THE CAPABILITIES OF USING CONCRETE IN SUSTAINABLE ARCHITECTURE

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ABSTRACT

Contemporary building materials manufacturers compete with each other in searching for a new concrete mixtures to increase the attractiveness of this material at all levels. Success can be seen in terms of life span of the products, appearance and structural strength.

In the past few years, concrete has also gained a reputation as one of the most environment friendly building materials. It is difficult to decide how much of this is due to efficient marketing efforts of the manufacturers but there is no doubt, that it has many beneficial effects on energy management of the building and intensively developed new technologies have greatly expanded its range of use.

The author of this article describes the main advantages of concrete as a material that participates in reducing the carbon footprint in the process of construction and exploitation of an architectural object. The studies is based on completed buildings in different regions of the world where the concrete was used as the basic structural and finishing material. As it turns out some of the popular devices installed in order to save energy seems to be unnecessary and easy to replaced by using in a conscious way one of the most popular construction materials.

Conducted by the author studies lead to the conclusion that there is no such thing as energy-efficient material. Only the way it is used can make it energy-saving. Conscious and skillful use of its wide range of properties can help to minimize the negative environmental impact of buildings.

Keywords: sustainable architecture, concrete, precasting, carbon footprint, energy efficient design

INTRODUCTION

Growing standards for energy efficient constructions are forcing designers to use more and more technologically advanced installations, that are helping to reduce the demand for energy, necessary for the proper functioning of the building. The aim of the energy consumption reduction is to protect the environment. Usually neglected is the issue of how energy consuming is the production of these devices, and what is the ratio of energy consumed by production to the savings that they bring. While carrying out research, all the successive stages of manufacturing and functioning of the installation should be included, especially: the process of preparing the documentation of such device, the extraction of raw materials needed for the manufacture, production, packaging, transportation, distribution, storage, installation, exploitation, maintenance, dismantling and recycling. Undoubtedly, these are not small amounts of energy, and as it turns out some of the devices seems to be unnecessary and easy to replaced by using in a conscious way one of the most popular construction materials – concrete.

THERMAL MASS

Factors, which make the concrete to be considered as environmentally friendly material are numerous. The most important one should be the thermal mass, if only because it is obtained incidentally, as a "side effect" of the applied technology. Until recently there have been performed reinforced concrete structures of buildings without taking this property into account at all. Today it is known that the properly used and exposed to the sunlight it can be very beneficial for the comfort of using and the reduction of energy designated for heating the building and its cooling. In some cases we can even eliminate the necessity to use the heating installation and air-conditioning [1]. To optimise the benefits arising from the fact of using the concrete structure, we should however consider the advantages of this material at the stage of creating the architectural concept. Not only that we will then receive the durable, solid construction of the building, resistant to the changing weather conditions, we will also save on the exploitation and maintenance, which in this case is almost completely unnecessary, and over many years of use it could generate significant costs.

Limitation of the maintenance, increasing thermal stability and this reducing the use of energy for heating and cooling results in the reduction of greenhouse gas emissions. "*…In recent British studies it was shown that the concrete/brick house with an average weight, which fully uses its thermal mass, within eleven years can compensate the emission of CO2 compounds in comparison to the equivalent wooden-framed house and then still gives savings of energy and CO2 emission throughout the whole period of building exploitation*" [2].

The principle of operation of the thermal mass is simple – during the heating season, during a day, the material accumulates the heat gains from free sources, e.g., heat generated by residents residing in the interior, or from solar radiation, and then gives it back at night, keeping the temperature of the room at the same time lowering its own. Over the next day it once again takes the excess heat, preventing overheating. This cycle is important both in winter and summer. Thanks to thermal inertia, concrete provides comfort to the users by reducing peak temperatures.

In addition, the benefit of the concrete is supported by the fact that the thermal mass is owned by the mere structure, that is the most important element creating the building. All kinds of devices, such as recuperator, controls of the mechanical ventilation, air-conditioning, heat exchangers or solar batteries are the additional elements, which is true, will be in accordance with the assurances of the producers and they will generate savings, but we should remember that their production is highly energy-consuming. This also applies to the installation, operation, maintenance and disposal.

CONCRETE AS THE FINISHING MATERIAL

In order to obtain the profits from the thermal mass you have to properly expose the material to the solar radiation. One should remember that all types of finishing in the form of plaster, panelling, panels, boards, wallpaper, etc. will to some extent constitute isolation, limiting the possibilities of the applied material. Optimal results can be obtained by leaving the floors, walls and ceilings with no additional finishing. It will be even better to use the coloured, dark concrete in the places of direct sunlight.

In case of a significant proportion of investors, such a situation may be impossible to accept due to aesthetics. However, it is hard not to notice the general trend, promoting the architectural concrete, exposed both on the building facades and in the interiors.

Since the invention, until the half of the past century, concrete was a very popular and willingly used building material. Always, however, in terms of nobility it gave way to stone, brick or even steel. Only thanks to the work of the French architect, Le Corbusier, the situation has changed. As M. Charciarek writes in the article entitled

Ethics of the concrete brutalism "Le Corbusier and masters of late modernism created objects, which through the so-called honesty and formula of the unfinished material moved the viewer into the world of the original and pure architectural form. For the first time the concrete was ennobled, saying that it is the "cast stone", its nobility was recognised and its rank was raised, using it in the significant realisations of public facilities." [6]
The aesthetics of the exposed concrete surfaces goes hand in hand with the strategy of the balanced development. Resigning from additional finishing materials their production is limited (and so is the emission of pollutants to the atmosphere), the performance of the thermal mass of the structure increases and the durable, timeless and stately architecture is obtained, as the concrete has already earned the title of the noble material.

VIABILITY OF THE MATERIAL

Manufacturing of cement, metals, transport, mixing, pouring concrete are the energy-intensive processes, but every object must have walls, columns, beams, floors. Any of the available materials will be used for this purpose, the environment will suffer to some extent. Therefore, the long-term benefits should be taken into account – the durability of the structure and its ability to generate profits from free (in the economic and ecological) sources of energy, thus leading to the reduction of CO2 emission. In connection with the changes of the climate and increasing numbers of disasters, the solid durable structures may prove crucial in the protection of human life. Concrete is non-combustible material (without any additional chemical impregnation), waterproof, and at the same time still economically competitive. Especially if you take into account its many years of exploitation at low costs of maintenance. Often, joining any investments, people still take into consideration the construction costs, mostly. Few investors are aware to decide about the selection of the particular technology based on experiences talking about the way of the material aging, the level of its energy consumption, environmental impact, maintenance costs for the next decades. It is assumed that the lifetime of objects of reinforced concrete is approx. 100 years and at low costs of their maintenance [3]. Thus, already at the design stage it is worth considering the construction of the permanent object with the stage development and with the possibility of adaptation for purposes other that the originally intended. Avoiding demolition works and the implementation from scratch of the next investment, there is a chance to protect the environment from degradation.

USING ADDITIVES

According to the simplest definition, concrete is "*the material formed by mixing cement, coarse and fine aggregates, water and any admixtures and additives, which obtains its properties as a result of cement hydration*" [4]

Fly ash used as additives (created in combustion processes in coal boilers) and the silica fume (created during the production of metal silicon) or blast furnace slag are by-products of the energy and metallurgy industry. Using them as concrete ingredients is aimed primarily to improve the material parameters, such as: resistance to aggressive substances, reduction of concrete shrinkage, sealing. However, it is difficult not to pay attention to other actions. There are used substances being the waste, which would constitute the pollution of the natural environment. Additionally, being an essential ingredient of the mixture, they limit the use of the mere concrete, and what follows is the reduction of the demand for its extraction. In some cases they also contribute to the limitation of the necessary amount of mixing water. This way you reduce both the energy consumption and CO2 emission of the construction process at the same time writing into the strategy of the sustainable construction.

DURABILITY

Striving to increase the durability of concrete mixtures also has the ecological aspect. High Performance Concrete (HPC) gaining the increasing popularity, characterised even by several times greater durability and thickness [5], thanks to additives in the form of reinforcing fibres, nanomodifiers or reactive powders allow the creation of constructions with much smaller cross sections of the structural elements. This way the number of extracted, transported and processed materials is limited, and as a result the emission of greenhouse gases is reduced.

COMFORT AND SAFETY OF THE USE

Existing legal acts and instructions in detail determine the permissible degree of radiation of the construction material to be used and the way of taking measurements [7]. Analyses conducted by the Association of manufacturers of the Mixed Concrete in Poland based on the quoted instructions lead to clear conclusions – "… *concrete, regardless of the type of cement of which it was made, and whether it was made with the addition of the fly ash or not, is characterised by a very low level of radioactivity and from the point of view of radiological protection it can be safely used in the construction of building intended for the permanent stay of people and livestock*." [8]

Commonly used admixtures, in themselves, are harmful substances for the environment and living organisms. However, due to their small amount (max 5% of cement mass) and the fact that after being introduced to the concrete mass they are not removed from it, very much limits their negative impact. The advantages arising from their use have already been described above. So, therefore, concrete can be considered as the "neutral" material, which does not emit harmful compounds. While it increases the comfort of using the building thanks to the mentioned thermal mass and the ability to alleviate peak temperatures and thanks to the physical mass, which contributes to the reduction of vibration. However, in order to obtain the fully silenced building in the reinforced concrete construction, it will be necessary to introduce the proper insulation and expansion joints.

Noteworthy is also the fire resistances of this material. You obtain the non-combustible structure and possible finish, without the need for using additional chemical sponges. In case of fire there is no danger connected with spreading of the fire or secretion of toxic gas. Limiting the spread of fire contributes to the environmental protection. The same applied to the lack of secretion of toxic substances and contamination of water used for extinguishing.

This property is significant that in recent years one can observe the rapidly growing number of fires. Therefore, the increasing emphasis should be placed on the designing of buildings, which will be able to resist the disasters. Besides, that they will provide safety to the users until help is granted, with the low costs and energy, there will be a chance for their re-using after the fire is extinguished. The situation is similar in case of floods and hurricanes.

ADVANTAGES OF PREFABRICATION

The use of prefabricated products is supported, among others, by the quality of finished products. They were manufactured for the purpose in the plant, in optimal conditions. Because of that the manufacturer may provide the constant quality control, without comparison better than the one, which is achieved at the construction site.

Another, very important factor, is the reduction of construction costs thanks to the prefabricated construction elements. Mass production, multiple use of the high quality forms, formwork and almost the whole mechanisation of the manufacturing process, significantly accelerate the production, and withdrawing from the full formwork, scaffolding, replaced with cheaper stamps shortens the accomplishment process of the object. Wall elements, ceilings or roofs can be made in the plant during the casting of foundations on the site, completely independent from weather conditions.

All these advantages are not only the economic benefits. Reusable framework reduce the use of material for their manufacturing, what is also a part of the strategy of sustainable development. Similar to the savings from the possibilities of the precise calculations of the demand for the material and the perfect balance of the proportion of components of the concrete mixture. In the factory operating on a large scale there is no talking about the creation of waste. The amount of the prepared material is dictated by the demand.

Prefabrication is a technology based on accurate calculations of the demand for the materials. So it does not generate losses due to the approximate estimated data. It also gives the possibility of the rational organisation of the transport facility, resulting in the reduction of its energy intensity.

Production of most elements in the factory reduces the total construction process of the object. This is connected with the reduction of the investment costs in the economic dimension but also timely limits the necessity to use the heavy equipment, thus reducing the level of CO2 emission. The use of prefabrication in the construction process is highly scored in the certification systems. In case of the American LEED, the prefabricated structure may provide even up to 23 additional points [10].

BIM TECHNOLOGY AND 3D PRINT

In recent years there has been a breakthrough in terms of the performance of the design documentation. The revolutionary BIM technology (Building Information Modelling) giving the opportunity to create the parametric model of a building with all installations, on a scale of 1:1, without undue simplifications, will allow the use of all advantages of prefabrication. It is possible to create the fragments of the object with a complex, even limited form, based on the digital model in the dedicated factory, and then to “fitting” them on the construction site into whole with accuracy up to millimetres, totally limiting the number of possible errors and collisions, e.g., of installations. In addition, the ongoing research on the use of large-format 3D printers on the site (e.g. technologies like D-Shape, Contour Crafting), give better and better results. Creating elements of concrete based on three-dimensional BIM models, will significantly improve both the project process and the implementation. The most important advantage of such a solution is the full creative freedom within the shaping of the architectural form. This would lead to the rejection of limitations associated with the necessity to design modular, repeatable elements. 3D printing also allows the total withdrawal from the manufacturing of expensive forms.

CONCRETE RECYCLING

According to the strategy of sustainable development, we should aim to design durable objects, giving the possibilities of each adaptation to the changing function. However, there is no doubt that the demolition of the already existing, just being built or the designed buildings will always be necessary. Despite all efforts, nothing will last forever. The trends in architecture change, the needs of the investors, spatial development plans, etc. Therefore, we must take into account the materials, which can be reused. Concrete is one of them. Currently, some debris, resulting from the demolition, is used as a foundation for roads or filling for trenches. In the near future the situation will have to change. We should aim at the maximal use of the created debris due to the increasing costs of their transport and storage [9]. There are being developed (and even they are already used) technologies that enable the processing of debris on secondary aggregates, being the component of concrete mixture. This will allow to significantly reduce the degradation of the environment caused by the extraction of natural aggregates, which is not the renewable material. An excellent role model are the countries like the Netherlands or Belgium, where they re-use up to 90% of waste from demolition [11]. However, we should remember about the deterioration of concrete parameters with the addition of recycled aggregates – especially in terms of frost resistance (due to higher water absorption) and resistance to compression. Currently, there are conducted studies and the successes are achieved in the area of improving the mixture with the addition of secondary aggregates.

PROTECTION AGAINST SOLAR RADIATION

Long-term impact of the solar radiation on the façade with large glasses causes the increase of air temperature in the rooms leading to the overheating of the interior. This phenomenon is called the greenhouse effect [12]. Cooling the building in such case is a much more energy intensive process than their heating.

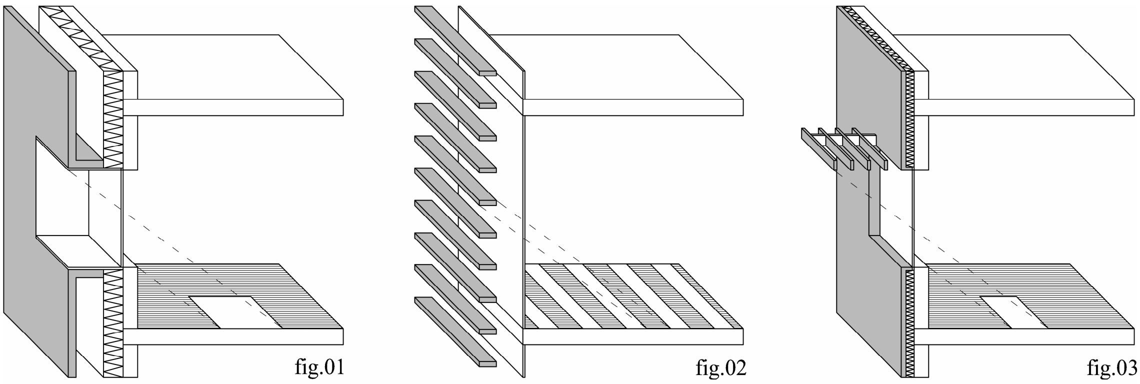
Currently, on the market there is available a series of solutions, which are designed to protect the interior from overheating. The most popular ones include blinds, shutters or light breakers (brie soleil), made of steel or aluminium. In most cases, however, they are strange elements in the object. Even if they were predicted at the initial concept stage, they do not always constitute the element of composition desired by the architect. They are more an accessory with one particular purpose. Therefore what is interesting are the examples of realisations, in which shading was obtained thanks to, e.g., unusual construction. In case of objects, which external walls were made of concrete elements, it can be assumed that the most popular ways are:

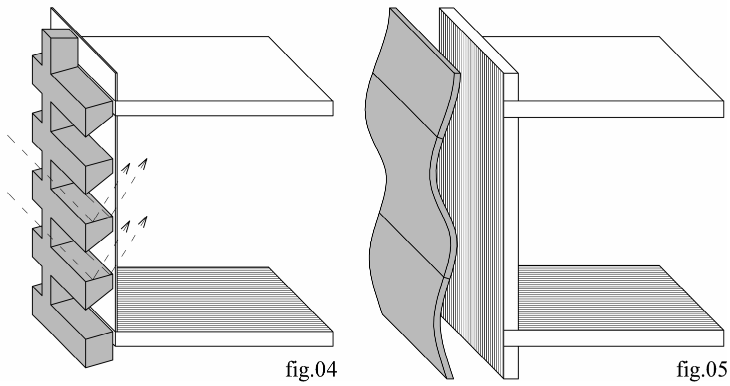
- Shaping the seemingly thick walls, with deeply embedded window joinery (fig. 01). This solution was used, for example, in buildings: Roc Mondrian Laak II, des. L I A G Architekten en Bouwadviseurs; in the complex of City of Justice, des. David Chipperfield; in Rivington Place, des. Adjaye Associates.
- Covering the glass façade with openwork from prefabricated concrete elements (fig. 02). This type of solutions completely change the nature of the façade, thus they have the form not only of the external blinds with the covering function but also they fulfil the decorative role (Silver Park Quay office, des. René van Zuuk Architekten), informative (energy generator Argos, des. MGP Arquitectura y Urbanismo) and even structural (Mini House w Kobe, des. Hiroaki Ohtani).
- Light breakers (fig. 03). Attached perpendicularly to the plane of the glass elements with a horizontal layout, they have both the shading and aesthetic role. They can have

the form of the horizontal beam (Hotel Diagonal Barcelona, des. Juli Capella) or a few strips, located at equal intervals.

- Filling the interior with the reflected light (fig. 04). In the elevation there appears a layout of gaps with planes arranged at the angle enabling the change of the direction of the arrangement of sun rays, so that they get directly to the interior. This method was applied, e.g., in the buildings of College of Europe w Bruges (des. Xaveer De Geyter Architecten), both in the classrooms and in technical areas. Through the use of white concrete, a lot of diffused and reflected light gets inside the interior.
- Light decorative covering, shading the construction wall (fig. 05). Eliminates the need to introduce the heat-insulating layer. Suspended on a steel or aluminium structure it covers the external bearing wall against solar radiation, and the ventilation gap created between them accelerates the ventilation process. Due to the lack of protection against low temperatures, this method is used in areas of subtropics, tropics and equatorial areas, e.g., Liverpool Department Store in Mexico (des. Iñaki Echeverria), office and logistic centre in Nola, Italy (des. Modostudio).

It is significant that in all these examples, apart from shading, concrete prefabricated products still fulfil other functions – structural, aesthetic (they shape the nature of the facade), covering, secreting, etc. They are an integral element of the building in every respect. Not only the equipment necessary to meet legal requirements or to provide the comfort of use.





01. Seemingly thick walls, with deeply embedded window joinery;
02. Glass façade covered with precast concrete decorative openwork element;
03. Standard light breakers;
04. Layout of gaps with planes arranged at the angle enabling the change of the direction of the arrangement of sun rays, so that they get directly to the interior;
05. Light decorative covering, shading the construction wall

CONCLUSIONS

Concrete itself is not energy-efficient material, however universal properties it has in connection with the creative and conscious design can make the architecture created with its use to meet all requirements of a modern sustainable constructions. The proof of this are the projects, which receive high ratings in the LEED or BREEAM certification systems. Aspirations of architects should thus focus on the maximal use of the potential of the mere material, and only then on using additional (and as it turns out, often unnecessary) devices used to provide comfort to the user and reduction of the carbon footprint.

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