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Louis Kahn's Tectonic Poetics: The University of Pennsylvania Medical Research Laboratories and the Salk Institute for Biological Studies

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Abstract

Based on his exploration of the "desire to be" in architecture, and the design principle of "served and servant spaces," Louis Kahn used the composition of structural elements to reveal the quality of a space and address the issue of where to place the laboratory's large number of mechanical ducts, pipes and conduits. The University of Pennsylvania Medical Research Laboratories and the Salk Institute for Biological Studies are two of Kahn's most celebrated buildings. They give ample expression to his poetic tectonic thinking, as well as the spatial, technological, and aesthetic innovations he pioneered for laboratory design. This paper analyzes the spatial composition and structural system of these two laboratory buildings, as well as the way in which the mechanical services were integrated into the structure. Textual research, analysis of diagrams, and the composition of three-dimensional illustrations were used to investigate how, in the process of giving shape to a space, Kahn made full use of the unique qualities of his materials to give expression to the concept of rational architecture. This paper then goes on to investigate the unique features of Kahn's tactic of incorporating the mechanical services into the structure of these two labs. The results indicate that complying with the structural order was Kahn's main strategy for integrating the mechanical ducts pipes and conduits into the space.

Keywords: Louis Kahn; tectonic; laboratory; structural form; mechanical services

1. Introduction

The rapid development of power resources and metal materials which followed the Second World War led to steady innovation in the environmental control technology being applied to architecture. Yet the invention of such equipment as the air conditioner and the fluorescent lamp gave rise to the problem of how to integrate the substantial MEP (mechanical, electrical, and plumbing) equipment and the large number of pipes, ventilation ducts, and electrical conduits (hereafter expressed with the umbrella term "mechanical services") into the design of a building. In "New Buildings for 194X," a competition held by *Architectural Forum* on post-war architectural development trends (mid-sized city, technology and technique developments regarding the integration of advanced facilities), the Italian-American architect Pietro Belluschi took first prize, winning out over a host of leading architects, including Ludwig Mies van der Rohe, William Lescaze, and Louis I. Kahn.[1]

Belluschi's design combined the availability of cheap electricity with the aluminum construction materials which were predicted to become abundant after the war. By using an aluminum-framed false ceiling and curtain wall window sill, he succeeded in integrating the air conditioning and electricity ducts with the lighting system (Fig.1.), at the same time making use of a modular suspended ceiling to respond to the need for partitioned office space. In the closing months of the war Belluschi got his chance to put his design into practice in the construction of the Equitable Building in Portland, Oregon.[2] Soon afterwards, the placement of mechanical services in a suspended ceiling became an extremely common feature of modern architecture.

In 1965 architectural historian Peter Collins set forth a review of the innovations in the treatment of space brought about by the development of environmental control technology and its application to modern architecture. He argued that in confronting the question of how to incorporate mechanical services, modern architecture has come up with two different approaches: concealing the mechanical services inside a suspended false ceiling, or else integrating them into the structural design of the building. The innovative spatial designs of Louis Kahn represent a major contribution to the integration of mechanical services into a building's structural design.[3]

In his 1969 book *The Architecture of the Well-tempered Environment*, Reyner Banham regards Kahn as the key person in the development of an approach to architectural design which integrates mechanical services into the structure of the building. Although this approach was largely rejected by modernist architects as an unacceptable mode of expression, it marked a critical juncture in the development of high-tech architecture, which embraced exposed mechanical services and structural frameworks as its trademarks.[4] Integrating exposed mechanical services often reveals the differing spatial characteristics of a wide variety of architectural styles, and also reflects the state of building materials and construction technology of the time. The technique of incorporating mechanical services into the

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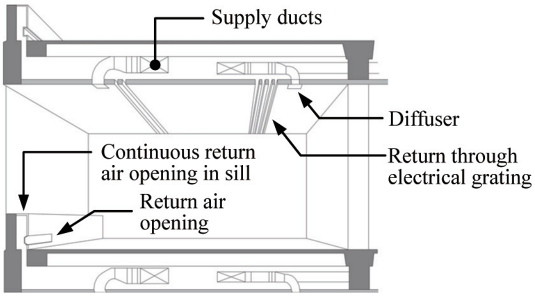


Fig.1. A Cross Section Perspective of Air Conditioning Ducts Incorporated into a Mezzanine Ceiling and a Curtain Wall Windowsill

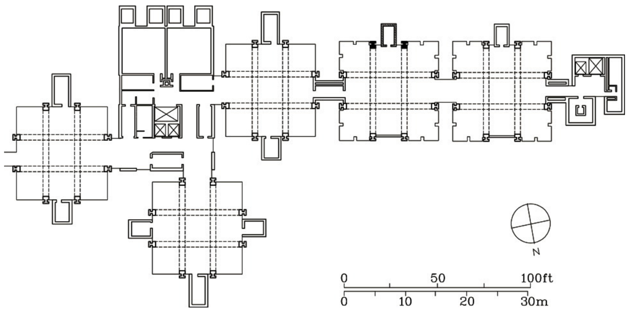


Fig.2. First Floor Plan of the MRL

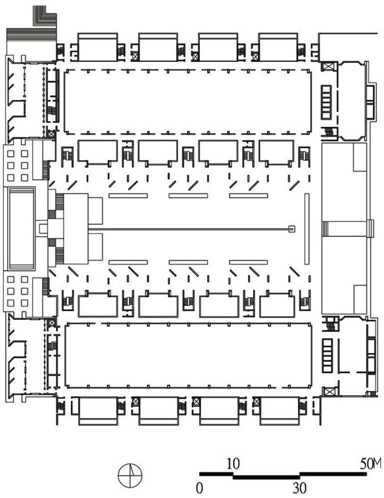


Fig.3. Floor Plan of the SIBS

architectural design necessitates constant innovation, and studying Kahn's works provides far-reaching insight into this process.

In addressing the issue of incorporating mechanical services, Kahn once wrote, "Columns and beams homogenized with the partitions and ceiling tiles, concealing hangers, conduits, pipes, and ducts deform the image of how a space is made or served and therefore presents no reflection of order and meaningful form…"[5] In other words, the exposed integration styles of mechanical services directly conveys the building's structural logic and the relationship between served and servant spaces. The use of suspended ceilings in modernist architecture to conceal mechanical services was not countenanced by Kahn, who believed that it was necessary to utilize concrete structural elements to achieve integration. Thus he asserted, "In the very fabric of making it must already be the servants that serve the very things I've talked about—its timbre, its light, and its temperature control; the fabric of the construction must already be the container of these servants."[6] It is this very consideration which gives clear expression to Kahn's operational approach based on the integration of the mechanical services into the concrete architectural structure.

Of all Kahn's works, the University of Pennsylvania Medical Research Laboratories (MRL) in Philadelphia and the Salk Institute for Biological Studies (SIBS) in La Jolla, California, are the most complex in terms of mechanical services. Both of these buildings give clear expression to Kahn's vision of using the structural form to incorporate the mechanical services. Due to the divergent locations and architectural designs, these two building are quite different; the MRL is a self-standing tower, while SIBS consists of two long, low-rise symmetrical buildings (Figs.2. and 3.). In order to meet the requirements of two different local environments, architectural plans, and purposes, Kahn began by investigating their fundamental spatial characteristics and structural form. In the course of designing the structure and mechanical service system of these two labs he developed a uniform approach which also takes into account the unique features of each project.

2. Spatial Characteristics and Structural Form

Kahn invariably set out by making an objective investigation of a building's special qualities and "desire to be," after which he made use of the concrete design procedures to give form to the intrinsic meaning of the abstract space. In the process of reflecting on the design of the MRL, Kahn came to comprehend the essential character of a lab space, about which he wrote, "…science laboratories are essentially studios…the air to be breathed must be separated from stale, waste air."[7] Furthermore, a lab space has to face the question of how to deal with a large amount of mechanical services. His design approach of using concrete structural elements to integrate the mechanical services reveals the process of spatial composition, concerning which he stated:

In Gothic times, architects built in solid stones. Now we can build with hollow stones. The spaces defined by the members of a structure are as important as the members. These spaces range in scale from the voids of an insulation panel, voids for air, lighting and heat to circulate, to spaces big enough to walk through or live in. The desire to express voids positively in the design of structure is evidenced by the growing interest and work in the development of space frames. The forms being experimented with come from a closer knowledge of nature and the outgrowth of the constant search for order. Design habits leading to the concealment of structure have no place in this implied order. Such habits retard the development of an art. I believe that in architecture, as in all art, the artist instinctively keeps the marks which reveal how a thing was done.[8]

In designing the MRL, Kahn experimented with applying combinations of a variety of structural styles in order to give form to the concept of building with hollow stones. His illustrations from the early stages of the project reveal that right from the start he gave careful consideration to the use of space within the structural framework as a way of transmitting and positioning the mechanical services. These illustrations also show how the arched beams of the earlier structural form later evolved into a combination of precast Vierendeel trusses (Figs.4. and 5.). Kahn took advantage of the hollow sections of the Vierendeel trusses and the orthogonal lines of the structural framework by placing the mechanical services inside these empty spaces. In this way

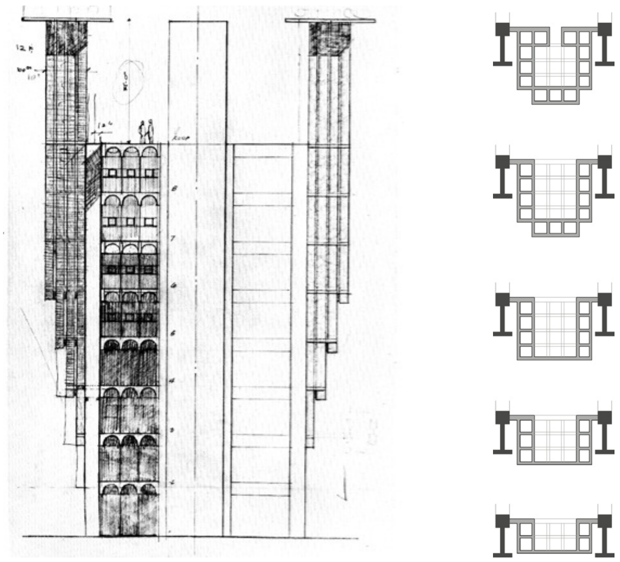


Fig.4. Early Elevation and Exhaust Shaft Floor Plan of the MRL

he was able to avoid the disorderliness which mechanical services can bring to a space, at the same time giving clear expression to his concept of "servant space."

Yet, exposed mechanical services gives rise to the problem of dust accumulation—a critical issue in a laboratory environment. In the early stages of designing SIBS, Kahn abandoned the exposed mechanical services concept in favor of concealing them in the structure, for which purpose he adopted a rectangular and triangular hollow concrete folded plate structure (Fig.6.). Afterwards, however, Dr. Jonas Salk, the institute's founder, requested changes in the overall design. At about the same time, Kahn realized the difficulties of mechanical services maintenance and replacement inherent in his design, leading him to abandon this approach as well.[9] Kahn then proposed a spatial arrangement which he called 'a laboratory for experiments' and 'a laboratory of pipes.'[10] In this design, the prestressed Vierendeel truss structural form was expanded into a fully independent mechanical service space, and the mechanical services were placed inside the truss space which exerts post-tensioning (Fig.7.). Analyzing the development and evolution of the designs of these two buildings, it can be seen that the structural form which Kahn proposed for integrating the complex mechanical services required by a research lab developed in a particular sequence: from his early idea of using the space inside of the structural framework, to the use of folded plate construction, and finally to the inclusion of a dedicated space for mechanical services and MEP equipment.

A basic requirement of a laboratory is the separation of the ducts for incoming fresh air and outgoing exhaust. Thus, in his design for the MRL, Kahn came up with the concept of nostrils for the intake of fresh air and exhaust towers for outgoing air.[11] He used reinforced concrete walls to construct the incoming and outgoing air shafts, and the external form clearly showed how the amount of exhaust increases incrementally from the lower to higher floors (Fig.4.). Due to budget constraints, however, Kahn was compelled to drop this feature and streamline the exterior form (Fig.8.). Kahn also used this architectural principle in his design of the air circulation system of SIBS. Yet, in consideration of the structure's long rectangular shape and distribution of the mechanical services, he attached the fresh air ducts to the outside of the main mechanical service block, and he

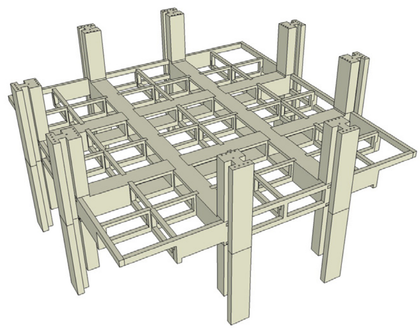
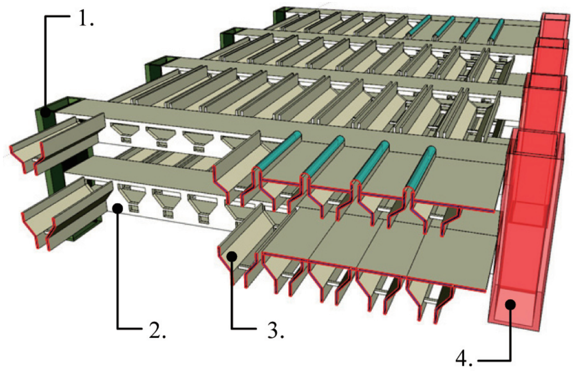


Fig.5. 3-D Perspective Drawing of the MRL's Structural Framework



1. Fresh air intake tower; 2. Rectangular folded plate beam; 3. Triangular folded plate beam; 4. Exhaust shaft and mechanical services room

Fig.6. 3-D Perspective Drawing of the Folded Plate Construction Plan for SIBS

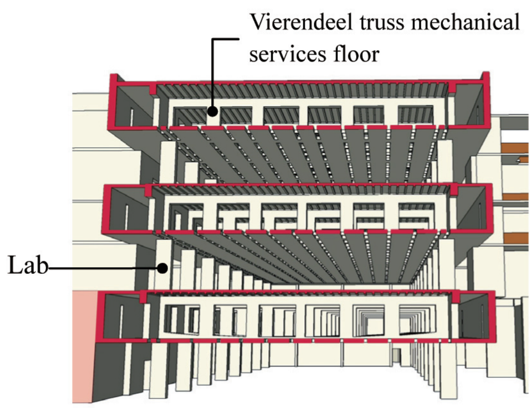
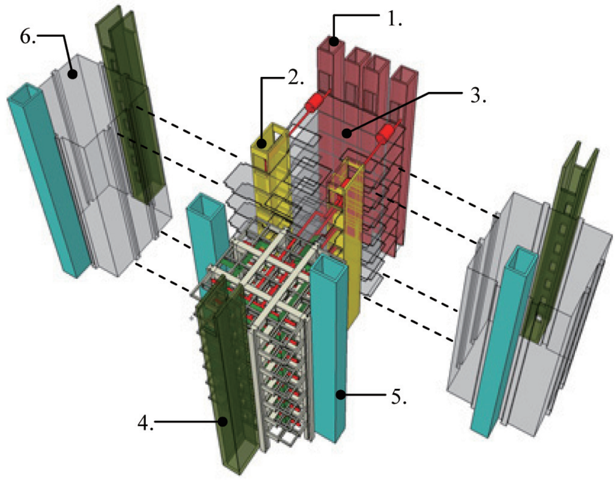


Fig.7. 3-D Perspective Drawing of Labs and Vierendeel Truss Mechanical Services Floors at SIBS

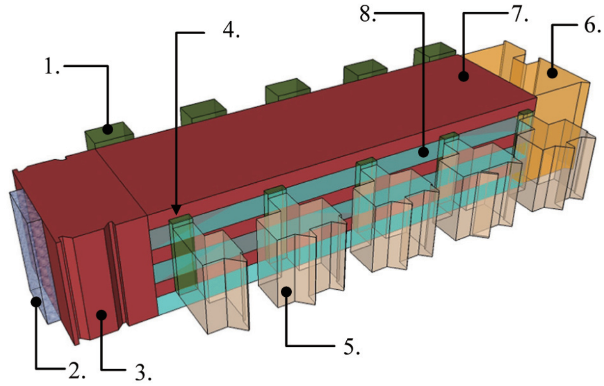
incorporated the exhaust towers into the structural system of each independent research tower. While neither of these air circulation systems could be said to have an independent structural form, they do include a dedicated distribution space (Fig.9.).

Kahn was determined to devise a structural form which would make the most efficient use of space. Thus he explored a wide array of structural possibilities in his search for a way to integrate the mechanical services into the servant space. In the process of designing the MRL and SIBS, Kahn brought into full play the structural characteristics of the Vierendeel truss and reinforced concrete by taking advantage of the voids in the structural elements to form independent



1. Fresh air tower; 2. Mechanical services transmission unit;
3. Central service block; 4. Stairwell tower
5. Exhaust tower; 6. Lab space

Fig.8. Served and Servant Spaces of the MRL



1. Stairwell, toilet, and storage tower; 2. Fresh air unit
3. Main mechanical services block; 4. Exhaust unit
5. Research room; 6. Office and library space
7. Mechanical services floor; 8. Lab

Fig.9. Served and Servant Spaces of the SIBS

servant spaces. Thus, by using a structural form of "hollow stones," he was able to give expression to the unique spatial characteristics of a lab with its multitude of mechanical services.

3. Served Space and Servant Space

In a 1957 speech delivered at the Royal Architectural Institute of Canada, Kahn set out his concept of served and servant space:

The nature of space is further characterized by the minor spaces that serve it. Storage rooms, service rooms, and cubicles must not be partitioned areas of a single-space structure, they must be given their own structure. The space order concept must extend beyond the harboring of the mechanical services and include the "servant spaces" adjoining the spaces served. This will give meaningful form to the hierarchy of spaces.[12]

With his design for the Trenton Bath House (constructed in 1959), Kahn used four square rooms surrounding an atrium to clearly articulate his notion of the organizational relationship between served and servant spaces, and to demonstrate its effectiveness in a practical application. Based on this concept, Kahn used the relationship between the building's mass and the independent towers to incorporate the mechanical services into the design of the MRL and SIBS. Thus his design included a clear separation of served and servant space, whereby the fresh air tower was connected to the central service block, and the exhaust tower and stairwell were connected to the lab building (Figs.8. and 9.). By making use of these organized spatial relationships, Kahn attempted to express the spatial differences and the primary and secondary relationships between the lab space and central service block, while giving due emphasis to the importance of adequate ventilation in a lab space.

It is worth noting that in the spatial design of the labs' service towers, one significant change came about due to consideration of the way in which a scientist approaches his work. In relation to his design for the MRL, Kahn stated that, "a scientist is like an artist...He likes to work in a kind of studio."[13] In consideration of the inherent difference between experimentation and research, he located the lab rooms in the darker area at the center of the complex, and the research rooms in the brighter areas on the periphery. In this way, he used the natural divergence between light and shade to bring into relief the internal logic of organizational functions.[14] Yet, Salk wanted the architecture of his institute to be an expression of the fusion of humanism and the spirit of science, so that scholars-in-residence could carry out their work in an environment conducive to self-cultivation. Moreover, research rooms do not require large amounts of servant space for mechanical services. Thus, in his design for SIBS, Kahn separated the research rooms from the labs, locating the former in an independent structure whose height is staggered half a floor in relation to the main building.[15] Such a spatial relationship helps the scientist make a mental shift when moving from experimentation to textual research and writing, and also provides an external sun block for the labs (Figs.9.-11.).

In recounting Salk's description of the plan for the lab space, Kahn wrote, "Salk said that medical research does not belong entirely to medicine or the physical sciences. It belongs to Population. He meant that anyone with a mind—in humanities, in science, or in art—could contribute to the mental environment of research leading to discoveries in science."[16] After thoroughly studying the essential characteristics of scientific research and lab space, Kahn made use of the concept of served and servant space to emphasize the importance of ventilation to a laboratory. He then went even further by using this concept to give expression to the spiritual import inherent in the harmonization of their unique qualities.

4. Integrating the Mechanical Services into the Structure

Based on his research into the qualities and potential of the materials at his disposal, Kahn invariably made use of variations formed by the structural details to respond to different requirements of the architectural design. Because the MRL and SIBS both required a flexible space with a relatively large span, and also due to the large amount of mechanical services, Kahn used the Vierendeel truss to integrate the mechanical services into the structure. The design the MRL had to take into account certain limitations with respect to budget, time, and materials, leading Kahn and structural engineer August E. Komendant to select precast concrete units as the most suitable construction material.[17] Thus the structural plan made use of 45' x 45' square modules which could be mass produced and installed

Fig.10. SIBS Research Rooms and Connecting Corridors

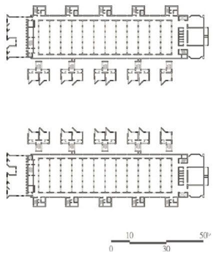


Fig.11. SIBS Lab Floors

to form a unified structural system of precast and prestressed concrete (Fig.12.). This precast system consisted of six modular components: structural columns, primary beams, secondary beams, side beams, main trusses, and secondary trusses (Fig.13.).

After considering a number of practical engineering factors such as installation and structural stability, Komendant specially designed a dual structure system using pre-tensioned and post-tensioned concrete to integrate the structural modules. Pre-tensioned concrete technology was used for the fabrication of the main structural beams, post-tensioning was used to give additional stability to the overall structural framework, and all the structural modules were fabricated on site. First, the structural columns were joined to the primary beams. Then the secondary beams were joined to the primary beams and structural columns to form the main bi-directional stress transmission route. Next, the side beams were joined with the structural columns, primary beams, and secondary beams to form a floor consisting of nine modules. Finally, the primary and secondary trusses were installed, dividing each module into four equal parts (Fig.14.).

Prestressing the reinforced concrete made it possible to reduce the thickness of the components' cross sections. Prestressing the Vierendeel trusses used as beams increased their structural strength and the size of their voids, providing increased spaciousness and flexibility in the placement of the mechanical services. In accordance with the principles of structural mechanics, a three-dimensional structural framework was assembled using the poststress method. After applying prestress, the precast framework followed three axes to distribute the stress. Combining the floor slabs which were poured on-site resulted in a stable column-and-beam framing system. Moreover, post-tensioning the precast units made the assembly process into a kind of weaving, exhibiting a type of structural trait which used the structural characteristics to give expression to the spatial form (Fig.14.).

In integrating the mechanical services into the structure, Kahn believed that the location of the ducts should harmonize with the structural order, thereby giving clear expression to the logic of integration.[18] In the MRL, the positioning of the mechanical services follows the structural order of the right angles of the Vierendeel trusses. Thus the air intake ducts are located in the lower part of the Vierendeel trusses, extending outwards in four directions from the center of the floor; and the exhaust ducts and drain pipes are located in the upper part of the Vierendeel trusses, surrounding all four sides of the floor (Figs.15. and 16.).

In relation to the logic of integrating the lab's incoming and outgoing air ducts, Kahn decided on the use four incoming air shafts to draw fresh air into the service rooms on the top floor. After undergoing mechanical heat exchange, the fresh air was drawn through ducts inside the two vertical transmission shafts. On each floor these ducts joined up with the horizontal ducts situated in the space inside of the Vierendeel trusses, delivering fresh air to each lab. Finally, exhaust air was removed from the labs and passed through two external shafts before being released into the outside environment. Taking a wide perspective, the unique characteristics and order of Kahn's applied structural system, the organizational relationship between served and servant space, and the incorporation of the exposed mechanical services into the structural form all clearly demonstrate the structural logic of how a lab space is configured and served (Fig.17.).

When actual construction began on the MRL in 1959, Kahn was commissioned for the design of SIBS. Realizing that the use of exposed mechanical services in a laboratory gave rise to the problem of dust accumulation, Kahn decided to adopt a different approach in his design for SIBS. In the early stages of the project, he proposed the use of breathing beams—a construction technique which uses precast rectangular and triangular folded-plate beams. Joined to the service towers, the rectangular folded-plate sections would support the longitudinal structure, at the same time connecting the incoming air tower with the outgoing air tower. The triangular folded-plate sections would serve as the route by which the mechanical services would be distributed into the labs (Fig.18.).

This design proposal, however, was not well received by

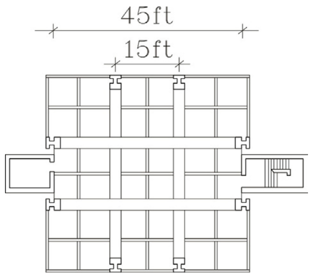
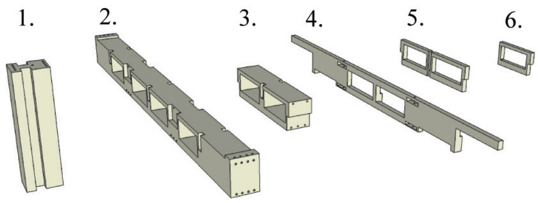


Fig.12. Structural Floor Plan



1. Column; 2. Primary beam; 3. Secondary beam; 4. Side beam; 5. Primary truss; 6. Secondary truss

Fig.13. Precast Concrete Structural Elements

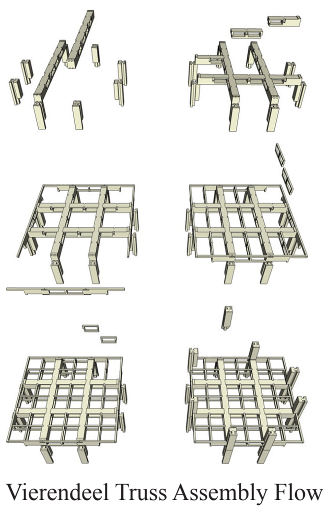


Fig.14. Vierendeel Truss Assembly Flow Chart

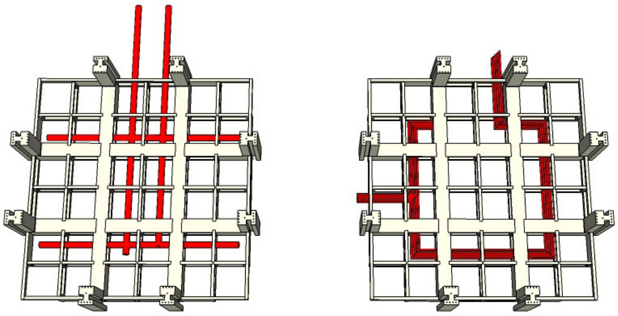


Fig.15. Distribution of Incoming Air Ducts (left),
and Exhaust Ducts and Drain Pipes (right)

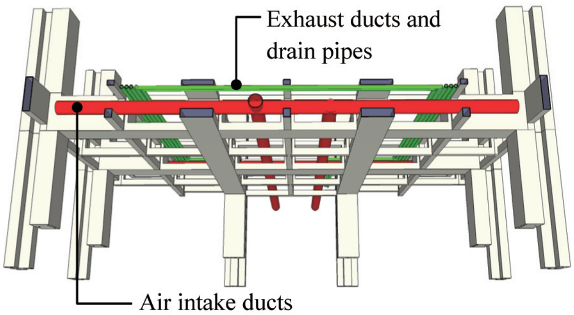
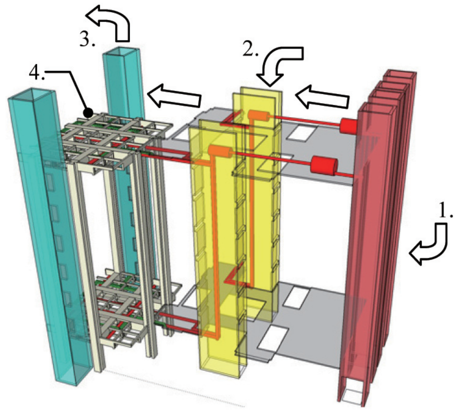


Fig.16. Incoming Air Ducts (below), Exhaust Ducts,
and Drain Pipes (above)

Salk, who had some reservations concerning the four-lab configuration and the scale of the interior space. He felt that the design's two inner courtyards would have a dispersing spatial effect, and would not be conducive to interaction between the researchers. Thus Salk requested that the lab space be designed to have more flexibility, believing that incorporating the mechanical services into the form of the triangular folded-plate construction was too constricting, and that it would create difficulties with regards to maintenance and replacement. For these reasons, he asked Kahn to come up with a whole new design. In addition, in the course of reviewing the design plan, Kahn's design team discovered several problems. For one, the space inside of the triangular folded-plate sections was clearly insufficient for containing the ventilation system, and such a constricted space would make maintenance and replacement extremely difficult. The biggest problem, however, was that the span of the folded plate sections in the labs was too wide, giving rise to the issue of how to connect the mechanical service system. In the end, Kahn had no choice but to abandon this design, despite the fact that he had already spent one and a half years on it.

After reconsidering the need for a structural form which could provide a space in which to conceal the mechanical services, Kahn decided to continue to use the Vierendeel trusses of the MRL. Yet, in order to create a more flexible space, he expanded the scale of the Vierendeel trusses into an entire independent mechanical services floor, thereby drafting a unique design which integrated the mechanical services into the space and structure. Finally, Kahn designed the labs into two rectangular masses 245 feet long and 65 feet wide. Each building was organized according to the principle of served and servant space, with an independent mechanical services floor above each lab floor. In addition, in order to provide the lab spaces with more direct access to the mechanical services, Kahn used an interstitial floor on the mechanical services levels. This efficient design eliminated



1. Air intake tower; 2. Vertical transmission shaft; 3. Exhaust tower; 4. Vierendeel trusses

Fig.17. Distribution of Incoming and Outgoing Air Ducts

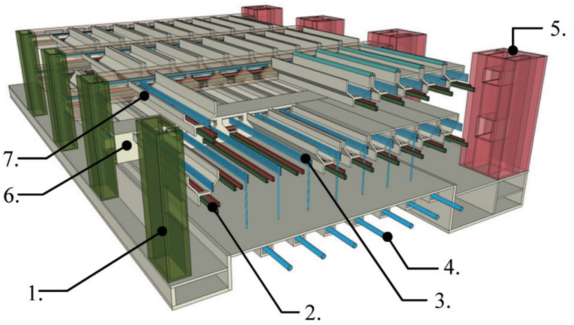
the problem of the floor obstructing the mechanical services, and also solved the problem of dust accumulation (Fig.19.).

After considering that California is subject to regular seismic activity, Kahn decided to use the post-tensioned concrete construction technique for the overall structural system of SIBS. This included the structural support columns as well as the post-tensioning cables imbedded in the lower sections of the Vierendeel trusses. Moreover, pre-tensioned cables were specially added to the structural sections which are connected to the ground floor in order to provide increased resistance to the lateral loads caused by earthquakes (Fig.20.). This was quite different than the construction technique employed for the MRL, which used only post-tensioning to assemble the precast concrete modules.

In light of the symmetrical design of the lab, Kahn used a basement on the eastern side to connect the two buildings. This allowed the mechanical service systems of each lab to support each other so that uninterrupted service could be provided even during maintenance. Moreover, for the same purpose, each set of ducts had at least two transmission routes. The main MEP equipment was installed in the eastern section of each building. Fresh air was brought in through an intake opening in the outer wall, and after undergoing heat exchange it was conveyed through ducts located on the Vierendeel truss mechanical services level, and then distributed into the labs. Due to the primary importance of adequate ventilation in a lab space, Kahn integrated the exhaust ducts into the concrete mass on the outside of the labs, thereby giving clear expression to the primary and secondary relationship between served and servant space (Figs.21. and 22.).

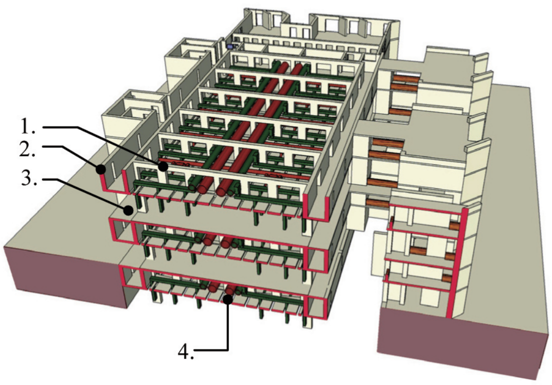
The mechanical services were arranged according to the space made available by the Vierendeel trusses on the mechanical services floor. Due to the addition of post-tensioning, the space inside the center of the Vierendeel trusses was relatively large. Thus, Kahn's design team located the larger ducts inside this space, and the branch lines were parceled out perpendicularly. The fresh air grilles were located at the center of each lab, and the return air grilles at the perimeter, in order to match the lab space configuration of experiment tables in the center and exhaust fans on the periphery (Figs.23. and 24.).

Although the MRL and SIBS are both science labs, each facility has its own unique requirements, leading Kahn to adopt two different approaches for integrating the mechanical services into the structure. First of all,



1. Air intake tower; 2. Air ducts; 3./4. Drains; 5. Mechanical services and exhaust tower; 6. Rectangular folded plate section; 7. Triangular folded plate section

Fig.18. 3-D Simulation of the Integration of the Mechanical Services with the Folded Plate Sections



1. Vierendeel truss mechanical services floor;
2. Maintenance passage; 3. Lab; 4. Interstitial floor

Fig.19. 3-D Simulation of the Integration of the Mechanical Services into the Vierendeel Truss Mechanical Services Floor

with respect to the structural form, in the SIBS design he increased the usability of the structural space inside of the Vierendeel trusses. In this way he expanded his earlier approach employed in the MRL design into a structural form which integrated the mechnical services into the building's spatial and structural scheme. This made maintenance and replacement of mechanical services much easier, and also provided greater flexibility for future expansion of facilities and personnel. At the same time, this design helped to offset the chronic problem of dust accumulation which can be exacerbated by exposed mechanical services. With regards to the SIBS spatial arrangement, Kahn enlarged his concept of served and servant spaces from a two-dimensional plane to a three-dimensional cross section. Additionally, in the vertical spatial arrangement, he added a new dimension to his design concept of "serving a space." Moreover, in dealing with the problem the MRL had with direct sunlight in the labs, in the SIBS design, Kahn extended the maintenance corridor along the outside of the Vierendeel truss service floor outwards in order to block the sun (Fig.19.).

While Kahn used the post-tensioned concrete construction technique for both labs, he had different reasons for doing so. In the MRL design, he used this technique in order to suit the assembly style of the precast concrete modules, but with the SIBS design it was used in order to provide the structural body with increased earthquake resistance. Regardless of the intended purpose of each building, the structural strategy was the same: to increase the empty space

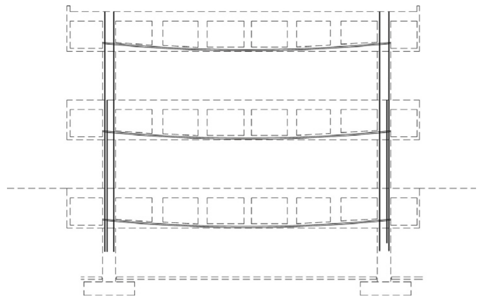


Fig.20. Configuration of Pre-tension Cables

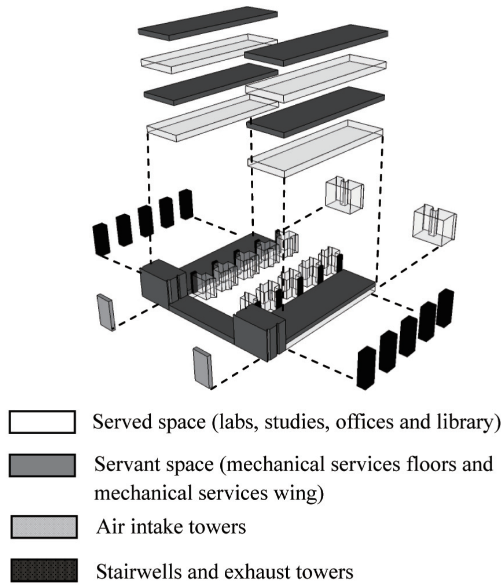


Fig.21. Served and Servant Space: the Layout of the Air Towers

inside of the Vierendeel trusses so as to have more surface area for the mechanical services. In the later design, with respect to the structural form, Kahn not only made use of the interstitial characteristics of the Vierendeel trusses, but also added several interstitial floors. Wanting to make the most of the special characteristics of his materials, in his approach to integrating the mechanical services into the structure Kahn gave clear expression to his architectural concept of "building with hollow stones."

5. Conclusion

Based on his exploration of the "existing will of architecture," and starting out from the special characteristics of the science lab, Kahn sought to further explore the integration of design with related details. He once wrote, "The intrusion of mechanical space needs can push forward and obscure form in structure. Integration is the way of nature. We can learn from nature."[19] By bringing into full play the inherent qualities of his construction materials, and accentuating the design concept of compositional order, Kahn transformed the mechanical services—originally regarded by modernist architects as an eyesore which ought to be hidden away—into an expressive element which can display the organizational logic of a space, and which directly conveys information about how space is constructed and how it is served. Moreover, in response to the large amount of mechanical services in a science lab, he employed the design strategy of harmonizing the ducts, structure and space.

By analyzing the strategies employed in the MRL and SIBS for incorporating the mechanical services into the

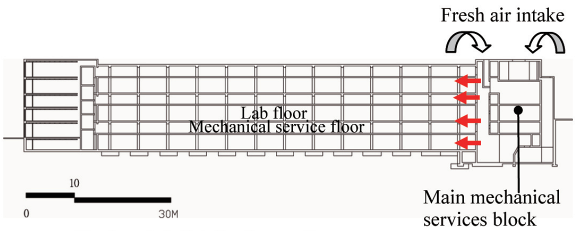


Fig.22. Lengthwise Cross-section
(Mechanical Services Distribution Analysis)

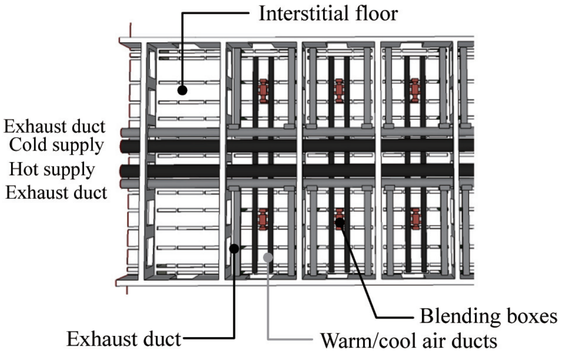


Fig.23. Configuration of Mechanical Services Inside the Vierendeel Trusses of the Mechanical Services Floor

Fig.24. Salk Institute Laboratory

structure, it becomes apparent that Kahn consistently conformed to the building's structural form and constructural order, whether the ducts are exposed or concealed. Thus the logic of integrating the ducts into the structural form is not only more intelligible; it also effectively addressed Kahn's concern with the problem of exposed ducts doing harm to the spatial order. In comparison with the methods for integrating mechanical services in common use during the 1950s—suspended ceilings and double walls—Kahn's approach of integrating them into the structural form gave more effective expression to the spatial characteristics revealed by the material properties of the structural elements. Moreover, his approach also resulted in greater convenience for future maintenance, replacement, and expansion of the mechanical services system. Finally, by separating the servant spaces from the served spaces, Kahn's lab designs gave clear expression to the distinct spatial qualities of incoming and outgoing air ducts, at the same time giving more effective expression to the external formal qualities required by the inherent characteristics of the space.

Kahn's use of structural form to integrate the mechanical services was not limited to his designs of science laboratories, as can be seen in his designs of public buildings with less complicated mechanical services. Moreover, Kahn believed that the character of a space is determined by the character of the structure, such that it is necessary to use different structural forms to manifest different spatial qualities. In this way he made the best use of a wide variety of structural possibilities to develop a structural form capable of integrating the mechanical services, and used this to come up with unique spatial forms for different types of buildings.

In his design of the Yale University Art Gallery (1951-53), Kahn used the spaces in the tetrahedral floor system to integrate such mechanical services as air conditioning and artificial lighting. For the Kimbell Art Museum (1966-72) he used the combination of a double wall, a cycloid vault, and an aluminum ceiling structure to provide a pathway for the incoming and outgoing air ducts. In his design of the Philips Exeter Academy Library (1965-1972), Kahn used a vertical utility shaft composed of brick and reinforced concrete to integrate the mechanical services, with the exposed level aluminum air ducts passing between the brick building and the concrete building. Moreover, he used the configuration of the ventilation ducts to emphasize the structural relationship between the two buildings, a relationship which can be seen as parallel to that between the reading (served) and storage (servant) areas of the library.

Thus it can be seen that even in the same spatial type, Kahn attempted to utilize different structural forms and details to respond to the unique spatial qualities and functions of each of these buildings. Even though Kahn adopted different structural forms to integrate served and servant spaces, all these designs were united by the way in which they brought the essential qualities of the materials into full play, and the emphasis they gave to the concepts of rational construction and the inherent desire to be. Whatever the structural form, Kahn's designs all had exhibiting the essential qualities of the space as their ultimate goal, the pursuit of which was a way of giving expression to the spiritual connotations of the desire to be.

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