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STRUCTURAL ENGINEER'S CONTRIBUTION TO THE REALIZATION OF ARCHITECTURAL CONCEPT

WKŁAD KONSTRUKTORA W REALIZACJĘ IDEI ARCHITEKTONICZNEJ

A b s t r a c t

Providing architects with the possibility to define spaces in a plastic way, prestressed concrete technology influenced the architectural trends of the 20th century. Taking a look at some iconic works realized using this material, it is worth to notice that they mostly are the results of a creative collaboration between the architect and the structural engineer. Often underestimated, engineers make a significant contribution not only to individual designs, but also to developing the architect's imagination. August E. Komendant, who was an influential modern constructor famous as a pioneer in the field of prestressed concrete, was a long-time associate of architect Louis I. Kahn. By analysing selected examples of their team works, it is also possible to investigate the interaction between architect and structural engineer.

Keywords: prestressed concrete, bearing structure, architecture

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

Beton sprężony dał architektom możliwość plastycznego kształtowania przestrzeni, wywierając wpływ na tendencje architektoniczne XX wieku. Patrząc na ikoniczne realizacje wykonane przy użyciu tego materiału warto zauważyć, że stanowią one na ogół efekt twórczej współpracy pomiędzy architektem a konstruktorem. Nierzadko niedoceniani, inżynierowie czynią istotny wkład nie tylko w pojedyncze projekty, ale również w rozwijanie wyobraźni architekta. Jednym z wpływowych współczesnych konstruktorów był August E. Komendant, wieloletni współpracownik architekta Louisa I. Kahna, słynny jako pionier w zakresie betonu sprężonego. Pochylając się nad wybranymi przykładami ich współpracy można również prześledzić interakcję pomiędzy architektem i konstruktorem.

Słowa kluczowe: beton sprężony, konstrukcja, architektura

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1. Transmutations of concrete

The use of reinforced concrete, which draws its origins from experimental works realized in France in the 19th century, has become more frequent during the following century, providing architects with the possibility to plastically shape spaces and, at the same time, nourishing the development of new architectural trends, including the modern movement. However, whenever an iconic design, which has been achieved employing advanced reinforced concrete technology, is concerned, it ought to be admitted that the architect is most probably not its sole author. Instead, such unique works can generally be attributed to a team of experts in various fields, whose cooperation results in creating a multidimensional, total work of art. In particular, the creative collaboration between architects and structural engineers has proved to be especially important. Frequently remaining in the shade of architect, a structural engineer often makes an important contribution to the design as well as to its implementation. What is even more important, however, by supporting the development of individual projects, an engineer also feeds the architect's imagination, making him familiar with advanced and innovative construction methods while assisting the decisions on the building's structure. Moreover, the extent of issues addressed by a structural advisor to improve the design is not exclusively related to the construction in the pure sense of the word. Among various aspects that are potentially discussed between an architect and an engineer, we should distinguish questions related to the definition of building's structural system, from its conceptual draft to the finishing details. During the 20th century, different contemporary building techniques involving prestressed concrete were developed as a result of the collaboration between architects and structural engineers. The innovative designs they worked on together have resulted in the elaboration and refinement of varied technical solutions associated with the concerned technology. Some of them have been invented to astonish the viewer with the capacity of modern construction techniques to reach what remained so far impossible, like for example large spans, while some other are dedicated to achieving the desired quality of finishing. The so combined pursuit of innovation and aesthetics allows the reinforced concrete building methods to be considered as a foundation for the transmutations of concrete to take place. Transforming one of most essential building materials into a versatile means to create refined modern spaces requires competences that are acquired through experience, which is a long lasting process of evolution and sharing interdisciplinary knowledge. The collaboration between the architect and the structural engineer is therefore not limited to one specific project, but it extends onto a long-term relationship in which the ongoing intellectual exchange between specialists of the two disciplines nourishes the evolution of their professional careers.

2. Louis I. Kahn and August E. Komendant

The development of prestressed concrete building techniques that occurred during the 20th century was undoubtedly powered by the activity of many design teams consisting of specialists in different relevant domains and focused on elaborating innovative architectural solutions. One of such influential consortiums was formed around architect Louis I. Kahn, who repeatedly associated with structural engineer August E. Komendant, with whom he realized several of his most recognized designs. Famous as a pioneer in the field of prestressed concrete structures, Komendant did not only provide his professional advice to the architect, but he also inspired him with new ideas. Tracing the development of their cooperation over exemplary projects should therefore allow to draw some general conclusions about the interaction of the specialists in the interrelated disciplines of architecture and construction.

Louis I. Kahn and August E. Komendant met for the first time in 1956 on the occasion of the national competition for the design of St. Louis Library. Kahn's proposition for the building was under development and required structural advice. For this reason, the architect made contact with Komendant on the recommendation of an associate[1]. Although the project was not awarded, it nonetheless constituted the starting point of the eighteen years of collaboration with the engineer. Until the architect's death in 1974, August Komendant contributed to several from among his projects and, at the same time, he participated in the development of Kahn's individual design philosophy. Owing to the conversations they exchanged during their meetings, Kahn had a unique opportunity to deepen his understanding of construction and relevant techniques. For him, this cooperation did also represent an important source of thoughts and theoretic ideas. Most importantly, the evolving understanding of structural order leads the architect to his concept of the ornament intended as the "glory of the joint" which is supposed to demonstrate how the elements of the building's structure were assembled. Being of the opinion that a space is not properly one until its observer is able to perceive how it was created[2], the architect insists on facilitating the viewer to correctly "read" the structure by distinguishing its bearing elements from the filling or the curtain walls. Thereby, having a good comprehension of building's construction had essential significance for Kahn, while his appointments with Komendant were the source of relevant information.

In their cooperation, Kahn and Komendant formed a team devoted to innovations in the field of concrete constructions. Passionate about modern building techniques, the architect appreciates the knowledge of his structural advisor and does not hesitate to ask his opinion on the aesthetic aspects of the design as well. Despite all the references Kahn makes to the historical types of architecture, he remains at the same time interested in recent technical achievements. In the innovative project of laboratories Richards-Goddard in Philadelphia, for example, Kahn manifests his great interest in the technology of precast and prestressed concrete, as it will be discussed later. Among several projects involving the prestressed concrete technology, the collaboration of Kahn and Komendant has also brought some innovative concrete shell structures, like we will observe in the example of Kimbell Art Museum.

3. The structural and constructive orders

"Order is"[3] is a prerequisite sentence for almost every discourse Kahn delivered on architecture. According to the architect, the order designates the profound nature of things, being a universal concept that applies to everything. The order is intangible and pre-existing to all creation of mankind. It can only be perceived intuitively and transmits the principles that

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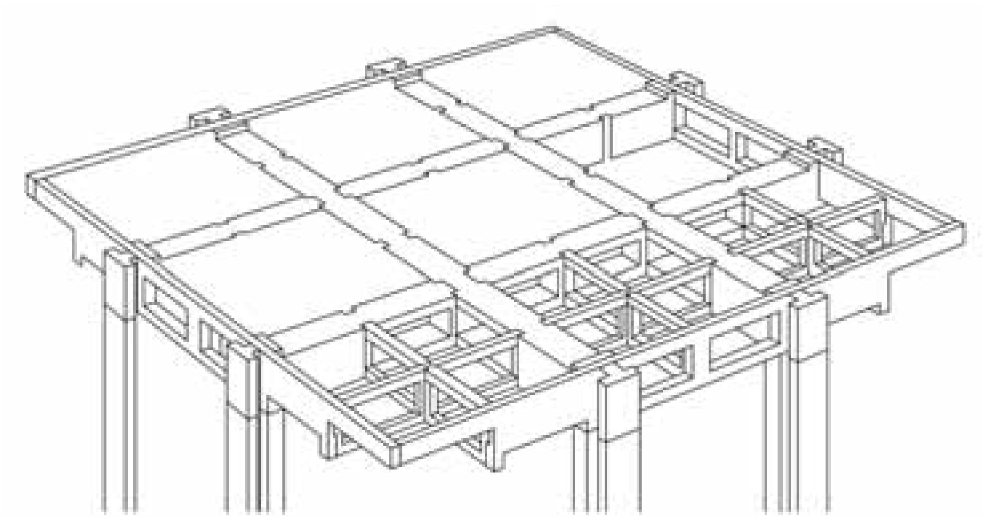
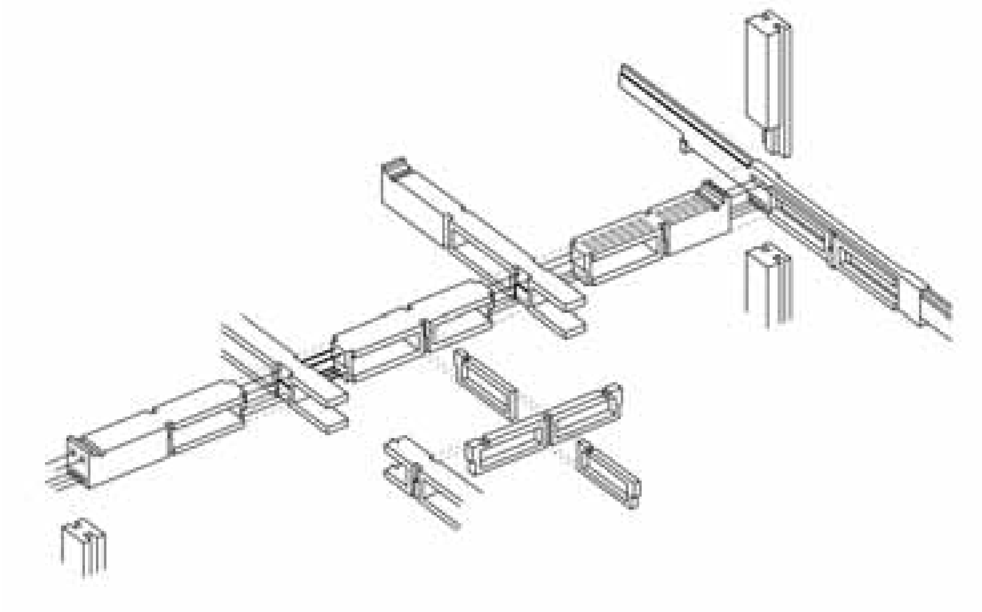
1 A. E. Komendant, *18 years with architect Louis I. Kahn*, Aloray Publisher, Englewood, NJ 1975.

2 J. W. Cook, Klotz H., *Questions aux Architectes*, Architecture + Recherches, P. Mardaga éditeur, Bruxelles 1974.

3 "Order Is" was the title of one of Kahn's writings which was published in Perspecta in 1955.



Ill. 1. Structural scheme of a typical unit from the Richards-Goddard laboratories in Philadelphia. Perspective view. Drawing by the author after the schemes by August E. Komendant [6]



Ill. 2. Principles of assemblage of the four Vierendeel beams. Richards-Goddard laboratories. Drawing by the author after August E. Komendant [6]

underlay the existence of all things. However, the order can create nothing itself: "Order, the maker of all existence, has No Existence Will"[4].

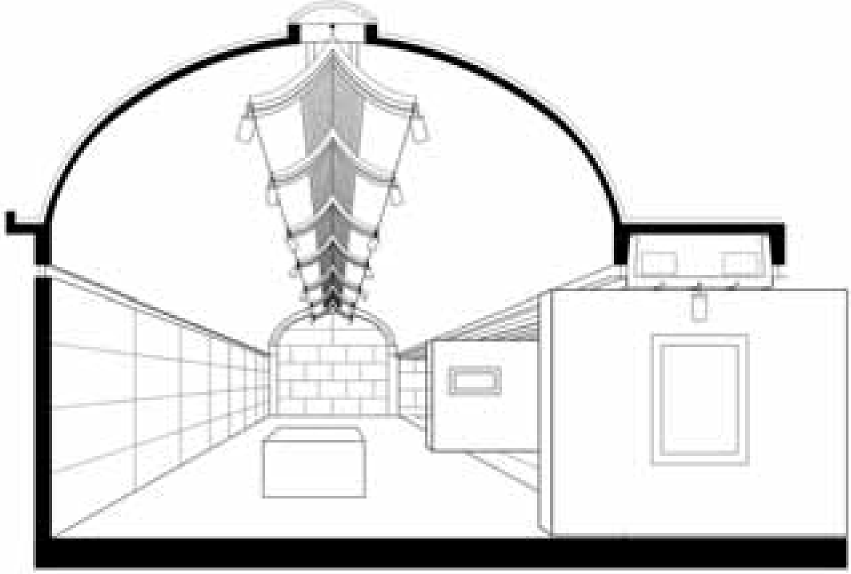
Louis I. Kahn distinguished a few forms of order. Primarily, there is the order of spatial hierarchy, structural order and order of construction. The structural order, in which the architect has identified the potential to express the individual character of varied spaces, is a different concept from that of the constructive order. The first of the two reflects the hierarchical importance of a given space and defines its form, dimensions and principles of its openings, while the latter is related to the building's implementation. The order of construction depends on the selection of building materials and relevant assembly methods. The importance of both structural and constructive orders for the architect's individual design method points to the role of the engineer as the source of relevant knowledge. The development of the notion of structural and constructive orders can be observed through the examples of selected significant projects.

3.1. Richards – Goddard Laboratories

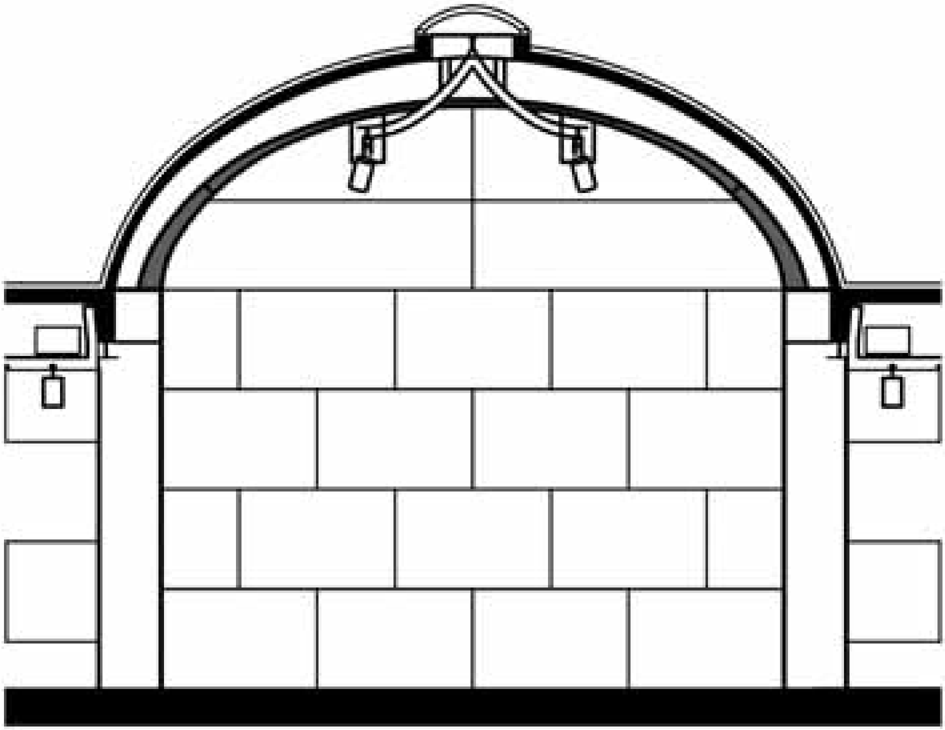
In his famous design of the Richards-Goddard research laboratories in Philadelphia (1957–65), Kahn selected such building materials that were grounded in the regional urban context, including the campus of the University of Pennsylvania. Effectively, the majority of buildings that surround the site were built in masonry with details in stone, which has been transformed by the architect into the assemblage of structural elements in concrete and the filling in masonry. Inspired by the tradition of New England, this choice of materials was preferred by Kahn. What is particularly important, however, is the fact that only the concrete is used for bearing elements of the structure, the brick being reserved for the facing. Nevertheless, the architect employs two different constructive orders relevant to the use of concrete. The first one corresponds to the method of prefabrication, while the other is related to the layered wall structure. The prefabricated method of construction was applied to the primary units of the laboratories. Supported by eight structural pillars placed on the building's perimeter, the slabs consist of four main beams, which outline the limits of each unit's square plan (ill. 1). The symmetrical and central disposition of each couple of pillars within the four identical facades corresponds to the cantilever angles. Subsequently, four other beams of type Vierendeel span the central void in perpendicular directions, intersecting in the center and thereby forming nine square fields. The advantage of using the Vierendeel girder type of beam in the case of laboratories is that it provides space and support for distributing the technical equipment. For assembly reasons, two of the four Vierendeel beams were precast in one piece, while the remaining two were divided into three segments (ill. 2). In the result, the slabs are split up into nine identical squares, each of which is further reinforced by two minor beams crossed in the center. Once mounted, the beams of each slab were post-tensioned in order to unite them structurally[5]. The assembly of all prefabricated members was carried out dry, as opposed to the cast concrete.

[4] Louis I. Kahn, *Form and Design*, 1960 [in:] Twombly R., *Louis Kahn. Essential texts*, W. W. Norton & Company, New York London 2003, p. 63.

[5] A. E. Komendant, *18 years…, op.cit.,* p. 10–12.



Ill. 3. Typical unit of the Kimbell Art Museum. Cross section with a perspective view of interior. Drawing by the author



Ill. 4. Kimbell Art Museum. Cross section of the typical unit highlighting the window slit detail on the back wall. Drawing by the author

Contrary to the precast concrete structure, which remains reserved for the main laboratory units, the system of poured concrete walls was used to enclose servant spaces. The service towers of the laboratories as well as their vertical communication are made of cast concrete and then clad in brick. The central unit of the Richards complex, which is servant in terms of its functionality, does not escape this principle and is realized with the use of second of the two constructive orders. This decision, however, could be explained not only by the will to express the spatial hierarchy, but also by the technical reasons, which made this unit not suitable for prefabrication, as it is mentioned by the structural engineer[6].

The differentiation of the roles attributed to specific materials refers to the notion of the constructive order, which was particularly important for Kahn in terms of communication with the user. Himself interested in innovative means of implementation, the architect had the intention to allow the building's users as well as its layman observers to gain an understanding of how it was raised. In the case of the Richards-Goddard laboratories, the principal role in terms of architectural expression is attributed to the assembly method of precast structural elements, thus all the components mounted on site involving the crane are left apparent in the facades.

Having marked technological progress in the field of precast post-tensioned concrete constructions, the structural design of the laboratories in Philadelphia made both the architect and the structural engineer famous, building the capital for their future collaboration.

3.2. Kimbell Art Museum

Over the years, the cooperation between Kahn and Komendant has resulted in more applications of unprecedented prestressed concrete structures. The project of the Kimbell Art Museum in Fort Worth (1966–72) can be cited as one of the most complicated designs, which required advanced structural studies. In accord with the notion of the constructive order, Kahn decided to assign the structural role to one material only. The choice fell on concrete, as it was most suitable to realize the concept of the skylight that runs all along the vault at its top. Lined with ambition to manifest how modern means of construction can materialize the utopian dream once imaged by Boullée, the idea to open the vaulting along its upper edge posed a major technical problem, hampering the project's development. August Komendant, who joined the design team in 1967, has found a solution. Namely, the engineer proposed to use a pair of symmetrical shell structures, the cross section of which had the form of a semi-cycloid. Acting as large post-tensioned beams, the two shell structures form the basic, multiplied unit of the museum (ill. 3). The vaulting is supported by four corner columns and stiffened by ending arcs.

Important for the architect in terms of legibility of the constructive order, the separation between all concrete members of the structure and the filling wall is done by means of narrow glazed slits, which is supposed to prevent a false impression that the wall is bearing. Because the section profile of the ending arches is thicker at the top and thinner

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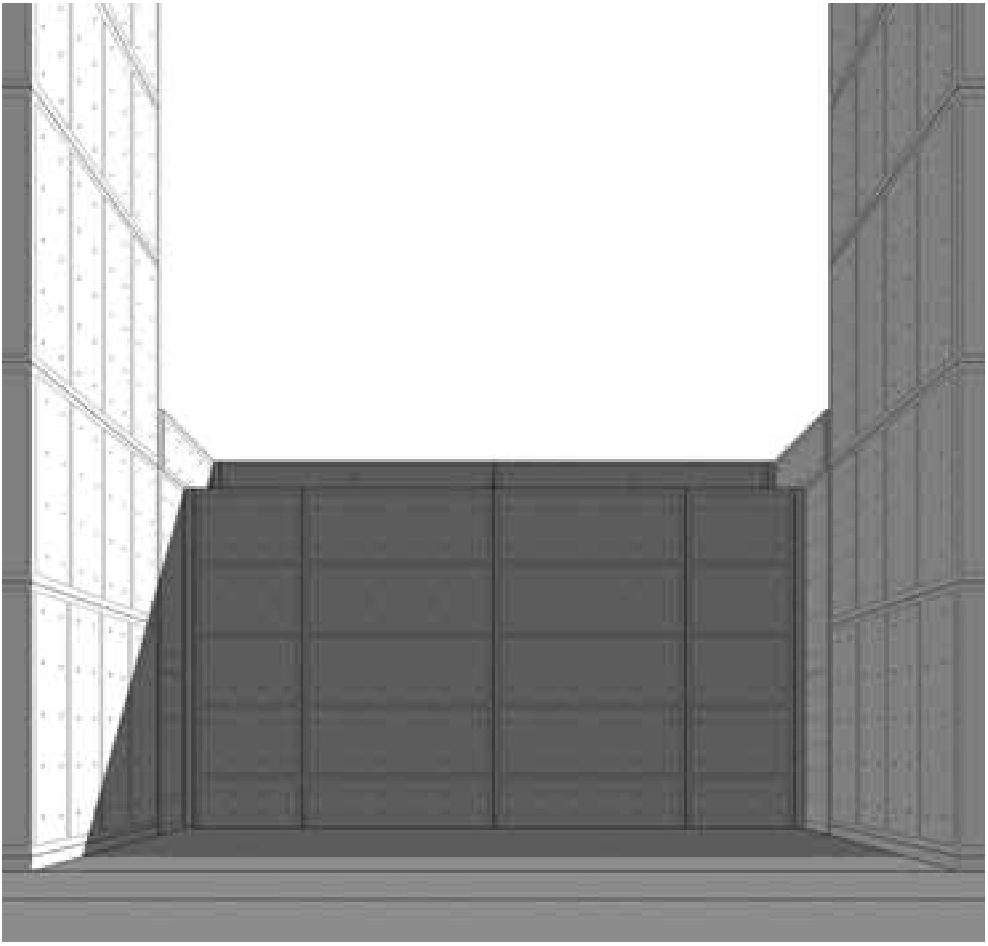
6 *Ibidem*, p. 10.



Ill. 5. Perspective view of the Salk Institute elevations showing the detailing. Drawing by the author after one of Louis I. Kahn’s original draughts from: Louis I. Kahn Collection, University of Pennsylvania and Pennsylvania Historical and Museum Commission, folder 030.I.C.540.018

at the junction with pillars, the window slit that separates it from the filling wall below has purposely non-parallel edges (ill. 4). Aiming to achieve an architectural expression that would be genuinely conform with the principles of the structural design, Kahn has moreover decided to realize the exterior walls of the lower level in concrete as they are all bearing members. Consequently, also the wall above the museum's lower entrance, which plays the role of a beam in the terms of structure, is made of cast concrete and remains uncovered. The architect's consistency to convey the information on how the building was raised does therefore not stop at revealing the innovative prestressed concrete structures resolved by Komendant, but it also includes conceptualization of new, individually created architectural details, like for example the untypical window slits employed in the Kimbell Art Museum, which are intended to strengthen the understanding of the constructive order.

4. Theory of the ornament

The notion of the constructive order introduces another important element of Kahn's design theory, which is his personal definition of the ornament. According to the architect, any ornament begins with the joint. "The way things are made, the way they are put together, the way one thing comes to the other, is the place where ornament begins. It is the glory of the joint which is the beginning of ornament"[7]. When he speaks of the glory of the joint, the architect is equally concerned by the legibility of the structure, perceiving the capacity of the joints to express the way a building was assembled. The ornament is therefore essential to convey a good understanding of the architectural work. In this sense, the design of the formwork apparent on the walls of the Salk Institute in La Jolla or a particular arrangement of bricks within a wall belong both to the domain of ornamentation. Moreover, the ornament is frequently used by the architect to separate the bearing structure from the filling as well as from the facing.

4.1. Salk Institute

As in the previously discussed designs, the bearing structure of the Salk Institute in La Jolla (1959–65) is realized in concrete. However, in this case, Kahn has considerably limited the use of filling and facing materials different then concrete, which results in large surfaces of concrete walls. Because the building of the laboratories is made of cast concrete, the architect has decided to concentrate on the design of its elevations (ill. 5). In accordance with his theory of the ornament, the architect strives to manifest the technology of implementation by means of customized facade design. For this reason, Kahn has delegated to La Jolla one of his employees, Fred Langford, who was given a mission to perfect the formwork design. Upon his arrival on the site, Langford commits himself to install a workshop where several samples of concrete would be manufactured for

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[7] Louis I. Kahn, *Talk at the Conclusion of the Otterlo Congress*, 1959, [in:] Robert Twombly, *Louis Kahn. Essential texts*, *op.cit.*, p. 60.

testing[8]. The trials to which these samples were subsequently submitted were not limited, however, to the tests of resistance. The concrete also had to satisfy Kahn's requirements regarding its color as well as the desired quality of its surface. In order to meet these expectations, Langford also tested different formwork materials. The result of his efforts is a customized formwork made of plywood and covered with polyurethane so as to ensure the effect of smooth surface and even color[9]. For an even more refined effect, the location of the joints was carefully distributed over the building's elevations and the holes of the tie rods were filled with lead. Other than their geometrical disposition and order, the number of tie rods is exaggerated, which points to the intended aesthetics of the constructive order.

5. Creative collaboration

Undoubtedly, the contribution of Komendant was essential to allow Kahn to implement the structures he destined for the envisioned spaces. Frequently, the architectural forms he imagined involved major structural problems and the role of the engineer was to resolve them through long debates with the architect. Nonetheless, it should not be overlooked that the benefits of their cooperation were reciprocal. While Komendant did his best to materialize the complicated buildings Kahn imagined, his participation in their design has made him famous.

As seen in the case of cooperation between Kahn and Komendant, the structural advice provided by the engineer can inspire the architect with new ideas and therefore have an influence on the architect's theoretical approach to design. The discussed examples of two important concepts developed by Kahn, namely the notions of the constructive order and the ornament, prove how the evolving knowledge of structural issues can affect an architect's regard to the space definition principles. The two discussed notions that evolved within the frame of Kahn's professional career have subsequently inspired other generations of architects, sometimes not aware of the debate that led to their formulation. Transforming one of the most essential building materials, which is concrete, into refined designs of innovative bearing structures, the effects of creative collaboration between architect and structural engineer make it apparent that the question about transmutations of concrete is not limited to the superficial aspects, but it can have influence on the most essential principles of architectural design.

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8 A. E. Komendant, *18 years…, op.cit.,*

9 D. Brownlee, D. De Long, Louis I. Kahn, *In the Realm Of Architecture*, Rizzoli, New York 1991, p. 133.

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