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RECYCLING AND UPCYCLING IN CONSTRUCTION

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Abstract. Waste is a serious environmental problem that poses a threat to the environment. The article describes the features of the use of recycling and upcycling in the construction industry. Comparison of the possibilities of these two approaches is relevant for determining effective strategies for the use of recycled materials and products in the context of the post-war reconstruction of Ukraine.

Article purpose is to manifest the possibilities of using materials used in construction and their scope in load-bearing structures and decorative elements.

Modern methods of handling secondary materials in construction were evaluated by the method of analysis of literature sources. Based on the comparison of existing recycling and upcycling projects for the construction of new buildings, the possibilities of using construction and demolition waste and solid waste in construction are determined.

In the construction industry, waste can be used in the following ways: through the reuse of materials generated during construction and demolition and recycling — processing waste into raw materials used in the production of building materials. There is also experience of successful use in construction of municipal solid waste generated not in the construction industry — upcycling. Materials and products for upcycling in construction are either the result of creative search of customers or executors of the project, or the result of previous organized work on the collection and sorting of solid waste. Therefore, in order to spread the effective use of upcycling, it is necessary to develop a solid waste management infrastructure and disseminate successful experience in project implementation. For efficient and cost-effective recycling on a large scale it is necessary to introduce and disseminate selective demolition practices; collection and separate storage of construction and demolition waste on the construction site; recycling and disposal of materials along with construction to reduce transportation costs.

Keywords: recycling, upcycling, construction and demolition waste, solid waste, secondary materials, reuse, recycled construction

INTRODUCTION

One of the most daunting issues of the world is the mounting waste problem, which impairs public health and pollutes the environment. Waste materials are a major environmental problem, which is a threat to the environment. It is important to reuse these materials and dispose them. Waste is also present in the construction industry. Recycling of construction materials provides an opportunity to achieve cost saving. These savings include the cost of new materials and also transportation and disposal costs.

The use of recycled materials also results in energy savings are reduced carbon emissions. The usage of recycled materials in construction is possible at the levels of load-bearing, enclosing structures, interior design, including its decoration. In some projects the usage of recycled materials already takes place at the design stage. Analysis of examples of recycling in construction will help formulate recommendations for possible waste management.

ANALYSIS OF PREVIOUS RESEARCHES

Olena Todorovych gives a general information of development of waste recycling technology [12]. Rostyslav Biletskiy writes about the classification of waste, investigation of waste recycling methods [16]. Boychenko B., Lejda K. and Ivanchenko O. consider the problems of waste disposal and recycling; the problem of transport waste and environmental issues related to the collection and disposal of vehicles and their components are considered [2]. Tomilenko M. and Ageeva H. report about a rule of «3R»: reduce, reuse, recycle in a construction field [13]. Given the relevance of the topic, the number of studies of recycled building materials, especially cements, is increasing. Their physical, mechanical properties, chemical composition, modifiers to them to improve their performance are studied [20, 23]. Gnatiuk L., Tsarik O. provide a detailed description of the role of trash in the different design fields [5]. Liliia Gnatiuk, Nataliia Voloshina and Hanna Novik analyzed the possibility of converting a decommissioned aircraft to a cafe [7].

The relevance of the topic explains the growing number of publications on the disposal of construction and demolition waste on professional resources of the construction industry. The problem is considered both in terms of waste reduction as an environmental strategy for resource management, and in terms of

business strategies for private construction companies [9,10,15]. The draft National Waste Management Strategy for Ukraine was proposed for the Program for the Promotion of Green Modernization of the Ukrainian Economy, funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) [8]. This document analyzes in detail the situation regarding the use of recycled materials made from construction waste of Ukrainian origin in construction and describes the role of all stakeholders in the waste management process.

PURPOSE

To manifest the possibilities of using materials used in construction and their scope in load-bearing, enclosing structures and decorative elements.

RESULTS AND DISCUSSIONS

Construction waste is a large and, to some extent, untapped resource. Most waste is taken to dumps and landfills for disposal. In many EU countries, the recycling of construction debris and waste is a great success. In Europe, the goal was to recycle 70% of construction waste (excluding hazardous waste) by 2020, but they already reached 90% in 2018 [18].

Construction and demolition waste consists of garbage generated during construction, repair and demolition of buildings, construction and dismantling of civil engineering structures (roads, bridges, hydraulic structures, etc.), as well as waste generated by man-made disasters (accidents), natural disasters and natural phenomena [20].

Construction waste often includes defective products, concrete and brick chips, mortar residues, scraps of steel reinforcement, used formwork and other equipment of the construction site, soil and stones formed during its cleaning. Waste from the construction of a new building can include packaging materials such as cardboard and plastic. These types of waste are most often sent for recycling, intended for other types of commercial and industrial waste.

The bulk of construction and demolition waste is made up of concrete or tiles in large quantities, wood and steel structures, but there are also often a variety of materials such as asphalt (pavement and roofing shingles), gypsum (the main component of drywall), metals, bricks, construction ceramics, glass, plastic, preserved building components (doors, windows, plumbing).

Theoretically, all construction waste can be used but subject to their separation. To do this, some companies provide large containers for the accumulation of construction waste separately by type: metal, plastic, glass, stone (brick, hardened mortar and concrete), wood.

In general, there are different types of waste management:

- "re-use" means any operation where products or non-waste components are re-used for the same purpose for which they were intended. Concrete elements, solid bricks, steel structures and large lumber can be reused in construction;

- "utilization" means any operation in which the waste is useful as it replaces other materials that would otherwise be used to perform a specific function [8]:

- "recycling" — an utilization operation in which waste is processed into products, materials or substances for primary or other purposes. It includes the processing of organic material but not energy recovery or conversion into materials to be used as fuel or fillers. For example, grinding of concrete, bricks, for the production of secondary raw materials for the use of crushed material as aggregates in new concrete; as unbound road base materials; for back filling. Shredded wood waste is used as a raw material for sheet materials of wood chips and wood fiber.

- "upcycling" — the process of converting used products, waste, garbage into new materials or products of better quality or those that have better environmental value;

- "downcycling" — the process of converting waste or unnecessary products into new materials or products of lower quality and less functionality.

In the context of this study, it is proposed to consider the use for the construction of new buildings and structures:

- recycled materials made from construction and demolition waste (recycling);

- recycled materials produced from waste from the non-construction industry (recycling);

- solid household waste generated in any sphere of life (upcycling).

Recycling has become an important part of community and business efforts to lower levels of material consumption, energy usage, carbon emission and landfill. It is part of the waste hierarchy — reduce, reuse, recycle. This suggests that it is most beneficial to the environment to reduce what we use in the first place. Where it is necessary to use things we should then strive to

reuse them and only finally to recycle them if no further reuse is possible. Building with recycled materials can be a great way to save money and the environment.

Recycling in the construction industry is most common in the construction and repair of roads, industrial sites, car parks, sidewalks and more.

Upcycling, as the highest form of recycling [31], demonstrates the most diverse and creative approach to construction from secondary resources because in this case truly unique objects are created. Unlike recycling, upcycling does not require expensive equipment and complex resource-intensive technologies for separating, crushing and processing materials. Upcycling in construction is the creative use of garbage and things that have served their purpose, from which unique housing is created.

Decommissioned vehicles (vans, cars, planes, buses, etc.) can be converted into a building by reconstruction or by supplementing with specially constructed architectural volumes. A striking example is the Locomotive Ranch Trailer from Andrew Hinman Architecture (fig 1), where an old streamlined aluminum residential trailer has been converted into a summer house. Some of the living quarters are located inside the trailer house and all additional and utility rooms and communications are located in a brick annex. A veranda was completed between these two volumes. All elements of the house are covered with a single steel roof and installed on a metal and wooden podium.

In modern world and domestic practice, the process of reconstruction of decommissioned aircraft for civil purposes is widespread, mainly commercial — hotels, restaurants, offices, etc. From a business point of view revitalization of industrial facilities is an effective management tool that allows to find effective ways to give a second life to used vehicles. Much less often decommissioned aircraft are used as residential, permanent or temporary facilities. An interesting and promising proposal for our country is Yu. Roznaleyevich (headed by L. Gnatiuk) to convert the IL-86 aircraft into a student dormitory [11].

It is possible to use decommissioned transport for construction in disassembled form. Parts of car bodies, fuselages are cleaned of harmful substances and contaminants, processed and found new applications as details of construction or decoration of a new building. For example, in the project of the 747 Wing House (David Hertz & Studio of Environmental Architecture), the

wings of the decommissioned Boeing 747 aircraft formed a complex roof of a building that resembles an airplane in plan. Other elements of the aircraft are involved in the interior. For example, a fireplace is built from the hood (fig. 2).

You can often see how the concept of downcycling is illustrated by the use of old car tires for landscaping — for zoning the yard, arranging flower beds, creating decorative objects. But obsolete tires can also become structural elements for construction. Tires are very polluting, especially because they are often improperly disposed, but because of their resistance to damage tires filled with soil are suitable for use in load-bearing structures. These structures have very good energy efficiency characteristics due to the thermal insulation capabilities of the soil filler. This solution (known as «earthship») is common in poor countries, where the technology of disposing of old wheels is not developed and prices for new building materials are high.

Along with tires, in the construction of the walls of such houses there is the use of cans, plastic bottles and other garbage that is difficult to recycle.

In some cases, recycled materials can make structures stronger, more efficient and less expensive to build than new materials. Charitable foundations have used plastic two-liter soda bottles to build shelters, schools and other buildings in impoverished areas. For example, a school in the Philippines [22] (fig. 3) which construction is based on old plastic bottles filled with adobe. They're inexpensive and about three times stronger than concrete.

A few years ago, Canadian entrepreneur Robert Bezot traveled from Montreal to the island of Bocas del Toro and was amazed at the amount of plastic waste. Together with volunteers he collected more than a million plastic bottles and built a real village out of them [28]. Thus, he cleared the island of waste and created an impressive environmental project (fig. 4). There are hotels, a castle, a prison, museums, educational centers, eco-houses, which are for sale. Robert Bezot wants to show people that plastic waste can actually be useful, such as building temporary shelters after disasters, swimming pools, roads, animal farms and more. Guests of the island, having come here on vacation, will be able to learn more about recycling.

Plastic bottles are one of the most common types of plastic waste causing irreparable damage to our planet and all its inhabitants. Therefore, with the right approach they

can become one of the most common types of building materials.

Tetra Pak packages are difficult to recycle due to their many layers. Such packaging is 75% cardboard, 22% polyethylene and 3% aluminum and requires serious equipment to separate into components. In 2021, for the first time in Ukraine, in the Kharkiv region, a full cycle of processing Tetra Pak packaging and its analogues was launched — in the future it could receive a second life in the form of paper and polyaluminum, which is widely used in the construction industry — facing boards for facades and interiors, roofing and other materials are made from it [4].

As Stilt Studios [30] has shown, recycled Tetra Pack cartons can be used as building material. Prefabricated house (fig. 5) with an area of 64 sq. m with every comfort, using recycled Tetra Pack cardboard boxes as wall and roof material, combines a unique design and plays a role in the local circular economy. The architecture uses the reflective properties of recycled materials, and the diagonally oriented floor plan creates interesting spaces.

Comparing these two projects, we can see that, unlike upcycling, houses built from recycled materials may not reflect the origin of the material in their appearance. Some of them - like a house in the Netherlands built from recycled brick — fit in perfectly with their neighbors (fig. 6). The townhouse designed by Architecture Maken [12] looks brand-new, but its bricks are made of 15 tons of waste and rubble, including ceramics, glass and clay. Dutch company "StoneCycling" [29] gathered the waste products from around the country, grounded them up and formed them into bricks.

The four-story townhouse has one large room per floor, with a kitchen and dining room on the ground floor, an office and bathroom on the second, a living room on the third and a bedroom and rooftop terrace on the top floor (fig. 7).

They can be sleek and modern or colorful and bohemian, depending on the owner's taste.

Building an entire home out of recycled materials may not be feasible for everyone, but there are plenty of ways to incorporate salvaged or reused materials into a home's design. For example, stores like Habitat for Humanity's ReStore outlets sell donated building materials like doors, windows, cabinets and fixtures at discounted prices.

The next amazing house is a "Cabana Floripa" (fig. 8), in the island of Florianópolis, Brazil, was made from demolished houses.

The creator of such construction is an artist Jaime [17], who collected scrap pieces of glass bottles, ceramic tiles, demolition wood, pottery scraps and mirrors and an assortment of trash, much of it from demolished houses, that he had found in the local area.

Mixed up with pieces of Mother Nature including tree branches used for shelving, the home is a fun and charming example of recycled housing, the colorful and enticing eco-friendly space.

Brazil has many initiatives when it comes to making products by recycling trash found on beaches and streets.

One of the most interesting projects is a "The Recycled Materials Village" that will demonstrate how to build safely, affordably, and efficiently with maximal use of recycled materials (fig. 9) [26].

Every aspect of this village will be open source for replication as either individual components or the complete village. This includes the residences, recreation spaces, social spaces, exercise spaces, large-scale kitchen and dining, commercial laundry and a broad diversity of outdoor social, recreational, and artistic components too. It includes all the construction, assembly, materials acquisition, aesthetic, and other details unique and specific to building with recycled/reclaimed materials.

The goal of this projects is to demonstrate the concept of building with reclaimed materials as relatively easy, affordable, sustainable, aesthetically pleasing, and interesting enough for widespread implementation.

Upcycling also includes the construction of residential buildings and public facilities from decommissioned transport containers, which is popular in many countries around the world. Obtaining the desired residential or commercial space is possible by connecting separate containers. Enclosing surfaces are lined with appropriate thermal insulation, which makes container houses energy efficient and provides optimal temperature conditions for its users all year round.

Some materials and products that are difficult to recycle can be reused in the decoration of buildings and even in the interior. Thus, for reception of interesting result it is necessary to abstract from their initial appointment. For example, ribbed metal panels are difficult to imagine in the interior of a living space — they are usually associated with non-residential buildings, such as garages, or with buildings in very poor areas. But after proper treatment,

these panels can be used to organize ventilated facades or even interesting to present in the interior, to obtain an unexpected expressive effect. The sheets of this material are quite thin and do not require expensive and complex equipment.

Thus, the study of foreign experience in the use of secondary materials shows that in the construction and treatment of buildings and interiors waste of a very wide range can be used. However, building materials must comply with a number of standards, in particular, fire (fire resistance, etc.). Certification of secondary materials for construction is one of the challenges the solution of which will give impetus to the development of recycling and upcycling in construction in our country.

There is a practice of reuse of building materials not only abroad but also in Ukraine. Kyiv was not completely destroyed after the Second World War but only the walls or the foundation remained of many buildings. Reconstruction of Khreshchatyk [1] was made of reused bricks, construction debris was ground for concrete. Brick itself was in short supply in the post-war years, so slag concrete was often used instead — a material obtained by mixing cement with slag or other industrial waste. In terms of characteristics, it was similar to a brick but it was cheaper, and there were enough raw materials for production.

Slag concrete was used to build industrial settlements, but in Kyiv it is still rare — mainly in Nova Darnytsia and in the Emergency Village on Chernihivska. In general, the experience of restoring Kyiv is diverse and gives several lessons. It shows that almost all damaged houses can be restored if you set such a goal.

We can think that the II World War and its consequences were long time ago. Unfortunately, the same thing is happening in Ukraine now. Since the beginning of the full-scale invasion Russian troops have destroyed thousands of buildings throughout Ukraine. Colossal destruction, for example, in Mariupol, according to preliminary estimates, destroyed about 80% of the city's housing stock, of which almost 30% cannot be restored. In Irpen near Kyiv more than 1,000 buildings were damaged: 115 were completely destroyed, 698 were significantly damaged and 187 were partially damaged. This is 71% of the city's territory [3,6,14].

It is obvious that the process of restoration and reconstruction of Ukraine will require, along with modern construction technologies, recourse to recycling and upcycling as environmental technologies of the future.



Fig. 1. Locomotive Ranch Trailer. Andrew Hinman Architecture. [23]



Fig. 2. 747 Wing House [21]



Fig. 3. A school in the Philippines made of old plastic bottles filled with adobe [22]



Fig. 4. Ecovillage made of plastic bottles on the island of Bocas del Toro [27]



Fig. 5. Tetra Pod / Stilt Studios [29]



Fig. 6. A house in the Netherlands built from recycled brick [12]

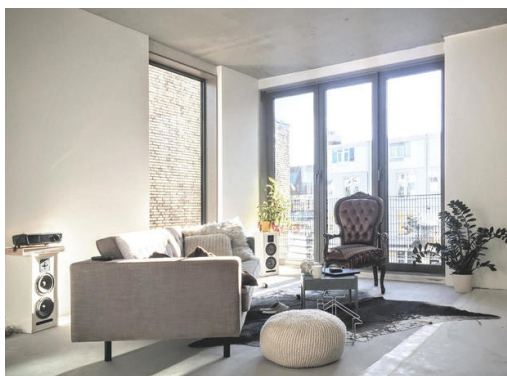


Fig. 7. The interior of a recycled brick house in the Netherlands [12]



Fig. 8. Cabana Floripa - Florianópolis, Brazil [17]



Fig. 9. The Recycled Materials Village [25]

CONCLUSIONS

Experts propose a system of normative, administrative, legal and economic measures to streamline the rational treatment of secondary materials in construction. However, given the insufficient development of construction and demolition waste management mechanisms in our country, it is necessary to take measures to create positive changes in the environmental behavior of people representing stakeholders in the construction and demolition of buildings and structures, as well as in the disposal, utilization and processing of construction and demolition waste. In particular, examples of successful implementation of original recycling and upcycling projects can give impetus to the creative search of architects and designers in rethinking and reusing waste as new materials.

Today, there are several ways to handle recycled materials, including reuse, recycling and upcycling. With regard to the construction of new buildings and structures, recycling includes the use of recycled materials generated from construction and demolition waste; recycled materials made from waste from the non-construction industry. Upskilling in the construction industry means the possibility of using for the construction of new buildings materials and products that are difficult to recycle and solid household waste generated in any sphere of life.

Analysis of examples of upcycling proves that upcycling in construction is a more individual

method than recycling. The experience of these projects shows that materials and products for creative use in construction are either the property of customers or the result of previous organized work on the collection and sorting of solid waste. Therefore, in order to spread the effective use of upcycling it is necessary to develop a solid waste management infrastructure and disseminate successful experience in project implementation.

In large construction and reconstruction projects, such as overcoming the effects of war and rebuilding the country, transport costs, which include the export of demolition products and the supply of new building materials, will be a significant part of the cost. Therefore, recycling — the use of recycled materials, which must be collected and prepared for processing separately by kinds in the place where they are formed, can be economically attractive.

Recycled materials and upcycling can also be used to decorate buildings and interiors. To do this, it is advisable to abstract from their original function and start only from their material, visual, formal capabilities and physical properties. The interior of a building made of recycled materials may or may not reflect the idea of environmental friendliness and features of the materials used. On the other hand, the interiors of buildings where upcycling is used are usually more visually related to the origin of the materials or products.

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АНОТАЦІЯ

Гнатюк Л.Р., Новік Л.Р., Мельник М. Ресайклінг і апсайклінг у будівництві. Відходи є серйозною екологічною проблемою, яка становить загрозу для навколишнього середовища. Стаття описує особливості застосування ресайклінгу та апсайклінгу у будівельній галузі. Порівняння можливостей цих двох підходів є актуальним для визначення ефективних стратегій використання вторинної сировини та продукції в контексті післявоєнної відбудови України.

Метою статті є розкриття можливостей використання матеріалів, що використовуються в будівництві, та сфери їх застосування в несучих конструкціях та декоративних елементах.

Методом аналізу літературних джерел були оцінені сучасні шляхи поводження з вторинними матеріалами в будівництві. На основі порівняння існуючих проєктів ресайклінгу та апсайклінгу для зведення нових будівель, визначено можливості використання в будівництві відходів будівництва та знесення і твердих побутових відходів.

У будівельній галузі відходи можуть бути використані такими способами: шляхом повторного використання матеріалів, що утворюються в процесі будівництва та зносу та ресайклінгу — переробки відходів у сировину, що використовується у виробництві будівельних матеріалів. Також є досвід успішного застосування у будівництві твердих побутових відходів, що утворюються не в будівельній галузі — апсайклінг. Перероблені матеріали та апсайклінг можуть бути застосовані як для зведення опорних конструкцій, так і для декорування будівель та інтер'єрів. Оригінальність матеріалів та продуктів, задіяних в апсайклінгу, як правило, накладає відбиток на дизайн інтер'єрів та екстер'єрів будівель. Натомість архітектура і дизайн будівель з перероблених матеріалів рідко відображає ідею екологічності та особливості застосованих матеріалів. Апсайклінг в будівництві є більш індивідуальним методом ніж ресайклінг.

Загальним викликом для обох підходів є питання відповідності як відходів будівництва і знесення так і побутових відходів нормативним вимогам до матеріалів, застосовуваним у будівництві. Матеріали та продукти для апсайклінгу в будівництві є або результатом творчого пошуку замовників чи виконавців проєкту, або результатом попередньої організованої роботи по збиранню та сортуванню твердих відходів. Тож для поширення ефективного використання апсайклінгу, необхідно розвивати інфраструктуру управління твердими відходами. Для ефективного та економічно доцільного ресайклінгу в великих масштабах необхідно запроваджувати та поширювати практики вибіркового знесення; збору та роздільного зберігання відходів будівництва та знесення на будівельному майданчику; переробки та утилізації матеріалів поряд з будівництвом для зменшення транспортних витрат.

Keywords: ресайклінг, апсайклінг, відходи будівництва та знесення, тверді побутові відходи, вторинні матеріали, повторне застосування, утилізація, будівництво з перероблених матеріалів

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