The Past, Present, and Future of Retractable Roofs

By Surinder Mann and Bryan Tokarczyk

Safeco Field courtesy of NBBJ

Minute Maid Park courtesy of HOK S+V+E

The idea of moving roofs on sports stadia has been around for thousands of years. In fact, the coliseum in Rome had a movable linen awning in ancient times.

By nature of the venue supported, stadia roofs free-span incredible distances. Much of their function is to protect the players and spectators from the environment. However, many of the activities require natural turf, and therefore sunlight - hence the introduction of one solution, the retractable roof system. This article examines the structure and background of the retractable roofs that have been built in the US over the last decade or so, and attempts to envision the future for this unique form of building.

Miller Park courtesy of HKS

Past

For over three decades, designers have seriously considered the working attributes of stadia roofs that can open and close upon command. The nature of the large facilities, long spans, and impressive loading conditions encourages designers to exercise all their design expertise, as well as seek out new skills.

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All sports facilities are shaped and sized by the fundamentals of the activity within. Stadia design traditionally considers the geometry of the field, ball trajectories, sunlight angles, turf growth cycles, and views of the neighboring city. Retractable systems also consider the basics of roof operating conditions and speed, as well as the perceptions of open versus covered activity. Permanently closed or open venues inevitably compromise one aspect for another. As John Hutchings emphasizes, "Most of the public interest in these types of venues stems from a desire of fans to be within the elements whenever possible."

Retractable roofs have improved the predictability of the game's scheduling over open venues, bringing more spectators from farther away to view a game or event, which was much more likely to be held than in the past. Owners have embraced this improvement in game predictability, as well as spectator comfort (from direct sunlight, heat, rain, and inclement weather), and natural turf availability as a plus-plus for their facilities.

Present

North America currently has six completed retractable roof stadiums, one in Toronto, Ontario (the first retractable), and the other five throughout the United States. In order of completion: Bank One ('98), Safeco Field ('99), Minute Maid ('00), Miller Park ('01) and Reliant ('02) have finished, what seems to be, the first phase of retractable roof construction. Many of the lessons learned from their concept, design, construction, and operation will be integrated into the next phase of retractable stadia facilities - which is currently underway. Taking a brief look at the current US facilities in these four areas may help to understand the complexities of, and solutions to, the key issues facing stadia designers.

Concept

In the concept phase of such facilities, constructing a team of key players is essential to successfully working through the feasibility of architectural, structural, and mechanization ideas. Unique to the retractable roof is the introduction of a mechanization team who will have the perspective of the roof's operability in mind. In early conceptual design, the fundamental decisions are made by a group of those key architects, structural engineers, and mechanization personnel.

Speaking to the contributions from these three parties, Larry Griffis "strongly encourage(s) collaborative effort in concert to influence the design early." Some design teams have felt so strongly about the requirement for a close group, they have moved many of their key personnel physically to the site for portions of the design and/or construction. (Also see Larry's article, *The Nature of Long Span*, in this issue).

During this early planning phase, broad topics such as spectator impression of open and closed conditions, roof placement while open, any constraints of a tight site, turf growth cycle, sun angles, or conditions with fire or smoke can influence options or directions.

The reasons for retractable roofs vary with location. Their design could be to keep out

rain, snow, or heat - but it is the dual concern for fan comfort and reliability of play that they are chosen. In Phoenix and Houston the issue was heat, in Seattle the rain, and in Milwaukee the cold.

Another aspect that makes the stadia unique is their project site. The retractable roof needs to be stored somewhere in the open position, and it is the rare site that has the room to completely remove it from the footprint of the building. In Seattle, the adjacent railway tracks provide a convenient place to place the roof structure out of the way. This was exploited to open up the full field for sunlight. In most cases, space is limited and the storage of the roof must take place in nearly the same footprint as the stands.

These cases can cause the structure to be squeezed into as small a depth as possible in order to avoid blocking the sun. In Milwaukee, designers created a fan shaped roof that nested to left and right field sides due to limited space. In Phoenix, the panel's profile was kept as shallow as possible by tracking the moving panels on each other.

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Roof loading conditions are an important early topic as they may vary while open, closed, and moving. Additional considerations for extreme weather, and the recommended or required position(s) of the retractable panels are discussed (usually with the assistance of a boundary layer wind tunnel expert). The choice of Safeco's site, for instance, was a thorough process that involved seismic assessment as well as the more conventional economic decisions before final recommendation.

In many cases, structure and schedule can easily drive the architectural considerations, more so than in a conventional roof system. "Architecture and structure are essentially one in the same in these facilities," says architect Bruce Marshall, "we must be very aware of how each impacts the other throughout the entire process."

Design

The design of a stadia structure is often an opportunity for the structural engineer to take a more prominent role in the design process. Says Kurt Nordquist, "designers were very understanding of the fact that the structure really needed to drive the design." More often

in these types of structures, engineers' work is on display for the visitor to see and touch. In retractable roof structures, not only is there a larger role available for the structural engineer, another key team member has their work on display - the mechanization systems designer.

As a team, the architectural, structural, and mechanization firms all have an opportunity to invite the public into their creation. Whereas architects are used to the public appreciating their work, it is a rare opportunity for the structural and mechanization teams to have such attention. As structural engineer Charles Keyes mentions with retractable design, "it's exciting to be in the center of everything that's going on."

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Regarding stadia design, the list of considerations between fixed and moveable roofs are very different.

Similarities in function have some aspects of fixed and moveable stadia design influenced by the same subtle issues. For example, the roof profile can affect the shedding ability of the wind or the patterns of snow accumulation which, in turn, possibly affects the roof loads, truss geometry, and roof weight. Also, any deviation from linear roof layouts (for example, baseball's radial field layout) will have inherent difficulties in material layout.

For retractable roof systems, many designers start with the consideration of the facility as a machine, and then proceed with the design from that point forward - hence, a sort of "mechanical architecture" could describe these types of structures. Designers of these dynamic and kinetic structures often find a significant challenge with the morphing nature presented by a retractable stadium.

Both mechanization and structural engineers are challenged to move thousands of tons across possible flat, sloped, and curved surfaces - in relatively short order. Restrictive panel depths, minimal mechanical complexity, and robust drive mechanisms all are design constraints to contend with. Drive mechanisms, whether direct-drive or cable systems, can be appropriate for the roof panel movement - their selection is essentially tailored to the particular building.

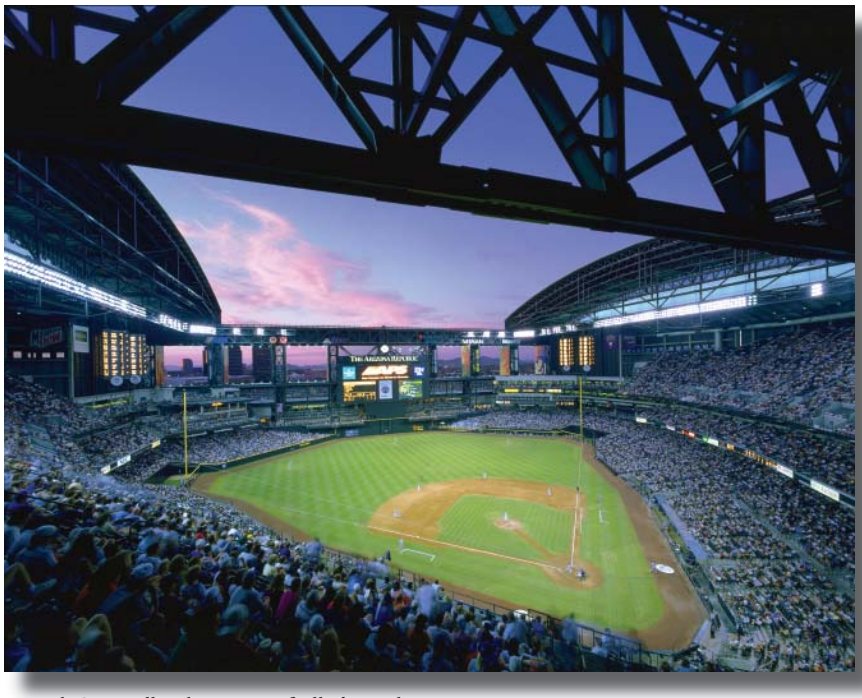
Another level of design difficulty for retractable roofs is thoughtful choice of loading condition to roof position. Some retractable systems are designed to withstand a variety of loads in any position, whereas other systems are designed for very specific loads in very specific roof locations and restraint (locked down) situations. Load combinations of gravity, wind, temperature, roof position, and the possibility of seismic activity and snow have driven previous designs to consider 1500+ load combinations for analysis. The basic function of the opening system can also be operationally hindered or restricted altogether from any of the environmental forces above (or the possible build-up of ice on surfaces and machinery).

Construction

The construction of the roof encompasses many issues. The super scale of these roof systems requires a balance of dynamics and statics. As Knut Hansen emphasizes, "Scale becomes the primary issue for constructability."

The staging of the roof segments during and after their construction, constant changes in loading conditions during erection, erection stability, and construction in place or on the ground all will add special considerations to the process. Many construction decisions came down to "an issue of timing and sequencing" says Mike Sabatini.

Reliant Stadium courtesy of HOK S+V+E



Bank One Ballpark courtesy of Ellerbe Beckett

The construction phase harbors much of the schedule risk of delays and complications - of which, the roof system of many retractable stadiums has been the focal point. To this end, some system designs may warrant keeping the roof erection separate from the superstructure for simplicity and to avoid potential construction sequencing problems.

Critical to the success of the roof construction is the early development of the erection procedure. As Stan Welton emphasizes, the design team needs to "work with them (erectors) to develop the critical aspects of constructing the roof."

A crucial aspect in the successful implementation of the design is the delineation of a well thought-out construction means and methods to the team. The design review of the project should indeed carefully step through the construction, erection, staging, and loading timelines of the roof systems and their impact on the superstructure, bowl structure, and substructure.

Operation

The operation of the first phase of retractable designs is yielding some valuable information (see reference to ARROW at the conclusion of this article). The lessons learned from the implementation of service requirements (both major and minor equipment wear-cycles and life span, equipment replacement and repair access, inspection periodicity and results, as well as real versus projected roof operation schedules) will all assist the next facilities in planning and design.

The operation of such facilities has given clues towards changes for future retractable systems. Integrating back-up systems right into the roof designs for worst-case scenarios has been suggested as an alternate to a non-operational system (or possibly a system left in an undesirable location of its movement path). As Bill Johnson says, success is easier achieved in a retractable design thru "simplicity, and the use of existing, off-the-shelf, readily available technologies."

Planning for future serviceability, for example, Safeco instrumented the roof system to record movement data. This was done to assist both the required damper service inspections and any potential damage assessment after a seismic event.

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Continued operation of the retractable roof system is a primary function of these facilities. Many key management decisions (such as prevention of a cancelled or delayed game) are based on the reliable operation of the roof system. The maintenance of these movement systems is crucial to their long life. The decision to use a manufacturer with a tested track record of service reliability for similar loading conditions versus a new, untested system of limited service information can indeed be both serviceability and design issue.

Future

What does the future hold for retractable roofs?

Although newer operators are pressing facilities for more adaptability and support functions, the entire structure may indeed

Image 1 courtesy of HKS

be smaller in size, with the exploitation of more standardized and reduced maintenance systems. The new generation may indeed be a smaller, more "kinetic" structure able to adapt to a few specific requirements.

Materials are starting to refine as the benefits of fabric, glass, and stronger steels are exploited in specific cases, especially when their use can replace two or more systems. The use of moveable stands and walls may also increase, to better allow the facility to create variable performance space and staging for year-round activity. Additionally, science may indeed create the turf system that will thrive on limited light or synthetic sources - allowing a fixed roof system of designed translucence from a fabric or fiberglass decking system.

Retractable stadia design will continue to emphasize more deterministic solutions - emphasizing simplicity when addressing complex global concepts. As Tom Scarangello states, "there is a growing level of sophistication and efficiency to the design process" with retractable roofs.

Earl Santee emphasizes the potential for international growth in retractable venues is "wide open." Earl believes the future is much larger overseas, stating there is "a myriad of potential international projects that moveable roofs could be developed for."

Dedicated sports venues in the US will likely continue, although the use of retractable roof systems may indeed morph into other sports venues (tennis, for example) and non-sporting venues (concert halls, amphitheaters, and smaller game facilities). As the learning curve flattens, these structures should become less mechanically complex and more affordable. The next generation retractable stadia may be influenced by their venue economics, which could indeed press for more multi-use type designs, increasing the ability of year-round revenue.

Many firms are currently working on new concepts for baseball, football, and mixed-venue structures. Phoenix will soon have not only a retractable roof stadium for their Cardinal football team, their facility will also "retract" the field surface inside and out of the building for a better growth cycle and alternate venue attractions. New York is proceeding with their plans for a retractable stadium for the Jets, expansion space for the convention center and facilities for their Olympic bid (*see image 2*). Additionally, Dallas is pursuing a new retractable facility for their Cowboys, contingent upon many important issues, namely a November vote (*see image 1*).

Others on the horizon, possible or not, include retractable baseball parks for the Minnesota Twins, Florida Marlins, New York Mets, and New York Yankees. Upcoming possible retractable football stadiums for the New Orleans Saints and Minnesota Vikings are also in development. Overseas, many are awaiting the completion of Britain's Wembley Stadium, whose main arch was just raised into place September 1st and will be the largest venue of its kind when finished in 2006.

Conclusion

Much of what we've learned from the past three decades of retractable roof design and construction will be integrated into the next stadia systems. Views and opinions of owners, contractors, specialty trade groups, designers, and engineers alike will help the next designs achieve more with less.

The accumulation of many of these construction aspects will be the goal of a new group called ARROW, formed to assist and guide many of the next stadium designers. Many of the initial decisions that led to the success of the past venues will be combined with construction lessons learned and operational maintenance solutions to assist the next designs. As Chris Pinto says, "maintenance is always more of an issue than planned" in these large facilities - and therefore crucial to the development of the next generation of retractable stadia. The group is currently under the control of Mike Duckett, who emphasizes their aim is to "share communication and lessons learned from previous parks with current operators, communities, and future designers."

Mike Duckett and the ARROW group can be reached at ***mduckett@SEWPBPD.com*** or 414.902.4040.

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Bryan Tokarczyk and Surinder Mann are structural engineers at KPFF in Seattle, WA.

Image 2 courtesy of Thornton Tomasetti