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CONCRETE'S DICHOTOMIES

DYCHOTOMIE BETONU

A b s t r a c t

The dichotomy of concrete can be expressed in its technical aspect as well as in its use as a material that develops multiple scenarios in space. Technological progress conveys us to review the perception of concrete not only as a rough and smooth, heavy and light material, but also cold and warm, transparent and non-transparent, fragile and bendable, monochromatic and coloured. With the appropriate admixtures or coatings, concrete can self-repair or conduct electricity. It is therefore expected that it still will be a plastic material that does not fit within the confines of the definition of art. The article presents examples of architectural facilities/projects, which, despite the lack of the latest "multi-tasking" super-concrete availability, involve the aspect of "transparency", "bendability", and "lightness" of concrete.

Keywords: concrete, reinforced concrete, dichotomies

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

Dychotomiczność betonu może wyrażać się w jego aspekcie technicznym, jak również w użyciu jako tworzywa budującego wielowątkowe scenariusze w przestrzeni. Postęp technologiczny każe nam zrewidować postrzeganie betonu nie tylko jako materiału chropowatego i gładkiego, ciężkiego i lekkiego, ale również zimnego i ciepłego, nieprzezroczystego i przezroczystego, kruchego i elastycznego, monochromatycznego i kolorowego. Dzięki odpowiednim dodatkom lub powłokom beton może się dziś samonaprawiać lub przewodzić prąd. Należy zatem przewidywać iż nadal będzie stanowił tworzywo plastyczne niedające wpisać się w zamknięte ramy definicji sztuki. W artykule zaprezentowano przykłady obiektów, w których mimo braku dostępu do najnowszych, „wielozadaniowych" superbetonów, zawarto idee „przezroczystości", „elastyczności" i „lekkości".

Słowa kluczowe: beton, żelbet, dychotomie

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1. Introduction

Over millennia, concrete has been discovered many times for architectural and sculpture works. As for a building material, its invention and spread are attributed to the ancient Romans and their mixture of stone, lime slime, pumice, and volcanic ash[1]. The most famous examples of the Roman *opus caementicum* were the Roman facilities, including the Pantheon, the Colosseum, and the Basilica of Maxentius. In subsequent centuries, the use of concrete in the shaping of space was disregarded. It was only the invention and patenting of Portland cement in 1824 that once again attracted the interest of the forgotten material. At that time, it was mostly used as the construction material, which, due to its unattractive visual impact, was usually hidden under a layer of stone, brick, or plaster. Non-cladded concrete, thanks to appropriate recipes and technologies, could even imitate a gemstone. The breakthrough took place at the end of the 19th century with the invention of reinforced concrete. The combination of concrete with reinforcement in the form of rebars, wire ropes, strings, cables and wire-based mesh, allowed the construction of buildings with such parameters and forms that were impossible to construct formerly. Although priority was given to the usefulness and durability of buildings, even the pioneering developments erected for industry included the aspect of aesthetics (ill. 1). Also, the popularity of the new material increased due to its property of fire resistance. Reinforced concrete quickly became one of the favourite materials used not only by architects and construction engineers but also by sculptors. In architecture, a significant milestone was the erection of *Unité d'Habitation* in Marseille, where Le Corbusier used raw, un-plastered concrete for the facade (Fr. *béton brut*). The rough surface of the facade of the building, with clearly stamped patterns of the wooden formwork, was treated as an added asset. Moreover, texture matched well with an equally expressive raw and strong form. The new aesthetics has become the precursory element of a new direction in architecture – Brutalism. Since then, reinforced concrete has undergone more dynamic transmutations.

At present, concrete is the most commonly used construction material and is also the second most widely used product on the planet. Its use is twice over that of, in total, wood, steel, plastic and aluminium, and per capita use is nearly three tons per year[2]. Thanks to improved recipes and technologies, the range of its usefulness is constantly increasing.

2. Concrete's dichotomies in architecture

The concrete's dichotomies in architecture can be seen on the one hand in terms of its technical and physical properties of tangible matter, and on the other as the material that develops multiple scenarios in space. These two perspectives never should be considered hierarchically, the more that concrete, in a special way, unites the Vitruvian triad: durability, utility, and aesthetics.

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[1] About 7000 B.C. in Yiftah El, Israel, limestone binder and ground limestone were used to build houses.

[2] http://www.wbcsdcement.org (accessed: 30.05.2017).

In the aesthetic dimension, with regard to spatial composition, the importance of the use of the material is important, as is the choice of colour from a colour chart. The purely technical dimension of a building or its shift to the aesthetic dimension and utility depends essentially on the intention of the creator. The same cube of concrete can both disappear irretrievably in foundations of a building as well as constitute an essential element in space development, serving as medium conveying emotions. Analogically, a book may be perceived only as sheets of paper or as a work conveying certain content and values.

The tangibility of concrete can employ almost all senses – firstly sight and touch, but also hearing and smell. Experiencing the material with a sense of touch, we are provided not only with its texture, roughness or smoothing degree, but also its temperature, i.e. tangibility of concrete forms in a specific spatial context. In the last century, with the development of modernism, we have been witnessing the systematic deprivation of the building mass in facilities. Lightweight building partitions threaded on ribbed structures contributed to the dematerialisation of building partitions, often distorting the boundaries between the interior and the exterior of the facility. Greater emphasis on the search for spatial solutions, while discovering the inside, downgraded the materiality of partitions. The underestimation of physical impact reduced significantly the range of effects on the human senses. In addition, in the era of the ecologically sustainable construction industry, paradoxically, it has caused the need for additional complex and expensive technologies.

At present, new concrete transmutations constituting a fascinating challenge in the development of space contribute to a greater attention paid to the materiality of partitions. The range of contemporary creative uses and solutions has expanded considerably. Technological progress conveys us to review the perception of concrete not only as a rough and smooth, heavy and light material, but also cold and warm, transparent and non-transparent, fragile and bendable, monochromatic (grey or brilliant white) and coloured (dyed or stamped concrete), waterproof and permeable. With the appropriate admixtures or coatings, concrete can self-repair or even conduct electricity. Research on concrete allows the simultaneous improvement of other technical parameters. In this context, apparently, this plastic material will remain unfitted to the confines of the definition of art.

The rawness of both texture and form, evident in facilities created in the spirit of brutalism, was regarded as the value bringing a connotation of strong, primitive, almost cave formations. An important element of creativity was coincidence and uncertainty of the final result after removing the formwork. Lowering concrete setting regimes, the cast monolith in a mould matrix, after cooling, could take almost any form. Also, the processing of green concrete, even with the simplest tools (trowel, brush, or tools used to form decorative plasters), could introduce the element of individualism. The new raw forms and textures remained in sharp contrast to former architectural accomplishments. The increasing aesthetics, under conditions of improved standardisation of work performance, combined with the expectations of contractors consolidating the image of cleanliness and trust of their institution, led to an ever-greater refinement of formworks. Modern projects are characterized by an incomparably greater conservatism in the manipulation of texture and form.

The element of coincidence and surprise of the casting mould has been severely limited over time. Accidental pits, stains, air-holes, honeycombing, “clouds” and discoloration, which for the sculptor and architect could be of artistic value, are regarded

Ill. 1. The integrity of architecture and sculpture with the conscious manipulation of form and texture in the pioneering building made in reinforced concrete technology. Water tower in Nysa from 1907 (ill. a-c: author, 2013; d: postcard from 1920, author's collection)

as construction defects under building regulations. More and more smooth, glossy and perfect surfaces, produced in bulk, can be artificial and boring just like everything in excessive abundance.

Nowadays, structural concrete (also called architectural or facade concrete) is increasingly used in architecture, utilising its textural and aesthetic properties while maintaining high durability parameters. Technological progress, and especially the introduction of patterned mould matrix, has significantly increased the opportunities for shaping the texture, form, and colour of the material. This type of concrete allows for the design and creation of repetitive, durable, and aesthetic forms without the need for additional processing or surface cladding. With the perfectly smooth and homogeneous concrete, one can make small architectural elements (benches, pergolas, bicycle racks, pots) as well as interior fittings (kitchen countertops, washbasins, furniture, lamps, and utensils).

Louis Kahn, probably basing on his own experience (ill. 2), kept cautioning the authors who did not respect the specificity and utility of concrete against perceiving concrete as a matter of secondary importance, emphasising that it is a very refined material. Leaving the surface of concrete after its maturation in the raw form (non-treated) requires contractors to possess an excellent knowledge of the technology of the work, including cleaning, polishing,

grinding, sand blasting, burning off, etching, hammering, pointing, striating, or bush hammering. Corrections and retouches, possible during mechanical surface treatment, chemical delaying of surface bonding/setting, or combinations of these methods, may involve additional complications.

The perception of the weight of concrete can be relative – referring to the material or aesthetic aspect. On the one hand, "weight" can be considered in the context of the mass of material with a specific physical and chemical composition, on the other hand, it can refer to the architectural form. The smaller weight of concrete resulting from the use of weight-reducing admixtures (*vide*: the Roman domes of the Pantheon) can combine lightness or solidity. Over millennia, concrete was associated with weight, solidity, and statics. Only the invention of reinforced concrete destroyed this approach, enabling the performance of fantastic ideas. New York's JFK airport terminal by Eero Saarinen, in the form of a bird rising to fly, brings the connotation of movement lightness. Works of Santiago Calatrava, though exposing excessively the structure, are characterised by dynamics of extremely expressive, often zoomorphic forms. His projects, as earlier Le Corbusier's works, show playing with natural light, which is let in even to commonly dark railway stations.

The grey matter of concrete combined with its physical coldness is generally associated with the cold. The period of Polish People's Republic, as a result of imperfections in materials and technology, projected the unappealing image of panel buildings stuck in mud and uncompleted investments (*vide*: the *Alternatywy 4* series directed by Stanisław Bareja). The scale of the monotony of anonymous urban tissue in "concrete deserts" also produced negative connotations, as Martyna Jakubowicz sang (see: "*No free love in concrete houses* "). At the same time in the world, concrete was used as a material to create original and wonderful forms.

Depending on the intention and sensitivity of the creator, using different processing techniques, the right pigment, degree of smoothing, texture, or form of the interior or the whole facility, the perception of concrete may vary. Raw concrete will always be perceived as colder than after the polishing.

The recent technologies and recipes, in physical and chemical terms, can redefine the concepts of cold and heat. Chris Tuan, professor of civil engineering at the University of Nebraska in Lincoln, patented the formula for electrically conductive concrete. The new mix contained about 20% of metal filings and carbon particles. Thanks to heating the surface to the environmentally safe temperature of approx. + 40^0C, ice and snow accumulated melted quickly. Research on new concrete is funded by the US Federal Aviation Administration (FAA), which is interested in implementing technology at airports. This will ensure the improved passenger handling and air traffic services. A remarkable achievement was the pioneering construction of the 231-meter Roca Spur Bridge near Lincoln, whose surface was lined with 52 conductive concrete slabs. During the five-year winter tests, the use of salts or de-icing chemicals that caused concrete corrosion and environmental pollution has been effectively eliminated[3] [11]. Conductive concrete can also be applied in dangerous traffic areas – road crossings, viaducts, bridges, flyovers, or motorway exits.

[3] http://www.news.unl.edu/newsrooms/today/article/de-icing-concrete-could-improve-roadway-safety (accessed: 30.05.2017).

Ill. 2. The performance imperfections in the main building of the Indian Institute of Management in Ahmedabad in India (Louis Kahn, 1961) have caused numerous cracks in reinforced concrete, including brickwork (photo: autor, 2017)

Transparency of concrete can be defined differently, depending on the degree of flow of electromagnetic waves (radio, microwave, infrared, visible light, ultraviolet, X-ray, and gamma radiation) or mechanical waves (sound, seismic, sea waves).

The traditional perception of concrete as a grey building material has changed with transparent concrete called LiTraCon (Light Transmitting Concrete), patented by Hungarian architect Áron Losonczi in 2001. Translucent and light-permeable concrete mix containing 4% of optic fibres forms the concrete mix homogeneous in its structure and outer appearance. Glass fibre in this amount does not impair the strength of concrete. The multitude of uses of LiTraCon seems to bring the revolution in architecture. Already today new material can be used both for the erection of building facades, interior walls, finishing elements and illumination of small architectural facilities. An individually moulded mix can be treated as another new type of material that allows for the creation of unique designs. The material can be used not only by architects, interior designers, construction engineers but also by artists, including sculptors in particular. At present, however, because of the high cost of production, all uses focus on the decorative function. It may be anticipated that the future use of LiTraCon may result in solutions that contribute to increased energy efficiency in buildings. Only increasing the flow of light

waves into parts without natural light could affect significantly the reduction of energy consumption.

The classic concrete mix consisting of mineral aggregate and Portland cement, depending on the thickness of the material to be tested, is transparent to X-rays and gamma rays (γ). Protection in the flow of electromagnetic waves can be achieved through so-called heavy concrete, containing heavy mineral aggregates (magnetite, limonite, barite, hematite), iron ore, or metal fillers, including iron or steel waste in the form of a waste shot (cast iron or metal). These tests, with the support of the FAA and Road Department in Nebraska, are also conducted by Chris Tuan. One of the applications of concrete can be the protection of facilities against industrial espionage, protection of nuclear power plants, or facilities already irradiated.

One of the most promising new materials is *bendable concrete* developed by researchers from the University of Michigan in Ann. Engineered Cementitious Composite (ECC) is characterised by the excellent formability of 3–7%[4] [9]. This is an excellent parameter compared to the formability of typical Portland cement (0.01%). Thanks to this property, it is up to 500 times more resistant to cracks and scratches and up to 40% lighter. Such outstanding properties of bendable, non-cracking concrete is due to the reinforcement by specially selected short polymeric fibres, which account for approx. 2% of the volume of the concrete mix. ECC has a much higher tensile properties superior to other fiber-reinforced composites[5] [6]. ECC appearance is no different from normal concrete, except that under the force it is flexible and bendable. ECC was applied, among others, at the repair of the cracked Mitaka dam near Hiroshima (2003); the reinforcement of the Glorio Roppongi skyscraper in Tokyo (2016), exposed to earthquakes; and on the construction of the Mihara Bridge on Hokkaido (2005), the concrete use was reduced by 40%[6] [9]. With all the advantages of bendable concrete, in addition to the ecological aspect of reuse of waste materials in the construction industry, the benefit of reducing energy consumption should also be emphasised.

Buildings constructed nowadays, thanks to the introduction of suitable admix, can be naturally grey, pure white, or fabulously coloured. It is possible to make various types of stamps on their surface, including photographs. Combining colours with a different texture of the concrete surface can lead to surprising plastic effects. One of the newest, however, already advanced technologies, is the transfer of photographs or graphics to the surface of concrete, called photo concrete. The photo concrete was first used in 1986 on the facade of the Lons-le-Saunier public library in France. At present, the transfer can be done in a process similar to screen-printing or by a specially prepared formwork. The first method, called Fotolith or Serilith-Gravur, resembles screen-printing. Before concrete is poured into the formwork, a film with a chemically active layer is applied to the surface of the formwork, which retards the concrete setting. After removing the formwork and rinsing the cement slurry/grout/paste, we obtain the right image. The reproduction accuracy depends on the composition of the concrete mix and the choice of retarding agents. In the second method – Photo-Gravur, patented by Reckli, the casting is preceded by the preparation of a three-dimensional image and a negative in the form of a shallow relief in CNC milling technology. The image on the

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[4] http://www.engineeredcomposites.com (accessed: 30.05.2017).

[5] M. D. Lepech, V. C. Li, *Large scale processing of Engineered Cementitious Composite*, ACI Materials Journal of Reinforced Plastics and Composites (2008) 105:358–366.

[6] http://www.engineeredcomposites.com (accessed: 30.05.2017).

Ill. 3. The integration of natural and artificial stone uniting sculpture and architecture (arch. arch. Timo and Tuomo Suomalien). The interior of the church carved in the rock in Helsinki Temppeliaukio is modelled by light falling through the openwork dome (photo: autor, 2015)

surface of concrete is best seen when light falls on the surface at an angle close to 45^0. Thanks to photo concrete technology, it is possible to transfer different content in the form of text or image. During 1996–1999, Herzog & de Meuron engraved the photographs of Thomas Ruff on facades of the building of the Technical College in Eberswalde near Berlin. The artist selected carefully the appropriate motifs from magazines and arranged them into horizontal strips running around the facade. According to the authors, the references were supposed to evoke the associations of dormitory rooms with posters. It seems that the excessive usage of photo concrete technology without the reasonable context or in the aggressive forms can cause chaos, anxiety, resulting in certain negative behaviours of space users.

The desirable property of concrete in an environment exposed to moisture is, usually, its water resistance. However, the main problem was to obtain concrete with a texture that allows the absorption of water from pavements, roads or car parks. Nowadays it is possible thanks to previous concrete. Due to the high porosity of the material, of approx. 15–25%, it should be treated as a kind of water permeable filter. The condition of successful application of the new material is the suitable permeability and absorption of the substrate as well as the possibility of discharging excess water. Another condition is proper maintenance. Pitfalls include clogged pores or standing water in periods with cold temperatures. However, with good maintenance, previous concrete can contribute to more sustainable water circulation in the environment.

Ill. 4. Le Corbusier, combining climatic and cultural conditions, introduced the *brises-soleil* on the west façade in the facility of the Mill Owners' Association in Ahmedabad, India (1951–54). On one hand, the concrete grating with diagonally shaped surfaces protects from excessive sun penetration and passers-by, on the other, it distributes air and models the facade with light, photo: autor, 2015

3. Summary

Contemporary technological progress provides creators with further possibilities in shaping the concrete mix based on an increasingly modified liquid rock. Unfortunately, considering the growing importance of space aesthetics and tight technical requirements, by no means imposed by architects, raw and rough concrete is used less and less. Therefore, there is even a nostalgia for expressive forms built in the traditional concrete technology, using the element of coincidence of matter, where the combination of space and matter plays an important role. Even when perceiving concrete as the imperfect material, it was possible to achieve great effects evoking connotations of the heat and cold, water-resistance and permeability, roughness and smoothness, or differentiation of transparency (ill. 3, 4). Thus, it is expected that concrete, together with its growing capabilities as well as limitations, will continue to be a fascinating creative challenge. In this context, it is, therefore, appropriate to agree with Władysław Tatarkiewicz that *borders are redefined continuously, and at any moment there may appear a work that does not fall within the arbitrarily accepted, closed definition*[7].

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