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On the cover, the inner blade pair slides into the poll-head casting on the windshaft of the Sophiamöllan in Viken, Sweden. (In this picture a wind gust has just rotated it to an awkward orientation—about 180 degrees off.) Photograph by Fredrik Rege. On the back cover, transferring layout of the laxning *mechanical lamination from the largest member* (huvudträ) *to the* backsadling, *positioned on top. Photograph by Magnus Frimer-Larsen.*

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1985

High and Mighty: The Wood-Framed Steeples of John McArthur Jr.

Model by author, in cooperation with Paul Trivellini. Collection of the First Presbyterian Church of Salem, NJ. Photograph by Janet Sheridan.

1 First Presbyterian Church, Salem, NJ (1856). Model showing McArthur's internal-armature framing system and modern tie-down system intervention (1997).

"An instinctive taste teaches men to build their churches in flat countries with spire-steeples, which . . . point, as with silent finger, to the sky and stars, and sometimes, when they reflect the brazen light of a rich though rainy sun-set, appear like a pyramid of flame burning heavenward." —Samuel Taylor Coleridge, "Satyrane's Letters" (1817)

THE 19th-century cityscape was defined by its church steeples, those towers that rose above the roofs of the crowded and busy city below and gave so many skylines their character. In the early 1850s, young Philadelphia architect John McArthur Jr., primarily remembered for his design of Philadelphia City Hall, was engaged in several ecclesiastical commissions, resulting in the construction of two steeples that towered over their respective cities. Was it, in fact, "instinctive taste" that taught architects like McArthur to build their churches and steeples? Or were steeples, along with the churches they surmounted, the result of a complex set of influences on architects and builders of the time? Through a comparison of McArthur's two timber-framed steeples, this article explores the structural experimentation that, in part, characterized this moment in McArthur's career.

By the mid-1850s, the skylines of both Philadelphia, Pennsylvania, and Salem, New Jersey, were punctuated by the wood steeples of McArthur's design (Fig. 2): those of the West Spruce Street Presbyterian Church (Tenth Presbyterian) in Philadelphia (steeple demolished 1912), at 248 ft., and the First Presbyterian Church of Salem at 165 ft.[1] While the two steeples differed in size, they were both remarkably tall structures and towered approximately six times higher than their surrounding neighborhoods. McArthur's steeples are emblematic of the way in which American spires of this period become exceedingly high, perhaps as a result, architectural historian Michael Lewis muses, of "untrammeled competitive zeal . . . [in the American] rollicking free-for-all between Methodists, Baptists, Presbyterians, Lutherans, Catholics, etc."[2] McArthur's steeples can be seen within this context, and also as a manifestation of his determination to accomplish architectural and engineering feats. Steeples, as virtuosic feats of structural accomplishment, gave architects in this newly emerging profession the opportunities they needed to establish their competency.

2 John McArthur Jr.'s steepled churches. Left: Tenth Presbyterian (1855–57), Philadelphia, PA, 1898 photograph. Right: First Presbyterian Church (1856), Salem, NJ, postcard ca. 1906.

Presbyterian Historical Society

About John McArthur Jr. On May 13, 1823, in Bladenock [Bladnoch], a small village on the River Bladnoch in the southern lowlands of Scotland, John McArthur Jr. was the firstborn to his parents James and Agnes.[3] John was designated as Junior, in keeping with 19th-century norms, to differentiate him from his uncle of the same name, a builder and, later, a member of the Carpenters' Company of Philadelphia. In 1834, John Jr. embarked on a passenger ship with his family.[4] Awaiting him on the other side of the journey was Philadelphia, typical of American cities with their vast opportunities and burgeoning ideas of egalitarianism that permeated economics, politics, and religion.[5] The economic expansion and populist movements of the early 19th century made dreams of artistic freedom and financial success seem within reach for American artists and architects, and were perhaps what propelled John McArthur Jr. into his career as an American architect.[6]

Within a few years of the McArthur family's arrival in Philadelphia, John Jr. was old enough for a carpentry apprenticeship. At the same time, his uncle John, who had previously emigrated from Scotland, was establishing himself as a builder in Philadelphia and accepted his namesake as an apprentice.[7] This relationship became the foundation of multiple collaborations between the uncle and nephew in the ensuing decades. During his apprenticeship, John Jr. developed aspirations to extend his knowledge beyond the craft of carpentry and toward the nascent profession of architecture. Despite his uncle John's offer to sponsor his "liberal," or formal, education, John Jr. opted to continue to work at carpentry during the day while attending drawing classes and lectures in the evenings.[8] McArthur's architectural education derived from a combination of craft apprenticeship, drawing school, and mechanics' institutes and is emblematic of the training that prevailed before the advent of formal architectural education in the United States.[9]

By his mid-20s, McArthur had been working as a carpenter for about a decade and finally launched his career as an architect. His hands-on training as a carpenter certainly made him intimate with the capabilities of wood and joinery—a skill which he would soon employ in his designs for timber-framed steeples. During the earliest period of his architecture career, McArthur also took on large projects acting as general contractor and as construction foreman.[10,11] McArthur's management of large construction projects was a common practice among contemporary architects and illustrates how in the period before the Civil War, leading architects, many former craftsmen, worked as builders to supplement their professional income from design.[12] In these early years of his career, it is clear that McArthur shifted fluidly between roles as a designer, construction foreman, and engineer. And like the architecture profession as a whole in the 19th century, McArthur's career was emerging from combined disciplines ranging from carpentry to "building mechanics."[13]

McArthur's Designs for Two Steeples McArthur's designs of these steepled churches happened at a time when steeples, as a building element, were a dominant and ubiquitous part of the cityscape and of Victorian culture. Steeples had the metaphorical power to connect earthly humans with the spiritual world above. Steeples were markers on the horizon, set against backdrops of brilliant sunsets, or of smoke billowing from factories of the new industrial era. And to some, like Hans Christian Andersen, steeples were a practical unit of measure, familiar to even the simplest schoolchild, through which he could convey the otherwise unfathomable depth of the sea.[14]

In addition to the important roles that steeples played in 19th-century culture, they also hold the potential to capture many significant things taking place at that time. They carried with them crucial implications for both the congregations that built them and the architects who designed them. The religious revivals of the 19th century resulted in fierce competition between churches vying for new converts to fill their pews. Evangelical sects, each competing for souls, used any means necessary, ranging from fiery preaching to impressive church edifices. An imposing steeple and spire could grab the attention of would-be churchgoers from miles around. With increased church membership came increased revenue and the resultant proliferation of church buildings. Waves of church-building commissions came with the waves of the religious revivals, with McArthur's steepled churches springing from the Third Great Awakening. The multitude of church-building commissions, particularly those with impressive steeples and spires, afforded architects opportunities to showcase their architectural and structural prowess. In this period, we observe architects, such as Samuel Sloan, pleased with themselves over the "considerable degree of attention" they received for the design of a steeple.[15] And at the same time we witness John McArthur Jr., in his design of the steeple of Tenth Presbyterian, silently accomplish the tallest structure in Philadelphia. A competition, spoken or unspoken, was indeed afoot.

The Structural Context of American Steeple Framing For the hundreds, if not thousands, of church edifice designs illustrated in builders' guides and pattern books throughout the 19th century, only a handful illustrate the structure within steeples. Moreover, while designs for churches called for ever-higher steeples, they rarely depicted these steeples' structural systems or explained how they might be built. Many of the wood-framed steeples constructed between the 17th and 19th centuries in the United States have been destroyed, the casualties of deterioration, structural failure, and fire. Beyond the physical loss of the actual structures, the record is obscured by the fact that few of the construction documents for these structures have survived. The steeples that do survive are exceedingly difficult to access and delineate, making the understanding of these complex structures even more difficult. Jan Lewandoski, who restored the timber frame of the First Presbyterian steeple, explains that "there are 10s of thousands of tall wooden steeples . . . with their framing hard to access and concealed from view, built by clever but unknown framers, which we could never examine in several lifetimes."[16] The result is that the record of steeple-framing technology is, at best, sparse. And, as far as can be determined, there were no patented designs for steeple framing, as there were for other wood structures, such as bridge trusses and floor girders. Perhaps the difficulty of reproducing these structures made protection of the designs by patent unnecessary.

In addition to the lack of documentation of how historic steeples were framed, there is also no general structural theory of steeples.[17] Despite the lack of a formal theory, there are general concepts about steeple-framing methods that are accepted in the discipline. In simple terms, it is helpful to think of steeples as comprising some combination of box frames, either stacked or telescoping, and spire cones, most of which are octagonal (Fig. 3). Additionally, some steeples contain central masts, either supported like columns, or hung like pendulums, a method dating back at least to Sir Christopher Wren (1632–1723) and James Gibbs (1682–1754).[18]

A common condition in mid-19th-century wood-framed steeples is that they are supported unevenly, with one side bearing on the front wall of the church building and the opposite side bearing on the first interior roof truss. This differential structural support often leads to deflection of the supporting truss, with the expected result that many roof-mounted church steeples lean back toward the nave when support is shared between an end wall and a less-stiff roof truss.[19] In the case of John McArthur Jr.'s wood-framed steeples of Tenth and First Presbyterian, both are fully supported by square brick masonry towers and so this issue is not a factor in their construction or performance.

A classic example of a simple stacked box frame is the steeple structure of Christ Church in Philadelphia, which comprises two stacked octagonal drums topped by the spire cone (Fig. 3A).[20] A more complex method of steeple framing is seen in telescoping framing, which is a common practice in church buildings, temples, and other tall wood structures worldwide, in which tall, exposed frames interpenetrate the wood frames or masonry stages below them. Telescoping frames often extend 12 to 16 ft. into the frames below them, lending them excellent resistance to wind loads. Lewandoski emphasizes their advantage, noting that steeples without some degree of telescoping among the frame stages are rare, possibly because of the high tendency for those stages to be blown off by calamitous winds in the absence of some other anchoring measure or a benign topographical location.[21] The assumption that the superior performance of telescoping framing over stacked framing represents an evolution of technology can't be proven, however, due to a worldwide lack of steeple documentation.[22]

Castleton Federated Church in Vermont combines deep telescoped framing with a pendulum-mounted central mast (Fig. 3B). Richard Upjohn's design for a "Wooden Church," presented in his 1852 book *Rural Architecture,* shows a very rudimentary framing system, which is appropriate for this modest structure with a steeple height of only 35 ft. (Fig. 3C). Samuel Sloan's design for the First Presbyterian Church of Kensington, Philadelphia, employs a basic stacked frame, modified with an external skirt of framing used to support an elaborate multistage pedestal (Fig. 3D). At some point the lantern and spire were removed and replaced with a squat, faceted onion dome, possibly in response to the steeple listing backward due to deflection in the roof truss. The obvious structural shortcoming of this system is that the primary load path of the bulky frame is directed to the weakest point of the supporting roof truss.

McArthur's Steeple-Framing System McArthur's structural system, perhaps by virtue of the sparseness of comparisons, appears to be atypical, experimental, and innovative in multiple ways, as was the case with many designers in the Victorian era. And, as we find, some of his experiments had both positive and negative effects on the long-term performance and survival of his steeples.

3A Stacked box frame, Christ Church, Philadelphia, Robert Smith, 1751–54.

3B Central mast spire, Castleton Federated Church, VT, Thomas Drake, 1832.

3C Stacked box frame, "Wooden Church" in Richard Upjohn's *Rural Architecture*, 1852.

3D Stacked box frame with external structure, First Presbyterian Church, Kensington, Philadelphia, Samual Sloan, built 1858 (published 1865).

3E Internal box frame armature, First Presbyterian Church, Salem, NJ, John McArthur Jr., 1854–56.

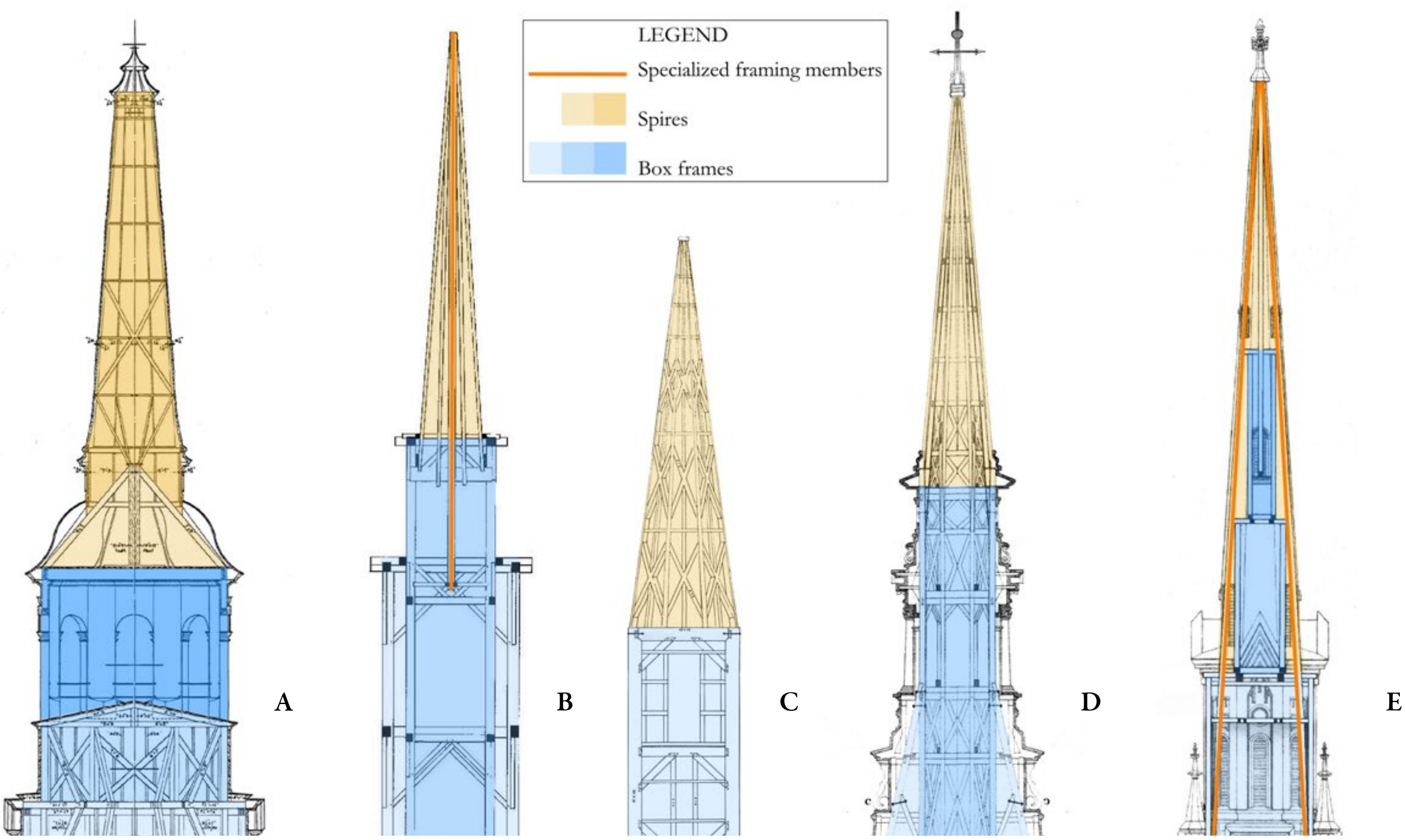

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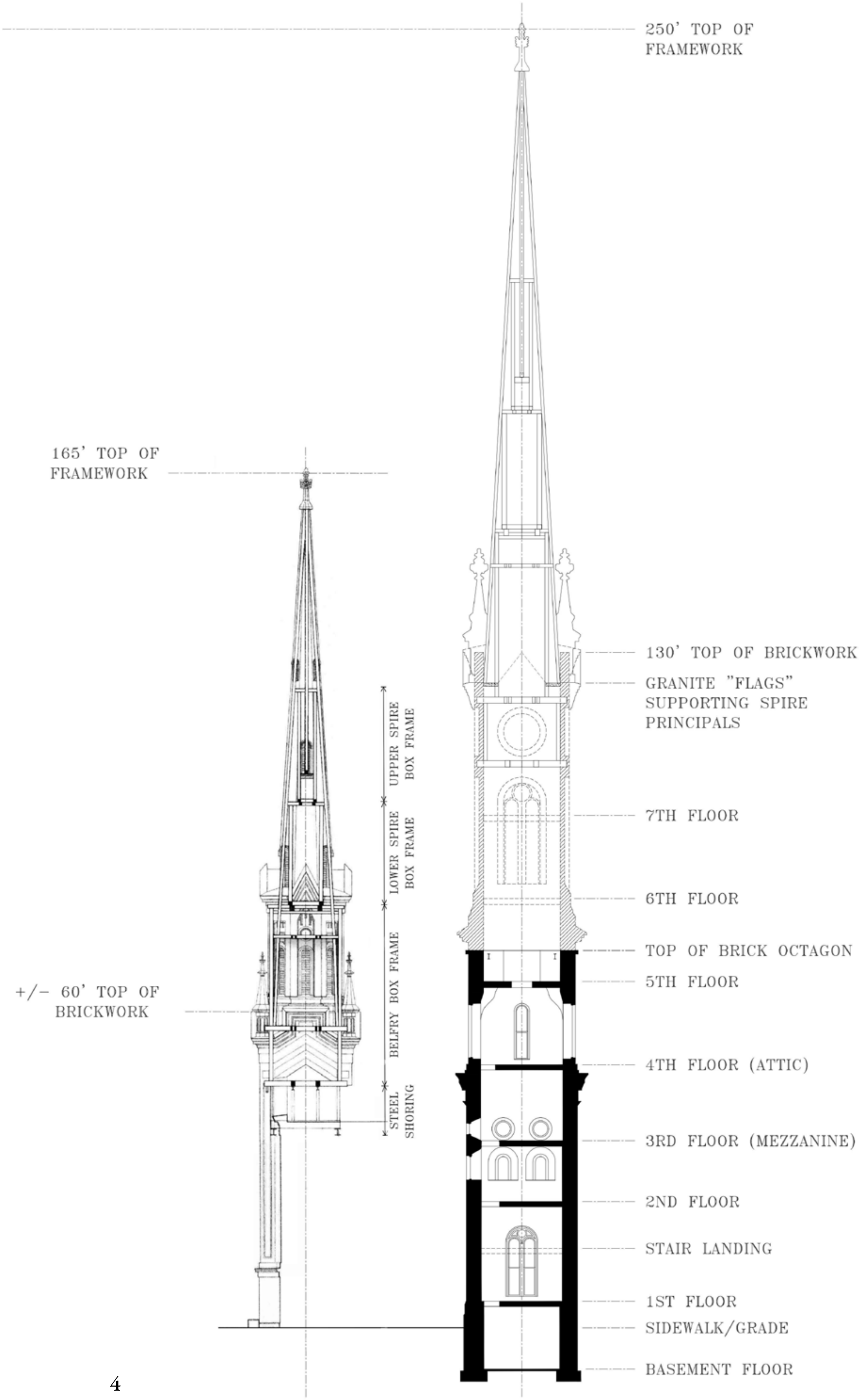
Illustration by Holly Boyer



Drawings by Holly Boyer

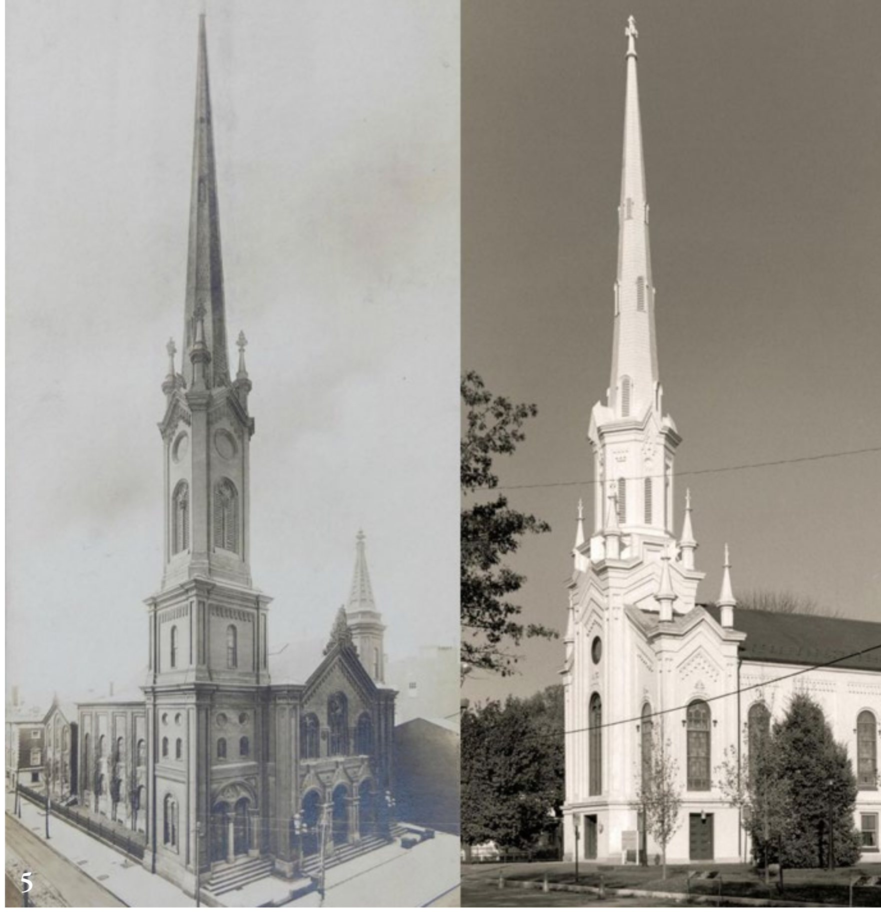
4 Sections of John McArthur Jr.'s steepled churches.
Left: First Presbyterian Church, Salem, NJ (1856).
Right: Tenth Presbyterian Church, Philadelphia, PA (1855–57).

In a departure from traditional stacked or telescoping framing, in his design for First Presbyterian (Fig. 3E), McArthur created an internal armature,[23] using stacked box frames within which the conical spire is interlocked. The conical spire encases the uppermost box frames and penetrates through the lowest stage. McArthur's design for the church did not initially include a steeple, but during the course of design or construction, he added a steeple as a change order. At that point, McArthur already had the design for the larger steeple of Tenth Presbyterian on his drawing board. It appears that McArthur took the steeple design from the larger church building, including the upper portion of the masonry tower, pinnacles and all, and appropriated it for the smaller church building (Fig. 4). The difference in height between the wood-framed portions of the two steeples is only approximately 15–20 ft.

In addition to the wood frames themselves being fairly close in size, records indicate that both steeples' frames were constructed of the same species of wood. The steeple frame of First Presbyterian was constructed of old-growth eastern white pine (*Pinus strobus*); McArthur's original specification for the steeple frame of Tenth Presbyterian called for "sound white pine."[24] The timber of First Presbyterian was of very high quality, being virtually clear with tight growth rings. The timber was not local, but rather rafted, as evidenced by the remains of large round pins that were used to lash the rafts together for transport down the Delaware River from northeastern Pennsylvania or the western Catskill Mountains in upstate New York.[25]

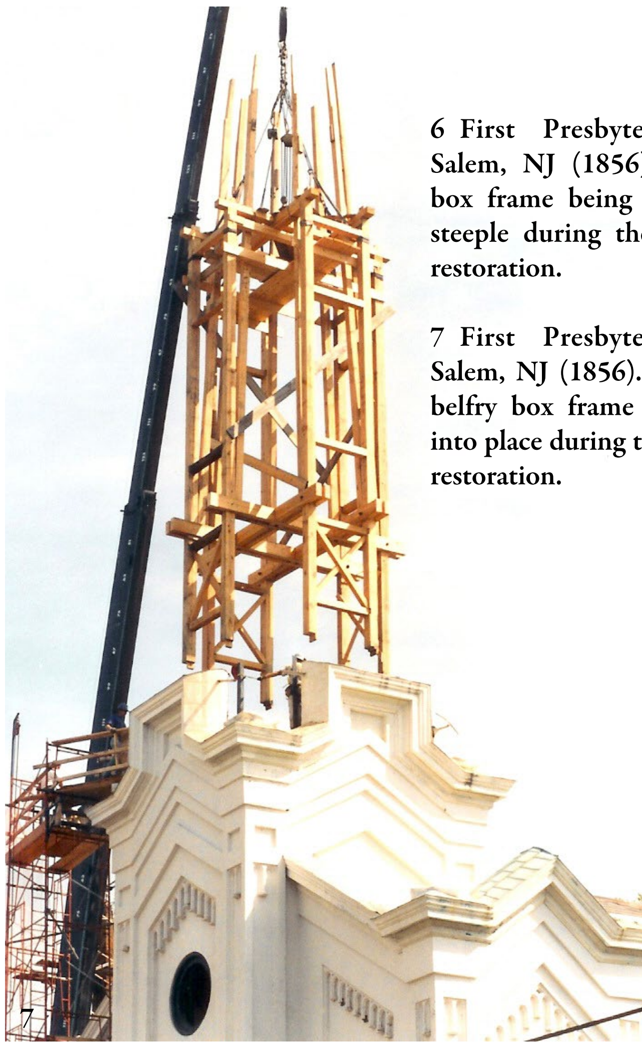
In all probability, McArthur used the steeple-framing design of Tenth Presbyterian on First Presbyterian with little modification, other than one notable change where he created the appearance of a masonry belfry by extruding the lower box frame to support the wood cladding (Fig. 5). This reveals an interesting moment in McArthur's early career when he was experimenting and economizing by adapting the same basic design to two different buildings. It is unclear how McArthur arrived at this internal-armature structural design, or the extent to which framing like this was used in other structures. However, the available literature, which is remarkably sparse, was surveyed by the author and a similar design was not identified. There are several aspects of this framing system that are unusual.

At First Presbyterian, three timber stages emerge from the steeple's brick tower, each of the frames stacked upon each other and bound to those below by the spire *principals*[26] as tension members, not by telescoping or interlocking of the frames themselves (Figs. 6 and 7). While the stacked framing itself is not unusual for the period, the use of the spire principals to bind together the assembly of the wood frame in tension is remarkable. The principals of the spire descend down the steeple, stabilized by *partners*,[27] which form the top of



Presbyterian Historical Society/Janet Sheridan

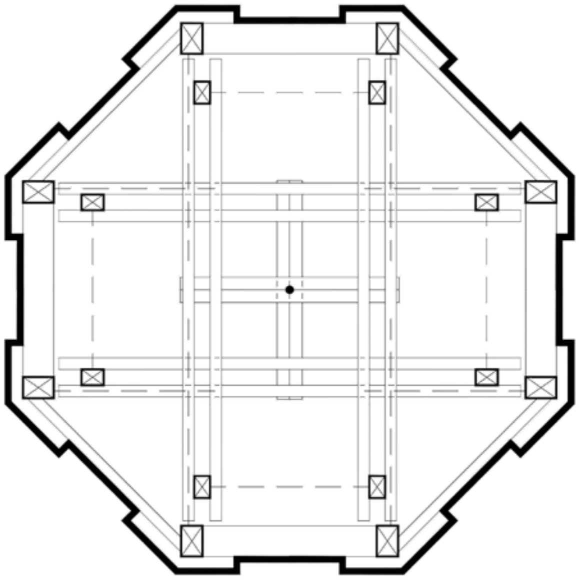
5 John McArthur Jr.'s steepled churches. Left: Tenth Presbyterian Church, Philadelphia, PA (1855–57). Right: First Presbyterian Church, Salem, NJ (1856).



6 First Presbyterian Church, Salem, NJ (1856). Lower spire box frame being removed from steeple during the 1997 steeple restoration.

7 First Presbyterian Church, Salem, NJ (1856). Reconstructed belfry box frame being lowered into place during the 1997 steeple restoration.

Photos by Janet Sheridan



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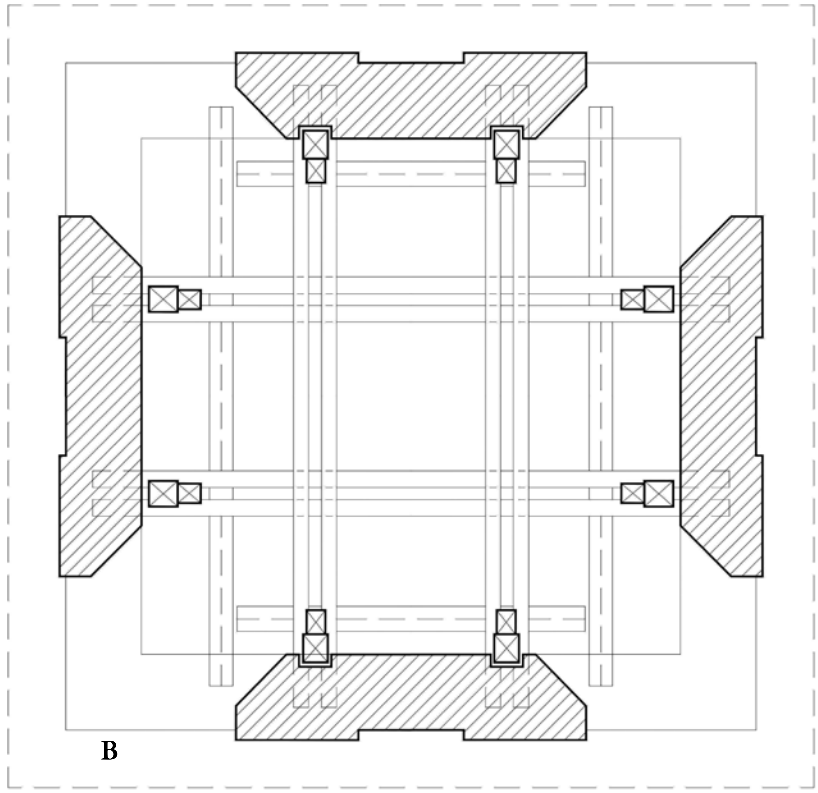
Drawings by Holly Boyer



B

8A, 8B First Presbyterian Church, Salem, NJ (1856). Plans at belfry and spire showing tic-tac-toe, or double-cross, grid configuration.

9

Photos by Janet Sheridan

10

9 First Presbyterian Church, Salem, NJ (1856). Reconnecting splices in 97-foot-tall spire principals (1997).

10 First Presbyterian Church, Salem, NJ (1856). Reconstructed wooden belfry on at-grade mount awaiting resetting on masonry tower (1997).

each framing stage, in a tic-tac-toe, or double-cross, grid in plan (Figs. 8A and 8B).[28] In McArthur's design, the principals were laterally braced at five points along their length: lower partner beams of the belfry frame, upper partner struts of the belfry frame, top beams of the belfry frame, top beams of the lower spire frame, and top beams of the upper spire frame (Fig. 9).[29] The slender 97-ft.-tall principals are concealed by the belfry frame and at their base are virtually buried in 24 ft. of timber work and masonry below. Typically, principals foot themselves on a wood plate at the base of the visible spire, at the top of either the masonry tower walls or the belfry, and then are buttressed by a skirting roof.[30] It appears that here McArthur's ambitious goal was to build something very tall and unusually resistant to overturning. The box frames, clasping the principals, act as an interior armature, transferring the lateral loads imposed on the exterior cladding of the spire to the box frames nested within.[31]

Another atypical aspect of the steeple construction of First Presbyterian is that McArthur extended the lowest framing stage of the armature beyond the limits of the spire in order to create a wooden belfry (Fig. 10). The resultant belfry is not dissimilar to the belfry of his Tenth Presbyterian, aside from the significant difference in scale, with the belfry of the Tenth being at least twice the size. In addition to taking cues from the form of Tenth Presbyterian, the wood belfry was sand-painted to give the appearance of sandstone, ignoring the principles of honesty in materials that were prevailing during the mid-19th century.

The Real (or Presumed) Structure of Tenth Presbyterian
McArthur's Tenth and First Presbyterian churches were commissioned, designed, constructed, and dedicated in an overlapping sequence during a five-year period between 1852 and 1857. It is impossible to know exactly the interchange of information that occurred between the two projects as McArthur worked out their designs and saw them through to completion. The entire belfry of Tenth Presbyterian was masonry—the telltale sign is the placement of the tower pinnacles at the top of the belfry. Despite the difference in the material of the belfries, the steeples' visual similarities, identical proportions, and overlapping design and construction sequence strongly suggest that both steeples employed the same internal-armature structural system (Fig. 5). The steeple of Tenth Presbyterian was demolished in 1912, leaving behind only two known photographs and few other clues as to the exact structure of this enormous spire (Fig. 11). The configuration of the framing of Tenth Presbyterian's steeple cannot be verified, as drawings or as-built records do not survive. The original specifications refer to section drawings that have not survived; this is a clear indication that McArthur personally designed the framing, as opposed to leaving it to the discretion of the builder. The survival of the smaller steeple of First Presbyterian can shed light on some of the similarities, and differences, with Tenth Presbyterian, and subsequently on McArthur as an architect (Fig. 12). As Lewandoski points out, we can surmise that "building to such great height and slenderness in an urban setting, where failure would be catastrophic, would call for an unusually good and perhaps innovative design."[32] The section included herein is conjectural, based on the extant framing of the First Presbyterian steeple. The conjecture is that the steeple of Tenth Presbyterian was the equivalent of the entirety of the First Presbyterian steeple, belfry included, perched atop a 130-ft.-tall masonry tower.

In his adaptation of the steeple design of one church building for use on the other church building, McArthur made structural design decisions, some of which improved the performance while others diminished it. One such design decision was to extend the lowest box frame into the masonry tower to a significant depth, presumably in both steeples. Evidence suggests that this strategy improved the performance of the shorter steeple but diminished the performance of the larger steeple. Architects and builders, faced with the challenge of how to anchor a very tall wood steeple to an otherwise masonry building, devised various solutions and often relied on wood or iron anchorages extending into the tower. Lewandoski notes:

> While it is possible to conceal timber frame stages within the masonry, it is not often done, considered either unnecessary or a positive danger to the masonry walls in case of movement of the flexible timber frames under wind loading, or damage to the masonry if the timber elements burn. Nonetheless, merely tacking a 70-ft. spire to a wooden top plate laid in mortar on top of a typical 18 to 24 in. of brick or stone was rarely thought adequate. Other methods were employed to resist uplift and overturning.[33]


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Photo by William M. Boyer

11 Tenth Presbyterian Church, ca. 1898 photograph.

12 First Presbyterian Church, Salem, NJ (1856).

Photo by Janet Sheridan

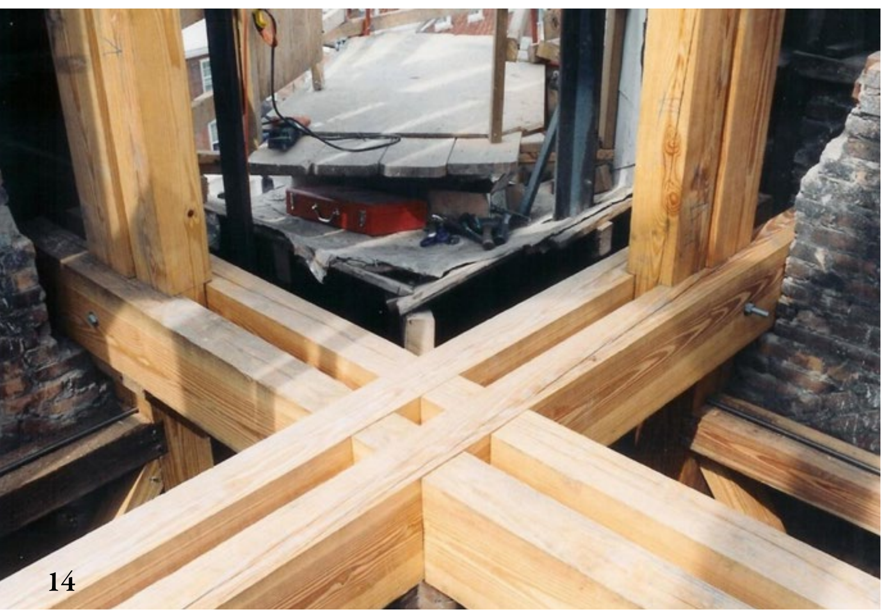


Photo by Janet Sheridan

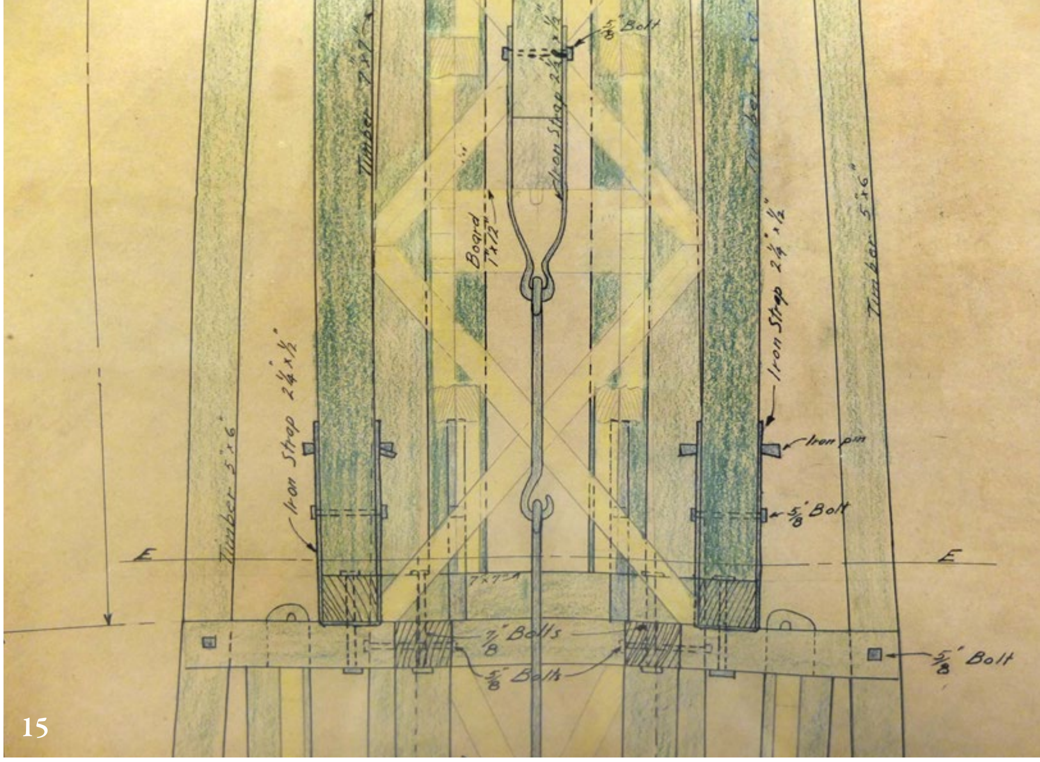
13 First Presbyterian Church, Salem, NJ (1856). Base of the belfry stage seated in the masonry tower over 14 ft. below the top of the walls (1997).

14 First Presbyterian Church, Salem, NJ (1856). Feet of the spire principals, about 3 ft. below the top of the masonry walls (1997).

McArthur's solution, to extend the timber box frame into the tower, effectively vertically cantilevering the steeple, was not typical because of the danger it poses to the masonry itself under extreme loading conditions: it is not a fail-safe system. This risky innovation to accomplish an aggressive structural design could, under certain wind conditions, cause the masonry tower to break apart above the frame embedment. The performance outcome for the two steeples suggests that while this design approach worked well for the First Presbyterian steeple, it may have been problematic for the larger steeple of Tenth Presbyterian. At First Presbyterian, the base of the belfry stage is seated in the masonry tower over 14 ft. below the top of the walls (Fig. 13). The feet of the spire principals are seated closer to the top of the masonry walls—about 3 ft. below (Fig. 14). The depth of embedment of the timber frame provided for a significant amount of mass to bear on the base beams of the frame, in addition to the dead load of the steeple itself. The long-term performance of the steeple at First Presbyterian demonstrates that the load conditions of the steeple are adequate to resist overturning without damage to the masonry of the tower.

However, the difference in performance of this feature between the two church buildings rests in the height of the steeples, as well as their heights above grade. The heights above grade of the two steeples varied greatly, with the steeple of Tenth Presbyterian taller at the top of the masonry tower by 65 ft., at the midpoint of steeple frame by 74 ft., and at the top of spire by 83 ft. These differences in height are extremely significant because windspeeds rise exponentially with increased height aboveground. This means that with the steeple of Tenth Presbyterian at a much greater height aboveground, wind loading on the structure would have been much higher. In looking at the history of the long-term performance of the larger steeple, it can be surmised that the top of the masonry belfry incurred significant damage under extreme wind loading conditions. During the winter storm of 1912, with wind speeds recorded up to 96 miles per hour, the Tenth Presbyterian steeple incurred severe damage, ultimately resulting in its demolition from the building.[34] Within the year following the storm, the church curators reported that the wooden portion of the structure had been removed in as far as the brickwork and the top of the tower was enclosed with a temporary roof.[35] While not accomplished immediately, likely due to a dwindling congregation and lack of necessary funds to do so, the congregation eventually demolished the 58-ft.-tall masonry belfry.[36] The removal of the masonry belfry, requiring significant effort, suggests that the masonry at the top of the belfry may have incurred damage during the storm, due to McArthur's atypical embedment of the lowest timber frame.

Another design decision McArthur made, which we learn of in his specifications, was to create a tensioning system extending from the peak of the spire. In his design for First Presbyterian, the eight principals converge to a center spire mast that extends approximately 58 ft. down into the spire. McArthur's specifications for Tenth Presbyterian require that "The top of the spire, immediately below the finial, shall be of solid timber, with an octagonal tenon, around which the top ends of the principals must be bolted," indicating the same construction detailing at both steeples.[37] The intended function of the center spire mast can be deduced from its original detailing. In McArthur's design for the First Presbyterian steeple, the bottom of the spire mast is connected by a system of iron rods and straps which extends to tie-down beams another 31 ft. lower within the steeple structure (Fig. 15).[38] Because the spire mast is bound down by an iron rod, its intended function can be understood as part of a larger tensioning system, as opposed to as a tuning mast, in which case it would be hanging free.[39] Lewandoski explains that this type of tensioning system was the easiest and most common method for resisting uplift and overturning.[40] Typically, these tensioning systems terminate to the masonry directly or to a timber let into the masonry, whereas McArthur's tensioning system is less direct, terminating to a level of partner beams that transfer the load indirectly through the principals of the spire to the framing stages and eventually to the masonry tower (Figs. 16 and 17). Generally, these types of tensioning systems were an imperfect solution due to their tendency to develop slack with seasonal expansion and contraction. Longer tie-down rods were desirable as they bring the tie-down loads deeper into the structure; however, the longer the tie-down rods, the more slack would develop. As Lewandoski explains, the problem is exacerbated as a



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Original drawing in collection of the First Presbyterian Church of Salem, NJ.

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Photographs by Carl Baumert, Keast & Hood Archives

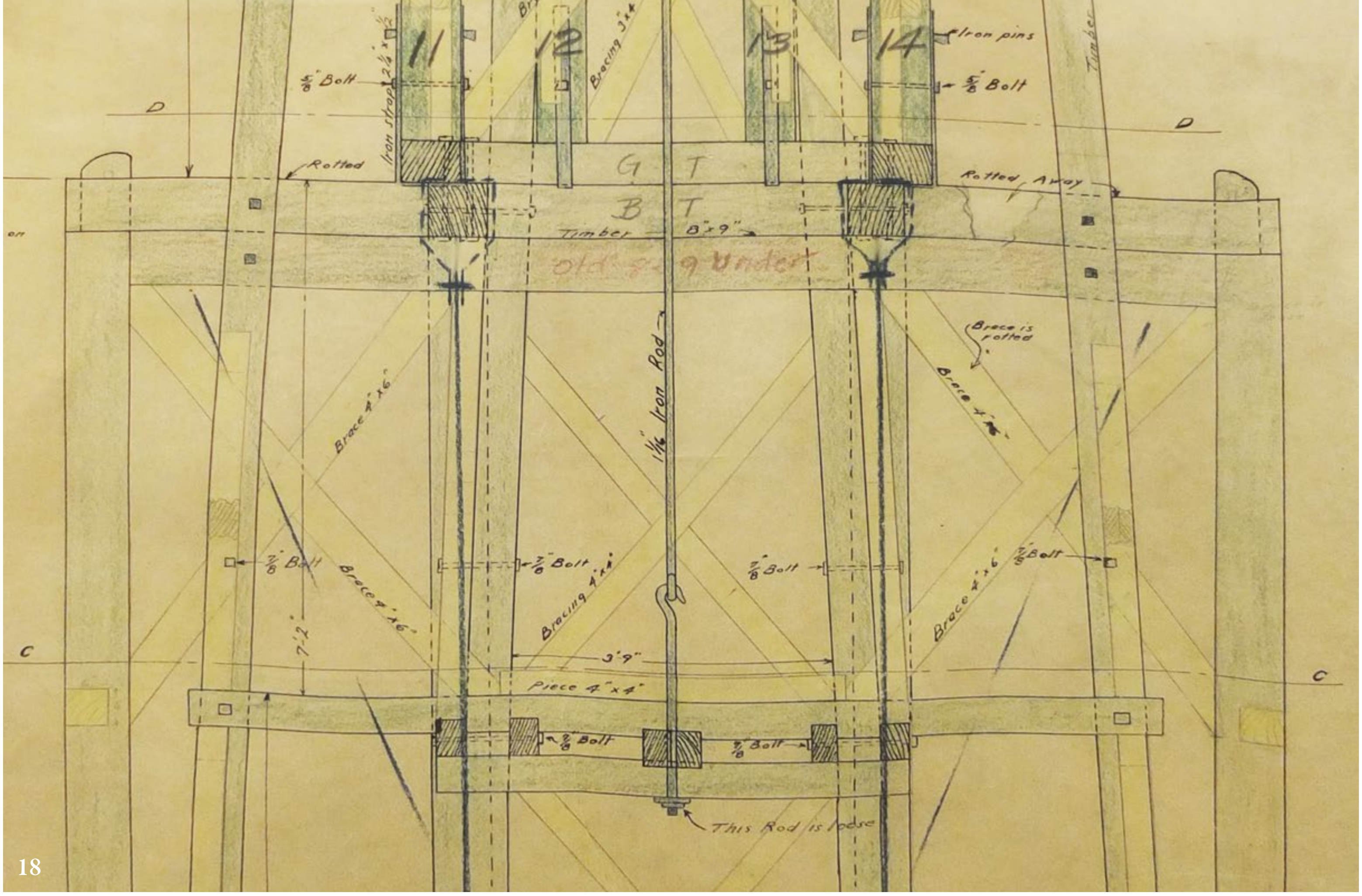
small increase in length of these vertical rods, combined with the fact that they offer no lateral stiffness, can allow substantial overturning to begin under wind loading, further stretching the rod or bending the eyebolts at their points of attachment.[41] A 1913 condition assessment drawing of the First Presbyterian steeple offers direct evidence of this problem of the slackening of the tensioning system over time where it is plainly noted, "This Rod is loose" (Fig. 18).[42]

Lastly, it seems that McArthur may have inadvertently created a design flaw in the spire principals of the larger steeple, a flaw that may have proved decisive for the structure's failure and subsequent demolition. The feet of the principals at First Presbyterian, the smaller steeple, were seated on wood beams approximately at the top of the brick masonry of the tower (Fig. 14). As with most steeples, the bases of the principals were supported by plates with a horizontal grain orientation, resulting in a favorable arrangement with respect to moisture wicking of the vertical members. However, in the case of Tenth Presbyterian, we learn of a very different arrangement. In his specifications for Tenth Presbyterian, McArthur requires that "granite flags eight inches thick must be built into the angles of the tower, to foot the principals of the spire upon."[43] The specifications go on to describe the connection detail: "The lower ends of those in

15 First Presbyterian steeple, bottom of the central spire post connected by an original tensioning system of rods and straps. Portion of condition assessment drawing by Frank N. Kneas (1913).

16 First Presbyterian Church, Salem, NJ (1856). Level of partner beams at termination of McArthur's tensioning system (1996).

17 First Presbyterian Church, Salem, NJ (1856). Hook-and-eye linkage in McArthur's tensioning system (1996).



Original drawing in collection of the First Presbyterian Church of Salem, NJ

18 First Presbyterian steeple, bottom of tensioning system showing problem of slackening over time where it is plainly noted, "This Rod is loose." Portion of condition assessment drawing by Frank N. Kneas (1913).

principal spire must be fitted into notches, cut in the granite blocks already mentioned, and secured by 1 in. and quarter round iron rods, extending through the sixth floor, as shown on the transverse section."[44] The granite at the feet of the principals suggests that McArthur was concerned that the great weight of the enormous steeple would force the hard end-grain of the principals into the softer side grain of a plate atop the masonry, resulting in crushing.

Opting to set wood members into pockets of stone was an extremely atypical practice since the feet of these members will quickly rot in that pocket, as is seen with joists necessarily set into the walls of masonry buildings.[45] With the feet of the principals already vulnerable to moisture wicking in this detail, it is made even worse by the wood members being perforated for the attachment of iron rods. This location on the steeple, directly under the skirting roof at the top of the belfry, would be prone to moisture entry at the intersection of complex roofs and exceedingly difficult to access for repairs. This questionable detail raises the question as to where McArthur got this idea, and why the builder, his uncle John McArthur (senior), would not have cautioned him against it. Nonetheless, the indication the specification gives us that the principals were connected to iron rods, an estimated 40 ft. to floor framing below, tells us about McArthur's strategy for anchoring the colossal spire. Because the spire, clad in wood shingles, would have been relatively lightweight, the weight of the spire alone could not be relied on to resist overturning at such height and high wind speeds. It appears that McArthur's strategy was to resist overturning by attaching the spire principals to the masonry tower through the use of long tensionable rods.[46]

The First Presbyterian Steeple: Performance and Longevity
McArthur's design for the steeple of First Presbyterian, as an internal-armature frame coupled with a tensioning system, indicates that he was aiming for rigidity in the structure. But being slender and framed of timber allow this steeple to be somewhat flexible, with the benefits that swaying rather than breaking convey. This structural flexibility had implications in terms of its performance in wind, integrity of external cladding, and subsequent performance in resisting moisture infiltration. A 1995 structural assessment performed in conjunction with repairs to the steeple indicates that the steeple is considered a "flexible building," as defined by the American Society of Civil Engineers (ASCE) based on the ratio of height to the horizontal dimension at the midheight of the structure.[47] The belfry is formed by the upper half of a 40-ft.-tall timber box frame, the bottom half of which is nested in the brick masonry tower. Resultantly, the belfry is well stabilized and relatively short compared to the spire above. The spire, however, is formed from tapering wood members that are 97 ft. long, making the spire relatively flexible and prone to lateral movement. The connection point between these two components of the steeple comprises partner beams on either side of each spire principal, compressed by through bolts. By the 1850s, through-bolted connections were common in bridges and roof trusses and were recommended in many builders' guides of the period; McArthur's prior familiarity with and use of through-bolted connections is evidenced in his design for a truss girder published by the Franklin Institute in 1849.[48] McArthur's use of this type of connection, consistent with construction practice of the period, was probably to simply clamp wooden bearing shoulders together.[49] However, perhaps unintentionally, the connections may allow the complex steeple framing to pivot at these points.

Whether it was McArthur's design intention or not, the flexibility in the structure nonetheless results in a dynamic structural relationship between the belfry and the spire above. The differential movement between these two components affects the structure's performance. In 1996, in conjunction with structural repairs to the steeple, Keast & Hood Engineers of Philadelphia analyzed the steeple as if it were a cantilever, supported at the top and bottom of the belfry. The results of the analysis determined that the moment and shear stresses were highest just at the top of the belfry frame at the juncture with the base of the exposed spire, with stresses almost six times greater than in the spire itself.[50] The increased moment and shear focused at the top of the belfry frame appears to have caused differential movement between the belfry and spire at this level. Consequently, joints in the skirting roof opened and permitted excess water entry by wind-driven rain. The water infiltration, in turn, caused deterioration of critical structural members at that level, allowing even more movement in the structure, thus creating a textbook amplifying feedback loop in the deterioration of the steeple. As early as 1913, a steeple assessment drawing prepared by an engineer from Philadelphia showed that significant deterioration had already occurred at this level of framing, due to leaks in the skirting roof (Fig. 18).[51]

Divergent Outcomes for the Two Steeples It bears noting that McArthur's two steeples had parallel lives in terms of their deterioration, the repair campaigns this necessitated, and catastrophic damage incurred by storms (Fig. 19). A comparison of the records of both churches reveals that the congregations were faced with the same catastrophic damage caused by major storm episodes. By the late 1870s, the steeples were in their third decade and were beginning to suffer the effects of age, with Tenth Presbyterian recording damage including decaying timbers, loosening iron bolts, damage to the finial, and lightning strikes.[52] By the time the Gale of 1878 struck, neither of the steeples were in top condition to withstand damage from the storm. The storm, a Category 2 hurricane with maximum wind speeds of 100 miles per hour, raged for three days, causing severe damage across the east coast. In Philadelphia, at least 700 buildings were destroyed while nearly 50 church buildings lost their spires.[53] Across the river in Camden, New Jersey, the spire of the Fourth Presbyterian Church toppled and crashed through the roof of the church.[54] McArthur's steeples survived, but both were seriously damaged and were repaired at great cost. A few months later, after the repairs to the Tenth Presbyterian steeple were complete, the curators reported that "the expense has been very large as examination showed great decay and more work than was expected," evidencing that the performance of the steeples was beginning to be affected by deterioration.[55]

Another 34 years passed before the next catastrophic storm struck on February 22, 1912, carrying with it winds recorded up to 96 miles per hour.[56] This time McArthur's steeples did not fare as well, presumably weakened by unnoticed deterioration that had been mounting over the years. The damage to both First Presbyterian and Tenth Presbyterian demanded the congregations' attention and ended in very different results. The Tenth Presbyterian congregation, due to the severity of the damage to the building and the risk of structural collapse, opted to demolish the steeple, which they had done before the end of that year.[57]

The congregation of First Presbyterian, however, took a different approach to the treatment of their steeple. Perhaps they were afforded greater latitude in their decision-making because the steeple was much smaller and access for repairs was more readily accomplished. Initially they made the decision to also demolish their steeple, obtaining an estimate for the work from John F. Hassler, the same steeplejack who had demolished the steeple of Tenth Presbyterian a few months earlier.[58] For the entire month of May 1913, the trustees and building

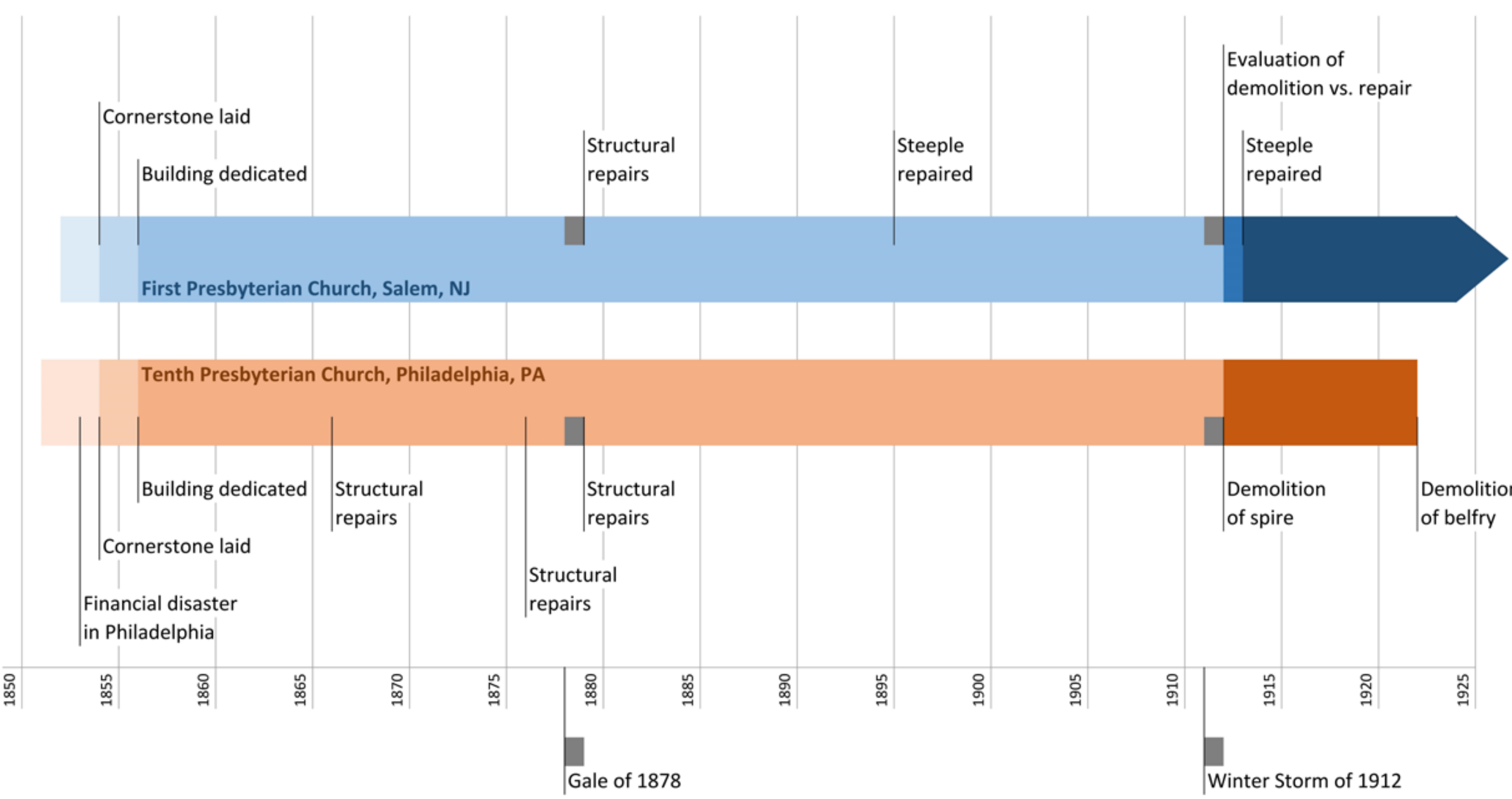


Illustration by Holly Boyer

19 Timeline of John McArthur Jr.'s steepled churches.

committee met repeatedly, deliberating over prices and demolition strategies for the steeple. One strategy the trustees entertained was that of removing the spire and leaving the belfry in place. It appears that the strategy would have involved taking down the steeple "as far as the base of the shingle part" and roofing over the belfry at the level of the skirting roof.[59] One congregant, who had recently visited Philadelphia and had witnessed Tenth Presbyterian's new steepleless look, testified to "the attractive appearance of the church after the steeple had been taken down."[60] The Trustees went as far as to request to see the contract between Hassler and Tenth Presbyterian. As deliberations proceeded, one elder of the congregation began to have different ideas about the best outcome for the steeple. Charles Ayars, who was president of the Ayars Machine Company and is remembered as an inventor and preservationist, couldn't resist the urge to climb up into the steeple and have a look for himself.[61] He brought along with him an engineer from Philadelphia, Frank N. Kneas, to conduct an assessment. The two reported to the trustees that the steeple could be repaired in lieu of demolition, making it "as strong and safe for the next fifty years as it had been for the last fifty years."[62] The trustees reversed their initial decision and authorized having the steeple "put in as safe condition as they possibly could," at a price of $500, 14 percent higher than the proposal for demolition. The structural repairs, delineated in a large drawing by Kneas, were completed by early 1914.[63]

The repairs staved off the deterioration temporarily, but over the course of the next 80 years, the condition of the steeple again worsened. By 1984, precipitated by another storm event, the steeple underwent repair by means of internal steel shoring totaling approximately 20 tons.[64] The steel shoring, while not quite efficient in its design or installation, did the job of circumventing the original load paths of McArthur's original design and buying time for the steeple. In 1996, the board of trustees of First Presbyterian contracted with a preservation architecture and engineering firm to conduct a condition assessment of the steeple. The assessment culminated in the recommendation that the steeple undergo a "functional restoration," which was designed and executed to fully restore McArthur's original structural configuration.[65] Modifications to the original design were limited to a change in wood species and the addition of a modern tie-down system to reduce lateral movement in the structure. Deteriorated wood members of old-growth eastern white pine were replaced in-kind with select structural southern yellow pine; the change was made to compensate for the reduced quality of modern white pine. The tie-down system comprises two tiers of tie-down rods through the belfry level and from the lower box frame to shoring beams deeper in the masonry tower, and diagonal cable bracing through the belfry level.[66] The "functional restoration" of the First Presbyterian steeple involved large-scale disassembly of sections of the steeple, brought to ground level for easier access.[67] Fortunately for this heroic repair, one of McArthur's two steeples remains in place as the physical record of his internal-armature structural design (Fig. 1).

Conclusion Understanding John McArthur Jr.'s steeple designs perhaps sheds light on what compelled him, later in his career, to repeatedly set out to design structures that would be the highest in their cities or country. Through the lens of his remarkably tall steeple designs, a picture of McArthur at this early period of his career emerges of him designing very tall wood-framed structures by applying his knowledge of materials gained from a decade working in the carpentry trade. Combined with his knowledge of wood and carpentry, McArthur also applied intuition, creating structures that were experimental in multiple ways. His experimentation had consequences, both positive and negative, for the performance and outcomes for both steeples. There remain questions to be answered, including: Where did McArthur get the idea to create an internal-armature steeple frame? Was it an idea he gleaned from a book or a colleague, or was it the product of his own structural experimentation? And how common or widespread was the use of this type of structural system? This study hardly exhausts the investigation of McArthur's use of an internal-armature steeple frame and its possible use elsewhere in America or abroad.

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