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REINFORCED CONCRETE AND CONSERVATION OF THE HERITAGE OF THE BUILT ENVIRONMENT

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ABSTRACT

Concrete is considered as an ancient building material, but in general, since the era of the Roman architecture it was not in use for many centuries. During all this time other traditional materials were used as the main materials of the built environment. The revival of the use of concrete, even in a new concept, is connected to the industrial revolution and the appearance of the modern movement in architecture. In terms of historic construction the use of reinforced concrete is relatively recent. Because of this, most of the activity in conservation of the built heritage has mainly concentrated on more ancient and traditional materials. But in the last few years, because of the aging and the deterioration of reinforced concrete buildings, there is a growing necessity to deepen the understanding of the built heritage of reinforced concrete buildings from an historic construction point of view. Aspects like the history of reinforced concrete in different places, construction technologies, structural analysis and other aspects, become crucial for the conservation act of reinforced concrete. This article deals with the history of the reinforced concrete, while creating a typology of the use of concrete in buildings according to engineering and architectural aspects. This, as a first step towards the creation of a large database, which may serve the conservation of the built heritage of reinforced concrete.

Keywords: *Reinforced Concrete, Conservation, Modern Architecture*

1. INTRODUCTION

1.1. Reinforced concrete and conservation

Reinforced concrete is one of the most common materials in our era. Many buildings in our built environment are made of reinforced concrete. This popular technology is one of the outcomes of the industrial revolution and it has had a great influence on the modern movement in architecture. But, nowadays, after over a century of utilization of this technology we face a new situation in which many reinforced concrete buildings arrived to a stage of intervention: destruction or conservation. However, in contrast to historic buildings, which were built before the modern era, the reinforced concrete buildings suffer a lack of professional knowledge about conservation. The field of conservation of reinforced concrete is still young and there is a great necessity to develop an infrastructure of knowledge to ensure the conservation. Fundamental research on the history of concrete and suitable conservation approaches and techniques are therefore needed (Heinemann et al. 2008).

This article is focuses on the historical development of the reinforced concrete mainly from the point of view of the connection between the structural aspects and the architectural language. As an outcome of this review of the historical development, a typology of different uses of reinforced concrete in buildings is developed according to engineering and architectural aspects, as a first step towards a creation of a large database, which focuses on the conservation of the built heritage of reinforced concrete. This database is especially important when dealing with conservation, where the authenticity of the architectural language and the structural aspects are strongly connected. The historical analysis of the different concrete buildings is made along history, until the sixties of the 20th century, based on

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the assumption that most of the buildings with a potential for conservation are in this era. The focus will be mainly on residential and public buildings.

2. CONCRETE IN HISTORY BEFORE THE MODERN ERA

2.1. Concrete during the early eras of civilization

Since early eras in the history of the human being it is possible to identify a large gamut of construction technologies and materials in the built environment. But, it is widely accepted that concrete in earliest time is identified mainly with the Roman Empire. It was one of the most dominant elements in the Roman architecture and its development. The Roman Architecture, especially of the city of Rome is not imaginable without the concrete. The best known concrete shell is the old pantheon (Berger 2008), which serves as an outstanding evidence, besides other evidences, for the ability of the Roma Empire to expand engineering abilities with this material. This, in spite of the fact that concrete as many other traditional materials at that time, had limited mechanical abilities. Its main problem, beside other problems, was its relative disability to resist tensile efforts. In spite, and even because of these constraints, it is possible to note that in many concrete buildings of this period, the unity between architectural and structural aspects is high and it is possible to identify strong relations between load, form, material properties and other architectural aspects. The limited character of the traditional materials forced the builders to be creative and integrative in their solutions and indeed the structural aspects are totally integrated in the design process. In this way the structural aspects have not only a functional importance but also an aesthetic and architectural influence. In this kind of projects, which can be called "archistructure" (architecture and structure), the structural aspects are amongst the most important form generators. In this case it is possible to say that architecture is much influenced by the structure, and that the structural system can not be separated from the visual-architectural system – They are one entity (Mosseri, 2006).

2.2 After the fall of the Roman Empire

In spite of the important role of the concrete in the successful Roman Architecture, this material was relatively forgotten throughout the middle-ages as many other things that the Romans did (Berger, 2008). During the period between the end of the Roman Empire and the modern era other traditional materials were used in a large scale but the same can be said about this architecture in relation to the unity between structure and architecture – archistructure. The builders of the great cathedrals of the Middle Ages knew no separation of art and technology, form and function, structure and construction (Berger, 1996). This in spite, and even because, the limited abilities of the traditional materials. The same can be said about many other buildings, which were built with traditional technologies and materials during the Renaissance and during the next centuries, until the modern era. The historical connection between structure and form can be seen clearly in many cases along the traditional architecture era.

3. REINFORCED CONCRETE IN THE MODERN ERA

3.1. The industrial revolution, the modern movement and reinforced concrete.

The industrial revolution has had a strong impact on different fields of life, including building technologies and materials. The modern movement in architecture, which had also a worldwide influence, is strongly connected to the industrial revolution and to the reinforced concrete as a unique and important element in this era. Indeed, many efforts were made since the 18th century to develop the concrete as a building material in the industrial era. The concrete was in focus again, many years after its intensive use in the Roman Empire, mainly because of its cheapness, fireproof ability and other important properties. Early explorations for new possibilities in the field of building technology and materials showed that a combination between concrete, which has relatively high compression abilities and low tensile abilities, with steel, which has high tensile abilities, beside other properties of both of the materials, can create new synergy. But the way to a real implementation of the idea in the building construction field was still long.

3.2. The beginning of the use of reinforced concrete in architecture

The efforts to develop the reinforced concrete as a leading building technology in the industrial era include different proposals and developments which were made in different places in Europe and

United States. The whole process can be determined as an evolutionary process that many pioneers were involved with. Between the pioneers of reinforced concrete for buildings, acting with a monolithic structure, it is possible to identify the French Francois Hennebique and the American Ernest Ransome who worked with reinforced concrete since the second half of the nineteenth century. Their main contribution is rooted in the invention of reinforcing the structural system, where steel rods were inserted to increase the performance of the concrete and create a monolithic structure. The monolithic reinforced buildings proved to be well suited to free plan, work-spaces with large openings where fire had been a danger before. Hennebique's system included slender vertical posts, thin lateral beams on brackets, and floor slabs. The concrete was one of the most flexible, one of the least determinant of form. It relied on the shape of the mould and the shaping intelligence of the designer. Some forms rather than others were certainly more logical in certain situations. But in spite all this, the material in and of itself did not generate a vocabulary and the architects of the last years of the nineteenth century made different attempts to discover a style based on the reinforced concrete (Curtis, 1982).
The new technology released constraints that traditional technologies had before. The main constraint which now was released is connected to the ability of reinforced concrete to cope with tensile stresses beside other stresses in relation to traditional materials. As an outcome new geometries and morphologies became possible such as large span horizontal lines and horizontal planar surfaces, which in general the traditional architecture could not be able to contain. From that time it is possible to distinguish a large gamut of morphologies – from those who continue the traditional connection between form and structure to those who keep less connection with this unity and in which the form is not obliged to have a strong correlation with the structural considerations. Even more, in some cases it is also possible to find a contradiction between the architectural form and the structural aspects. The new technology of reinforced concrete enabled in many cases this freedom between form and structure, mainly where there were no extreme structural conditions like large spans, outstanding loads, light-weight requirements and others. In cases where one or more of these conditions existed, naturally the historical connection between structure and form became important and even crucial and less freedom was left to the designer.

3.3. First steps towards new language based on reinforced concrete in the modern architecture

One of the seminal experiments in France is connected to Anatole de Baudot who was influenced by the ideas of Viollet-le-Duc. Between the years 1897-1905 the church St. Jean de Montmartre in Paris, was erected according to his design. The skeleton of this church gave the impression of a light structure with large spans and apparently thin supports. At the outside facades of the church, little effort was made at expressing the skeleton (Curtis, 1982). It can be said that in spite of the use of the new technology and the freedom that it enabled the connection between structural considerations, architectural language and historic tradition remained relatively strongly connected.
In parallel, another significant activity in architecture of reinforced concrete in Europe is identified with Auguste Perret. Perret was a French architect, who contributed tremendously to the penetration and diffusion of the reinforced concrete in the modern architecture. In 1902 he designed the Appartment at 25 Rue Franklin Paris – using reinforced concrete. After this project he continued to design other reinforced concrete buildings and to have a great influence on the use of the reinforced concrete as a leading technology in the modern movement of architecture. In these cases there is no great influence of the reinforced concrete on the architectural language – the new technology still serves the historical language of architecture.
A great contribution to the exploration of different possibilities enabled with reinforced concrete technology belongs to the great Swiss engineer Robert Maillart. In his unique approach he integrated the engineering and scientific knowledge with aesthetic and artistic values and in his work it is impossible to separate the structural aspects from other aspects as in many cases in the traditional architecture along history before the modern era. Rhine Bridge in Tavanasa (1905) (Frampton, 2007) is a unique example for the unity that can be achieved also in reinforced concrete between engineering performance and the geometry and form of the structure. The same can be said about other important engineers who worked at that time, like Eugene Freyssinet.
In other places also it is possible to find a dynamic architectural activity with reinforced concrete. For example in the USA, Frank Lloyd Wright begun to design with reinforced concrete: Village Bank project of 1901, and the E-Z Polish factory and Unity Temple, completed in Chicago in 1905 and 1906 respectively (Frampton, 2007). Anothter example of an architect who was involved at that time with

reinforced concrete in the USA is Albert Kahan. In 1909 he used concrete in designing the automobile factory in Detrit, Michigan (Curtis, 1982).
The challenge to cover big spans with reinforced concrete technology was achieved in 1913 by max berg. In Jahrhunderthalle, Breslau, he covered a circular space of 65 meters in diameter, using reinforced concrete elements. The circular building was erected with many ribs surrounding the space and supported by an upper ring at the centre and a lower ring in its turn supported by massive pendentive arches. The unique skeleton of this structure was covered outside with Neo Classical elements (Frampton, 2007). This structure is one of the landmarks in the development of the use of reinforced concrete, in which the structural considerations had a great influence on the architectural language, mainly in the interior of the building. This development can be identified as the continuation to the historic unity between structure and architecture. It it is also possible to note the contribution of other important architects and engineers in this era to the acceptance and promotion of the reinforced technology. But the greatest influence on the penetration and the absorbtion of the reinforced concrete as an important element in the modern architecture is due to Charles Eduard Jeanneret who is also known as Le corbusier.

3.4. Le Courbusier and beyond, reinforced concrete and the modern movement

Le courbusier has had an absolutly central and seminal role in the development of the 20th century architecture (Frampton 2007). In his professional career he was exposed to different ideas including the ideas of Perret about reinforced concrete during his work in his atalier. In 1914 Le Corbusier designed the Maison Dom-Ino, which can be considered as one of the important landmarks of the modern architecture connected to reinforced concrete. Beside this and other activities he announced the "five points of a new architecture" – free standing supports (pilotis), the roof garden, the free plan, the ribbon window and the freely composed facade (Nuttgens, 1997). These principles gave a direction in many cases to a relatively modest and simple geometry. This geometry was in many cases abstract and orthogonal. The structural result of this approach was very often an orthogonal skeleton with a standard grid. Here it is possible to find relatively more freedom and separation between the structural system and the architectural considerations. It is clear and obvious that the reinforced concrete has a great contribution to this freedom. The international style and all the developments after it are strongly connected to the abilities of the reinforced concrete. The ideas of Le Corbusier and others were absorbed and diffused in many places and the modern movement continued to be more and more acceptable and favorable. In the practical world and in the academic life, for examples in schools like the Bauhaus in Germany many of the activities were influenced by the modern movement ideas. The reinforced concrete technology played an important role in this process, along with other technologies. Meanwhile, different experiments and new possibilities with reinforced concrete continued to be explored using different ways of thinking.

3.5. Exploring new possibilities of reinforced concrete architecture

Many projects of the modern movement, which were built according to modern thinking, were in many cases with a relatively modest and simple geometry, mainly abstract and orthogonal. The structural result of this approach was very often an orthogonal skeleton with a standard grid. But, in parallel to this tendency, it is possible to identify different architects and engineers who continue to look for and to explore other possibilities to use reinforced concrete in different ways, in continuation to other pioneers who begun to act before them like Robert Maillart, Max Berg and others.
One of the most creative and artistic person in the history of reinforced concrete in the modern era is Pier Luigi Nervi, an Italian engineer who was recognized mainly since the thirties of the 20th century. Nervi. His unique works contributed to the development of the art of engineering with reinforced concrete. Amongst his central projects during the thirties it is possible to identify the Stadium of Florence, a cantilever roof which was erected in 1930-32 (Fleming et Al. 1999). After this project he continued to design many outstanding works like The Hangar in Orbitello, palazzeto dello Sport in Roma and others. At the same time also Eduardo Torroja from Spain explored possibilities of using the reinforced concrete for shell structures and indeed he can be considered between the main pioneers of the reinforced concrete shell. Amongst the central works in which he was involved, it is possible to mention the design of the Algeciras Market 1933 and Zarzuela racecourse grandstand – 1935 (Fleming et Al. 1999). (See also Benardo,2003).
Meanwhile in the USA also Frank Lloyd Wright pursued his creative work with reinforced concrete in other directions. In the Kaufman House – Fallingwater – built in 1936, he showed the outstanding

capacities of the reinforced concrete to enable the design of a unique and impressive cantileverd structure. The unique expressivity of this building and the creation of a new interpretation of the modern language of architecture could not exist without the reinforced concrete. In addition to the activity in this stream which can be called the impressive stream of reinforced concrete, it is possible to identify architects like Erich Mendelsohn who also explored the possibilities of using the reinforced concrete, creating a different language which is more expressionistic and impressive.
Following Nervi and Toroja and their contribution to the concrete shells it is important to note Felix Candela, who was born in Spain and lived in Mexico Candela contributed mainly to the structural art in the field of reinforced concrete shells since the fifties of the 20th century using in many cases geometries of hyperbolic paraboloid in his shells beside other geometries. Among his works are: The Cosmic Ray Pavilion (1952), La Virgen Milagrosa (1953-55) and others (Fleming et Al. 1999). (See also Princeton 2008).
In addition to the different designers like Candela, Toroja, and Nervi who integrated the structural engineering considerations in their creations in a very creative way, it is possible to bring other designers. A good example is Eero Saarinen, an outstanding architect who dealt with reinforced concrete (as well as with other materials) in artistic and creative way. Amongst his famous reinforced concrete projects is the TWA Terminal, New York 1956-62 (Gympel,1996). Another outstanding example is Heinz Isler, a Swiss creative engineer who continued to investigate and develop the concrete shell structures. He liberated the shell design from the constraints of the classical geometry and gave the shells the natural geometry they want to take on, to be in funicular equilibrium for their own load and a given support condition (Berger, 2008). According to this concept different outstanding thin shell structures were built like the industruial plant in Recherswil, Switzerland, completed in 1965 and other shells (Berger, 1996).

4. A TYPOLOGY OF REINFORCED CONCRETE ARCHITECTURE

4.1. General

According the historical analysis above it is possible to create a typology, which identifies main streams of reinforced concrete architecture in the modern era, based on the relation between the structural aspects and the architectural language. This is especially important when dealing with conservation where the authenticity of the architectural language and the structural aspects are strongly connected. In general it is possible to identify four streams in modern reinforced concrete architecture, as specified in the next paragraphs.

4.2. Architectural engineering – archistructure – reinforced concrete architecture

In this kind of architecture the structural aspects are very central and there is a structural awareness during the design process – as a must because of structural extreme conditions or as a choice of the designer. It can be said that the structural aspects can be considered as form generators. Examples of this architecture are projects of Max Berg, Eduardo Toroja, Piere luigi nervi, Felix Candela, Heinz Isler and others. In this case the structural efficiency is relatively high and in many cases it is nearly impossible to separate the structural system from the architectural system. These designers with artistic-structural art continue in many aspects the way of the Roman Designers, Gothic cathedrals, Gaudi, Violett le Doc and others.

4.3. Functional reinforced concrete architecture

This kind of architecture is the most common architecture of the modern reinforced concrete architecture. It usually contains orthogonal lines, abstract elements, and smooth surfaces. Accordingly the structural system usually has a set of isolated piles which allow the plan and the facades to be free and flexible. In many cases this system is piles and beams or frames. This structural system is relatively simple from the point of view of the structural performance, in spite of the fact that it is not as structurally efficient as other efficient structures. From one side the structural aspects are not the form generator but from the other side they are respected mainly from a functional point of view. This structural system can be visually exposed or hidden. Different projects of Le Corbusier like the Maison Dom-Ino, works of Walter Groupius and others can be brought as examples.

4.4. Form – impressive reinforced concrete architecture

This kind of architecture has in many cases an impressive form and the architectural language can include non regular forms and geometries that in many cases can be in contrast with the structural

considerations. Because of this fact the structural system is complex in many cases and its structural efficiency is relatively low. Example of this architecture can be The Falling Water of Frank Lloyd Wright and other buildings of this kind, where the structural efforts are relatively high, as a choice of the designer and not as a must.

4.5. Hybrid reinforced concrete architecture

This kind of architecture is a combination of the three streams which were introduced above. Accordingly, it can have different variations of two or more streams combined together. For example a combination of a shell structure with a regular – conventional modern architecture. The hybrid situation can appear not only in existing historic buildings but also in cases where a new building which belongs to one stream is added to an historic building which belongs to another stream.

5. SUMMARY

This article focuses on the history of reinforced concrete in the modern movement and suggests a typology of the different streams of reinforced concrete architecture, in the light of the relations between the structural aspects and the architectural language of the different buildings along history. This analysis is especially important when dealing with conservation, where the authenticity of the architectural language and the structural aspects are strongly connected. The aim is to create a basic knowledge which will have to be further developed, as an essential and important step towards a more professional conservation of reinforced concrete buildings.

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