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To cite this article: Dorota Janisio-Pawłowska 2019 IOP Conf. Ser.: Mater. Sci. Eng. 471 072048

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Applications of Concrete in Contemporary Sacral Architecture

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Abstract. Defining the contemporary sacred space is connected not only with the search for the sacredness of the interior, but also with the balance between the selection of the most appropriate construction systems, which are made of concrete and reinforced concrete, together with the possibility to create the whole building, the form which is the intention of its creator. New kinds of materials, which are now less and less constrained by structural obstacles, have broadened directions of exploration and development of new forms in architecture. Undoubtedly, the invention of reinforced concrete, in the second half of the nineteenth century, was also the beginning of a revolution in architecture and the source of new challenges in creation of the sacred space. The use of concrete and reinforced concrete, as well as its combinations with other building materials, can be traced on various buildings. Having considered more than a century of experience in the use of these materials in the construction of architectural objects, including sacred space, the selected churches from different time periods of different scales were analysed. In order to compare the way of using the potential of concrete and its application in the construction of sacred objects, the analysis began with the church of August Peretta in Le Raincy. The author of the construction used thin reinforced concrete supporting columns and a vault as a reinforced coffered ceiling. The latest example of such a building is the church of Lech and Wojciech Szymborski in Warsaw, which is currently being built using the combination of technological and technical possibilities, as well as the most suitable selection of concrete mixtures. All that in order to create a unique building with a main nave structure both in a frame and plate system. The changing role of concrete and reinforced concrete is evident in the creation of new forms of sacred buildings, regardless of their scale. Moreover, the ongoing transmutation of concrete is visible through the creativity-enhancing fascination with this material, which has become, not only readily available, but also commonly used as a replaceable, multifunctional substitute in fine arts, technology and decorative elements. Furthermore, it has been repeatedly used as a construction material, which, when left without further finishing, results in being either an internal or external finish. The article is an attempt to answer the question how the approach to the use of this material has changed in the creation of the form and its interior, while paying particular attention to its internal and external exposure.

1. Introduction
This article discusses the analysis of the use of concrete in selected contemporary objects of sacred architecture. Based on the analysis, the changing use of concrete in the construction of churches was traced. The aim of the work is to present the contemporary possibilities of the application of this material and the way it is perceived in designs by both creators and recipients.
Concrete has now become the most commonly used building material for many structures, including sacred ones, created in the recent decades. Concrete has been used since the formation of Mesopotamian city-states, including Ur, around 2500-2000 years BC, where kilns for burning lime were discovered, which demonstrated lime mortar was used in these areas. Mortar was also used to build the defensive walls of Troy and Mycenae. Following the improvement of the building material, around the second century BC, when in Italy volcanic ash was added to it, concrete became more and more widely used due to its improved strength and durability. This allowed for the creation of even bolder constructions. An example of such an impressive, concrete structure is the most famous temple of ancient Rome - the Pantheon, the construction of which involved the material of different density. The structure is covered by a concrete wall-based dome with embedded relief arches to properly support it, whereas in order to reduce the weight of the concrete, pumice aggregate was used [1].

The stages of improving and identifying suitable mixtures and additives to concrete have transformed into an eternal process of evolution of this material. Analysing its further development and the variety of its applications, it is worth recalling the French gardener, Joseph Monier, who invented reinforced concrete in 1867.

The end of the 19th century abounded in expanding new applications for the use of concrete and its mixtures in the construction industry. The possibilities of wider economic use, in order to create bolder constructions, were sought after on a wider scale and announced the beginning of an upcoming revolution in architecture. In 1892, Francois Hennebique patented the principle of erecting uniform of skeletal structures made of reinforced concrete. Soon after, in 1893, Francois Coignet and Luis Charles were the first to apply concrete for construction purposes in sacred architecture, creating the Le Vesinet church in Seine-et-Oise, the concrete-form object, whose construction material was covered with a cladding [2].

The potential use for constantly improved concrete and reinforced concrete has expanded and influenced development in a bid to find the most convenient creative solutions. In the second half of the 19th century, there was an intensive growth of construction engineering, and a number of new possibilities and construction techniques were developed with the use of reinforced concrete, what resulted in many new creative projects.

Technological progression has given rise to changes in sacral architecture, and since then it has always followed new technical and structural possibilities of a specific era [3]. As a consequence, concrete and reinforced concrete have become indispensable building materials in modern churches over time. After more than a hundred years of use of concrete in the construction industry, the number of objects created with its participation constitutes a wide vast of analysis of various applications of this material in the group of sacral objects.

2. Reinforced concrete as a base material in sacral constructions

In sacral architecture bricks have for centuries been regarded as one of the most acceptable materials used in sacred spaces. With time, however, the brick began to give way to other materials - concrete and reinforced concrete. Currently, it is said that concrete is being sacralised, which suggests that over the period of hundred years, it has become the basic building material of the new era. However, expressing the right form in architecture requires a use of a variety of materials, in order to combine, reveal, obscure, deform, and use them for decorations. As a result, a closed or open space is created, limited by the material used, which after certain time starts to be perceived only as a construction element.

The beginning of the 20th century brought a significant breakthrough in sacral architecture, which was influenced by modernism and architectural avant-garde, as well as the events in the Catholic Church itself, in the second half of the century. The published findings of the Second Vatican Council also concerned the construction of new sacred buildings which influenced the shape, structure and form of today's churches. In order to confirm the statement that reinforced concrete is the basic material in sacral construction, one can rely on the author's doctoral thesis [4]. In this work, the analysis of more than one hundred objects created in the post-war years in the Diocese of Szczecin-Kamień in Poland showed that concrete and its derivatives were the most commonly used materials for building contemporary objects,
and a significant part of the structures is based on reinforced concrete [4]. The work of many architects in the analysed period shows a broad interest in the material, whose method of use has evolved along with the created forms.

In the area of the research presented here, architectural objects created at extremely different times and locations of various scale were analysed. August Perret, hailed as the father of reinforced concrete, designed the church in Le Raincy shown in figure 1, which is said to be the first religious building of reinforced concrete; the church has become the model repeatedly imitated in contemporary Europe. The object was created in 1922 as a hall structure, which is set between a traditional grid of pillars and the openwork walls, filled with colourful stained glass windows. The interior was designed without unnecessary decorations, with slender pillars, acting as a structure supporting the vault, made of reinforced concrete [5]. As Marcin Charciarek writes [20], geometry and an elementary shape dominate in the whole form. In the work of August Perret, one can notice the main goal of his creative explorations was to create the monumental architecture with the use of reinforced concrete [6]. As Gino Malacarne writes, August Perret presented the skeleton of a building in such a way as to resemble the skeleton of an animal, which is rhythmically balanced and symmetrical. Furthermore, it contains components of various forms, so the building should also be rhythmic and possess all the elements, which are necessary for the function of the object [6].

During the phase of experimentation by different artists with the possibility of using reinforced concrete in construction, first in Szczecin and then Prussia, in 1919, the first church was built in a modern style of construction using reinforced concrete. With the use of technique, so far applied in industrial constructions, the Garrison Church, designed by Adolf Sthal and shown in figure 2, was designed as a three-nave basilica with a tall tower and a rectangular nave, similar to a square with a spacious apse on a half-ellipse [7], whose main nave was covered with a reinforced coffered vault. This church, against the backdrop of the contemporary architecture of the city, is an innovative work and the first in which the brick as a traditional form and material that was the most often used in construction was abandoned. These two objects, completely different in form and structure, created by August Perret and Adolf Sthal, contrast with each other, despite the fact that in both the innovative solution was the use of reinforced concrete. However, the lightness of the first allows to describe it as the pattern, which has been repeatedly imitated and proclaimed as the first modernist church.

Figure 1. The church designed by August Perret in Le Raincy in 1922, [8]
As a result of the far-reaching changes in perception of the form of sacral architecture and the possibility of using new materials and spreading the idea of modernism, on the eve of the entry into force of the provisions of the Second Vatican Council, sacral buildings are being created while their authors experiment and seek for new solutions for the form. The most interesting, according to the author, are constructions such as the Chapel at Ronchamps Le Corbusier 1955, Oscar Nemeyer cathedral in Brasilia 1958, Frederick Gibberda cathedral in Liverpool 1962. In these objects, the most commonly used construction material was reinforced concrete, which allowed for unlimited possibilities of obtaining designed planes and curvatures, adopted for the construction of facilities with such a complicated geometry.

The arrangements of the Second Vatican Council gave the artists freedom of choice in the language of art, however, the liberation of form from the framework of symbolism became a challenge [5] for many of them. In this new design, only reinforced concrete could be a non-limiting material and a new way of perceiving the sacral space. The multiple possibilities of using concrete and reinforced concrete gave rise to many questions among the creators and clerics: whether and how concrete and its texture enable the aesthetization and sacralisation of modern churches? [9 p. 281]. This question shows how this material became a creative and an indispensable structure and often called a contemporary stone that defines the emerging churches.

In the post-conciliar period, a significant number of objects were created, both in Europe and beyond. Among the creators of these facilities, Mario Botta, should be mentioned - the author of many chapels, churches and the Cathedral in Evry built in 1992-1995. This architect is an admirer of Le Corbusier and therefore the material he used. A cathedral of his work is a concrete bevelled cylinder, as
tall as the city walls and made of concrete with small window openings, the form encloses the space of the cathedral [10 p.125]. The seemingly traditional brick material on the façade may give the wrong impression of the material used for the construction of the object, which in fact was concrete.

In 1975, the creator of Alvar Aalto designed a church in Riola, Italy, where the reinforced concrete was used for the construction of the object, whereas the material of the structure creates an exposed skeleton with repeating ribs inside. These visible frameworks correspond to the assumptions of August Perret, who believed that if the frames are not worthy to remain in the view, it means that the architect did not fulfill his task [6]. The authors of the Jubilee Church in Rome, built in 1996, Richard Meier and Partners also used reinforced concrete as the basic material for creating the sacral space. The juxtaposed sections of the sphere form the structure and surface of the walls, while the material left was used as a finishing element, which was given self-cleaning properties. The statement that the church does not consider any style as its own, has resulted in a new creative approach to design. In connection with this, many unprecedented geometry constructions appeared, structures that use not only reinforced concrete but also steel and glass. The unlimited possibilities of combining plastics with the brick also gave rise to the treatment of the form of the object as a component of many elements, which, in the most appropriate way, was ensuring that the requirements of the Council are met. A new sacral space was created, where concrete and reinforced concrete took the leading role as a contemporary material forming the space and construction of the object.

3. Contemporary sacral architecture from Poland, analysis of selected objects
The analysis covers selected sacral objects built in the second half of the 20th century, created in the spirit of the arrangements of the Second Vatican Council. In Poland, in contrast to the dynamically developing architecture of the idea of modernism of the so-called artists of the west, due to the prevailing political situation in the country, years had to pass for constructors to be able to incorporate inspirations from well-known world artists into their projects. However, the period of the last forty years, despite many obstacles, abounded in the unique scale of the intensity of sacral constructions.

Due to the political situation that prevailed in the discussed period in Poland, the analysis will ignore the aspects related to the difficulties that accompanied the investment from both the formal and financial side. In the sacral architecture of the discussed period, the implementation of new recommendations of the Council brought both good and functional, as well as aesthetically weaker solutions of the newly-built sacral objects. The scale and size of the functional program of the emerging churches was associated with the place where they were located. It can be assumed that the majority of large churches were built on newly created housing estates, at that time built from a large slab, for production of which concrete was mainly used. Mass sacral architecture, as the construction of churches built until the 90s has been repeatedly described. It was also characterized by the specificity of the material commonly used, which was concrete, being most popular, the cheapest and the most commonly used construction material.

The notion ‘concrete churches’ is also a designation attributed to objects created in the analysed period. Despite many generalizations, which may suggest that all massively built objects, made exclusively of concrete and reinforced concrete, do not constitute high artistic value, among them are some which deserve special attention. It is important to discuss those building due to the innovativeness of the construction solutions applied there, with the use of concrete and reinforced concrete. The geometry of the obtained effects of the search for the architectural form, which suits the sacrum space in the opinion of their authors, is also interesting.

An interesting object which combines elements of elementary geometry is one of several churches created by Adam Szymski, the church built in Szczecin in 1980-1989, which is presented in Figure 3. The author assumes the composition of the temple as a massif rock, which breaks and divides into many planes – resembling the cracking of a rock tomb. In the ground floor plan, the accepted solutions of the spatial concept are visible. The frame of the main nave creates seven wall elements of irregular size and variable inclination towards the interior, in the shape similar to the letter "C". In order to obtain the
intended effect, the main walls of the frame were made as reinforced concrete planes, which the author diverged from each other connected by the use of skylights, i.e. light gaps filled with stained glass. In this way, the effect of a form rising from the ground was achieved; the whole assumption is represented on a model shown in Figure 3. The spatial form, with the structure of irregular planes, was crowned with a reinforced concrete and a flat roof designed as cross-sections, transversely separated by the upper longitudinal skylight. By cutting the planes on the longitudinal axis, a directional light was introduced that illuminates the nave. The temple was built on an irregular polygon plan, ending with an unresolved presbytery, its main nave is a single-space hall. The piling-up form contains two levels of the temple – one proper level of the main nave and the other, available according to the design, from the ramps beginning horizontally in higher parts of the terrain leading from the entrance directly to the choir, which surrounds the three sides of the temple. Expression and multi-directionality of the form is achieved through the several horizontal roofs, which are composite surfaces of diagonal walls. The chapel is linked to the building, and together they create the whole of the assumption. It is accessible from the nave of the church, and its form is distinguished from the body of the temple in the plane above the side walls, which close with a system of sixteen structural elements, reinforced concrete oblique pillars described in a circle. The pillars converging upwards form a bevelled cone – a tent with light between gaps [4 p.110-121].

The Church of St. Jadwiga Queen of Poland in Krakow by Romuald Loegler, built in 1981-1988, presented in Figure 5, is an example of a monumental two-level temple. The upper church is almost a central plan, a compact rectangle close to a square. The whole mass is made of raw concrete, so that the interior façade is a smooth architectural surface, which looks as if it remained unfinished, visually visible along with elements of the formwork. A single-space hall interior is a cube is traversed diagonally, with staggered quarters, filled with glazing. The two quarters of the cube above the presbytery were raised, thus they accentuate its form. At the intersection of diagonals of the arms intersected by the upper
There are four pillars that support the roof pitch [4]. The church is a dense block resembling a cube, in which the symbol of the cross was inscribed, expressed by the upper intersections of the vault forming the skylight bands. The object shows the full spectrum of the possibilities in the use of a new material in sacral architecture, which is concrete and reinforced concrete, it occurs here almost everywhere on external and internal surfaces, remaining completely unobstructed. As Józef Szymon Wróński writes [4], a new reinforced concrete material had been used for the first time on such a scale when creating a sacral building in the city of Krakow.

Władysław Pieńkowski designed several dozen churches in Poland; his signature material used in the construction of temples was also concrete. With its use he designed, characteristic of his style, seemingly cold, concrete temples. It is impossible to confuse his work with other artists who, using concrete, designed characteristic vaults and pillars of the interiors, coffered ceilings over aisles, and concrete window fillings as mullions in windows or stained glass windows. He designed churches without unnecessary decorations, the only ornament were openwork glazings, which provide light that fills the sacral space. The author used the principle of leaving elements of the construction of the pillars as a pure skeleton, where reinforced concrete pillars order the interiors of his temples. The repeatability of the pillars and the skeleton is similar to the solution used in afore-mentioned church by Alvaro Aalto. The object that shows the character of Władysław Pieńkowski's works is the church of St. Dominic in Warsaw built in 1983-1994, shown in Figure 6. The architect created a temple with a geometrical simple form inspired by Gothic, which is evidenced by the use of brick as a visible material on the façade; it also fills the interior in spaces between the ribs. The entire frame structure of the object is visible in the interior. Intricately designed, reinforced concrete ribs have their form, they are not just simple elements of construction left in the sight, here they are the element of the whole plasticity of the interior. Just like unfinished raw concrete, they remain a rhythmic, repetitive element, which supports the reinforced concrete coffered vault. The spaces between the ribs filled with a brick wall are interspersed with tall narrow windows formed of an openwork concrete filled with glass.

Figure 5. The Church of St. Jadwiga Queen of Poland in Krakow by Romuald Loegler built in 1981-1988, [11]
Among the authors of the Polish architecture of the post-conciliar period, it is worth mentioning that the discourse carried out in the course of creation has always concerned one thing: how to achieve the intended effect of a form to give a recognizable character to a sacred object, and at the same time create a mystical space for the faithful? The transmutation of concrete over the last decades has given this material the character of plastic, which is unrestricted in its nature. Over the last twenty years, the design method has undergone significant changes, the emergence of a number of tools, supporting the design of architect and constructor, including programs for parametric and surface design led to new creative searches. During design, the software capabilities of the tools used nowadays allow to continuously analyse the form of the object in combination with changes in its structure. Any changes can be easily implemented during the design process. Virtual change of materials used for the construction of the object makes it easy to keep track of the effects that these changes will bring.

Today, the largest sacral building in Poland the Church of Divine Providence in Warsaw, which is still under construction and designed by architectural studio W. Szymborski & L. Szymborski, shown in Figure 7. The temple is an example of the construction that has been built for many years, however, its virtual construction is not yet fully completed. The emerging object is a solid form based on the arrangement of the Greek cross with a single-space interior, the main nave of the church has a frame and plate construction system, based on the projection of the circle, the frames are arranged at an angle on the circumference of the circle, converge at the top creating a dome. A museum was designed inside, which was placed on a plate running circumferentially above the side nave. The walls of the museum are supported by flat roof slabs [13]. The dome of the temple is made as a single rib-plate coating. The whole of the proposed design assumed the use of new technologies in the construction and implementation solutions, known from visualization and design. From the very beginning the form was designed to be a concrete object. The stages of the construction, altogether with the system of
successively provided executive documentation, allowed for the preparation of several types of concrete mixtures with different properties that could meet the requirements necessary for the implementation of reinforced concrete elements. As Kazimierz Flaga and Wioletta Jackiewicz-Rek [11] write, the mixtures were often designed on the basis of individual guidelines, and they were allowed to be used in implementation on the basis of tests confirming the required features. The described practice proves the changes in the possibilities of using concrete, which, as it can be seen in the described example, is designed individually for contemporary objects.

![Figure 7. The Church of Divine Providence in Warsaw designed by the architectural studios of W. Szymborski & L. Szymborski, under construction, [14]](image)

4. Results and discussions
The sacral objects discussed here, both from pre- and post-conciliar period, including examples of churches established in Poland, fully demonstrate the course of the changing approach to the use of concrete in sacral architecture. The analysed churches were mainly made of concrete; in a few cases it was only a component of the materials used. The main structural elements were made of reinforced concrete, which was often used as a material for vaults and flat roofs. Both Perret and Le Corbusier used concrete for construction; however, it often constituted a finishing layer shaping the façade or the interior. The flat roofs exposed without the top texture in the church of A. Perret gave rise to the next direction of using raw concrete. Nowadays, the fashion for this way of applying this material has been adopted and is the most frequently used method for presenting walls in the interior of the building as well as finishing the façade. This type of concrete is referred to as architectural concrete, which probably through improved mixtures and additives remains more interesting in its structure. Among the completed objects there are also places where the space of the sacrum, defined in the architect's intention, was not only represented by means of form, but also the material was treated as a creative measure. Failure to understand this destroys the original idea, an example of which is Szymski’s church discussed above, where the reinforced concrete faces of the walls were covered with substitute corrugated sheets and wall panels, which destroyed the form of the object. A full fascination with the possibilities of using concrete and displaying it as a material without limitations is visible in the church of Loegler, which
proves that this material can be fully regarded as worthy of the sacral space. Transmutation of concrete is its still incomplete plasticity and new ways of presenting and technologies associated with it, which leaves their ways of its use undiscovered. The discussed methods of analysis of concrete mixtures for the construction of the Church of Divine Providence in Warsaw and computer simulations of their strength, allow to present the visual effect of using a new material during the simulation of a virtual model. Similar project activities in subsequent projects will allow analysing new technological solutions that can show much more possibilities of using new concrete based materials. An excellent aid for simulation of planned achievements are undoubtedly tools, which support the design, and the detailed models of objects prepared thanks to them will allow to achieve the intended effect of virtual analyses for the actual use of concrete.

5. Conclusions
Concrete has become an indispensable building material for contemporary temples. August Perret and Le Corbusier already used concrete and reinforced concrete to create the sacral spaces. In over a hundred years of history of refining concrete and reinforced concrete, today we can talk about the sacralisation of this material, which has become a modern stone. The churches which were made with its application often retained the raw appearance of the building material, which constitutes a finishing structure or façade material of many constructions. When building churches, it was used both for foundations, walls formation and the solid form of the object, openwork forms for glazing in window zones, reinforced concrete columns forming the ribs of the structural skeleton, for flat roofs and reinforced concrete structures of coffered ceilings. Its multidirectional applications confirm wide possibilities of using this material in contemporary sacral objects. Today’s technological possibilities, such as computational analyses and simulations, allow for the selection of the most suitable concrete mixtures during the construction to ensure an optimal visual effect, taking into account the whole design of form of a sacral object.

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