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THE ISSUES OF REUSING CONCRETE AND ITS STRUCTURES IN ARCHITECTURE

PROBLEMATYKA RE-UŻYCIA BETONU I JEGO STRUKTUR W ARCHITEKTURZE

A b s t r a c t

The issues connected with the exploitation of the natural environment for building purposes indicate the problems of sustainable building and pay attention to the utilization of natural resources and energy. Keeping the balance between the use of construction materials and their renewability is becoming a necessity nowadays. Concrete constructions are one of the components, which might be used again in the building industry, ranging from the materials obtained in the process of concrete recycling to reusing entire concrete slabs obtained from the demolitions of the objects. Reusing concrete slabs might be an alternative to architectural solutions due to reduced costs at different stages of an investment and functioning of a building. In this article, the examples and experimental solutions are described, which refer to reusing prefabricated concrete slabs in new architectural objects. The current problems are connected with using the devastated and neglected concrete structures for their new functions, and they also include the issue of overlapping layers: the primary and original usage. The structure and scale of an object were adapted and a newly designed function compliant with the new needs and visual aesthetics is being placed in an original frame.

Keywords: concrete, material, slabs, building structure, architecture

S t r e s z c z e n i e

Zagadnienia związane z eksploatacją środowiska naturalnego dla celów budownictwa coraz częściej zwracają uwagę na problematykę zrównoważonego budownictwa mając na uwadze zużycie surowców naturalnych i energii. Zachowanie równowagi pomiędzy zużyciem materiałów budowlanych a ich odnawialnością staje się obecnie koniecznością. Konstrukcje betonowe są jednym z elementów, które można ponownie wykorzystać w budownictwie, począwszy od materiałów powstałych w wyniku procesu recyklingu betonu, jego komponentów, a zakończywszy na ponownym użyciu całych płyt betonowych uzyskanych z rozbiórki obiektów. Re-użycie płyt betonowych może być alternatywą dla rozwiązań architektonicznych z uwagi na obniżenie kosztów na różnym etapie inwestowania i funkcjonowania budynku. W artykule

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przedstawiono przykłady i eksperymentalne rozwiązania dotyczące ponownego wykorzystania prefabrykowanych płyt betonowych rozbiórkowych w „nowych" obiektach architektonicznych. Aktualna problematyka wiąże się z wykorzystywaniem zdewastowanych i zaniedbanych betonowych struktur na nowe funkcje, w których występuje zagadnienie nakładających się warstw: pierwotnego i oryginalnie występującego użytkowania, dla którego przystosowana była struktura i skala obiektu oraz nowo projektowanej funkcji, zgodnej z nową potrzebą i estetyką wizerunkową, umieszczoną w pierwotnej oprawie.

Słowa kluczowe: beton, materiał, płyty, struktura budowlana, architektura

1. Introduction

Concrete is a commonly used construction material around the world and its range of uses is actually unlimited. Currently, its features are being improved, especially its durability, which gives more possibilities of its use in very complicated engineering objects of complex constructions. The popularity of concrete and its various kinds causes that big amounts of debris and concrete waste are generated, especially due to renovations, modernization, bulldozing of building objects, demolitions of buildings, roads, pavements but also because of natural disasters and earthquakes. The amount of concrete waste, which is generated, rises a serious problem connected with its collection, storage, and, at the same time, it is causing an urgent need to make another use of it, either through recycling or through reusing. On the other hand, the exploitation of the natural environment for building purposes is currently focused on the issues of sustainable development and sustainable building, which adopt the methods of saving natural resources, energy and caring for nature. In order to save the values of natural environment consciously so that future generations could make use of it, and to provide humanity suitable living conditions, the construction waste policy should be managed in an appropriate way. To achieve it, it is necessary to reach the balance between the use of construction materials and their renewability. Another important issue is the life cycle of a given architectural object or building, its length and predictability of using the construction materials in the process of recycling, even at the early stages of designing and building. Currently, in Europe, and around the world, the solutions of using so called "concrete waste" for different building purposes are applied successfully. Concrete in the form of debris and aggregate is reintroduced while concrete building components, such as slabs obtained from the demolitions of whole objects, might be used for different purposes, but also to build new architectural objects.

2. Recycling of concrete

Reusing of concrete, to the largest extent, is connected with the construction industry and material production. This concept covers two ideas- recycling and reusing. Recycling is about obtaining the resources and restoring them for another use and utilizing the waste at the same time because re-using it is impossible. The process of reclaiming may be carried out numerous times and leads to producing new construction materials.

The recycled aggregate is fully valuable construction material and processed from debris and reinforced concrete might be used as a substitute for raw materials, such as sand, gravel and limestone. Concrete plays a huge role in the process of recycling of other waste materials, not to mention the artificial ones. When used as bonding or aggregate in a cement mixture, materials may change the parameters of concrete when its higher resistance to stretching and bending is considered[1].

Recycling of concrete started in the USA and Japan in the 70s of the 20th century and was connected with the use of recycled aggregate to build new architectural objects. Currently, further research is carried out worldwide, which leads to obtaining (through sorting and removing cement paste from the grains of the primary aggregate) reclaimed concrete aggregate of high quality and construction aggregate. However, the future of recycling concrete debris is seen in the creation of a closed circuit of materials in such a way that it could be used in manufacturing construction concrete and placed as the processed waste in new building objects[2]. The parameters of construction concrete, which is obtained on the basis of the recycled aggregate, are slightly worse when considering distortions in comparison with concrete that comes from the natural aggregates. Currently, while the less advanced technologies are applied, the concrete aggregate is most often used in manufacturing non-constructive concrete for road and airport bases and the composition of their surfaces or the asphalt concrete but also to build acoustic screens, slopes, foundations, various fillers, reinforcements, for example, of railways, in the production of pavements and benches. However, to a large extent, it is downcycling or making use of the waste in its degraded form. Recycling of the building materials and their components including the concrete has its future in designing consciously and commonly for the needs of recycling and dismantling. However, it means that any renovations and rebuilding should be carried out not because of fashion or changes in functions but because of justified reasons connected with the exhaustion of the building object's potential[3].

3. Reusing concrete slabs

Reusing means making use of valuable construction elements in new architectural objects. The most popular example of such solutions is using the concrete slabs from the demolished prefab buildings. Such an attitude to the issue of reusing construction materials is connected with the concept of the design for a future dismantling and the use of components in other projects, i.e. closing a life cycle of construction materials. Following this trend, a building is considered in terms of the applied building technology and as a collection of building components, for example, prefabricates and construction materials. In compliance with this assumption, the smallest number of elements should be processed and as many of them as possible should be obtained[4].

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[1] http://www.izolacje.com.pl/artykul/id934,materialy-budowlane-produkowane-z-wykorzystaniem-odpadow?print=1 (accessed: 12.06.17).

[2] B. Zając, Gołębiowska I *The Evolution of the Recycling Technology of Concrete,* Inż. Ap. Chem. 2010, 49, 5, p. 134, 135.

[3] M. Golański, *Recycling of the Building Materials, Building Journal* 9/2011, p. 46–51.

[4] *Ibidem* p. 49.

In the 90s of the 20th century in Germany, a strong movement of modernization of the buildings, which had been erected in the industrial technology, began. To a large extent, modernization involved the technical renewal of the buildings, the inner functional and spatial rebuilding but also lowering the height of the buildings, partial or even complete demolitions took place in order to regain the land for new investments[5]. It led to a fruitful opinion among German specialists in the field of modernization that one cannot permanently and considerably reshape the building environment by getting rid of social threats and monotonous housing architecture without any drastic changes connected with demolitions and reshaping the housing environment. An additional argument appeared due to an increasing number of unoccupied buildings and high costs of maintaining them, while many dwellings were abandoned in good technical conditions until the moment of demolitions. When it comes to demolitions, making a good use of prefabricated slabs should be considered. At the same time, in Germany, some institutions carried out the first research, which was financially supported by the state, aiming to implement the idea of reusing the components obtained from demolitions[6] and building new architectural objects.

The technology of reusing concrete slabs involves constructing small single-family buildings, small residential houses in close proximity to the demolished structures, sometimes even on the same site or in a more distant area. In some cases, parts of the buildings are dismantled, decreasing their scale at the same time and the new components are made of distinct architectural traits from the obtained slabs in compliance with the local community's expectations. Reusing constructions from concrete slabs has many benefits for the environment and introduces some savings in the process of the whole building undertaking. There is no need to invest in new lands because the existing utilities and infrastructure are adopted, also the cost of transportation and removal of the building waste is minimalized. The cost of building the flats from the used components to their shell structure is 30% lower than the one from the new elements and it is much quicker. By using dry concrete slabs, the construction time is shortened and just a few days are needed to build the shell structure. The amount of building blocks, which might be used, is also unlimited because a number of buildings for demolitions may be unlimited, too. The slabs are most often used for the construction of the external walls, interior partition walls and horizontal partitions of ceilings and roofs. Due to an easier way of bracing the walls in comparison with the previous methods, they might be dismantled at a given time while the building is exploited. Constructing the interior but also placing the windows and doors may be done without any confinements and it might be achieved by cutting the concrete slabs. One of the advantages is building the housing environment of small residential or single-family houses for attractive investment price. If the buildings appear in the near vicinity or on the site of an old prefab construction, the visual chang of the environment has a beneficial impact on the local social issues and comfort of living.

A negative aspect of reusing is the necessity of high transportation costs of the slabs without the possibility of a long storage because it is not profitable and technically harmful. The experts in Germany clearly recognize the distance of transport as 300 kilometers and

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[5] The modernization process involved among others: The Senate of Berlin, The Technical University of Berlin, (TU Berlin), the Institute for Regional Development and Structural Planning (IRS).

[6] A special program about the possibilities of reusing dismantled prefab components in housing development, supported financially by the Federal Office for Building and Regional Planning (BBR).

exceeding it would make the whole building process much more expensive. Another disadvantage of slabs is their fixed basic sizes, which unable the creation of more complicated architectural shapes of the new buildings[7]. This aspect might be omitted by connecting the old constructions with new building technologies or by cutting the concrete elements appropriately in compliance with an architect's needs and visions.

The projects, in which the dismantled slabs are employed, may be currently seen in different parts of Germany although it is an alternative solution to a model, which assumes complete demolitions and freeing land for investments. One of the examples is rebuilding and modernization of tower blocks in Cottbus-Sachsendorf. One of the objects was dismantled and the slabs were used for constructing five two and three-storey residential buildings, in which 2, 3, and 5- room flats were designed. In this solution, the existing ground floor and parts of the first floor, which were not dismantled, were used.

Other examples relate to the solutions of detached houses near Berlin in a new location. The pilot program conducted by an architect, Herve Biele from the Conclus firm, together with the cooperation of the Institute for Building Preservation and Modernization at Berlin's Technical University[8], led to the construction of three buildings. In the projects of these residential objects, concrete walls, ceilings and floor panels served as a load-bearing construction without any additional reinforcements and the elements were connected with steel lintels. In this way, 95% of the construction structure of the building was obtained. Cutting the interior slabs to the correct dimension was not a problem while the external panels stratified losing their homogeneity. Achieving a standard of completion of an object with an insulation and protection layer did not last longer than 3 months[9]. The technical standards of the buildings do not differ from the latest technologies and the benefits of concrete panels is their ability to store the heat, their sound absorption and readiness for quick use (the elements are not dried out), which speeds the investment process. The examples of such buildings are varied in terms of a plan, spatial form and offered cubature. The most famous building is the house "Z" located in Mehrow near Berlin of 212 square meters from 2005, which was erected at the same time as the two other examples described above, and a residential detached house-called 'shoebox' near Dresden built in 2010, whose author is Norman Hose.

3.1. The examples

The "L" House in Schildow near Berlin.

It is a two-family house with a garage and facility rooms of 186 and 101 square meters of living space, which serves as a distinct architectural example in comparison to the previous ones due to its pitched roofs. The two-storey object offers the spacious interior with two-storey living room and the entresol. To build it, 60 ceiling panels and 50 chunks of wall panels were used[10]. The pitched roof together with the walls and floors were completely

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[7] http://www.spiegel.de/international/recycling-architectural-disasters-a-communist-block-house-renaissance-a-367335.html (accessed: 15.06.2017).

[8] IEMB TU Berlin.

[9] https://betongelit.files.wordpress.com/2009/07/werkinfo.pdf (accessed: 08.06.2016).

[10] The building was improved with the pro-ecological solutions such as cells, photovoltaic panels, heat pump.

constructed from the concrete slabs, which were obtained from the demolition. The building in the Marzahn district was "the giver" of the material, the same as in Mehrow[11].

The "K" House in Schoneiche near Berlin.

A single-family house of 154 square meters of living area was built in the neighbourhood of the "L" house. A rectangular two-storey solid includes an atrium illuminating the inner spatial area of the house from the top. In order to build it, 22 ceiling and 19 interior wall demolition slabs were needed[12].

The houses erected from the demolition slabs are economical in use and with the support of the modern technologies might meet the ecological standards and show the benefits for environment[13] in compliance with the rules of sustainable building. Despite many benefits, they have not been supported by the state institutions in other European countries and approved by their architectural and building communities. There is still a dispute when it comes to the concrete slabs, whether they are only a waste or component, which might be used in a construction materials cycle. Although in Poland we do not face a problem of unoccupied buildings, the issue of tower blocks cannot be avoided, their further exploitation and the topics related to their space conversion for other purposes.

4. Concrete structures and their adaptation

Many building structures made from concrete remain neglected and devastated, many buildings have an inconvenient location due to undergoing spatial changes while the others because of their location have acquired strategic characteristics in a given area. The inability of total rebuilding of the objects often gives an inspiration to administrators and investors to adopt them completely or partially, converting the older and exploited elements or adopting the whole structures to the new needs and functions of a given location. However, the most important is establishing what kind of function would be the most appropriate and economically justified. An adaptive reuse refers to using an old object again for purposes other than they were originally designed or built for. It is often a compromise between the demolition and the necessity to preserve the structure in its original condition. However, it gives the designers a possibility of repairing the invested environment, bringing it back to life, imposing new visual values, which is a fascinating creative activity.

The example of such an object is the Danish National Maritime Museum in Helsingor created in 2013 and based on the Bjarke Ingels Group's project[14]. The concept assumed a conversion of a 60-year old concrete dock into a modern and full of elegance museum with amazing spatial solutions. The technical solutions required an archaeological supervision due to the fact that the object was built under the sea level. The walls of the old dock were 1.5 m

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[11] https://betongelit.files.wordpress.com/2009/07/werkinfo.pdf (accessed: 08.06.2016).

[12] *Ibidem*.

[13] http://architecturemag.typepad.com/my_weblog/2006/07/cut_and_paste.html (accessed: 20.07.17).

[14] David Zahle was the project's leader, the designers of the KiBiSi group specializing in the small architecture were invited to cooperate, together with the exhibitions' experts from Kossmann.dejong while the issues of landscape architecture were overtaken by Jeppe Ecklon.

thick and the floor's thickness reached even 2.5 m. The walls were cleaned and the interior of the dock was connected with the multi-level steel bridges (each of them weighed about 100 tons), which navigate the visitors to the specific sections of the museum, galleries and an auditorium[15], or in a direction of Kronborg Castle, which is located nearby[16]. The galleries and exhibits, which present the Danish maritime history, were placed around the concrete walls of the dock. They are as high as 7 meters and thanks to the glass walls, the rooms are open towards the interior, the centre of the whole space. The bridges cut this space and at the same time connect the particular sections of the museum below the ground level, giving the whole structure a sculptural character. Such a solution assumes uniting the old with the new, as the designers emphasize, and while being on the bridge we are actually in the museum, keeping an eye contact with the historic part of the city. The solutions, which were applied in this project, have a two-level character, below and above-the-ground sections[17], but they also reach further in their two-layered quality. It is ranging from the old dock's structure, which served to build the ships and historic heritage of this place, to the freedom of the spatial vision, which is connected with the sea, metaphorical yearning of a man for discovering mysterious lands, contained in a modern and elegant form. Further on, the duality concerns the materials, too- the remained concrete and its strong form, which was broken with steel elements of the ship's constructions and sheets of glass walls, making this neglected space delicate and prestigious.

One of the many issues of reusing spatial structure, which undergoes transformation, is the presence of overlapping layers connected with the original use and purpose, the original scale and the used material (in this case it is concrete) together with another layer related to a new purpose, a new function and form inscribed in the old structure. Joining these layers may cause numerous and functional problems but it also causes that the significance of the space is extended and its architectural traits connected with the modern use are revalued.

At this point, it is worth referring to the issue of "shearing layers" of an object, what should be taken into account because of the way and speed, at which particular parts of the building are exploited and how these layers influence each other. Fixed elements such as a site or construction change in the most slowly way while the exterior and installations are explored the most quickly[18]. Because of the functionality of an object, it is hard to predict the users' needs in the long run. That is why, the future possibility of the shape conversion and the object's space should be taken into consideration. It is essential to examine the solid structures, which have their own flexibility and allow for conversions. It is a concept compliant with an ecological design, emphasizing adaptive abilities of the objects[19].

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[15] http://www.architektura.info/index.php/architektura/polska_i_swiat/narodowe_muzeum_morza_w_danii (accessed: 21.06.17).

[16] Kronborg Castle in Helsingor added to UNESCO's World Heritage Sites list.

[17] http://www.big.dk (accessed: 20.07.17).

[18] The concept of so called "shearing layers" of a building is described in the article of Michał Golański "Recycling of the Building Materials" referring to an architect F. Duffy and S. Brand's book "How Building Learn".

[19] M. Golański, *Recycling of the Building Materials, Building Journal* 9/2011, p. 48, 49.

5. Conclusions

In architecture, the idea of reusing concrete has three tiers- the material, constructional and structural one. Although the activities in these three dimensions may occur independently, their common denominator is meeting the objectives of sustainable building. Slowing down the process of exploitation of the natural environment should take place together with considering the issue of reusing resources, components and building materials. When discussing the idea of reusing the materials and construction elements, the strategy is needed. Even on the early stage of designing a building it allows to predict dismantling and reusing construction components, processing and employing the dismantled materials in order to provide their cycle. Recycling and dismantling concrete elements for another use is the prospective issue and requires the approval of research institutes and architectural circles but also raising social awareness in this field.

The predictability of exploitation of the building structures and using their potential allows to provide the continuity of their usage in compliance with the modern ecological concept, which assumes the possibility of an object's adaptation to the changing conditions and needs, keeping the object's functional value in this way. Flexibility and universality of the concrete structures, even when they are considerably exploited or devastated, allow for combining them through other building technologies in order to gain better visual and aesthetic solutions.

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[2] Zając B., Gołębiowska I.*, The Evolution of the Recycling Technology of Concrete*, Inż. Ap. Chem. 2010, 49, 5, p. 134, 135.

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[3] https://betongelit.files.wordpress.com/2009/07/werkinfo.pdf (access 16.06.2017).

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[5] http://www.architektura.info/index.php/architektura/polska_i_swiat/narodowe_muzeum_morza_w_danii (accessed" 21.07.17).