THIN CONCRETE SHELLS AT MIT: KRESGE AUDITORIUM AND THE 1954 CONFERENCE

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Abstract

This paper presents original research on two historical developments in the field of thin-shell concrete structures in the United States, both at the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts in the 1950s. The first topic is the design and construction of MIT's Kresge Auditorium (1953-1955), enclosed by a concrete shell on three supports designed by architect Eero Saarinen (1910-1961). The second topic is a seminal conference on the architecture, engineering, and construction of thin concrete shells hosted by MIT in 1954, which included presentations by architect-engineer Felix Candela (1910-1997), engineer Anton Tedesko (1903-1994), architect Philip Johnson (1906-2005), among many important designers and scholars.

Both the building and the conference are historically significant, and together, they mark the peak of a design era optimistic about the enduring value of thin-shell concrete structures. However, they also reflect the underlying tensions and contradictions of thin-shell concrete technology that contributed to its limited use in subsequent decades. The project therefore serves as an early example illustrating the limitations of thin-shell concrete applied to arbitrary formal ideas.

The concurrent conference often related directly to the design and construction of Kresge Auditorium: both its structural engineer (Charles Whitney, Ammann and Whitney) and contractor (Douglas Bates, George A. Fuller Company) presented papers, and a proceedings summary notes that "this conference has…cantilevered out from Saarinen's dome." The conference highlights broad enthusiasm for thin-shell concrete structures, but also reveals disagreements between theoreticians and practitioners, architects and engineers, and designers and builders. This paper gives a critical review of the influential conference, based on conference proceedings and supporting historical documents.

In summary, this paper contributes new knowledge on the history and significance of paired events in thin-shell concrete in the 1950s at MIT. In addition to detailed accounts of both the building and conference, the paper offers original insight about their contextual role in the rise and fall of thin-shell concrete technology in the design and construction community.

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HISTORICAL CONTEXT

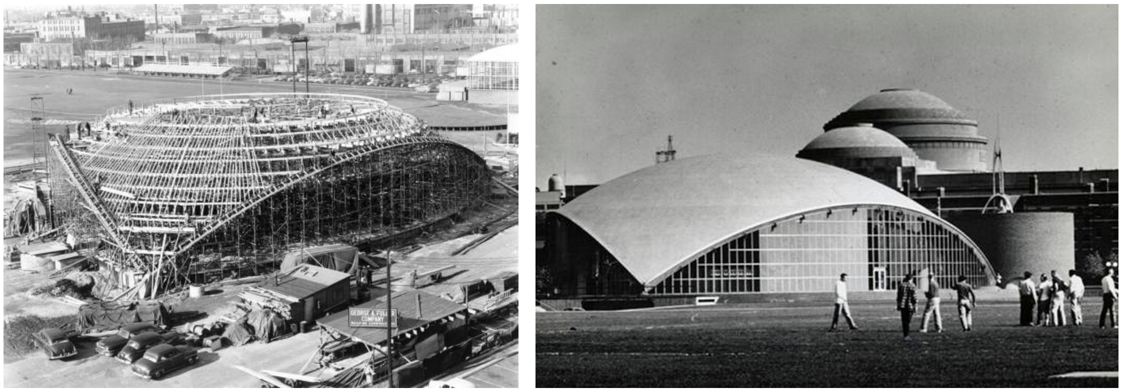
Thin-shell concrete is one of the most important developments in twentieth century construction history. Formalized in the 1920s in Germany by Franz Dischinger and Ulrich Finsterwalder (May 2012), this material and structural system have been used to achieve great spans, unprecedented material efficiency, and dizzying geometric complexity that captured the imagination of the modernist movement in architecture. But thin-shell concrete structures also embody a fundamental contradiction: on the one hand, they offer an infinite spectrum of possibilities for new structural shapes, as described by engineers like Heinz Isler (Chilton 2010). On the other hand, their success depends on a precise and sometimes intractable relationship between geometry and structural behavior; just because a shape is rendered in thin concrete does not mean it behaves as an efficient shell.

This paper is about this fascinating contradiction, which lies at the root of the well-documented rapid rise and subsequent decline of thin concrete shells in the post-war American architecture and engineering (Billington 1983). This paper examines this trajectory through the lens of a particular moment and place, 1954 and the campus of the Massachusetts Institute of Technology (MIT), a snapshot that reveals a critical shift for how thin-shell concrete structures in the United States would be perceived and constructed during the Post-War period.

Three events in Massachusetts occur in June 1954, and each provides a different perspective on the nascent interest in thin-shell concrete as a means for architectural expression and structural efficiency. First, the construction of Eero Saarinen's Kresge Auditorium, a shell shaped like one-eighth of a sphere and supported on only three points, on the MIT campus is underway (Figure 1). The concrete pour for the shell was completed in April 1954 (Boothby et al. 2005), and the removal of the supporting formwork led to substantial deflections at the free edges, much larger than anticipated. The contractor, George A. Fuller Company, and the engineers, Ammann & Whitney, developed a solution: strengthening nine of the vertical window mullions, originally designed for horizontal wind load only, to support the gravity load of the shell along its free edges, as shown in Figure 2. The existence of the supporting mullions was not publicly disclosed until September 1954, three months after the conference at MIT, in an article by Joseph Lacy of Eero Saarinen and Associates stating, "At a meeting of all interested parties it was decided to substitute three struts for the same number of window mullions at each edge beam, in order to fix the elevation of the edge beam" (Lacy 1954, Zakem 2006).

Second, the 1954 Conference on Thin Concrete Shells is hosted at MIT on June 21-23, 1954 by the departments of Architecture and Civil Engineering. Two primary themes emerge: an optimism and intrigue in the possibilities that thin concrete shells could achieve, both in terms of architectural innovation and structural resiliency, and a vigorous debate on the best approach for engineering such forms, argued between those who favored rigorous calculations and those who preferred empirical approaches. The engineering firm and contractor responsible for Kresge Auditorium are present at the conference, and speak proudly about the project without mentioning the large deflections and necessary changes.

Third, separate from the MIT conference, the 86th Convention of the American Institute of Architects also occurs in Boston in June 1954 with Saarinen, designer of Kresge Auditorium, featured as a speaker. In his speech, "The Changing Philosophy of Architectures" he outlines the specific approach he used for the design of Kresge, a view he reiterates and refines over the course of the decade. He states, "The Structural Principle: From as far as I can remember in modern architecture, structural integrity and structural clarity are basic principles. In recent years, these principles have received a new impetus…An example of what I mean is demonstrated in the domed auditorium we are building for MIT” (Saarinen 1954). Notably, any discussion of the flawed structural performance of the Kresge Auditorum is absent from this discussion.



(a) (b)

Figure 1: Kresge Auditorium (1954-1955) on the MIT campus. (a) Under construction, with formwork shown (MIT Museum, Photo W16-214a). (b) Photograph after completion (Yale University Library / Eero Saarinen Collection Manuscript and Archives).

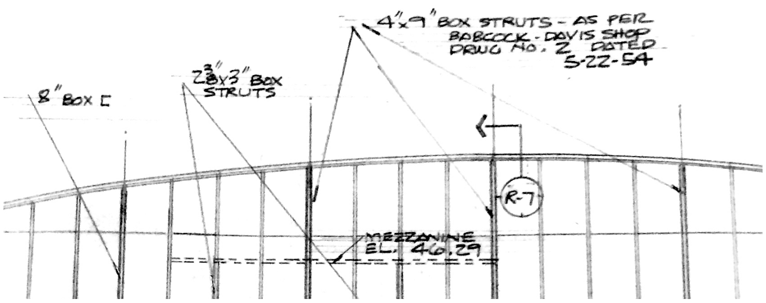


Figure 2: Revised drawing dated June 21, 1954 showing revised mullion design submitted in May 22, 1954 (Yale University Library / Eero Saarinen Collection Manuscript and Archives / MS 593 / Box 167).

A REALIZED SHELL: KRESGE AUDITORIUM

Saarinen was one of the most prominent American architects of the 1950s, and he was at the forefront of using thin concrete shells. Colleague Bruce Adams states, “Eero has been thinking of doing an auditorium in thin-shelled concrete for ten years now. This is the first place it happened” (Handy 1955). While the origins of Saarinen’s inspiration for thin-shell forms remain unknown, Saarinen was perhaps influenced during his studies in Paris 1929 and subsequent travels in Europe during the 1930s by the early reinforced concrete domes of Dischinger. The design of Kresge Auditorium, conceived by Saarinen between 1950 and 1953, rises 15 meters in height and spans 48 meters. The truncated dome has a thickness of 9 cm except along the edge beams that vary in depth up to 45 cm at the point supports. The stated design loads included a dead load of the structure was found to be 83 pounds per square foot (4.0 kN/m^2) with a live load of 30 pounds per square foot (1.40 kN/m^2) (“Tripod dome built on tricky formwork” 1954). The project was not without its engineering challenges, and the building would require significant repairs beginning as soon as 1960. The trials of maintaining the structure have been documented thoroughly in the literature (Cohen et al. 1985, Boothby and Rosson 1998, Boothby et al. 2005).

However, at its dedication in 1955, the building is deemed a rousing success, and is heralded for its impact on the campus and on the architecture world more broadly. Immediately after the opening, publicity and interest in the structure are widespread and almost unanimously supportive. Project 5007, as it is referred to within the Saarinen office, garners nicknames such as the “Opal on the Charles” (Weeks 1955), and descriptions like “Concrete Has Spread across the Sky” (Handy 1955). Saarinen declaratively predicts, “We are very much in the beginning of a whole new period of architecture” (Handy 1955). His standing as the public face of modern American architecture solidifies, and he is featured in magazines like *Vogue* (Saarinen 1955); Figure 3 shows a series of photographs of Saarinen taken next to Kresge by *Harper’s Bazaar*.

Figure 3: Saarinen posing with one of the supports of Kresge Auditorium for *Harper’s Bazaar* (Yale University Library / Eero Saarinen Collection Manuscript and Archives / MS 593 / Box 168 / Folder 503).

Although thin-shell concrete existed as a construction system for several decades, Kresge Auditorium is the first highly public execution of the system in the United States, and it attracts attention from both the architectural community and the general public. The building is featured in 14 articles between 1953 and 1956, including many in *Architectural Forum* and *Architectural Record* and one in *Time*, which hail its innovations ranging from the triangular shape, the curved shell form, and the three supports. The first critical article is published in 1956 (Zevi et al.) and features reviews from three leading architectural theorists: Bruno Zevi, J. M. Richards, and Siegfried Giedion. Zevi invokes another expert in efficient structural form, architect-engineer Pier Luigi Nervi, in his discussion, attributing the following quote to Nervi: “I could demonstrate that structural thought and common sense have been allied in all ages. Today structural ideas are invaded by extravagance, and they are deprived of all justification.”

The main complaint is that the dome comes down on three points instead of many, leaving long stretches of unsupported free edges. Zevi also calls the building a “mistake” and a “pseudomystical experiment,” derived from a Romantic obsession with pure geometry rather than functional or spatial needs (1956). In a subsequent letter to the journal, *Architectural Forum*, Nervi issues a correction, insisting he was misquoted, but essentially confirms the attributed criticism: “I assure you that the critical observations on such works…concern a theoretic aspect of the static scheme: the conflict between the exterior aspect of a thin vault and the static impossibility of a real thin spherical vault supported at three points” (Nervi 1956).

J. M. Richards wonders about the appropriate role of technology in architectural design: “It is a question first of whether technology is to be servant or master, and then of what kind of service is to be asked of it. To place the resources of technology at [Saarinen's] disposal is not to grant the architect a license to invent pleasing and dramatic forms into which the needs of the building must fit somehow… Mr. Saarinen's mastery is of a more positive kind. He has used technology to convey an architectural idea" (Zevi et al. 1956).

The first more direct critique comes several years later. In 1964, artist George Maciunas indicts Saarinen and Kresge Auditorium in an article entitled "The Grand Frauds of Architecture" (other named culprits are Mies van der Rohe, Gordon Bunshaft, and Frank Lloyd Wright). He describes the design strategy for Kresge Auditorium as follows: "Employ nonfunctioning 3-support 'efficient' looking dome and support it with inefficient but well concealed columns." In the following decades, this criticism grows, bolstered by scholars like David Billington (1983) and Robert Mark (1990), who repeatedly use the building as the canonical example of the dangers of employing willful "geometric" instead of "structural" shapes in shell design.

This debate raises a key question for thin-shell concrete as a technology: what is the role of architecture and architects in the pursuit of efficient structural form? Geometry typically falls into the realm of architectural design, given its broad spatial and aesthetic implications, but in thin-shell structures, geometry must also be responsive to engineering principles. Kresge Auditorium is important not only because of its failures, but because it is the first building to bring this conflict to the forefront in American design culture.

MIT CONFERENCE ON THIN CONCRETE SHELLS

Before Kresge Auditorium's completion and the subsequent reactions, American and international designers were growing increasingly intrigued by the possibilities of thin-shell concrete structures, an optimism witnessed at the 1954 conference at MIT. Noting that the conference had "cantilevered out from Saarinen's dome," the proceedings summary describes a strong vision for the future of architecture dominated by thin-shell concrete technology ("It seems evident that at the very least one can say thin shell construction has come to stay" [Hitchcock 1954]).

The conference proceedings reflect a growing interdisciplinarity in the realm of shell engineering; they are evenly divided into three categories: "Architecture," "Structural Analysis and Design," and "Construction." The conference attracts 450 attendees across each of these disciplines. According to a 12-page report on the conference activities in *Architectural Forum*, the "main interest fell on the wide variety of highly functional and expressive shapes—where structure and enclosure are one—that have been achieved" ("Shell Concrete Today" 1954).

The proceedings include 18 papers, with topics ranging from formal possibilities to lighting and acoustics to calculation methods to economics and construction. In summarizing the "Architecture" session, H. R. Hitchcock writes, "Here it appears that the two approaches of the architects and the engineers have crossed one another recurrently. The architects have no monopoly on visual invention since engineers in this have certainly shown themselves to be by no means uninterested in what are often considered purely architectural problems" (1954). Kresge Auditorium clearly looms heavily as a harbinger of the future; later in his summary, Hitchcock notes, "…the relevant proportion of major structures—major in size like the hangars, major in significance like the MIT [Kresge] Auditorium—does give special poignance to what might be called 'neo-vaulting,' a feeling that we may be turning some sort of a corner" (1954).

Beyond this general optimism for thin-shell architecture, a major and timely theme to emerge from the conference is the debate between mathematical purists and the intuitive shell builders, exemplified most strongly by the Spanish architect-engineer Felix Candela (1910-1997), who presents a wide range of his built work utilizing hyperbolic-paraboloid geometries (1954a). In

ENR's write-up on the conference, the author notes, "Belittling the importance of the mathematical theory of elasticity in thin-shell design—even going so far as to claim that it is now one of the main obstacles to the normal development of structural knowledge—Mr. Candela expounded his theories of the behavior of shells and showed pictures of the daring structures he designed and built" (1954). In his presented papers, Candela notes the limitations of mathematical theory in applications with complex geometry, and states, "I am wondering what could be the progress of mankind, if nobody were allowed to perform any jump or movement without a previous mathematical determination of the force that must be asked from a certain muscle?" (1954b).

While the conference ostensibly bolsters thin-shell structures as the construction technology of the future, the debate sparked by Candela and his opponents reveals fissures in this utopian vision. Who should have control of the geometry of thin-shell structures? Should their genesis come from analytical equations, experience-based intuition, or architectural ambition? The only presentations related to Kresge Auditorium, from engineering firm Amman & Whitney's Charles S. Whitney and from contractor George A. Fuller Company's Douglas Bates, are silent on the issue (and also silent on the ongoing deflection issues with Kresge, addressed two month prior to the conference). Considered a bold success at the time, Kresge Auditorium represents an approach endorsed by neither Candela nor the mathematical purists: a form generated for architectural expression. Despite the animated debate at the conference, this third outlook, which prioritizes geometry for its own sake (despite claims of structural provenance), would have the greatest influence on American and international shell design in the coming decades.

CHANGING ATTITUDES AND THE DECLINE OF THIN-SHELL CONCRETE

Eight years after the MIT conference, the World Conference on Shell Structures is held in San Francisco, CA. Less than a decade later, this conference demonstrates a more grounded view, and also a much more extensive community, through its proceedings and descriptions of the event. The proceedings includes 75 papers, covering topics such as limits of scale and economic feasibility, issues largely absent in the 1954 conference. Many of the papers present real completed shell projects, in contrast with the theories and possibilities presented in 1954. Conference Chairman Egor P. Popov states, "The urban skylines may be invigoratingly refreshed by an infinite variety of new forms. However, for these forms to be sensible, and to exploit the inherent economy of shell construction, the highest level of engineering talent is required" (1962). According to a report in *Architectural Record* (1962), the conference draws an audience of 700, and one in ten is an architect. Instead of discussing formal possibilities, most presentations focus on the equations required for analysis, with the new inclusion of numerical (i.e. computational) methods. There is a sense that such methods will be necessary to enable new forms dreamt up by architects, rather than for the collaborative synthesis celebrated in the 1954 conference.

Kresge Auditorium is not discussed widely at this conference; by this time, its deflection problems are well known. Even Saarinen, a firm believer in the sculptural forms he insisted were inspired by expressions of structural clarity, acknowledges and partially agrees with the criticisms in an undated quote: "In retrospect one has to criticize this building. It looks like a half-inflated balloon. The windows bulging out, the round base, the narrow edge beam, and the complete spherical shape, I believe all contribute to that…The complete geometry did not come off….We learned a lot on that building. We learned that one cannot depend on geometry for the sake of geometry" (Saarinen, "General Statement"). The shift towards architectural surfaces,

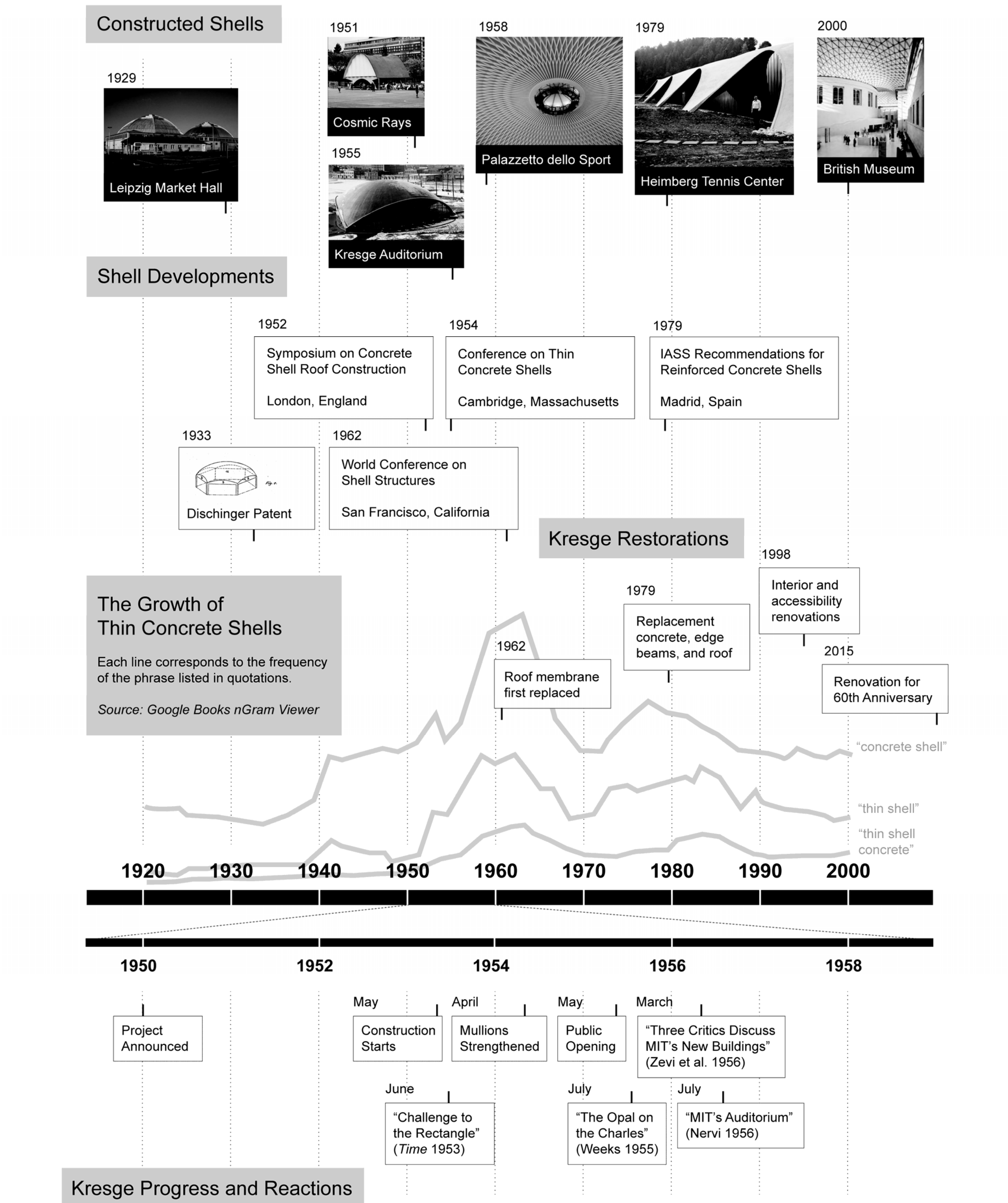


Figure 4: Timelines showing the growth and subsequent decline in interest in shell structures, which peaked in the decade after Kresge Auditorium was completed. The lower timeline gives a magnified view of events related to Kresge's progress and reactions.

represents a narrative where architectural designers claim structural significance to their forms in addition to geometric expression. Saarinen never quite achieves a truly efficient structural shell in his career, although he progresses in that direction after Kresge (Whitehead 2014).

CONCLUSIONS

The legacy of Saarinen's Kresge Auditorium can be sensed strongly in the architecture of today. While interest in thin-shell concrete has declined significantly since its mid-1960s peak, as documented in Figure 4, there is a persistent fascination with geometrically complex architectural surfaces which make various claims about structural performance. A recent essay wonders why the contemporary preoccupation with "blobs" fails to acknowledge possible connections to appropriately shaped structural shells (Bechthold 2010), discussing the same issues first uncovered by Saarinen through Kresge: the difficult reconciliation of architectural intention and technical performance when goals deviate from pure structural expression. Grid shells, like the roof over the British Museum Great Court (2000), inherit the possibilities of twentieth century concrete versions, and also face similar challenges in terms of geometry and behavior.

This paper has contextualized Kresge Auditorium within twentieth century shell history with a specific focus on American architecture. While this building is not significant in construction history in terms of its structural efficiency or unprecedented span, it marks a critical historical turning point in the shift of shell structures from the domain of engineering calculations and intuition to the realm of architectural formalism and the public imagination. In combination with the 1954 MIT Conference on Thin Concrete Shells, this project can be seen as an expression of naïve exuberance, but also an important predecessor to architectural attitudes today.

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