

RECYCLING OF BUILDING MATERIALS: AN OVERVIEW

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ABSTRACT

The present article aims to investigate the issue of recycling building materials. The subject area was determined with regards to building materials' use and the related environmental costs. The research methodology comprised source materials, as well as the analyses and experiments conducted by the authors. The obtained research results present the current trends and definitions of terms related to the presented issues. Re-development potential and methods regarding the most typical building materials, as well as the main architectural trends towards using recycled materials, are presented in the article.

Key words: ecology, environment, recycling, re-consumption

INTRODUCTION

In the 21st century, challenges related to the progressive degradation of the natural environment emerged. Nowadays, more than ever, environmental protection issues have become a leading concern in the field of human activities related to climate change, air pollution, and use of the natural resources (Skowroński, 2015). The industrial revolution enabled the mechanized production of materials and their mass-scale manufacturing. This process continues; it determines how we design, manufacture, and terminate the life of everyday products and buildings. Such factors as environmental costs resulting from natural resources, the energy required in the process of materials' manufacturing, or waste generated in the aftermath of this production have not been important in these processes so far. On the other hand, growth, meeting the demand for these materials, and profit from their production were all that mattered.

This production model, used for decades, has led to environmental degradation in many areas of the world

through contamination of the environment by water, soil, and air.

The construction sector exerts a significant impact on environmental costs; the share of this part of human activity in the production of generated waste amounts to nearly 36% (Eurostat, 2020). Most of this waste comes in the form of demolition debris. Apart from the composition of this waste, its volume and therefore related storage problems pose a considerable issue.

Building construction-related activities exploit natural resources and require significant amounts of energy to produce materials. At the same time, by-products of these processes are discharged into water and the atmosphere. The energy expenditure necessary to transport heavy and large-volume construction elements is also crucial.

The entire process begins with obtaining raw materials, often at a considerable distance from their final implementation site, which incurs the extraction energy and transport costs.

The ongoing construction processes, urban sprawl, population growth and therefore the demand for the

construction of new buildings and the renovation of existing ones cannot be stopped or slowed (Firląg, 2019). In the 1950s, cities were inhabited by 750 million people; currently, the urban population totals about 4 billion that is about 55% of the entire world population. According to the United Nations Human Settlements Programme (UN-Habitat), it is estimated that cities generate 70% of the global GDP, consume 60% of the energy, and produce 70% of the global waste. Therefore, solutions should be considered to reduce the costs borne by the environment to the necessary minimum.

METHODOLOGY

As a result of preliminary research, the main issues of the topic were outlined, while the scope of possible research materials was determined. The research subject refers to the use of building materials in the recycling process, the minimization of waste generation once the building's life cycle is over, and alternative raw materials' use in construction production, with regard to limited natural resources.

The analysis of literature materials, as well as the author's observations and personal experiences, was conducted. In the initial research stage, general concepts that determine the directions for using raw materials and materials in relation to environmental issues were defined. Subsequently, an attempt was made to analyse the most typical construction materials in terms of their processing potential or their application different from the original one. The analysis was supplemented with examples. The architectural trends that apply recycled materials were presented sequentially, together with the area and method of their application.

RESEARCH FINDINGS

Sustainable development

The concept was first coined in 1987. Three primary areas that influence economic sustainability were described. These include the following: the natural environment and the requirement to strive for a careful use of its raw materials in such a way as not to cause degradation or the emergence of negative factors in its remaining areas; an economy based on equitable ben-

efit distribution to all users of the environment; and a society characterized by equalizing opportunities and raising the living standard (World Commission on Environment and Development, 1987). Although these guidelines are rather general, they indicate issues to be considered in each action likely to impact the above-mentioned areas.

Circular economy

Its assumption is based on discontinuing the linear usage of materials and raw materials. Currently, the construction process involves producing material with raw materials and energy, implementing the product, its eventual demolition, and storing waste "from the cradle to the grave" (McDonough & Braungart, 2002). Breaking the linearity of this process by reusing some or the total of the material by means of "the cradle to the cradle" recycling may be the proper solution to this problem (McDonough & Braungart, 2002). Such an approach makes it possible to reduce the burden on the environment and extend the life of previously obtained raw materials so that these products are turned into waste as late as possible (Kozłowska, 2013).

The 3xR principle

In the second half of the 20th century, with rising awareness of humanity's impact on the natural environment, a waste management solution was identified to mitigate the negative effects of human production. This waste management hierarchy consists of three basic aspects: reduction, re-consumption, and recycling. Reduced consumption refers to the production of materials to the necessary minimum. Re-consumption, on the other hand, can be defined as reusing materials and products to extend their life. Recycling comprises allocating used material for reuse or their subsequent processing. The sequence in which these processes occur is important; it begins with reducing the demand for new products, which is responsible for generating the highest environmental costs during the extraction and production process of raw materials.

Possibilities to use the materials

Pro-ecological solutions that enable material reuse in various areas of everyday objects are at an advanced level. However, in the case of building materials, the

situation slightly differs. This is mainly due to the high cost of applying such solutions compared to traditional construction materials (Skowroński, 2011).

One of three directions can be assumed regarding material reuse, namely: new products that incorporate recycled materials or are made entirely of waste materials; the use of dismantled construction elements in new investments; and the use of buildings or their components, in part or as a whole, on site, by means of renovation of the existing buildings. The latter seems to be the most practical solution in terms of natural environment protection issues. Unfortunately, it is also burdened with high financial costs incurred by adapting the facility to modern requirements.

Metals

The manufacturing process of metal elements is energy-intensive, from the extraction of the ore for its production to the final product. However, metal is the material with the greatest potential for further

processing, remelting, and use in a different form. Importantly, this process may be performed multiple times, extending the life cycle of the raw materials. The value of metal may be evidenced by the fact that it is a desirable material obtained from demolitions, as metal elements rarely end their life cycle in landfills. In contrast, metal components are mostly reprocessed. In this respect, steel structural elements with a standardized cross-section have the greatest potential, as they can be implemented in other structures upon disassembly. However, standards regarding the steel class and strength parameters of such elements must be met.

Wood

Wood is a versatile material whose applications include structural elements of beams, columns, prefabricated elements, roof trusses, façade and roof coverings, window and door joinery, and interior furnishings. As in the case of metals, wooden elements can be recovered



Fig. 1. Old barn wooden covering

Source: https://static.dezeen.com/uploads/2016/08/rural-loft-by-digsau_dezeen_2364_ss_7-852x609.jpg [accessed 22.07.2022].

for other investments in an unchanged form, e.g. structural beams and columns, provided their condition is satisfactory, facade cladding, and joinery elements. Waste wood whose condition is too poor to be incorporated into another facility can be used as a raw material for products such as MDF or OSB boards, or for paper production. In recent years, a widespread application of recycled wood is to use wooden facades of old farm buildings for new investments in public utility buildings and residential buildings as a facade covering. Wood subjected to natural aging processes gains value due to its texture and colour, which cannot be obtained artificially or planned (Fig. 1).

Masonry elements

Mortar-joined masonry elements offer a certain recycling potential. This applies mainly to facade coverings of higher aesthetic qualities, mainly

bricks and stone elements. To a lesser extent, the recycling potential emerges with regard to elements such as ceramic, concrete, and silicate blocks. However, the problem stems in this case from the method of joining such elements, i.e., with mortar or glue. Additionally, their brittleness and, usually, an additional layer of plaster may pose difficulties. Currently, this group of materials has a rather low recovery potential when it comes to masonry elements of a demolished building. Therefore, most of this material ends up as construction debris. Additionally, it is worth considering the amount of work required to recover small-size elements. Recycling may be unprofitable in the case of materials with little aesthetic value. One desirable material in this category is the demolition brick which can be used in new investments or as a material for renovating historic buildings (Fig. 2).

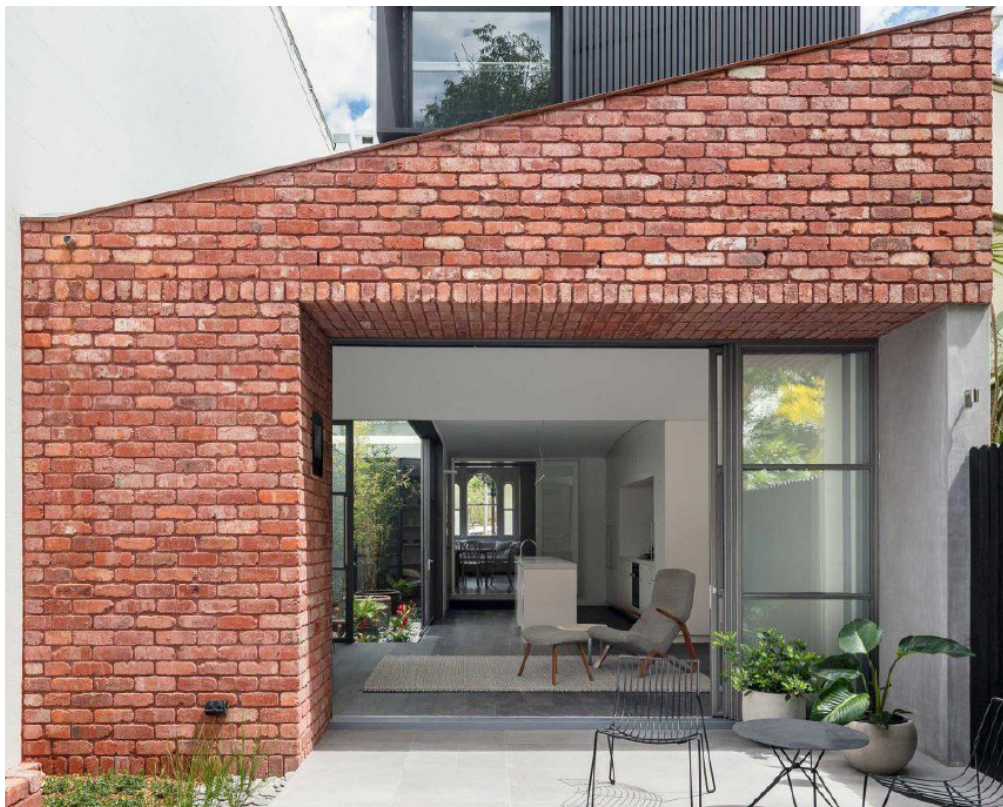


Fig. 2. Recycled brick

Source: <https://thebrickpit.com.au/wp-content/uploads/2019/11/Glebe-House-web-main-1024x682.jpg> [accessed 22.07.2022].

Glass

Glass used in construction processes mostly in the form of elements single glazing panes of such elements as internal doors, glass packages of two and three chambers in windows, elevation panels, and elements of glass railing. Recovering these materials in an unchanged form and reusing them in another facility is minimal for several reasons. Firstly, it is difficult to disassemble and transport glass in such a way as not to damage fragile glass elements. Secondly and more importantly, the parameters of these elements pose problems, especially with regard to the thermal insulation properties of glass packages, which often fail to meet the requirements for newly erected buildings.

Glass is recyclable, but the process requires significant energy expenditure in the event of glass melting. Another possibility to reuse glass waste in new materials is by grinding and implementing it as an aggregate additive to concrete and asphalt, granulated glass in plasters, decorative elements such as terrazzo, in the production of interior furnishings (table countertops, furniture boards). Glass can also be processed as an insulation material in the form of glass wool.

Concrete

Concrete is the most widely used construction material. This mixture of cement, water, aggregates, reinforced concrete reinforcement steel and chemical additives has the largest share of all materials in the newly erected buildings. However, the material is burdensome to the natural environment. The consumption of natural resources, their extraction costs, and expenditures on processing and transport all significantly impact the environment. The life cycle of concrete components usually ends in construction debris. It is impossible to recover individual components from concrete; therefore, the material has a relatively low value as a demolition material; it is mainly treated as demolition waste.

The supply of natural resources added as a component to concrete, e.g. aggregates such as sand, is shrinking. Therefore, it is necessary to look for alternatives to concrete components. Ideally, they should be ensured that such elements are made of recycled ingredients. Research on such solutions is currently being conducted, whereas these alternatives have not yet been widely applied. Studies undertaken at the

University of Cambridge have led to the development of a technology in which plastics are used in concrete production to replace sand. To ensure the strength of the concrete mix, only 10% of the sand was replaced by plastics, which is not much, but marks a step in the right direction (Skowroński, 2015).

Prefabricated standardized systems may offer a solution to the lifetime of problem of the concrete elements. Such systems may prove flexible enough in terms of their connection and composition to be implemented in various architectural assumptions; once the lifetime of the building has ended, their elements could, upon disassembly, be implemented in other buildings. Prefabricated concrete elements may be versatile enough to be widely applied in various types and forms of buildings. Standardized concrete elements are available for bridge and cubature structures based on the column and beam system; these elements can be reused in other investments.

Plastics

Plastics are widely used in construction in the form of PVC, HDPE, polypropylene, and polystyrene elements; they are used in the production of window frames, pipes, thermal insulation, and foams. Depending on the composition of given plastic materials, it can be reprocessed, mostly in the form of insulation materials, window frames, synthetic coatings, internal lining elements, carpets, tiles, and installation elements (Janiak, 2017).

CASE STUDY OF RECYCLED MATERIALS BUILDINGS

Two main trends may be observed in building architecture (Świątek & Charytonowicz, 2005).

The conventional trend assumes that recycled materials serve as an additive introduced into the structure of the facility. This material is non-distinguishable and does not define the object's architecture. In line with this trend, plastics may be used as additives for concrete, facade coverings, processed wooden, or insulation elements. However, such components are not the main elements of a given building; its style is not defined by these components. They only constitute a filling for the building material.

The expressive trend, on the other hand, clearly exposes the recycled material to create the character of the object. It is an alternative solution to the conventional one; it uses the principle of upcycling that is, increasing the value of elements usually treated as waste. Such components may not necessarily be waste originally used in construction; they can also originate as everyday items, such as glass and plastic bottles, furniture elements, paper and plastics. The application possibilities and methods to reuse these materials are limited only by the imagination of the creator.

Within both the conventional and expressive trend, the use of recycled materials may be conditioned by additional factors, such as the availability, cost, material situation, or the designer's willingness to take a position. The 2013 Rising Sun pavilion in Hong Kong, project by Daydreamers Design, is an example of such an approach. The dome-shaped structure covered with PET mineral water bottles forms a temporary pavilion used during the Chinese Mid-Autumn Festival. Each bottle has LED lighting that provides visitors with additional visual impressions (Fig. 3).

The 2008 Papierhaus PHZ2, project of Dratz & Dratz Architekten in Essen presents a similar solution, in which the raw material from recovery is brought to the forefront. In this project, blocks of compressed wastepaper were incorporated into the facade. The facade is distinguished by its texture and colours, while the concept and the source of the material are visible (Janiak, 2017; Fig. 4).

By applying material solutions based on waste upcycling, these two projects illustrate the creators' manifesto, thereby providing space for discussion on waste re-use. Such solutions are needed to bring waste management issues to attention and demonstrate the possibility of non-obvious re-use of waste. However, widespread application of such concepts in construction is unlikely; their aesthetics, durability, and usability are debatable, especially in developed countries.

The situation differs in middle-developed and underdeveloped countries, where the use of waste results from purely economic factors and the lack of building materials. Inhabitants of poverty districts and slums use the materials available to create shelter and



Fig. 3. Rising Moon pavilion

Source: <https://www.archify.com/hk/photo/detail/154776> [accessed 22.07.2022].



Fig. 4. Paperhouse

Source: <https://inhabitat.com/wp-content/blogs.dir/1/files/2012/12/dratz1.jpg> [accessed 22.07.2022].

living spaces. Most commonly, they apply sheet metal, plastics, and masonry elements. In this case, the aesthetic factor is less significant than the construction economy.

The economic need gives an incentive to search for solutions and use existing structures, not only in terms of material. The amount of work required to build a building provides an important financial factor in any investment. The use of ready-made components, such as shipping containers or construction containers, may be seen as one of the solutions to reduce these costs and construction time. Their modularity and self-supporting structure offer great opportunities to arrange the building layout in a relatively short implementation time. An additional advantage of this solution lies in the possibility of further re-use of containers in subsequent investments. The disadvantage, in turn, stems from the difficulty of shaping the object's form freely, owing to large container modules.

The Implant investment at ul. Chmielna 75 (75 Chmielna Street), project by Jakub Szczęsny, Warsaw is an example of a successful application of this modular technology (Fig. 5). The complex, designed entirely of standardized modular elements with a steel structure, provides space for cultural, gastronomic, and service, similar to analogous projects in other parts of the world, such as ArtBox in Hong Kong, or Boxpark in London. This solution offers an advantage related to the ease with which the building's functions and space can be transformed, depending on the changing social and economic factors. Upon the end of the building's life cycle in this function, its layout may be changed or dismantled, whereas the structure may be used in another investment.

Extending the life of buildings is a desirable trend in architecture. This goal can be achieved in two ways. Firstly, by striving for a universal design that allows the building's function and internal layout

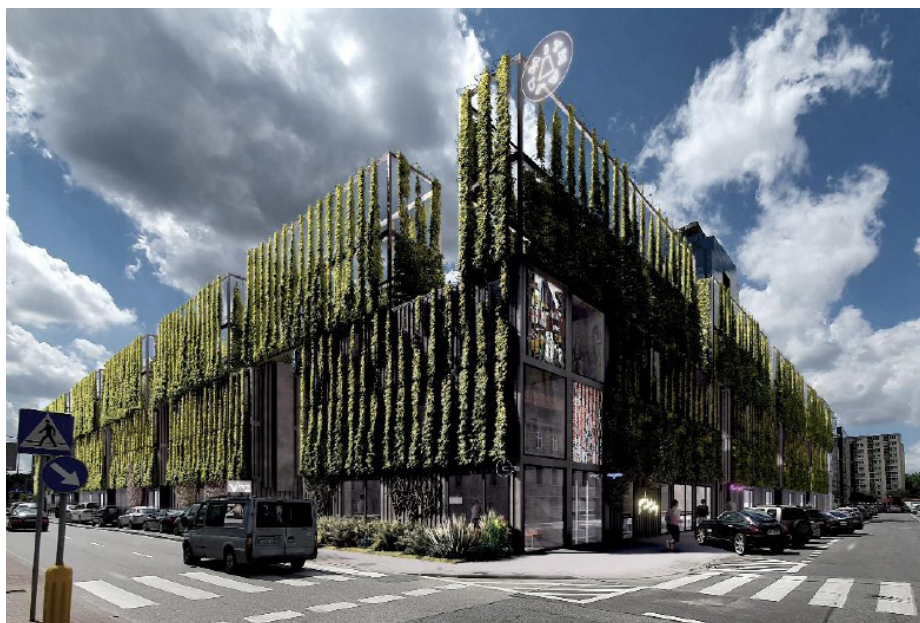


Fig. 5. Implant building

Source: www.implantwarsaw.com [accessed 22.07.2022].

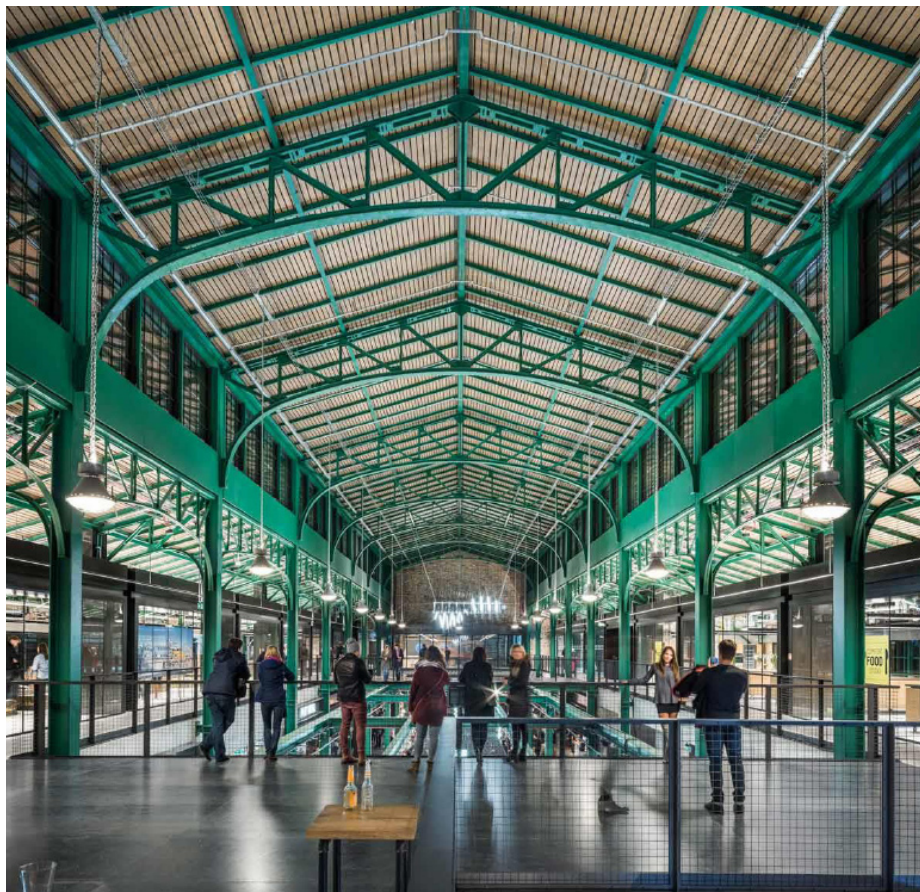


Fig. 6. Hala Koszyki

Source: <https://brickarchitecture.com/images/projects/hala-koszyki-jems-architekci/newformula-3.jpg> [accessed 22.07.2022].

to be modified in the future. In this case, however, problems arise from the necessity to predict future generations' needs, as from well as the demographic and economic situation. The second way to extend the building's life cycle is by adapting existing buildings to new functions while maintaining their structure entirely, or by retaining the most important and characteristic elements. This trend has been gaining popularity in recent years. An example of such an approach is Hala Koszyki (The Koszyki Market Hall), project by JEMS Architektki, Warsaw. The former market hall has been adapted to new functions that correspond to the modern lifestyle in a large city. After its renovation, the so far barren space has become a bustling place, whereas a significant part of its original structure has been preserved (Fig. 6).

CONCLUSIONS

The degradation of the natural environment, shrinking natural resources together with the simultaneous production of significant amounts of waste introduced into the environment, is becoming more conspicuous nowadays. This situation prompts the search for pro-ecological solutions with which to eliminate these adverse effects of human production-related activity. Architects, material producers, and the increasingly aware recipients of these services and products are beginning to pay attention to sustainable development issues and the possibility of re-using materials. Limiting the amounts of manufactured products, re-using the ones that have already been produced, and using waste in future production will reduce the progressive degradation of the environment to some extent. Amount of 25% of construction waste could be recycled; the situation in which construction materials simply became debris upon the end of their life cycle should no longer be accepted (Mazur, 2021). It is possible to achieve this goal, but time is required to develop technologies that take economic aspects into account, so that these products stand the competition with traditional materials. Additionally, social awareness in this field.

Authors' contributions

Conceptualisation: P.Ł. and A.S.; methodology: P.Ł. and A.S.; validation: P.Ł.; formal analysis: P.Ł.; investigation: P.Ł.; writing – original draft preparation: P.Ł.; writing – review and editing: A.S.; visualisation: P.Ł.; supervision: A.S.; project administration: A.S.

All authors have read and agreed to the published version of the manuscript.

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RECYKLING MATERIAŁÓW BUDOWLANYCH

STRESZCZENIE

Celem pracy jest zbadanie zagadnienia recyklingu materiałów budowlanych. Określono problematykę tematu użycia materiałów budowlanych i koszty środowiskowe z tym związane. Metodyka badań obejmuje materiały źródłowe oraz własne analizy i doświadczenia. Wyniki badań prezentują aktualne trendy i definicje pojęć związanych z omawianą problematyką. Przedstawiono potencjał i sposoby ponownego zagospodarowania najbardziej typowych materiałów budowlanych oraz główne nurty w architekturze wykorzystujące materiały z odzysku.

Słowa kluczowe: ekologia, środowisko, recykling, rekonsupcja