Keywords: Eero Saarinen, Kresge Auditorium, MIT Chapel, music, acoustics, religious buildings, auditorium, shell/membrane design, structural design, graphic statics, interdisciplinary, student life, Massachusetts Institute of Technology

Saarinen's Shell Game: Tensions, Structures, and Sounds at MIT

Abstract. For all of the criticism of Eero Saarinen's Kresge Auditorium and MIT Chapel, they exist as a highly focused moment of deliberate experimentation with geometric form in materials old and new which both contrasted the typical forms of rational modernism and resonated deeply with the modernist quest for the incorporation of novel structures. This paper explores the metaphorical and literal tensions through three dichotomies: geometrical ones with implications for acoustics, programmatic ones with implications for use, and structural ones between the appearances and actual structural actions of the architecture. I seek to illuminate how the geometric issues of both buildings relate to structural optimization. I also approach the Auditorium and Chapel from the roles of having been a performer and composer of instrumental and vocal music for both spaces while earning degrees at MIT in architecture. The simple act of listening defies one's typical expectations in both spaces, and the dichotomies of geometry, use, and structure illuminate the relationship of sound to place in these architectural spaces.

Prelude: Sites and Sounds

Nestled in a small stand of London Plane trees planted west of Massachusetts Avenue stands the MIT Chapel designed by Eero Saarinen. Designed in tandem with the grassy oval and the spherical Kresge Auditorium, Saarinen's chapel creates a small, closed, cylindrical form in the midst of its domed and rectilinear neighbors on the MIT campus. The exterior form (modified in recent decades by causeway-like ramps moderating the level change at the entry) encloses a space that is purposefully hidden. Across Kresge Oval, the auditorium seeks a less contemplative and more forthright appearance from Massachusetts Avenue; its curtain wall broadcasting views of the lobby since its entry is at the grade of the broadly sloping turf.

While the chapel is relatively recent, merely a half-century old, it hearkens back to more primal architecture concepts, focusing on simple elements of water and light. While sited within viewing distance of a major river, Saarinen's design includes a shallow pool of water that functions as a reflecting pool to the exterior as well as reflecting light to the interior. While the exterior remains a quiet, closed cylinder surrounded by still water, the interior of the chapel is a ring of undulating brick ripples.. Provided it has not been seasonally drained from the concrete "moat," the water reflects light through small horizontal curved windows up onto the brick; these ever-changing patterns of light are the primary contact the interior space has with the outside world, the light having been mediated by the water's surface. For many traditions, the single overhead oculus piercing the curved, black, night-like ceiling is an appropriate connection to divine connotations (fig. 1).

Fig. 1. MIT Chapel, main aisle (view toward Bertola screen). Photograph by the author

Fig. 2. MIT Chapel, exterior approach. Photograph by the author

While the water reflects light upward, the oculus admits a stream of light downward onto the altar and circular marble slabs, bringing the “light of the world” to a surrounding environment of darkness.¹ While the quality of light from the oculus is diffused by the grate-like structure therein, the altar screen is a powerful connection from the light source through the space to the ground. Descending from the heavens to the realm of humanity, the deceptively simple yet intricate structure uses wire and metal plates to reflect light (see fig. 7). Designed by Harry Bertioia (another alumnus of the Cranbrook School in Bloomfield Hills, MI, which Eliel Saarinen designed and his son Eero attended), this structure uses the individuality of the rough metal plates to be beautiful not only in surface detail, but also as a whole when perceived from further away in the space. Since it is supported at its top and bottom by the building, it does not tend to read as “sculpture” separate from the architecture, but rather as an emphatic focal point within the aesthetic whole. The sculpture mediates the transition from the light of above to the illuminated marble below, reflecting the mediation between God and man at times of worship.

The use of light and water for elegant architectural principles is not limited to the round interior of the chapel space. In contrast to the open sunlight of Kresge Oval, the trees around the chapel provide a filtered mosaic of light and shadow on the brick cylinder as well as the ground (fig. 2). The water surrounding the chapel creates a physical and visual separation penetrated only by the bridge-like passage of the entryway. Rather than having the spatial feel of a traditional narthex, this low, translucent corridor provides a transitional, intermediate space that sets the viewer on a linear course down the chapel’s main axis to the altar and oculus (fig. 3).

Fig. 3. Chapel, entry lobby. Photograph by the author

The chapel also benefits from Saarinen's careful treatment of exterior space. The aforementioned axis is aligned, not with the center of the auditorium, but with the off-center placement of the south auditorium entrance (fig. 4). Furthermore, the whole chapel-auditorium combination has been placed to the south of the main axis of MIT.

Fig. 4. Detail of a map of the MIT campus, showing the placement of Kresge Auditorium and the MIT chapel

By shifting the axial emphasis, a bold and unusual concept for compositions of circular forms, Saarinen creates asymmetrical outdoor spaces amongst the trees, giving each building its own sense of place and identity without competing for prominence. Even the use of brick in the chapel and the exterior terrace of the auditorium helps to build a visual relation to the curved brick forms of Aalto's Baker House visible beyond (see fig. 10). Prior to the existence of Kresge Auditorium, the MIT Chapel, and the raised oval of landscaped space, this area behind the apartment buildings (now Bexley Hall) on Massachusetts Avenue was a flat, open space.² While the chapel may now appear more "central" to the overall campus, it predates all of the subsequent dormitories on Amherst Street as well as the student center. Therefore, it was slightly more on the outskirts of campus at the time of construction, but foreshadowed the growth of West Campus as a residential area. Along with the formal development of the humanities as a school and of students' living opportunities on campus, Saarinen's buildings constituted a concurrent attempt to develop the opportunities for spiritual space in an urban, secular environment.

In the highly crafted exterior space between the chapel and auditorium, the surrounding forms are mainly horizontal, except for the single element atop the chapel. Theodor Roszak's design for the Bell Tower cannot be appreciated at the same proximity or level of detail as the interior sculpture due to its physical location, but it contributes a bold upward gesture that relieves the staid, earthbound forms of the chapel and auditorium.³ Although one MIT description calls it a symbol of "the history and authority of three major religious persuasions," [MIT, *Art and Architecture* 1988: 45] this seems to contradict and limit the more broad definition of an inherently 'multidenominational' or 'nondenominational' chapel, and is not supported by Saarinen's own statements. The bell tower can also be perceived in campus lore as an abstracted 'rocket to the heavens,' or a gestural steeple, but its essence seems to exist not in its overt symbolism, but rather in its verticality as the one element that aspires above

and beyond the surrounding tree canopy, extending the worshipful interior space into the exterior environment and the atmosphere above.

The auditorium has no such pinnacle; it is often recognized and published for its iconic copper-paneled roof, but it did not initially have such a covering; at the time of its opening the stark whiteness of the membrane prompted critical reception.⁴ Even though the initial membrane failed and reroofing was necessary less than a decade after initial construction,⁵ the copper has persisted in a role as the metallic analogue of brick in having a surface which becomes richer with age.

Kresge Auditorium, MIT's performance and rehearsal hall, is the chapel's fraternal – and far from identical – twin. Kresge's graceful roof, sheathed in copper, its triangular plan and its glass-and-steel windows contain a hive of activity. A little theater, a concert hall and rehearsal rooms within are used for everything from drama to dance to music performances, as well as symposia and science, technology and engineering conferences [Wright 2005].

Moreover, these program spaces designed for sound are column-free: the main hall seating over 1200 and the theatre for 200, and the remainder of subterranean spaces for rehearsal, storage, and service purposes are supported from below. Early site schemes foresaw the demolition of Bexley Hall along Massachusetts Avenue and a more formal relationship to both the main entrance at 77 Massachusetts Avenue at street level or via other overpasses and underpasses, none of which were built. Saarinen's vision of a consistent northern edge was compromised by the looming brutalist symmetries of Eduardo Catalano's Student Center in 1968, but have been improved by the elegant glazed scrim of the Zesiger Fitness Center completed by Roche/Dinkeloo (the successor firm to Saarinen's) in 2002 (fig. 5). The character of the auditorium is less baroque and fine-grained in the scale of its detailing than the chapel, its curtain wall mullions less delicate and its glazing more conventional, but even the exterior components of its support structure at the corners define the lobby's interior geometries within the enclosure.

Fig. 5. Kresge Auditorium, exterior view, approach from Massachusetts Avenue (Zesiger Center at right). Photograph by the author

1 Geometries: Formal and Informal

First, the techniques of form introduce geometrical complexities into the aforementioned first-level simplicity. Both the chapel and the auditorium are constructed on a circular plan and a solid of revolution: a cylinder and a sphere. The solid is shown plainly in the case of the chapel, while the sphere (112-ft radius) is truncated into an eighth, i.e., one rotated quadrant of three-dimensional space such that its center (origin) is far underground (fig. 6). The chapel is embellished by surrounding the cylinder with its moat, while the auditorium ripples with further repeated concentric brick plinths, stepping down to the lower land elevation to the west.

Yet the circles are presented as both a *solution* and as a *problem* to be solved: Saarinen speaks of the cylindrical plan as a result of site explorations to create a form that maximizes its similarity as seen from many vantage points, and as a function of minimizing the maximum interior distance [Saarinen 1962: 34-6]:

We believed that what was required was a contrasting silhouette, a form which started from the ground and went up carrying the eye around its sweeping shape. Thus, a domed structure seemed right. There were other reasons, too, that influenced us toward a dome. There was the large dome of Welles Bosworth's central building at MIT. A dome is an economical way of covering an area with concrete. It is a shape which provides a pleasant atmosphere for an auditorium. And a thin-shell concrete structure seemed an appropriate form to express the spirit of this advanced school of technology. [...]

After many experiments, exploring different shapes in the site plan, the round cylindrical form seemed right. The circular shape also seemed right in plan – for this was basically a chapel where the individual could come and pray and he would be in intimate contact with the altar. [...]

The interior wall was curved, both for acoustical reasons, and to give the space a lack of sharp definition and an increased sense of turning inward.

The circular geometries that circumscribe both buildings are only a point of departure Saarinen seeks to resolve with a few modifications, to make them less – rather than more – “sharply defined.” He therefore juxtaposes elemental⁶ or *formal* objects with *informal* spaces within – not spaces that are casual, but that are intentionally irregular such that they cannot be summarized in a single Platonic solid or form. The circular

Fig 6. Kresge Auditorium, sketch of geometry
(sketch by the author,
after [Saarinen 1962: 127])

geometries are contradicted to create dynamic spatial tension and reduce acoustical deadness – the irregularly sinusoidal brick waves, the eccentricities of floor steps, the inverted conical ‘bowl’ of the chapel ceiling that tapers asymmetrically, the contrasting curvatures beneath the auditorium ceiling, and so forth. In doing so, Saarinen provided clues of the external structure to the internal space, yet did not let the geometrical structures dictate the interior spatial configurations.

Furthermore, within their enclosure, the subordinate spatial divisions emphasize the difference in scale between the public realm in the auditorium and the corresponding public realm of the narthex in the chapel. Both admit entry from two sides with symmetric pairs of unsheltered doors,⁷ but whereas the Auditorium beckons the eye upward to dynamically sloping planes beneath the seating above, the chapel presents a striking contrast of a tightly compressed, rectilinear narthex as a “decompression chamber” in Saarinen’s terminology. His evocation of the parlance of modern travel emphasizes the tubular room’s bridgelike connection, leading directly across the rhomboid grain of the marble floor tiles toward the eccentric internal steps.⁸

In both interiors, wood heightens the “informal” (or even “aformal”) qualities not only through its material properties but as a material placed to curve alongside areas of human interaction, with varying and increasingly variable radii of curvature. Their variations increase or form a visual crescendo toward the focal areas. Saarinen shows a hierarchy between arc segments with fixed curvature and these splines with variable curvature: their curves appear to be chosen and expressive, which implies that they stand in implicit contrast to the exterior fixed geometry, which we shall revisit in considerations of the structure.

Therefore, at the auditorium and at the chapel (as in the TWA Flight Center and other works) Saarinen’s apparent formal virtuosity with curves is not arbitrary and plastic [Saarinen 1962: 11], but is instead grounded by the hierarchy of axial relationships. That this is accomplished entirely without radial subdivisions is notable: Conventionally for the time, many other American modern architects incorporated centralized and circular geometries into contemporary religious and meeting structures. For example, in the Midwest, Frank Lloyd Wright’s Annunciation Greek Orthodox Church (Wauwatosa, WI; 1956), Alden Dow’s St. John’s Lutheran Church (Midland, MI; 1953) [Robinson 1983], and John Randal McDonald’s St. Therese Convent (Kenosha, WI; 1953) [Beno 1997] all use centralized forms and directed natural light to achieve intimacy within a larger congregational space. In contrast to Saarinen’s consistent use of curvilinear geometry, Dow and McDonald introduce various polygonal geometries to rationalize the construction of the form. Wright and Dow place the altar in the geometric center, with seating in a circumferential pattern. These other structures are between the chapel and the auditorium in scale, so their degree of intimacy is somewhat diminished, but they make Saarinen’s use of axiality rather than centrality that much more startling: since both the Chapel and Auditorium have no object or emphasis at the geometric center, one discovers their centers through acoustical reflections or deadening (where not to sit or play) rather than through material or spatial paths that heighten the center’s importance.

2 Uses: Program and Experience

Along with the spatial reciprocity between the interior and exterior forms, there is a temporal tension between the use of the spaces as originally programmed and as experienced. These relate to differences of illumination quality and sound quality. While a full discussion of the programmatic goals of the MIT administration and possible

unexecuted alternative schemes for both buildings would be somewhat conjectural, it is evident in the dedication that there was a burgeoning ambiguity as to how both spaces would be used primarily for intended programs of spoken lectures and ‘non-prescribed’ multid denominational worship.

First, both spaces seem to have been commissioned and envisioned as paired meeting places for an “academic community” that would also accommodate secondary performance uses. Just as MIT’s application to the Kresge Foundation for a \$1.5M grant noted that the auditorium should be “less distinctly religious in atmosphere” but “could be used for larger religious gatherings”,⁹ MIT President Killian’s dedication stated that worship is first (for the auditorium, no less) and that music and drama linger further on:

In visualizing an auditorium for MIT, we sought a building to provide a similar nucleus for our academic community, especially for our student body. We felt it would be proper and possible to design a building which would be appropriate for worship, for academic ceremonials, for educational meetings and conferences, for music and drama, and for the maintenance of the civil life of our academic community.¹⁰

Fig. 7. Kresge Auditorium, interior (view toward stage and organ loft).
Photograph by the author

The wood strips over plastic cloth that shield the acoustically absorptive glass-fiber blankets at the rear of the hall are the most visible acoustic measures, and they form an architectural transition between the reflective wood panels to the open wood screens at the transverse aisle (fig. 7). Saarinen’s sectional drawings show the front movable portion of the stage configured lower as a seating or small theatrical ‘orchestral pit’ area, rather than having the movable portion elevated for an enlarged ensemble, since at design orchestra performance was intended to comprise perhaps 5% of the use.¹¹ Reporting in *Progressive Architecture*, George Sanderson observed the Holtkamp organs included in both the auditorium and chapel, but these permanent instruments, ancillary to the spaces,¹² were only the first indications of the role of music:

[sidebar] Though the large 1238-seat auditorium was designed primarily for voice projection, it is also used for such musical events as organ recitals and symphony concerts.

[main text] On Dedication Day, we experienced the hearing environment under a wide variety of speeches, fanfares and processional marches by a Brass Choir; and the MIT symphony Orchestra, Glee Club, and Choral Society performed Aaron Copland's "Canticle of Freedom," especially composed for the occasion, and later in the program, a noble Bach cantata [Sanderson 1955].

The Copland piece, revived and performed by the MIT Wind Ensemble and Chamber Choir in 2000,¹³ is not one of the composer's most known or lauded works, but the precedent had been set at its premiere: large orchestral performances would define much of the auditorium's role on campus, and MIT has still not erected a purpose-built music performance facility. As a result, without significant wing space and only the freight elevator connecting to the Little Theatre to move its large instruments, the space serves for rehearsals and performances of acoustic and amplified music from student and professional chamber quartets to international dance festivals.¹⁴ Saarinen's landmark pair of structures serve as cultural sites within a campus possessing strong traditions of music performance in ways that have therefore become highly particular to both spaces.

The tension between the initial secondary role of music and its expanded role in the use of the Auditorium is mirrored in the chapel, where the initial primary intentions focused upon Saarinen's aforementioned "bilateral lighting" and its "unique" role in accommodating multiple religious traditions. Saarinen stated:

The challenge of the interior was to create an atmosphere conducive to individual prayer. Since this is, uniquely, a non-denominational chapel, it was essential to create an atmosphere which was not derived from a particular religion, but from basic spiritual feelings. A dark interior seemed right – an interior completely separated from the outside world (to which the narthex passage would serve as a sort of decompression chamber). I have always remembered one night on my travels as a student when I sat in a mountain village in Sparta. There was bright moonlight over head and then there was a soft, hushed secondary light around the horizon. That sort of bilateral lighting seemed best to achieve this other-worldly sense. Thus the central light would come from the altar – dramatized by the shimmering golden screen by Harry Bertioia – and the secondary light would be light reflected up from the surrounding moat through the arches [Saarinen 1962: 36].

In this and other accounts, the role of the space for performance and for being a haven for long reverberant sounds are generally absent from the architectural accounts, save for the shaping of the interior wall for factual acoustic reasons rather than the expressive axial reasons stated above (figs. 8 and 9).

The actual impact of this powerful lighting scheme described earlier therefore varies with the actual worship practices in the chapel. As the definition of such a space as "multidenominational" has expanded from merely connoting Jewish, Protestant and Catholic in the 1950s, many of MIT's religious groups use the chapel for their respective worship times during the day and at night, and even more use the spaces in the adjacent Building W11 with its offices, meeting areas, tradition-specific food preparation areas, and other spaces absent from it.¹⁵

Fig. 8. MIT Chapel, screen detail (view upward toward ceiling detail at top of brick).
Photograph by the author

Fig. 9. MIT Chapel, interior lighting (showing light bouncing up through perimeter slot).
Photograph by the author

Some religious events do not occur within the chapel because its axial orientation is not compatible with their traditions, and others meet in spaces which are more “open” and less solemn than the chapel. In actual worship services, however, the incandescent lighting from the ceiling is almost always employed; natural light is almost always too dim to read comfortably in the space. Although the electric lighting is providing the actual usable light, the reflected light from the water and the overhead oculus remain lit in such a manner that the daylighting diagram remains evident while acknowledging the artificial light as secondary.

As the space is used for more than conventional religious observances and memorial services, its acoustics, which make a single voice able to dominate even when a hundred people are in the space, have also played a major role in defining it as a nonreligious performance venue. Its interior soundscape, with its acoustical properties similar to ecclesiastical buildings orders of magnitude larger, make it a compelling space for performances as well as for other student-initiated ceremonies. While its visual size makes chamber music of recent centuries seem appropriate, the persistence of sound and the delay between when multiple musicians hear each other indicate otherwise. The present Thursday Noon concerts offer the MIT community a range of musical genres, with a particular emphasis on early music suited for long reverberation times. As in the auditorium, the fittingly modernist pipe organ is a visually dominant but rarely used harbinger of the musical activities: the harpsichord or piano are used far more regularly, and a single tiny note can fill the volume. Thus, while performing in the space, qualities of liveness and of warmth to the resonance of a wide range of frequencies transform otherwise ordinary instruments’ and voices’ sounds into highly enriched and sustained echoes.

Fig. 10. Kresge Auditorium, exterior (view with temporary tents and Aalto's Baker House in rear).
Photograph by the author

Therefore, while the design and the initial reception focused on the properties of vocal acoustics, in the decades since the acoustics have supported a broader range of instrumental uses; the importance of musical performance has illuminated how these two spaces have become small oases of natural materials, providing vibrant settings for student life within MIT's campus. The performance spaces may be within, but the periphery of the Auditorium plinth and the concrete edge of the moat serve as larger performative settings for campus social life: the brick steps form a rich outdoor setting with the curtain wall as a backdrop and its turf a stage for a variety of temporary pavilions such as a tensile fabric tents (fig. 10). These tents, stretched over the oval, take ideal shapes in their tensile material, their forms an inverted counterpoint to the compressive arches and domed shapes nearby. But how do Saarinen's iconic structural shapes communicate their structural logic?

3 Structure: Appearance and Reality

The dichotomies of human use and experience inform the third and most striking tension, between the appearances of purely compressive forms (masonry walls with arches, concrete shells), and the actualities of why and how they do not act in pure compression.

Saarinen states that the dome was chosen not only for its resonance with the other domes on the campus, but also for its efficiency as a modern form. Given uniform loading on the roof, the shape of a doubly-curved vaulted (rather than necessarily hemispherical) structure which is funicular and resists gravity loads in pure compression would approximate a catenary; the minimum radius of a catenary is less than that of a circle that passes through the same points, but the difference would be relatively slight given the shallowness of the vault. Saarinen recognized the impulse of structural integrity, but as with the initial catenary shape for the Gateway Arch in St Louis, his architectural articulation of the Auditorium form complicates its visible lucidity. The complications are not with the circular profile but with the manner in which it is supported and truncated: Domes and spherical shells can be easier geometries for engineers to calculate and builders to construct than those based on parabolas or other conic sections, and for a complete dome, the circumferential hoop action of the shallow dome-like shell contribute to its inherent stability and efficiency.

But since the one-eighth sphere is placed such that its outer perimeter is curved and ventures beyond the triangle inscribed by the three points of support these areas at the perimeter (shaded in fig. 6) are not acting in pure compression – transmitting loads directly to the three points of support – but are instead in tension. This means the shaded areas require substantial thickening of the shell overall and specific tensile reinforcement that contradicts the pure structural logic in order to maintain the external appearance.

The dome is an equilateral, spherical triangle whose apexes reach down to the ground. There, they rest in pintle-like supports that are free to rotate. The structure is complex and, for a thin shell, quite thick. The structural, reinforced concrete part of the shell varies in thickness from 3.5 in. at the crown to 11 in. at the edges and over 20 in. at the points of the shell that sweep down to the supports [*Engineering News Report* 1963].

An ideal shell supported on the three points could be found experimentally using a hanging model or analytically using structural computations, but its form would be irregular rather than comprising conventional conic sections. Unlike other masterful

compressive concrete shells by Felix Candela or those built more recently by Heinz Isler, designers have recognized that when Saarinen chopped the dome into a tricorner form, he destroyed the inherent balance he sought:

The underside of the construction is a geometrically exact part of the surface of a sphere. Construction and form coincide. The hemisphere, out of which this form is cut, is statically in equilibrium under vertical loading. But, as soon as a piece is cut out of the hemisphere, the balance is destroyed. Additional forces have to operate at the edges to restore the shell's equilibrium. The distribution of these forces is not externally apparent in the construction of the auditorium. The form reflects the pure geometry of the sphere. As in other instances, the problem lay in deciding whether a shell ought to assume a form chosen beforehand, or whether the form should be dictated by the distribution of forces [*MIT buildings bibliography*: 126].

Fig. 11. Auditorium, Lobby (view south toward support condition). Photograph by the author

For Saarinen, the sculptural ideal of the spherical segmentation dominated over the tectonic ideal of other doubly-curved shell forms optimized to the points of support (fig. 11). It is now notable in retrospect that this prefigures the same challenges relative to the Sydney Opera House (which Saarinen championed as a competition juror), a design whose sketched shells were ‘simplified’ and modified into spherical geometries (long after Saarinen’s death). These changes, imposing a single radius on each spherical segment, facilitated constructability and analysis by the team at Arup [Roman 2003; Jones 2006] (including the young engineer Peter Rice), but the result is vastly thickened and the shell functions structurally due to its thickened qualities rather than its shape. In a sense, all of the sculpturally shaped shells from Kresge onward through the Sydney example have demonstrated that even the prospect of a ‘thin’ shape creates numerous challenges in realizing the project:

‘What’s the philosophy behind a building like this?’ I asked one who had to do with the auditorium. ‘To enclose space at the least possible cost.’ He replied. ‘Did it?’ ‘Well, not perhaps this time, but from what we’ve learned if we had three to do each would be cheaper than its predecessor and the third would be considerably less expensive than the traditional form’ [Weeks 1955].¹⁶

...[T]echnical problems ...arose as work proceeded, in spite of the most careful and expert analysis by Amman and Whitney, the engineers. ...[N]ot only has the structural analysis been thoroughly justified in practice but I have found the architect very willing to discuss his problems in most frank terms. Amendments to the design have been of a minor nature and were introduced as a result of contingencies which could not have been foreseen in the design stage of such a revolutionary structure, and they in no way detract from the appearance of the building [Scott 1955].

Yet the auditorium’s shell is not a question of mathematical analysis, as these and other commenters seem to imply. Rather, it is a choice of conscious design manipulations: at MIT Saarinen set forth the spherical shell as an inevitable and efficient structural solution of supreme priority, placing all interior acoustical and construction modifications as inherently secondary to the structural motivation. Again, to continue the above assessment from 1955 by architect, planner, and founder of the BDP music society N. Keith Scott:

There can be little doubt that the architect’s departure from the logical approach to design, as we currently understand that term, has created many structural and mechanical problems, and in many instances he has relied upon the sheer ingenuity of modern technology to get him out of difficulties...In his choice of structural form Saarinen flouts every precept of basic acoustical design, for the concave ceiling and the curved rear wall combine to prohibit good hearing conditions unless there is a vigorous appliqué design to counter the tendency to focus sound [Scott 1955].

Nonetheless, Saarinen remains steadfast in his logic:

One concept underlying auditorium design is to let the functional requirements – acoustics and sightlines – determine the form. But there is no one ideal acoustical shape. Though function has to be respected, it seemed equally justifiable to let the basic form come from structure. Thus, in developing the design of this building, we felt very strongly guided by Mies’ principles of architecture – of a consistent structure and a forthright expression of that structure. As there are many ways of doing equally functional things, we built dozens of models. As an auditorium requires a triangular shape, we tried spanning this one-room building with a dome supported at three points – the shape of one-eighth of an orange. At first it seemed strange, but gradually it became the loved one [Saarinen 1962: 34].

Therein lies Saarinen’s shell game: the sphere persisted in the guise of a purely efficient solution, even though this purity was no longer an ideal form for the truncated plan shape or for other interior aspects.

Nevertheless, the descriptive elegance of the one-eighth orange, melon, or other handy illustrative fruit from the apocryphal story has persisted in historical discourse. In the years since shells have no longer been economically efficient since expenses of labor and formwork have outpaced material conservation in many Western economies. Practitioners and students who study the auditorium rarely anticipate or comprehend the structural gymnastics rendered invisible from within and without.

At a much more subtle scale, the brick arches of the MIT chapel have similar hidden inner workings: While arches effectively support planar brick walls, transmitting their distributed loads to discrete points of support, the curvature in plan of the cylindrical face means that in perimeter the brick swerves beyond the line of action of the arch.¹⁷ This eccentricity invites viewers to speculate as to how ‘true’ the brick is. Saarinen may have stated that this is undeniably a masonry structure –

It seemed right to use a traditional material, such as brick, for the chapel – for brick would be a contrast to the auditorium and yet the same material as the surrounding dormitories. But we felt that brick should be used with the same principles of integrity to material as concrete or steel. This is forthrightly a brick structure [Saarinen 1962: 36] –

but in truth this is an expression of structure rather than a diagram of its performance, as the visible brick surfaces enclose the layered assembly within.

The arches on the outside occur where the exterior wall and the undulating interior wall meet. In retrospect, especially having looked again at the archivolt of Romanesque churches, I wish that we had given these arches a richer, stronger three-dimensional quality. And I am aware that the connection between narthex and chapel is clumsy. However, I am happy with the interior of the chapel. I think we managed to make it a place where an individual can contemplate things larger than himself [Saarinen 1962: 36].

While no other permanent shells have been built at MIT since 1955, issues of shell geometry have been a recurrent leitmotif of design exploration: architectural faculty members such as Eduardo Catalano were famous for their shells, such as the hyperbolic paraboloid for a house in North Carolina. Longtime faculty member Wacław Zalewski built dozens of highly efficient thin-shell roofs for factories and other spaces in his native Poland and in Venezuela before teaching at MIT from 1966–1988.¹⁸ Several generations of designers in the MIT community have collaborated on recent educational exhibits and publications that seek to communicate the usefulness of graphical approaches for designing vaults, domes, and even more conventional trusses, walls, and columns. These educational aims, used in teaching at MIT and by associated faculty members practicing and teaching far abroad are captured in *Form and Forces* [Boston Structures Group 2009], a book that provides instruction in the processes of graphic statics as well as form optimization for all major structural systems, and uses works such as Saarinen’s main terminal at Washington Dulles International Airport to illustrate applications of structural design strategies that use the shape of structures for strength and efficiency rather than for arbitrary purposes. Saarinen’s works do in fact demonstrate effective structural logic. Saarinen himself was aware of these dichotomies. In an address given at Dickinson College on December 1, 1959, he said:

The principle of structure has moved in a curious way over this century from being ‘structural honesty’ to ‘expression of structure’ and finally to

‘structural expressionism.’ Structural integrity is a potent and lasting principle and I would never want to get far away from it. To express structure, however, is not an end in itself. It is only when structure can contribute to the total and to the other principles that it is important [Saarinen 1962: 6].

And in a letter to a friend dated June 3, 1953:

Esthetically, we have an urge to soar great distances with our new materials and to reach upward and outward. In a way, this is man’s desire to conquer gravity. All the time one works, one concerns oneself with the fight against gravity. Everything tends to be too heavy and downward pressing unless one really works at it [Saarinen 1962: 5].

Postlude: Performing and Hearing

Finally, the acoustic qualities that result from and within Saarinen’s shells, vaults, and walls are among the most iconic of American modernism. While scholars such as Emily Thompson [2002: 319-320 ff] have articulated the rich evolution of the “modern sound” for controlled acoustics in the earlier decades of the twentieth century, Thompson rightly foreshadows how changing tastes and preferences motivated consultants such as Bolt, Beranek, and Newman to reach beyond reverberation time toward a more qualitative assessment of parameters such as the “initial time-delay gap” that linked data and perceptive opinions. Leo Beranek’s book *Music, Acoustics, & Architecture* focused on a litany of eighteen qualities that support excellence in concert hall acoustics, and reverberation time is *not* one of them although it plays a constituent part in half [Beranek 1962].

Fig. 12. Chapel, Interior (Detail at perimeter). Photograph by the author

Fig. 13. Auditorium, Lobby Ceiling and curtain wall. Photograph by the author

The single most important quality, according to Beranek, is intimacy, followed by (in combination) liveness, warmth, and the loudness of direct sound and loudness of the reverberant sound, and then (in combination) diffusion, balance, and blend.¹⁹ These qualities relate specific acoustic phenomena to a range of geometrical and material connections, and translate them into the language of musicians. For example, the relative audibility of bass-range sounds improves warmth, while intimacy is measured by the shortness of time (the duration or “gap” mentioned above) between the initial sounds and the first reflected sounds as determined by the proportions and physical geometry of the surfaces that bound a space. That these experts collaborated with Saarinen for the auditorium indicates that its acoustics should be viewed as a transitional experiment leading up to the major works Beranek and his colleagues collaborated upon, and an example of a building notable in that the reverberation time is not what characterizes the success at the auditorium for various performing forces.

When the Kresge building was in its next-to-final stage members of the Institute faculty used to wander into the main auditorium and standing in the pit clap their hands for the joy of hearing the sound bounce from the cement floor to the cement dome and back again; then they would seek out Mr. Newman and tease him. But the acoustical engineers had the last laugh; with delicate wooden gratings, with unobtrusive backstops of plastic fabric hung over fiberglass pads, with sound-absorbent seats, they have controlled and clarified the voices that come from the stage...[who] spoke well and were heard with ease. The single voice and the solo instrument are beautifully accentuated, but it is still a question of how true a blend we shall get from the full orchestra [Weeks 1955].

Just as the roof membrane and metal panels over the shell were substantially replaced not long after construction, the interior of the Auditorium has also had ongoing

acoustical tweaks as visible in the configuration of the “clouds” to become more undulating and more extensive. In its ‘deliberate reach for shape, beyond the definition of function’ that made it “a pivotal one in US architecture today” in 1955 and a half-century later, Saarinen created structures for creating community and introspection, but the new faithful that come to venerate are the architects themselves:

Fifty years after the construction of Kresge and the chapel, architects still make pilgrimages with their sketchbooks and cameras, and try to figure out how this master of mid-century modernism did so much with seemingly so little.²⁰

The acoustical tensions and dichotomies between the spaces as perceived visually and aurally serve to reconcile the internal complexities with the overarching gestures which makes Saarinen’s works such resonant contributions to American modernisms. That they have not only iconic imagery but iconic sounds is further evidence of how they transcend the limitations of forms that could be static. Saarinen’s work here and elsewhere constitutes not a series of built diagrams – simple forms reduced to their least complicated – but rather a group of richly particular humanistic experiments that negotiate the architectural pursuits of external clarity and internal discovery. Saarinen places these in dynamic tension such that the act of listening within the spaces – however unexpected and atypical – is just as particular and unrepeated as the forms and lighting effects. Echoing the common theme in religious traditions continuing in the chapel, the architecture and the soundscape of the Auditorium are in their world but not of it; they recognize their role in the urban campus to transcend their context and create independent environments for listening. Therefore, the visible architecture is not an end but rather a means towards creating a more total sensory environment for spiritual and temporal meaning. In Saarinen’s words:

I look for the day when our spiritual qualities catch up with our physical advances. Then our architecture will take an important place in history...
[Peter 1994: 193].

Notes

1. The chapel design at MIT contrasts Saarinen’s chapel at the Lutheran Seminary in Ft. Wayne, IN. In this instance, Saarinen designed not only the chapel and its environs, but the residences and other surrounding campus buildings. That chapel, however, is a large, pointed form based on an abstracted stave church, relating to the Lutheran church’s Scandinavian heritage. Unlike the brick chapel at MIT, the example in Ft. Wayne is constructed mostly of concrete, yet it shares the strip of horizontal windows that admit light into the nave from a shallow outdoor pool. Due to the lighter tone of the concrete and the angled walls, the author observes that light is reflected somewhat more readily into the space than at MIT, but without the textural surface articulation achieved with brick.
2. The wartime growth of MIT had brought in many commuter students, and there was a large parking lot for a time. After World War II, the development of student life and humanities programs as described in the 1949-50 MIT Lewis Report coincided with the construction of MIT’s first dorm west of Massachusetts Avenue.
3. “The chapel’s spire and bell tower, designed by sculptor Theodore Roszak, were added in 1956. The bell, also designed by Roszak, was cast at the MIT foundry, which was then located on the top floor of Building 35” [Wright 2005].
4. “Seen by night, with its lights within, it is an opal; by day it suggest one of those curved white hats the ladies have been affecting this spring, or, less elegantly and to the critics, it suggests a diaper. Since the married students are housed directly behind the Auditorium it might be that Mr. Saarinen had this symbol in mind, though I doubt it” [Weeks 1955].

5. "Kresge Auditorium at MIT has been completely reroofed just eight years after it was opened. The surface of the auditorium's remarkable three-point supported, concrete dome roof was in trouble almost from the beginning. MIT's maintenance engineers, who incidentally collaborated on the original design, watched in dismay as violent and unexpected thermal stresses weakened and destroyed the outer layer of the shell's three layer system" [*Engineering News Report* 1963].
6. "In designing a chapel suitable for use by worshipers of all faiths at the Massachusetts Institute of Technology, Eero Saarinen chose as his starting point the elemental cylindrical form. The way he made the form live without destroying its essential simplicity reflects his careful consideration of every part" [Grubiak 2005].
7. See comments in [Weeks 1955].
8. One could compare the form of these in plan to conventional depictions of moving sound sources and Doppler waves, but that would be highly conjectural and is not supported by Saarinen's documentation.
9. See [Grubiak 2007], note 33, "Submitted application to establish at MIT a Kresge School of Human Relations," 11 April 1950, AC 4 MIT Office of the President, 1930-1958, box 131, folder 12, MIT Archives.
10. See also [Grubiak 2007], note 32: "Full text of an address prepared by Dr. James R. Killian, Jr., President of the Massachusetts Institute of Technology, for delivery at the Dedication of the Kresge Auditorium and the MIT Chapel at 3:30 o'clock on Sunday afternoon, May 8" with annotations, AC 4 MIT Office of the President, 1930-1958, box 131, folder 8, MIT Archives.
11. "50% for lectures and drama, 15% for organ, 5% for orchestra, 18% for chamber music and operetta, 12% for soloists and glee club" [Beranek 1962: 109]. In the past decade, the relative proportion of orchestral and large chamber rehearsals and performances has exceeded all other uses, perhaps even large but infrequent conference lectures.
12. "Most organists point out that the reverberation time is too low..." [Beranek 1962: 108].
13. December 2000, Kresge Auditorium. The author played in the MIT Wind Ensemble for this performance.
14. MIT has a music faculty larger than most other non-conservatory institutions in Boston, serving over a thousand students who participate in music courses and ensembles each year; the minor course of study in music is among the largest in the Institute, and MIT music majors, such as Alan Pierson (Alarm Will Sound chamber orchestra), Andrew McPherson (Tanglewood composition fellow), and others, have become nationally recognized composers, conductors and performers.
15. The chapel was envisioned in some Saarinen studies to have a stronger rear bar with library and office support functions, a version published but not executed; the rear wall simply lines the alleyway with a single mute egress door; the masonry itself had deteriorated over the length of the wall and its southern end was rebuilt in 2007-8.
16. Weeks also muses: "If in the intermission, there should be a choice between continuing with a difficult play or concert or going home to an open fire, I wonder whether the fire would not win."
17. Special thanks to Edward Allen FAIA for his illumination of this related point and for his helpful commentary on structural design issues more broadly
18. In retirement, Zalewski has collaborated and co-taught with former faculty such as Edward Allen FAIA, who along with MIT's architecture, building technology, and engineering faculty and students have explored the analysis and design of compressive structures with newfound computational tools as well as centuries-old practices of graphic statics. See also <http://www.shapingstructure.com> and <http://web.mit.edu/masonry>.
19. Cf. [Nuzum 2009]. Beranek's eighteen qualities are: [intimacy (presence), liveness, warmth, loudness of the direct sound, loudness of the reverberant sound, definition (clarity), brilliance, diffusion, balance, blend, ensemble, immediacy of response (attack), texture, freedom from echo, freedom from noise, dynamic range, tonal quality, and uniformity. Even though Beranek developed an interrelated way to use these qualities to 'score' concert halls, Nuzum notes that the manner by which the eighteen qualities are inextricably linked to each other means that at least nine of them relate directly to reverberation, further evidence of the qualitative specificity

of Beranek's descriptions: "Just as the Inuit people of the northern reaches of North America are said to have hundreds of words for all the different kinds of snow, in the world of acoustics, reverberation is known by many names" [Nuzum 2009: 10].

20. William J. Mitchell, professor of architecture and media arts and sciences, quoted in [Wright 2005].

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