in the years of 2011-2013 [9].

| Year | Refuses produced per a year in thous. of Mg |
|------|-----------------|
|      | In all         | Subject to salvage | Neutalized |
|      | Total          | Neutralized        | Stored     | Refuses gathered so far |
| 2011 | 8 236,9        | 7 968,0            | 117,8      | 0,6  117,2  -  151,1  1 982,5 |
| 2012 | 5 756,2        | 5 603,1            | 63,6       | -   60,4  3,2  89,5  2 029,1 |
| 2013 | 5 741,6        | 5 616,8            | 64,4       | 0,1  63,3  1,0  60,4  2 005,2 |

The data indicates that the level of the building wastes salvage in 2011, 2012 and 2013 stood respectively at: 96.7%, 97.3% and 97.8%, and thus the goal for the year of 2020 was achieved. In
fact, this level was reached already in 2006. The realization of large cubature investments made a contribution to it, as well as those in road-making and on the railway, which on the one hand resulted in considerable increase of the production of the wastes from group 17, on the other hand it provided opportunity for their re-use.

Composite materials, because of their various composition they feature a varied pace of wearing out, and the weakest of them decides the termination of their use. The worn out materials of a such composite are difficult for separation, and after their crumbling they feature a worse quality, which limits the possibility of their renewed usage.

Wood is characterized with a high degree of salvage and the possibility of use in an original or similar application. This material often undergoes downcycling i.e. using in a more degraded form. The level of wood salvage is proportional to the size of its cross-section, i.e. large balks are more often salvaged than small-dimension timber elements [6,15].

Building debris is the most often salvaged and recycled building material, used secondarily as aggregate. There are two ways of producing recycled aggregate: on the site of disassembly or building work, of rebuilding or repair, and ex situ – in salvage works. Considerable savings, in which of the transport cost, may be obtained by the production of recycled aggregate on the site of its origination. The precise amount of recycled aggregate produced in Poland is not known. The Polish Association of Aggregate Producers Employers estimates that the production capacity of recycled aggregates in 2020 will reach ca. 20 m tons which will constitute ca. 10 % of the total aggregates production. It may be assumed that the significance of recycled aggregates will increase. The examples of other countries indicate it, and obliged: running out of material resources, the increasing number of disassembly work connected with the road renovation in Poland and environment protection. In some European countries (e.g. Germany) there are legal regulations determining what part of waster raw material obtained in disassembly of buildings must be re-utilized. In some others, in spite of a lack of official regulations, the value of these materials appreciated. This tendency is present also in Poland. The recycled aggregate is used most often wile: making introductory underlay and the connecting layers of roads, while forming and compacting grounds (brick debris with lime), hardening of yards, car parks and service roads, and while preparing lower strength concretes. The basic factor which hinders the usage of building debris aggregate as a high-value raw material is its changeable physical and chemical parameters, which results in a high level of uncertainty about its strength parameters.

Brick is a typical material designed for recycling. The level of salvage of this material depends on segregation of different kinds of bricks during disassembly. The highest cost of a renewed use of bricks is their cleaning.

Steel is a material which undergoes recycling easily through the thermal process. Presently ca. 40 % of steel from disassembly work is salvaged for recycling [6].

As for plastics, the building trade is a buyer of over 20 %of plastics production. Because of their characteristic long term usage, plastics are the source of a large amount of wastes. Today the recycling possibilities of plastic wastes are considerable – the material, the raw material and the energy salvage is carried out. The choice of the utilization process depends on the qualitative composition of a waste. Plastic wastes originating from the selective collection are most often a subject to material salvage (the homogeneity and relative purity of waste are required to make a product which meets the quality requirements), and raw material salvage when the wastes are processed to the form of polymers, heavy oils and technological gases.

A plastic waste which underwent the process of an introductory processing makes a homogenous, segregated granulate used successfully as an additive to a primary raw material, usually in the share of 10-30%.

PCV is a commonly used hard plastic in the building trade, applied among others to production of windows and doors, pipes, cables and floor coverings. Another, equally widely used plastic is Styrofoam (expanded polystyrene). This is the material used in making thermal and acoustic insulation and fire-resistant building divisions. This material features a wide possibility of recycling depending on the stage of its production and usage, which is shown in Fig. 1.
In production plants the wastes which are produced in cutting styrofoam to size are directly turned to the earlier stages of production and are re-used. Because of its properties, crumbled styrofoam may be used as insulation backfill everywhere, where air cavities occur. The other way of its usage is for making of soil fluffy, which during building work losses its dimensional structure and becomes devoid of air. Therefore the Styrofoam wastes are ground (the diameter of such produced gains amounts from 1 to 30 mm), and then it is used as a drainage or fluffy material to improve aeration and water infiltration in heavy grounds. Crumbled styrofoam may also be a partial replacement for building aggregates in preparation of plasters and mortars. An addictive of fine fractions allows to eliminate or to restrict the impact of thermal bridges, increasing the general thermal insulating capacity of a division. Styrofoam wastes may be also used for production of insulating materials, e.g. styrozole-water-resistant insulating material of the technological properties which surpasses properties of other materials (because of its water-tightness of 1.2 MPa, relative elongation 425–560%, and adhesion). Because of its properties a such insulation may be used in various conditions, as horizontal and vertical water-resistant insulation of building divisions, also these on the ground.

On the industrial scale Styrofoam wastes are used to production of light concretes (styro-concrete) and cement-styrofoam mortars (Polytech). Depending on the proportion of cement and Styrofoam, there are three classes of mortars: 20/80 (contains 200 kg of cement and 800 dm$^3$ of styrofoam), 30/50 and 35/50. Polytech mortar is used in: dwelling and industrial building trade, preparing floor underlay, leveling layers, insulating courses on floors and roofs, thermal insulation of balconies, decks, swimming-pools as well as insulation of other horizontal and vertical divisions.

Destroyed in incineration plants styrofoam wastes may be a valuable fuel - 1 kg of Styrofoam allows to save 1.3 l of oil [15]. Plastics are also used as modifiers of bitumen mixtures in road-making in order to increase the strength of the surface [6,15,16].

Asbestos-cement sheets do not undergo recycling. In the seventies they were mainly used as a roof and elevation sheets. Since 1997 in Poland there has been a ban on usage of asbestos products, and up to 2032 the program of co-financing of the activities connected with its removal is to take place. Up to 2010 the only way of managing asbestos wastes was their storage on appropriately secured yards. Presently there are possibilities of utilization of materials containing asbestos, but the interest in this technology is removed because of the high costs [4]. In 2009 the Council of Ministers passed a resolution on establishing of the Program of Cleaning Poland from Asbestos for 2009-2032 (Polish: POKA).

The principles of removal of asbestos-cement sheets is determined precisely in the Decree of the Minister of Economy, Labor and Social Policy of April 2, 2004 on the methods and conditions of a safe usage and removal of products containing asbestos [14]. According to the decree,
a firm which removes asbestos from a building becomes a producer of dangerous wastes and it must at least have a decision of a district head approving the "Program of dangerous wastes management" keep an appropriate documentation of turnover of dangerous wastes. These wastes should be collected selectively, they must not be mixed up with other wastes. They can be removed only by people, who were trained by authorized institution on Occupational safety and health. In Poland, contrary to other EU countries, there is no obligation of having a special licence for the work with asbestos containing materials.

Apart from salvage of building materials, research programs are also carried out in Poland focusing on the recycling of other groups of wastes in order to produce new building materials. Elaborated by the Institute of Mechanization of Building Industry and Rock Mining from Warsaw (Polish: IMBiGS) the method of producing light aggregates from building, industrial and special wastes, is an innovative solution on the global scale. Sewage sludge presents an important problem because of its negative impact on the environment, connected with the contain of heavy metals, microorganisms and contamination retained in the process of sewage treatment and at the same time it considerable volume.

The technology of producing artificial light aggregates on the basis of sewage sludge, uses as the principal ingredients:
- silica wastes in the form of powders of the diameter of < 0,063mm, produced during exploitation of natural aggregates and presently unused in economy (exclusively stored);
- waste glass – flux reducing the temperature of thermal synthesis of aggregate, obtained during industrial procedures;
- sewage sludge, which reduce the energy intensity of a thermal process through its heat of combustion of 3MJ/kg and give porosity to the aggregate.

Thanks to the mentioned composition there is a possibility of choosing proportion of ingredients in order to obtain appropriate properties of the aggregate, and the possibility of arbitrariness of the granulate size. The technology of sintering of aggregates requires the temperature of 1200°C, which guarantees neutralization of all microorganisms occurring in sewage sludge and also makes them free of cinders, however heavy metals are inbuilt in the silicate crystal structure.

According to the research done by IMBiGS [K7], artificial light aggregates on the base of sewage sludge feature the following mechanical– physical properties enabling the usage in building trade: bulk density in loose state of <1200 km/m³; density – 550 mg/m³, absorbability– 33.0%, crushing resistance – 3.1 MPa, frost resistance - <1.0 (%), content of overall sulphur – 0.1%, the content of sulphates dissolved in acid – 0.0, washing out of dangerous substances - determination of the content of dangerous substances in water solutions: chromium (Cr) < 0.05-0.11 mg/l; cadmium (Cd) < 0.02 mg/l; nickel (Ni) < 0.1 mg/l; lead (Pb) < 0.2mg/l; zinc (Zn) < 0.09 mg/l [7, 17].

Artificial light aggregate on the base of sewage sludge, produced on the industrial scale, will be delivered to the client mainly in the form of pellet or granulate. The light color and light weight of the product ensured it an interest on the part of firms creating ecological "green terraces", and also of gardeners, farmers and florists who use it as a drainage material. The material can also be used to produce light concretes (under research) and as a filler in filters. It seems that there will be more applications of this material.

Presently in the Institute of Building Engineering of Warmia and Mazury University in Olsztyn the research is being done on porosity, absorbability, adsorption and roughness of light aggregates containing sewage sludge.

6. Conclusions

Building industry is a trade which generates big amounts of building wastes, therefore the question of their management must be solved reasonably. The aim of reinforcement of efforts for the sustainable development in building industry requires a consistent strategy in the field of building wastes management.

The constraints in renewed usage of wastes issue mainly from an inappropriate form of their collection – too little attention is paid to the introductory segregation. It is necessary to a introduce system solution for creation of a desirable attitude among investors and constructors who produce building wastes during construction work, repairs and disassembly of buildings and of road infrastructure concerning the proper management of these wastes.
Only a small part of building wastes is further processed for building and road aggregate, constituting a complement of the market of natural raw materials, and thus also the protection of the natural resources of our planet. The Styrofoam wastes maybe be used easily by every consumer without a damage to the environment. In the case of hard plastics, the best solution is an introductory segregation and giving them over to utilization.

The salvage of building wastes in Poland stands at 70% by weight, hence the aim for 2020 foreseen in the Poland-wide Program of Wastes Management was achieved.

The level of recycling of building wastes is an indicator, showing if a given nation is considered as eco-friendly and if it carries out polices which fulfill the principles of sustainable growth. The recycling of building wastes in Poland is considerably different from that of the solid market economies, both in quantity and in assortment. The lack of regulations which force the producers of building wastes to reach a certain level, as it is the case in the group of other wastes (e.g. those originating of cars which are no longer in use), is not a motivating factor to efforts in this field. There is also a lack of effective promotion for re-use of recycled materials in given building applications.

Prepared by the Polish scientists an innovative method of producing light aggregates in the process of thermal synthesis of community, industrial and building wastes may constitute one of alternative solutions of the problem of recycling of these wastes not only on the Polish scale.

It is purposeful to continue analyses and research of the possibilities of prevention of building wastes production, with special attention to recycling.

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