Design Considerations for Retractable-roof Stadia

by

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ABSTRACT

As existing open-air or fully enclosed stadia are reaching their life expectancies, cities are choosing to replace them with structures with moving roofs. This kind of facility provides protection from weather for spectators, a natural grass playing surface for players, and new sources of revenue for owners. The first retractable-roof stadium in North America, the Rogers Centre, has hosted numerous successful events but cost the city of Toronto over CA$500 million. Today, there are five retractable-roof stadia in use in America. Each has very different structural features designed to accommodate the conditions under which they are placed, and their individual costs reflect the sophistication of these features. These stadia also share some noticeable characteristics, particularly in their retractable mechanisms. There are currently five more projects for retractable-roof stadia in planning or construction in this country. These new structures will utilize design features from their predecessors, but the prices of these new projects are growing disproportionately to their technology and costing as much as $800 million. Beyond its multipurpose capabilities, a retractable-roof stadium carries an image of technological sophistication and distinction to it home city and thereby sells itself.

This thesis attempts to identify the important design features of existing retractable-roof stadia that are or will likely be repeated in new ones. Recommendations for the future of this building type will be made in terms of possible improvements to design and of potential future markets for construction. A financial study will also be made to observe the funding processes for these structures and the escalating trend in total cost.

Thesis Supervisor: Jerome J. Connor
Title: Professor, Civil and Environmental Engineering

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1.0 Introduction

For thousands of years, stadia have welcomed crowds of visitors and set the stage for great spectacles, entertaining performances, and unforgettable experiences. In the past century in America, these structures, particularly those for sport, have been designed to conform specifically to the purpose for which they are built, and the resulting forms have thus necessitated advances in technology. These sports facilities are generally either open-air stadiums or fully enclosed arenas, built to serve unique purposes during certain times of the year.

In the 1960's and 1970's, a series of circular stadiums and giant domes were built as multipurpose facilities to host games for different sports as well as other entertainment events. Over time, the appearance of these venues has fallen out of style, and because of their geometric design, the seating arrangements were favorable for neither sport. In recent years, these structures are considered antiquated and are being replaced by a new stage of stadium construction.

Today, there are two popular trends in evaluating aging stadia. First, they can be renovated extensively to preserve their physical integrity and to ensure that they are profitable to owners and aesthetically pleasing to fans. The other option in this situation is to tear down the existing structure and build a new stadium, one with a retractable roof.

A moving roof provides some obvious benefits to spectators in terms of acoustical effects and protection from weather, but the owners of the stadium can gain even more from the additional revenue produced by them. However, these stadia can incur very large expenses to build, and thus the specific designs of these buildings are directly driven by the costs of the solutions available.

Six retractable-roof stadia have been built in North America to this point, and several others are being designed and funded presently. As their technology becomes more sophisticated and the cost for these structures rises, the motivations of each city government in deciding to build one can be analyzed in terms of their potential benefits. While the long-term future of this building type is unknown, it has established itself as a very attractive option for new stadium construction today.

2.0 History of Retractable-roof Stadia

2.1 Types of roof systems

For sports stadia, there have been eight principal roof types, each with their own advantages and disadvantages: (1) post and beam, (2) goal post, (3) cantilever, (4) concrete shell, (5) compression/tension ring, (6) tension structures, (7) air-supported, and (8) space frame. A particular system is employed based on the shape and purpose of the stadium: for example, post and beam construction is often used for rectangular fields because of its simplicity but creates obstructed views of the playing field and structural complications in different weather conditions.

The type of covering is an important component of each roof system and must conform to a strict set of requirements. Roof coverings must be lightweight, tough, water-tight, incombustible, aesthetically acceptable, cost-effective, durable to outdoor weathering, and able to span the stadiums support structure. They are generally divided into opaque, such as metal sheeting or concrete, and translucent, such as rigid and non-rigid plastics, and are implemented appropriately according to the system. Therefore, multiple roof types have been developed to accommodate different needs and circumstances as well as to provide alternate design options for the same stadium.

2.2 Motivations for retractable roofs

As sports stadia evolve, certain motivations arise to push the limits of technology for roof systems and to design a single structure which can create both indoor and outdoor environments for multiple purposes. These motivations can be characterized as technical, aesthetic, and financial.

First, the comfort of spectators is controlling several secondary design features, such as restaurants, luxury accommodations, and other functional facilities, so that sports stadia will offer the same amenities as hotels, airports, and malls do to their customers. If this notion is taken one step further, the next phase for the structure would be to control the weather by means of a moving roof and, thus, offer the spectators options not only of amenities but also the very environment in which to watch the event. An environment

which supports natural grass growth is also very desirable to preserve a traditional playing surface.

Next, new stadia are being located closer to the rest of their home city than in recent years. During the early twentieth century, sports stadia were built next to warehouses and factories and seemed to blend in with adjacent buildings of the area. As these cities grew over time, surrounding development and increased traffic called for new stadia to be built outside city limits. Now, with their unique forms and huge dimensions, these structures are seen as important visual signatures and are again being moved closer to the financial centers of cities.

Finally, there are serious financial motivations in considering building a retractable-roof stadium. Although they incur considerable costs during construction, their functionality is important for securing revenue streams throughout the year. During the intended sport season, this type of structure can ensure a pleasant viewing experience for spectators, regardless of weather conditions, and thus increase ticket sales, namely through establishing a loyal fan base. During the rest of the year, the playing field can be covered or removed, and the indoor space can be utilized for singular events such as concerts, conventions, festivals, and other sports. Therefore, a movable roof is necessary to transform a sports stadium into a multi-purpose facility.

2.3 Rogers Centre

Figure 1: Rogers Centre

The first such stadium with a retractable roof in the world was completed in 1989 in Toronto, Ontario, Canada, and then called the SkyDome, but since renamed the Rogers

Centre (Figure 1). Designed by local architect Rod Robbie and constructed by Mike Allen, Bill Neish, and RAN Consortium, the structure boasts a height of 310 feet with a roof span of nearly 700 feet and can accommodate from 37,000 for basketball to 65,673 at full capacity events. Weighing 22,000,000 pounds, the roof is composed of four panels, three of which slide on old railway sidings under the larger stationary one and are powered by 72 motors; the final panel actually rotates 180 degrees to close the stadium.

The immense steel trusses of the roof system are connected to wheeled bogies at each end, which rest on the track supported by the concrete superstructure surrounding the building. Upon computer operation, the panels are driven by large motors underneath

Figure 2: Rogers Centre (roof open)

the stationary panel at the north end and open or close sequentially in a total of 15 minutes. While open, the Rogers Centre allows 100% field exposure and 91% seat exposure to sunlight (Figure 2); however, maintaining an indoor grass field throughout the year requires more consideration than sunlight alone, such as climate and drainage systems. Thus, the playing surface is artificial turf, which opens the stadium up to a

number of other venue types such as concerts, operas, demolition derbies, trade shows, religious festivals, circuses, carnivals, conventions, and several sports.

Aside from these impressive and successful engineering figures, the Rogers Centre was a financial disaster for much of the 1990's. Several factors played into the design of this new stadium. Foremost, the city was crying out for a replacement to Exhibition Stadium, which had been built in 1949 and hosted most local sporting events and gatherings since its inception. Popular opinion circulated the city in favor of a dome similar to those constructed in the United States in the 1960's and 1970's. The location for the structure would be in the entertainment district of the city adjacent to two major expressways and the CN Tower, a national landmark and icon. As North American culture was spreading into shopping and residential areas of Canada, these considerations affected preliminary designs of the stadium which included hotel accommodations as well as other amenities such as restaurants and a fitness club.

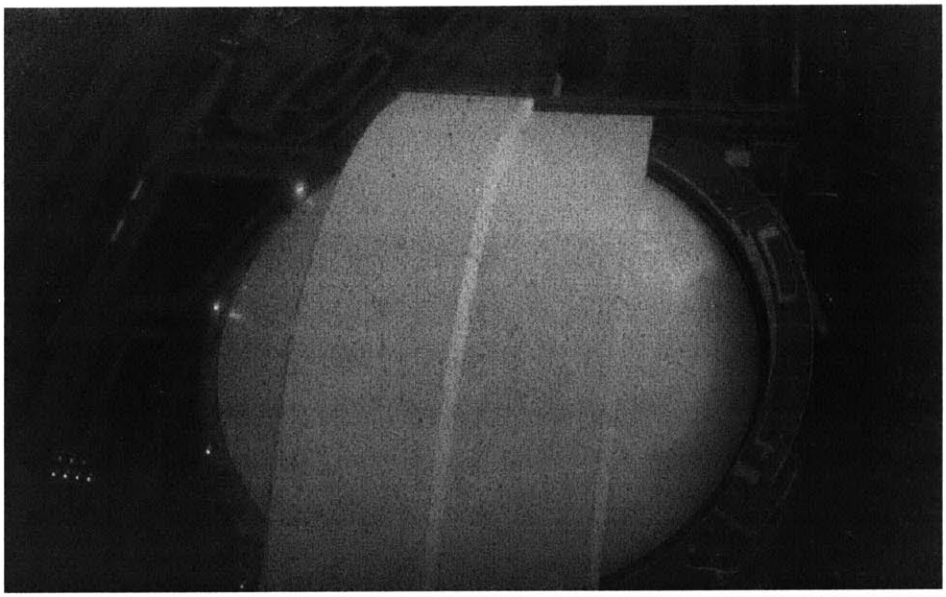

Figure 3: Rogers Centre (roof closed)

Financing the stadium, however, had historically proven to be a major hurdle to new stadium construction, since the public and private sectors had both tried unsuccessfully in the past to fund this venture. The City of Toronto together with a private alliance of investors known as Dome Consortium Investments, Inc. (DCI) originally agreed to fund the stadium for CA$150 million. However, due to the relatively untested technology of moving structures at the time, construction costs soared to CA$578 million by completion of the project. In 1990, the Rogers Centre collected

revenue in 185 days but still could not repay the debt to the city; in 1993, there were 256 event days but the debt still stood at CA$400 million after four years of existence.

Altogether, the city of Toronto has spent approximately CA$2 billion dollars to make the stadium a tourist attraction. The lack of short-term success with the Rogers Centre was clearly a deterrent for other cities considering similar new construction at the time. Today, sixteen years later, the technology of moving structures has greatly evolved, and retractable-roof stadiums are becoming more visible across the country (Figure 3). Though it has received many accolades as an engineering feat and was even dubbed the "World's Greatest Entertainment Center," the Rogers Centre has evidenced the potential financial burden with this building type and is an important precedent for the evolution of sports stadiums.

3.0 Technical Case Studies of Existing Stadia

Currently, there are 5 retractable-roof stadia operating in America. This analysis critiques each structure technically as well as financially to understand better the relationships between design decisions and cost and to note the progression of technology within this evolving building type.

3.1 Bank One Ballpark

In 1994, when Major League Baseball announced it would expand by two teams, Phoenix was among the candidate cities. With the sixth largest population in the country and growing, the area was very eager to acquire a professional baseball team to complement its three other major sports franchises. The team would require a new stadium, but shortly after the announcement, the council of Maricopa County, in which

Figure 4: Bank One Ballpark (roof closed)

Phoenix is located, had failed to pass a sales tax increase to fund construction. Almost a year passed before an agreement was reached to approve the increase, pending the city was awarded a team. When Phoenix was eventually selected for the location of a National League team, one of the heads of the stadium committee and a powerful local sports executive, Jerry Colangelo, saw the long-term importance of generating revenue for this project and strongly urged the design to include a moving roof.

Opened in 1998, Bank One Ballpark carries the distinction as the first retractable-roof sports stadium in the United States (Figure 4). Designed by architect Ellerbe Becket, the building plan is rectangular for efficiency in creating a structure over which a roof can open simply and repeatedly. Inside, the 200-ft height and nearly 1000-ft length give the stadium "the feel of an airplane hangar" to its visitors; green steel members and a red brick exterior try to make it resemble older ballparks and blend in with the warehouses surrounding it. Because of the innovation and uncertainty associated with this type of structure, the project was driven not by aesthetic appearance but rather cost and schedule primarily.

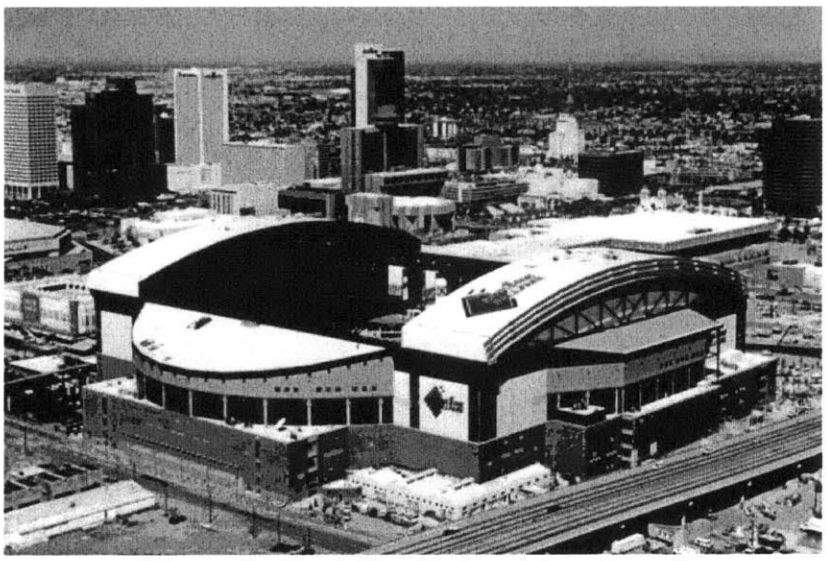

Figure 5: Bank One Ballpark (roof open)

During night games at Bank One Ballpark, as many as 49,800 spectators come early to count down to the opening of the roof. The roof system on Bank One Ballpark consists of two telescoping sections which bi-part over the middle of the field (Figure 5). The 6 equal moving panels, which span 517 feet and reveal 5.5 acres of sky (Figure 6), rest above 2 stationary ones when the roof is open (Figure 7). The panels are supported by nested trusses which taper and reach depths of 40 to 50 feet at some points. Each side of the roof is independent and can be opened or closed accordingly to maximize or minimize sunlight throughout the day. The retractable mechanism consists of wheels at the ends of the panels resting on rails and two 200-horsepower motors employing 4 miles of steel cable. The weight of the 6,900-ton roof can cause stresses in the wheels in excess of 100,000 pounds per wheel, yet the system can open and close in as little as 5 minutes.

A stadium with a retractable roof was necessary to control the desert climate of this area for sporting events. Temperatures are consistently above 100°F in Arizona during the summer months, and daytime heating of the steel and concrete elements can make the experience for spectators even worse. Using 12 air-handling units, the powerful cooling system in Bank One Ballpark can produce 8,000 tons of air-conditioning and

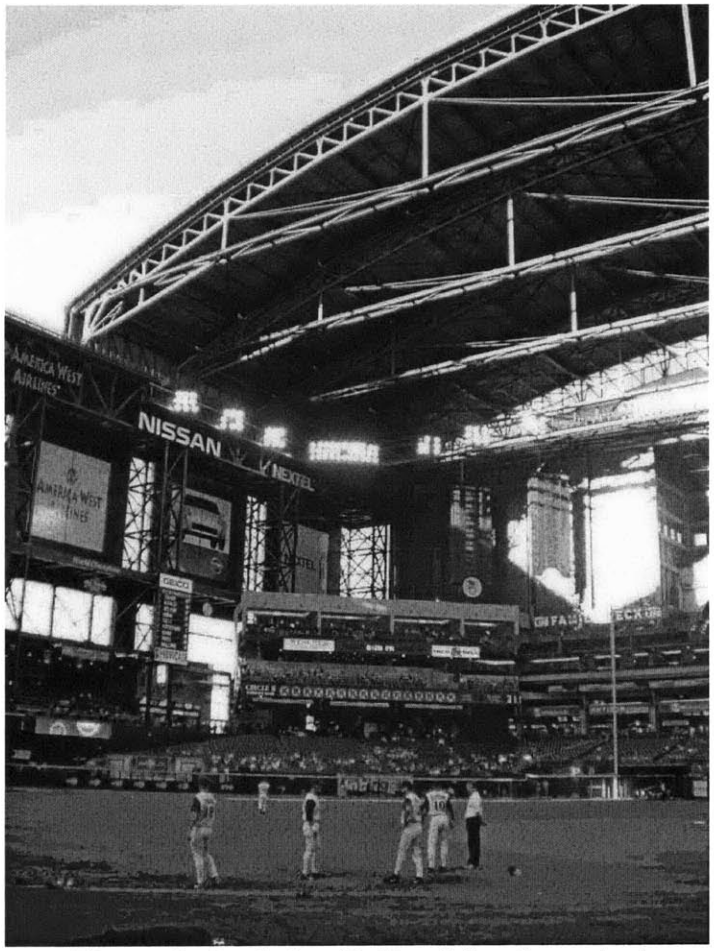

Figure 6: Bank One Ballpark (roof opening)

lower the inside temperature by 30°F in 4 hours. To enhance the outdoor environment of the stadium without unnecessary heat, the north wall was designed with 6 square panels, each measuring 60 feet on a side and opening with 2 hinged covers. This feature, combined with the movable roof, is significant in creating the feel of an open-air stadium and releasing fans from the confinement of watching sports in a large building.

Although it has been regarded as a success, Bank One Ballpark is not without its share of problems. The entire project cost at the time of completion was $354 million, $70 million of which was incurred by the roof. Considering cost-effectiveness as a key

consideration throughout construction, this is a substantial fraction of the total cost, even for such a new and unconventional building type. Many of the cost overruns for this project were assumed by the Arizona Diamondbacks organization, which today has almost $150 million in long-term debt and consequently has difficulty competing. Next, the wheels on which the panels rest were made of low quality steel that was not specifically machined and hardened for extremely high stresses; as a result, they must be replaced in 10 years (and possibly every 10 years thereafter) and could potentially shorten the life of the project. Finally, the main contractor for the project has filed a $34 million lawsuit against the architect, construction manager, Diamondbacks, and Maricopa County Stadium District. This grievance clearly indicates that there were possible inefficiencies in the stadium's design and notable conflicts between different parties during the construction phase.

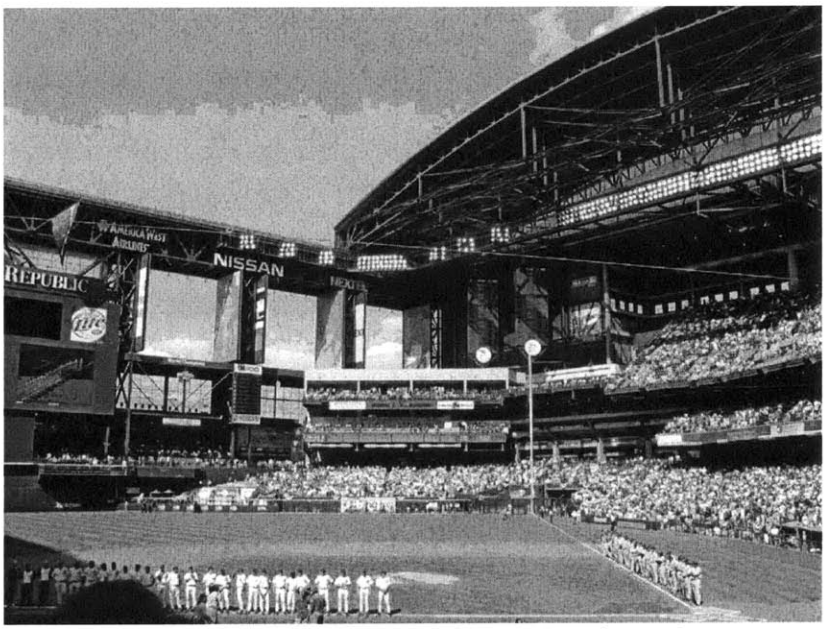

Figure 7: Bank One Ballpark (roof open)

Bank One Ballpark has hosted football, basketball, baseball, and soccer games as well as a number of concerts, festivals, and other events in 7 years of operation. It has expanded on the technology of retractable-roof stadia by using a different roof system from its main predecessor, the Rogers Centre, and has shown the potential benefits of this building type for sports teams in the United States. Its influence on successive stadia will be interesting to observe, especially if they continue to gain in popularity and success as cutting-edge performance venues.

3.2 Safeco Field

Since 1977, the Seattle Mariners of Major League Baseball had played their home games in the Kingdome, which had been regarded as one of the ugliest stadiums in the country and nicknamed "The Tomb." Attendance had consistently been mediocre, as the team did not sell out a home game until 1990, and in 1994, the structure underwent roof repairs costing nearly as much as the original project itself. Consequently, after that season the Mariners organization threatened to relocate the team if the county would not agree to build a new stadium with a moving roof. The local government attempted to pass a tax increase to fund the stadium until the plan was barely denied a referendum in September 1995. However, the Mariners finished that season in the postseason on a strong note and captivated the baseball fans of Seattle. When the governor soon called for a special session with the Washington State Legislature, a new financial agreement with the state was reached for the Mariners to stay in the city and play in a new stadium.

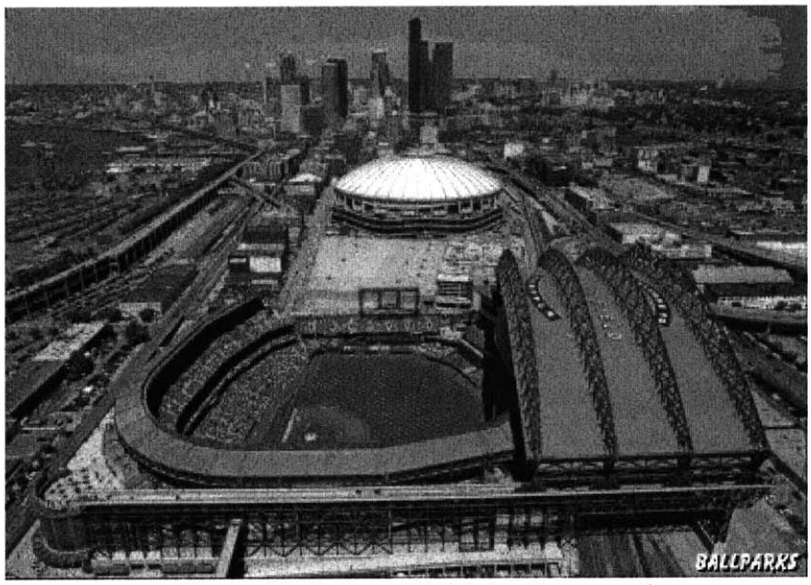

Figure 8: Safeco Field, looking north

Due in no small part to the lack of popularity with its predecessors, Safeco Field was conceived with aesthetic appearance and fan experience as top priorities. Architect NBBJ of Seattle designed this stadium to resemble the older ballparks of America; in this sense, the retractable roof would cover the field like an umbrella more so than enclose it. This idea was important for enhancing the environment during the game and making

spectators feel that they were in an open-air stadium. Additionally, residents of the Seattle area particularly enjoy spending time outside, and thus a new sports stadium should embrace and support that pastime as much as possible.

In considering different types of roof systems for Safeco Field, NBBJ looked to the Rogers Centre in Toronto to imitate a telescope-style design of roof panels with more simplicity and less cost. This roof system (Figure 8) consists of 3 moving panels which span over 600 feet each and cover almost 9 acres. The middle panel rises 275 feet above the field and allows the other two to slide underneath as all three move to the east end of the stadium. The panels themselves are composed of thin gypsum and glass-fiber board covered in a weatherproof skin and move by rolling on rails on the North and South sides with 128 steel wheels, 36 inches in diameter (Figure 9). They are pulled by cables from 96 10-horsepower motors which can open or close the stadium in 20 minutes.

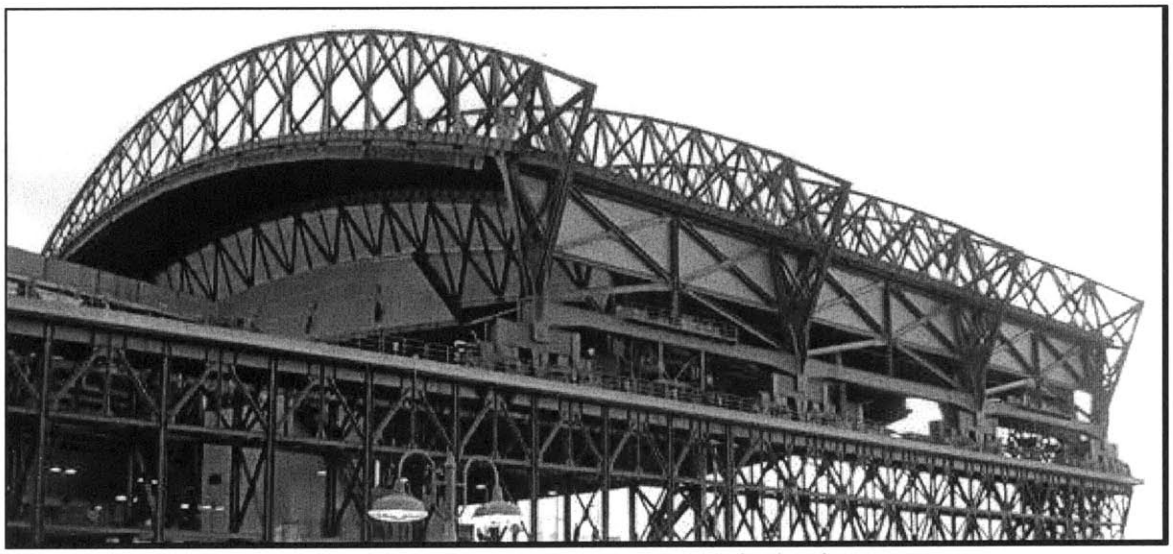

Figure 9: Roof mechanism and wheels

Some of the natural conditions of the Seattle area dictated other important design features of the roof system. The 11,000-ton covering is self-grounded and will not malfunction in the case of lightning strikes despite the amount of machinery and electrical systems present. The roof panels can support up to 7 feet of snow and continue to open and close carefully in winds of 70 miles per hour. Because of the "open" nature of this stadium, these high winds introduce the problem of uplift failure, and the roof has been equipped with operable lock-down devices that tie the sections to supports below. Seismic activity has played an especially significant role in designing to prevent

catastrophic failure. On the North side of the roof, 18-inch dampers were installed on each panel and monitored with electronic strain gages to predict when they would fail and need replacement. These devices were successfully tested on February 28, 2001, when a 6.8 magnitude earthquake shook Seattle but caused little damage to the structure.

The technical designers of Safeco Field attempted to save money on the total project cost through efficient use of materials. The members of a support system for a stationary roof must be designed to carry a large portion of the load in the event of

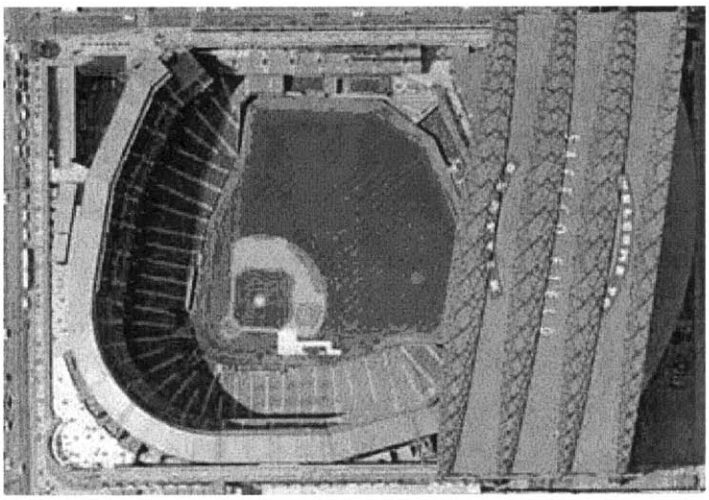

Figure 10: Parallelogram roof panels

individual failure. With a sectional moving roof, however, some areas of the building's infrastructure will never receive these high loads and, thus, can be fabricated with less material. Next, originally 5 panels were called for in the roof plan, which eventually reduced the total to 3 and saved as much as $30 million. These panels also save on material costs by independently resting on 800-ft runways unlike Bank One Ballpark, which uses a telescoping system of sections. At Safeco Field, the panels are actually parallelograms, not rectangles, and minimize the roof area while still covering the field (Figure 10).

Despite these savings, unfortunately, the stadium has been a financial burden to the local area. The total project cost in 1999 was $517.6 million, which is far above that of Bank One Ballpark and approaching the initial cost of the Rogers Centre, built 10 years earlier. King County, where Seattle is located and which currently owns Safeco Field, collected $340 million in taxes for the structure, while the Mariners paid only $75 million and another $100 million is still being settled in lawsuits. The roof required just

under $67 million (comparable with Bank One Ballpark), of which $14 million was spent on the mechanization system alone. By employing a large number of wheels to move the panels, the stresses on them were reduced for the same massive roof load, but much larger beams were needed to distribute this weight along them. Additionally, these wheels have already undergone preventative repair measures, and some cracks have been discovered in the concrete infrastructure of the seating area.

Figure 11: Open North outfield wall

According to its reviews from fans, Safeco Field has been very successful as a nostalgic yet modern ballpark. Its roof is used in roughly 30% of games each season, mainly in April, May, and September, as well as several other venues during the year. The structure creates a pleasant outdoor experience reminiscent of open-air stadia with a North outfield wall completely open to a view of the city (Figure 11). It shares this design notion with Bank One Ballpark in Phoenix, Arizona, and has influenced this building type with its unique design features to satisfy complex requirements.

3.3 Minute Maid Park

The Reliant Astrodome had served as the home for the Houston Astros of Major League Baseball since 1965 and had been nicknamed "The Eighth Wonder of the World." Thirty-three years later, however, the massive structure was out of date and

style, and the team was interested in a new stadium with a natural grass playing field. Instead of building an open-air stadium exposed to the potentially harsh weather of the area, the city of Houston decided to utilize state-of-the-art structural motion technology and construct a retractable-roof stadium for the Astros.

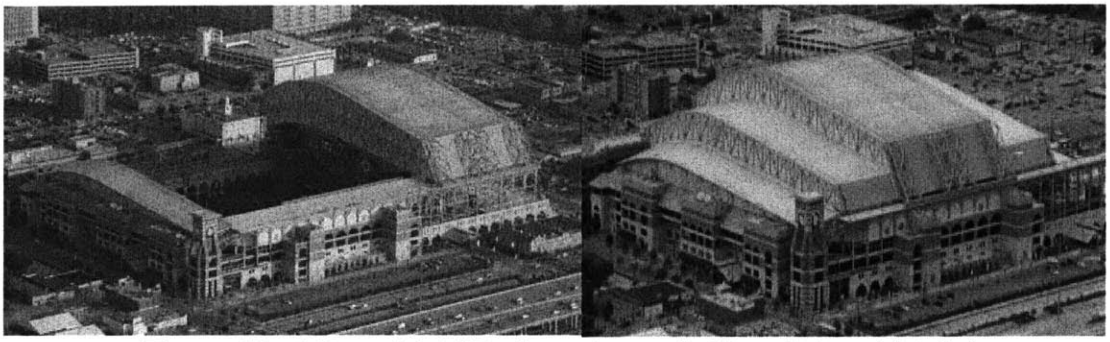

Figure 12: Minute Maid Park roof open (left) and closed (right)

Minute Maid Park opened in 2000 with much to offer. Local spectators could watch professional baseball outside for the first time in the 35 years without fear of oppressive heat or dangerous hurricane conditions. In the stadium's first year, the Astros reached a record in attendance by surpassing 3,000,000 for the first time, and the venue was also chosen for the 2004 All-Star Game. The success this structure has enjoyed has fundamentally been the result of keen design solutions that have capitalized on prior retractable-roof stadia.

Completed just one year earlier, Safeco Field and Minute Maid Park have a number of distinct similarities, as well as subtle differences, that demonstrate the fast-changing nature of this building type. Minute Maid Park has a comparable 3-panel roof system: a 250-ft wide middle panel under which two 125-ft edge panels slide, spanning 580 feet across the stadium and storing above the seats at the North end (Figure 12). The two structures strive for the aesthetic appeal of a traditional older American ballpark, with red brick façades and green steel members, complemented with modern comforts and amenities. Notably, the Astros asked for a view of downtown Houston, which they received in the form of a 120-ft glazed outfield wall (Figure 13), the same area left open in Safeco Field for spectators to admire the skyline of Seattle.

Safeco Field and Minute Maid Park employ vastly different wheel suspension systems in the rolling mechanisms of their respective roofs. For any such stadium, the steel tracks on which the roof panels roll have particular high and low points resulting

from construction tolerances, thermal expansion, or other effects. Therefore, it is essential for these mechanisms to include suspension systems to prevent individual wheels from taking excessively high portions of the roof load.

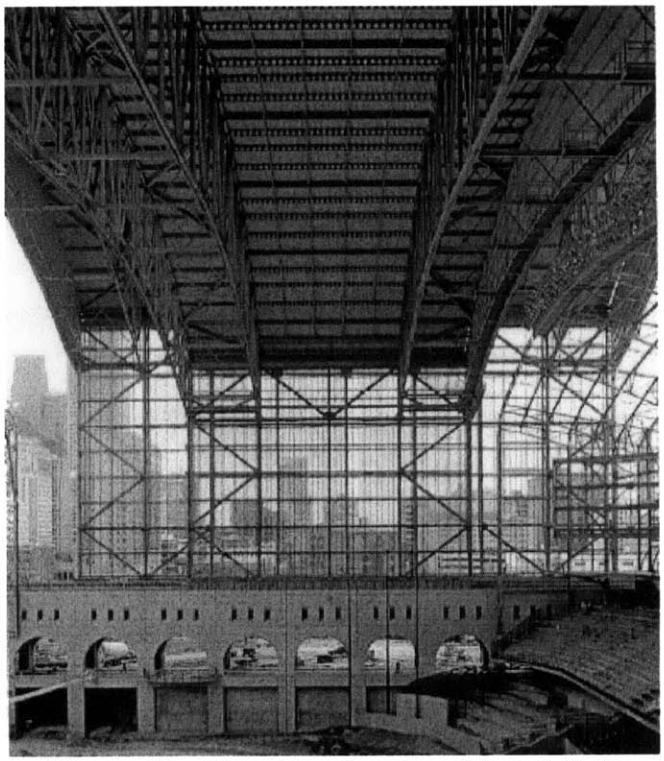

Figure 13: Movable glazed wall in left field

At Safeco Field, a series of balance beams and 2-wheeled bogies compose a pivot beam suspension system (refer to Figure 9). This system distributes the roof load over all 128 wheels using pivot beams and bearings (Figure 14). As the roof load increases, however, more wheels are needed to distribute the load safely, and this in turn requires more pivot beams and, in this case, greatly increases material costs. For Safeco Field, the transporter assembly is roughly 20 feet deep. This suspension system can also add to the height of the roof and negatively affect the aesthetics of the structure.

Minute Maid Park, on the other hand, was designed with an independent wheel spring suspension. In this system, the vertical motion of all 140 wheels on the assemblies is controlled by springs made of layered urethane and steel (Figure 15). Although this form of suspension does not distribute loads completely uniformly, it is less complicated and expensive than the pivot beam suspension and does not subject any wheel to excessively high stress. For Minute Maid Park, the transporter assembly is only 6.5 feet deep.

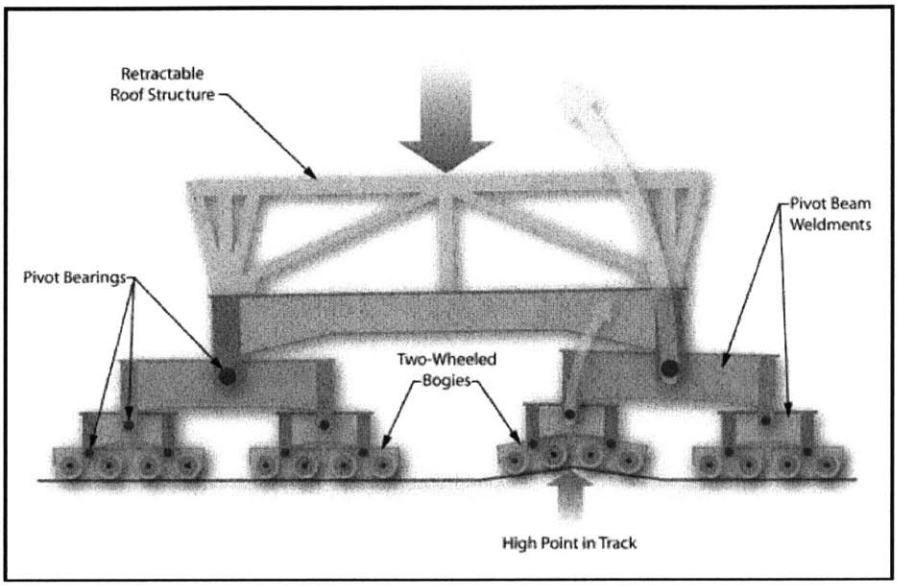

Figure 14: Safeco Field Pivot Beam Suspension

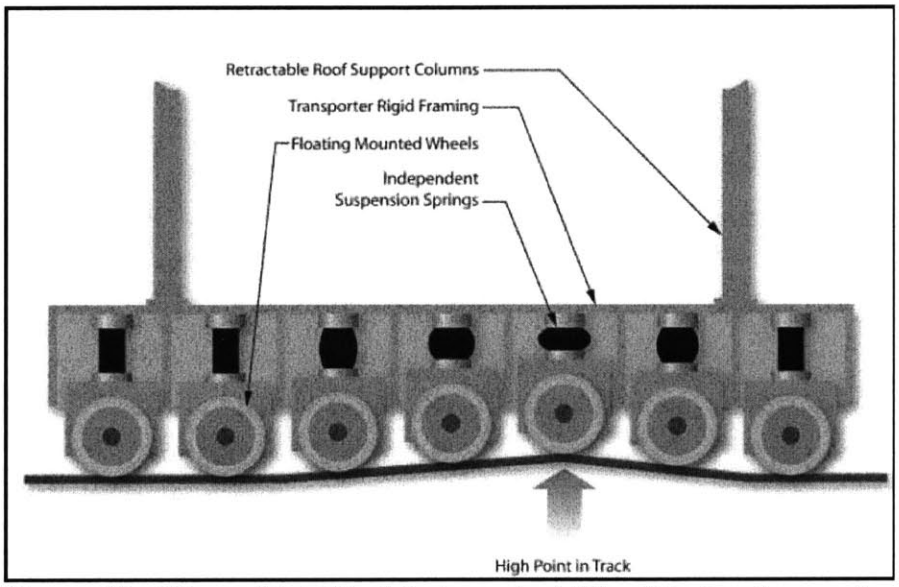

Figure 15: Minute Maid Park Independent Wheel Spring Suspension

While both stadiums have the wall open in left field to a view of their cities, the roof of Minute Maid Park actually rests on this wall as the two move together as one unit. This modification from conventional roof motion on level rails introduces complications with a design requirement called lateral release. Natural lateral forces, such as wind and seismic loads, cause unavoidable deflections in the structure; however, avoidable forces, such as thermal expansion and foundation settlement, can produce reactions in the rigid frame several times greater than those from natural forces. Since the wheels on which the

roof rests are designed for gravity loads rather than lateral thrust, a lateral release system must be incorporated to relieve these horizontal reactions from the retractable mechanism.

Figure 16 shows the distribution of roof load through the system and the resultant reactions at the supports. Problems occur with fixed moment connections on *both* sides of the roof, and the solution at Minute Maid Park to control horizontal deflection and transfer load is shown in Figure 17. For each truss in the roof, this thrust release system uses a release hinge and hydraulic damper (see inset on Figure 17), similar to Safeco Field, above the moving wall on the west side and a rigid connection to the transporter assembly on the east side. Each column in the wall also connects rigidly to the transporter assembly and acts as a long moment arm putting only moderate lateral forces on the wheels.

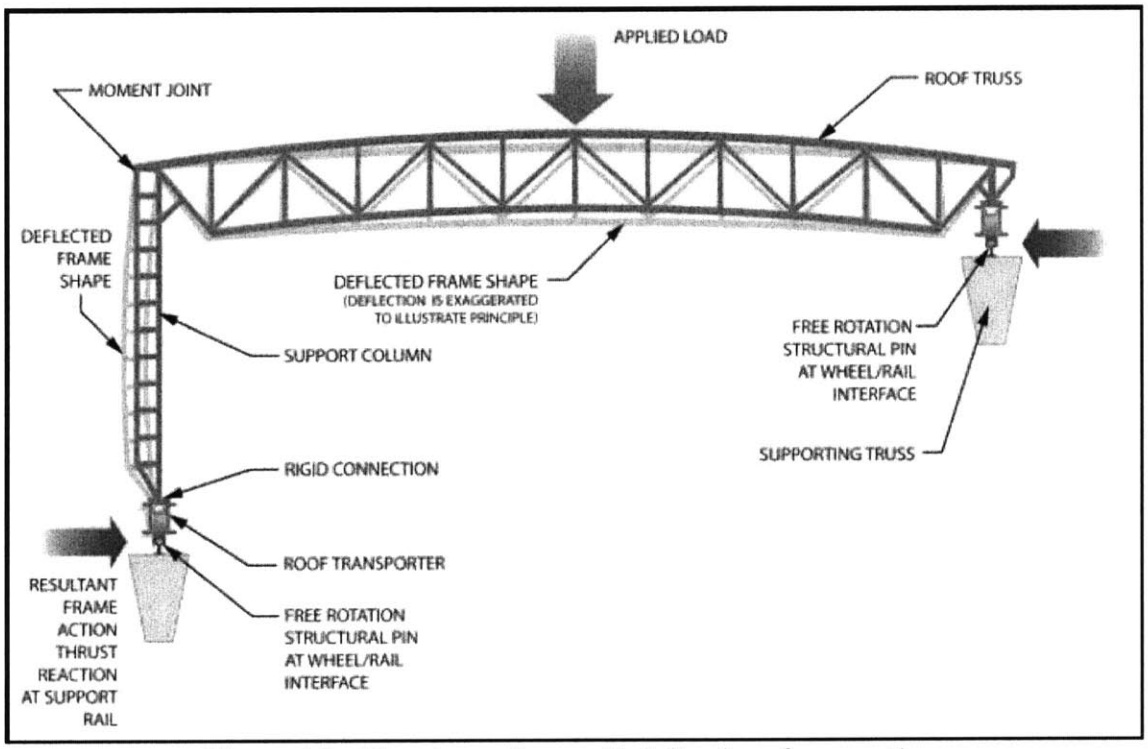

Figure 16: Thrust reactions with 2 fixed roof connections

With these differences in mind, Minute Maid Park cost almost half as much as Safeco Field in total cost ($277 million), roof cost ($32 million), and mechanization cost ($7.5 million) for a relatively similar stadium. The weight of the roof was also lower at 9,000 tons, and the construction time was comparable. The development of Minute Maid Park has shown the rapid yet successful evolution of this building type through improved cost-efficiency and simplicity of design.

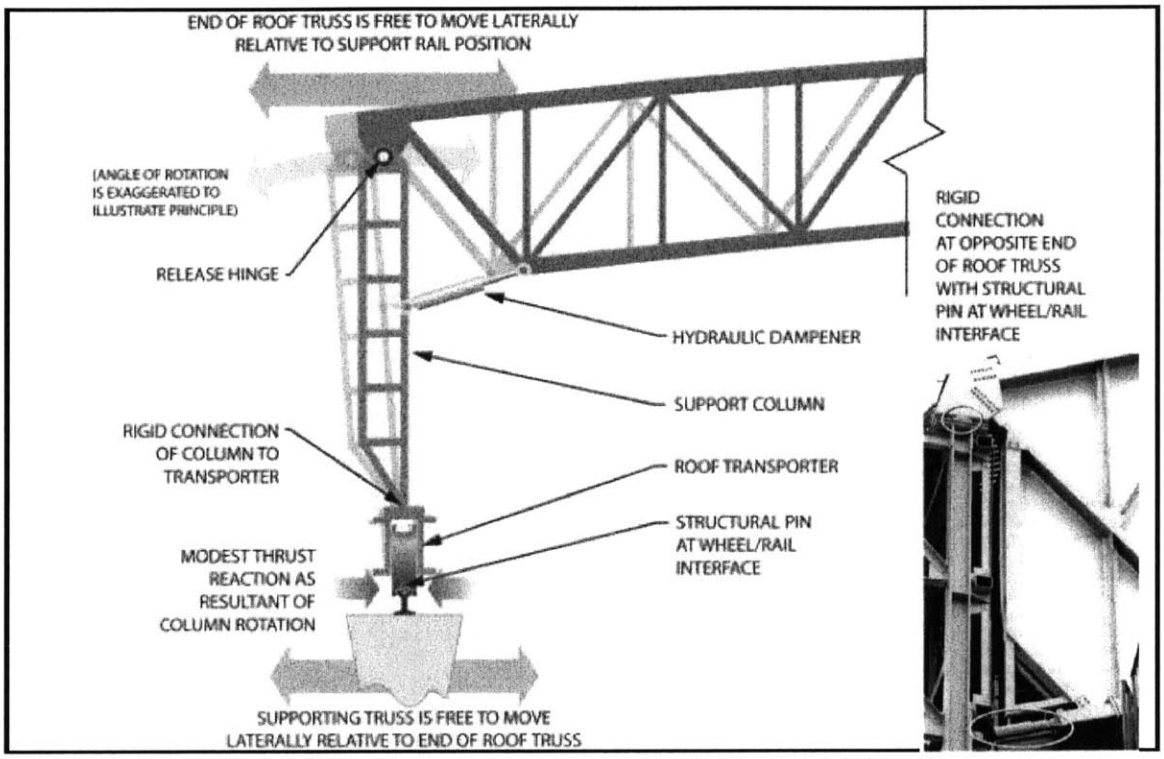

Figure 17: Thrust release system with hinge and damper

3.4 Miller Park

Thirty years after their first game at County Stadium, the Milwaukee Brewers of Major League Baseball were looking for a more modern stadium to play in. Given the sometimes extreme northern climate of Wisconsin, a ballpark with a retractable-roof would provide reliable comfort for spectators throughout the season and a unique structure to the area. However, in this particular case, mistakes in the design process and poor decisions throughout the entire project have been detrimental to the stadium as a whole.

After several delays in construction, Miller Park finally opened in 2001 but has been plagued by problems and litigation ever since. In its first season, attendance reached a new record at over 2,800,000 but returned to average in 2002, possibly indicating that fans were not impressed with the new stadium. Unique to Miller Park, the roof system uses a "fan" arrangement of 7 panels (Figure 18) which pivot from a point behind home plate and move along a semicircular track; three move over a fixed panel on the left field side and two move over a fixed panel on the right field side.

Figure 18: Miller Park with roof closed

These panels span almost 600 feet across the stadium and reach 330 feet at its highest point. When they are open, the trusses above the sections resemble the structural steel bridges in the nearby Menomonee River Valley region. Each panel rolls along a steel rail on a pair of 2-wheeled bogies, and thus there is no need for a suspension system within this mechanism (Figure 19).

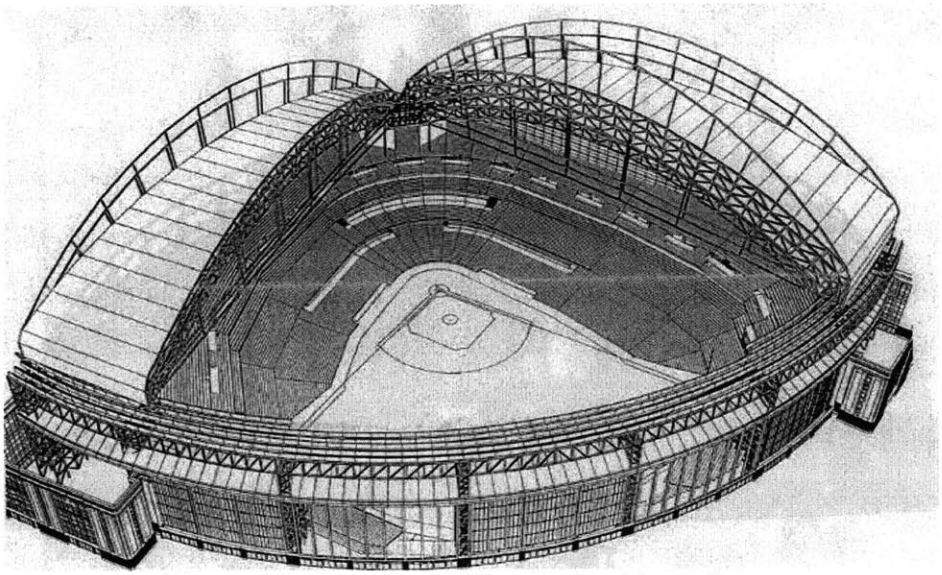

Figure 19: Sketch of Miller Park with roof open

Behind center field is a popular feature combined with retractable roofs as seen in these projects: moving walls. At 70 feet high and 140 feet long, two movable panels of the stadium's perimeter roll along rails, much like the roof sections, between three stationary sections. These walls are made of a translucent material that brings additional

natural light into the stadium and enhances its bright appearance during the day (Figure 20).

Before the stadium committee of Miller Park wanted to commit to this unique roof system, the collaboration of HKS, Inc., NBBJ, and Eppstein Uhen Architects performed a preliminary pricing on the entire roof system with a standard estimate of 35 lb/ft2 as the roof load. After the dimensions for the stadium had been established, designers discovered that they forgot to account for snow load, which would raise the estimate to 125 lb/ft2. Redesigning the structure would be too costly and time-consuming, and thus the roof was reinforced with extra connections, contributing up to 40% of the total roof weight.

This increase has put additional stress on the wheels of the roof mechanism around 500,000 pounds per wheel, far above safe limits as they are known. These stresses are causing the wheels to slip when the roof panels move, and as a result, 5 bearings, which have a 20- to 30-year life, have already been replaced, and the bogie drive-train system is scheduled to be replaced after the 2005 season (Figure 21).

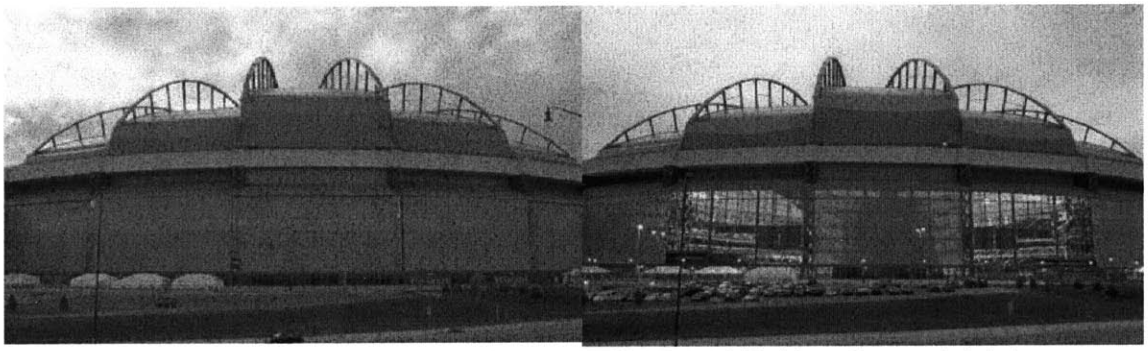

Figure 20: Movable translucent walls closed (left) and open (right)

The roof of Miller Park opens in a slightly different manner than other retractable roofs and actually leaves gaps between the sections. This feature makes it challenging to waterproof the roof surface and join the different panels closely without hitting. The difficulty associated with this connection has lead to persistent roof leaks in the first two seasons of play, most notably on August 21, 2002, when a thunderstorm sent cascades of water onto the playing field. The previous system of flexible rubber flaps has been replaced by a U-shaped foam-filled membrane at the interface of the panels (Figure 22). The cost associated with this repair was between $1.5 and $2.5 million.

In July 1999, while raising a section of the roof, three construction workers were killed in an accident as the crane tipped over and the section was dropped. The mistake was caused by a miscalculation in the size of the boom. The stadium was damaged in the accident, and opening of the ballpark was delayed a year due to various setbacks in construction sequences.

The contractor for the retractable roof, Mitsubishi Heavy Industries of America, had completed smaller-scale operable-roof projects in Japan and adapted their methods to the larger panels of Miller Park. Obviously, this conversion is not that simple and could have led to a number of mistakes in building procedure. After the project was completed, Mitsubishi claimed that the roof had cost them $133 million to build and filed an $87 million damage claim against the district and HCH Miller Park Joint Venture. The claim has since been reduced to $37 million but is still pending.

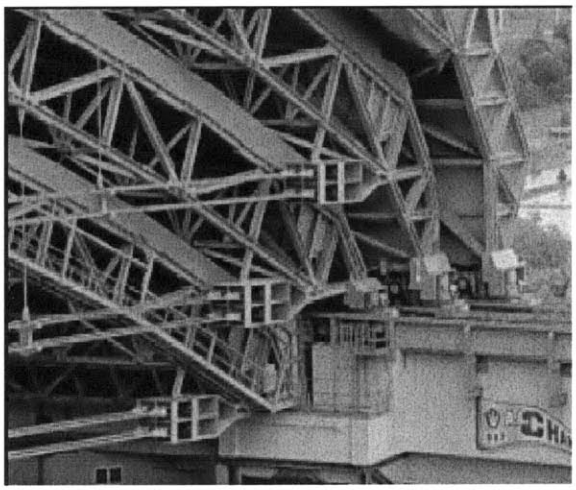

Figure 21: Roof wheels

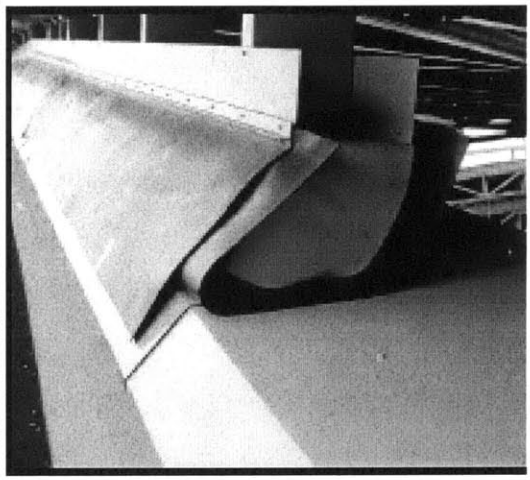

Figure 22: Foam membrane

What began as a promising project combining classic architecture with modern cutting-edge technology fell victim to a series of gross oversights and costly errors during multiple phases of the project. Today, many of these problems have been corrected but not without serious expenses. Miller Park cost an estimated $400 million, and that figure should continue to rise as various pieces of the structure must be repaired or replaced for safety standards. Although the ballpark is in full use today, the mistakes which stemmed from complications in design and construction should not be repeated.

3.5 Reliant Stadium

Since his unsuccessful attempt to secure a National Hockey League team in Houston in 1997, former owner Bob McNair began plans in the same year to bring a National Football League team back to the city. Just two years later, city officials and potential owners had finished plans for a new structure, and the city stood as a solid candidate for an expansion team in 2002. When the city of Los Angeles, another potential candidate, was not able to develop a feasible ownership and stadium situation, the NFL soon awarded their 32nd franchise to the owners in Houston.

This building was not intended solely for the use of the new NFL team. Moreover, some of these same owners had a vested interest in the Houston Livestock Show and Rodeo, a long-standing organization whose attendance and revenue growth would greatly benefit from a new, sophisticated local venue. Therefore, to compromise the NFL team's desires for a natural grass surface with the sheltered requirements for the HLRS, the owners chose to build a stadium with a retractable roof to ensure the best entertainment experience for both events.

As the first retractable-roof stadium in the National Football League, Reliant Stadium is a distinctive type of structure from the baseball parks that came before it. It stands 40 feet taller than and 1.5 times as long as the nearby and so-called "Eighth Wonder of the World," the Reliant Astrodome (Figure 23), but its size does not

Figure 23: Reliant Stadium (foreground) under construction and Astrodome

prevent it from enhancing the visitor's experience in a number of ways, namely letting in more light and providing better seating viewpoints. The building somewhat resembles Bank One Ballpark in appearance and support structure but clearly shows the results of 4 years of advancements in retractable-roof stadia.

During the initial stages of the roof design, the engineers for the project, HOK Sport and Walter P. Moore and Associates, recognized two critical points from recent history. First, the roof design drove scheduling and construction time early in the project sequence, due to the extensive space, equipment, and labor necessary. Second, the success of the roof system depended heavily on the relationship between the transporter supplier and the engineers themselves. With this knowledge, the team architect was able to convince the owners to retain the same supplier from Minute Maid Park's roof (Uni-Systems, LLC) and to hire a roof-fabric supplier as a consultant.

The original roof design for Reliant Stadium was an accordion-style, fabric covering which was rejected because of the uncertainty and complexity associated with it. Instead, the designers chose a roof system consisting of two large panels which bi-part above the 50-yard line on the field and come to rest above the end zones (Figure 24). These sections span 385 feet across the opening and are 240 feet long; each is supported by five 30-ft deep trusses which move along a conventional rail assembly using just 40 wheels and 80 5-horsepower motors. The roof can open or close in about 10 minutes.

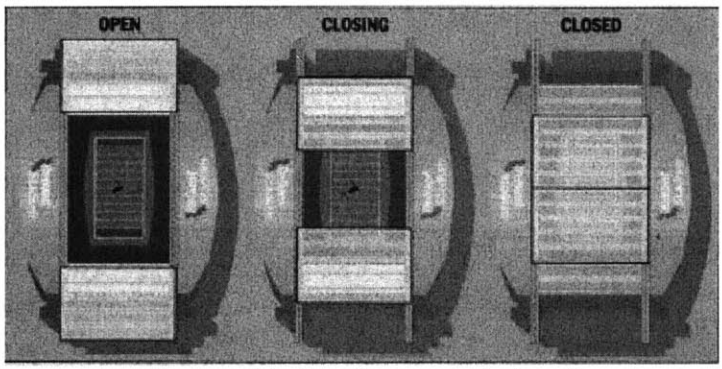

Figure 24: Roof open and closed

The transporter assembly can afford to be less substantial than those of other retractable-roof stadia because this roof is much lighter at a little over 1,000 tons. The covering surface is a Teflon-coated fiberglass fabric which is about 25% translucent; although much more expensive than some alternatives, this material is better acoustically and visually than thick, opaque panels, and the additional cost is actually offset by the

smaller moving mechanism (Figure 25). However, with a lighter roof and the possibility of hurricanes in the area, the roof system includes operable clamps in normal weather and additional tie-downs for extremely high winds.

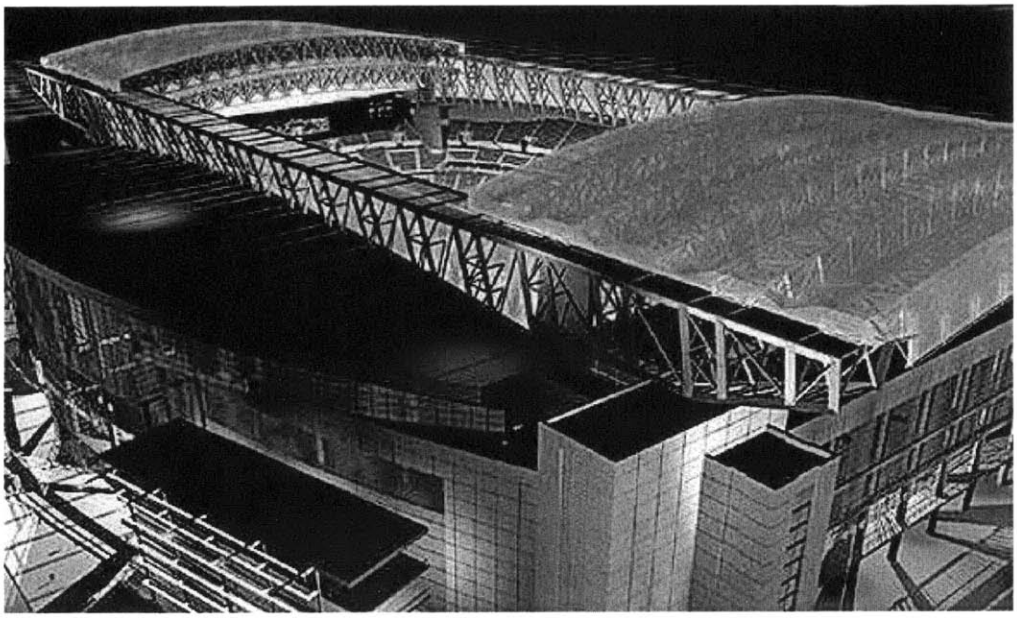

Figure 25: Teflon-coated fiberglass fabric

The light roof also eliminated the need for a special wheel suspension and instead employed a linked carrier suspension system (Figure 26). With only 4 wheels per truss, a series of carriers are linked by pinned arms, which allow sufficient load distribution among the wheels on the same rail. As compared to previously discussed suspension systems, this one greatly reduces the amount and type of material needed (and thus the cost) and maintains a simple yet flexible solution to roof motion.

Where the roof of Reliant Stadium lacks in weight its support structure compensates with daunting dimensions. The rails on which the panels roll are ultimately carried by two supertrusses, which span 650 feet inside the stadium and an additional 167 feet beyond the ends to support the open roof, for a grand total of 984 feet each. Supporting these massive elements are four concrete supercolumns, measuring 153 feet tall and composed of 13,000 lb/in^2 concrete. Like that of Bank One Ballpark, this support structure functions as a free-standing system in a rectangular building, similar to a four-legged table; the six immense sections total over 3,000 tons and distribute a sizeable amount of gravity and lateral loads to the ground.

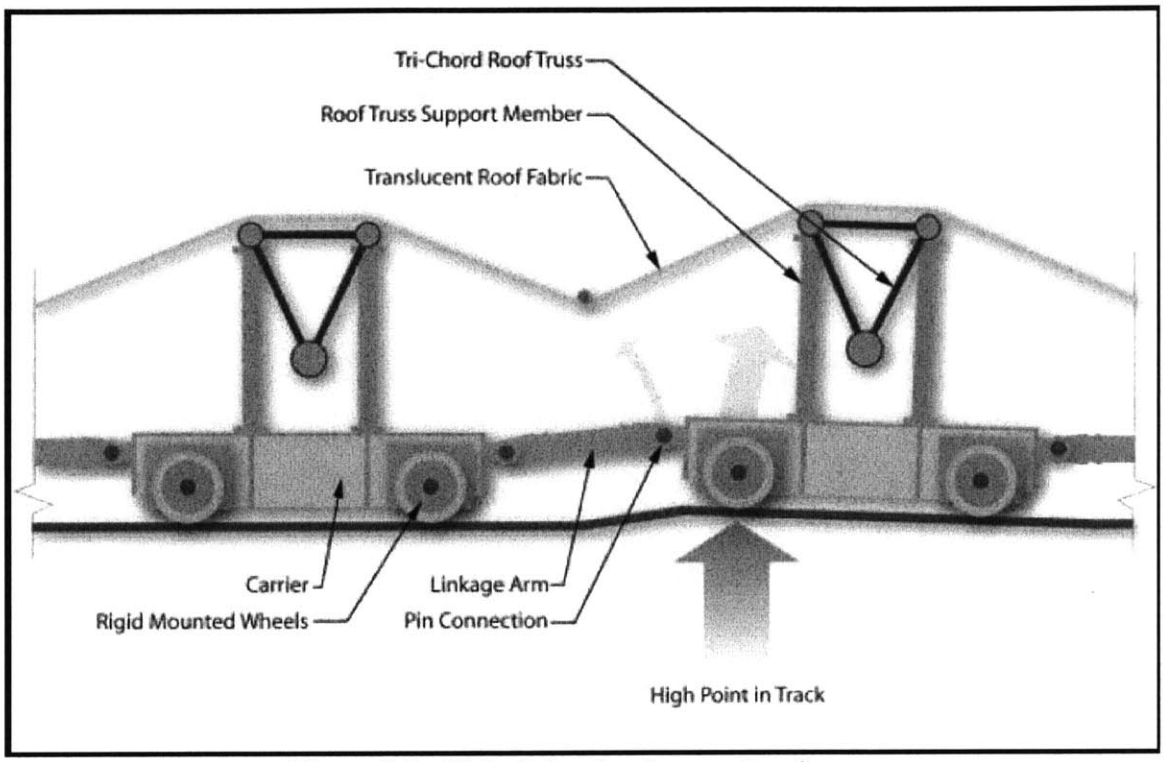

Figure 26: Linked Carrier Suspension System

The roof itself specifically handles wind and seismic loads with a lateral release mechanism called 4-bar linkage. Similar to Minute Maid Park's roof, this system uses a fixed connection at one end of each truss and a hinge at the other end. In contrast, though, the horizontal roof deflection in Reliant Stadium must be resolved over a distance of *10 feet*, between the moving trusses and the supertrusses supporting them (Figure 27). The roof at Minute Maid Park has a hinged connection to a moving wall, and the height of this wall allows greater deflections in the roof for much smaller reactions at the wheel-to-rail interface.

Therefore, 4-bar linkage was designed to connect the ends of the trusses to the transport carriers. As the roof deflects horizontally, the bars pivot to allow this motion but also continue to transfer the gravity load of the roof down through the wheels with minimal horizontal thrust at the wheel (Figure 28). In fact, the roof can sway up to 21.5 inches in either direction safely. This innovative solution prevented the flexibility of the structure's roof from hindering its operation and instead created a simple mechanism with little added material.

Reliant Stadium has had a short but very successful existence, highlighted by record attendance at the Houston Livestock Show and Rodeo as well as hosting Super

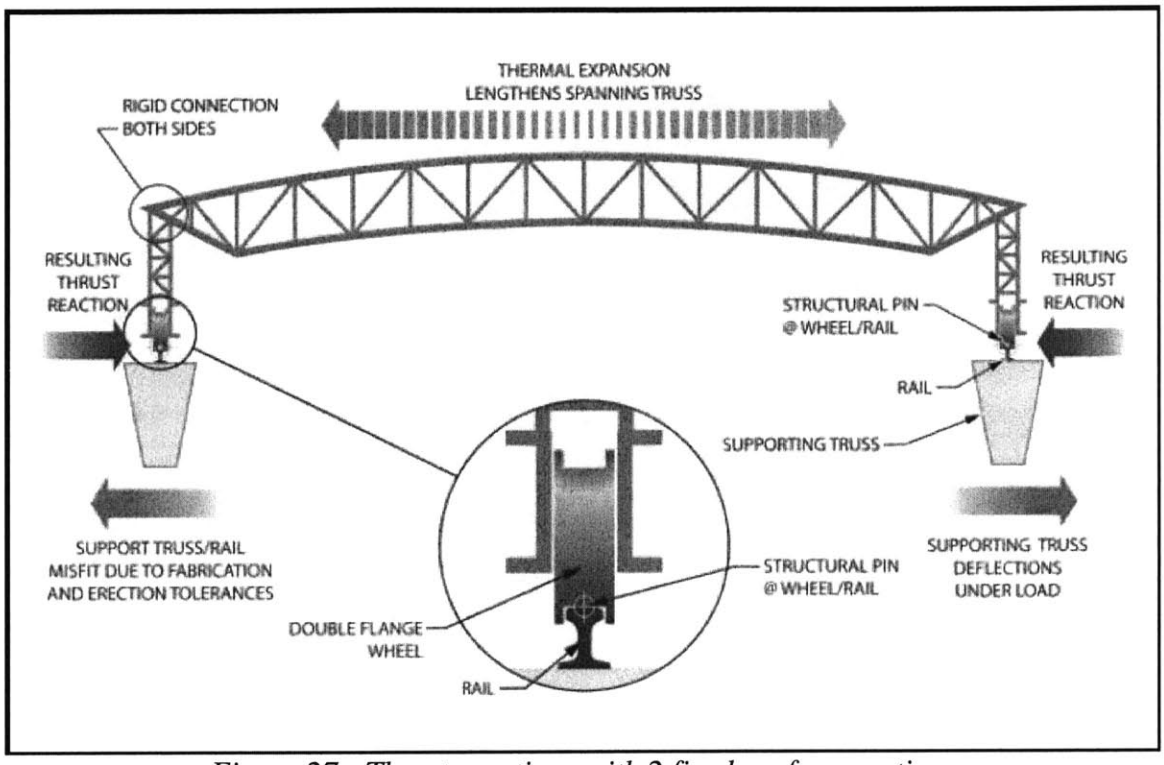

Figure 27: Thrust reactions with 2 fixed roof connections

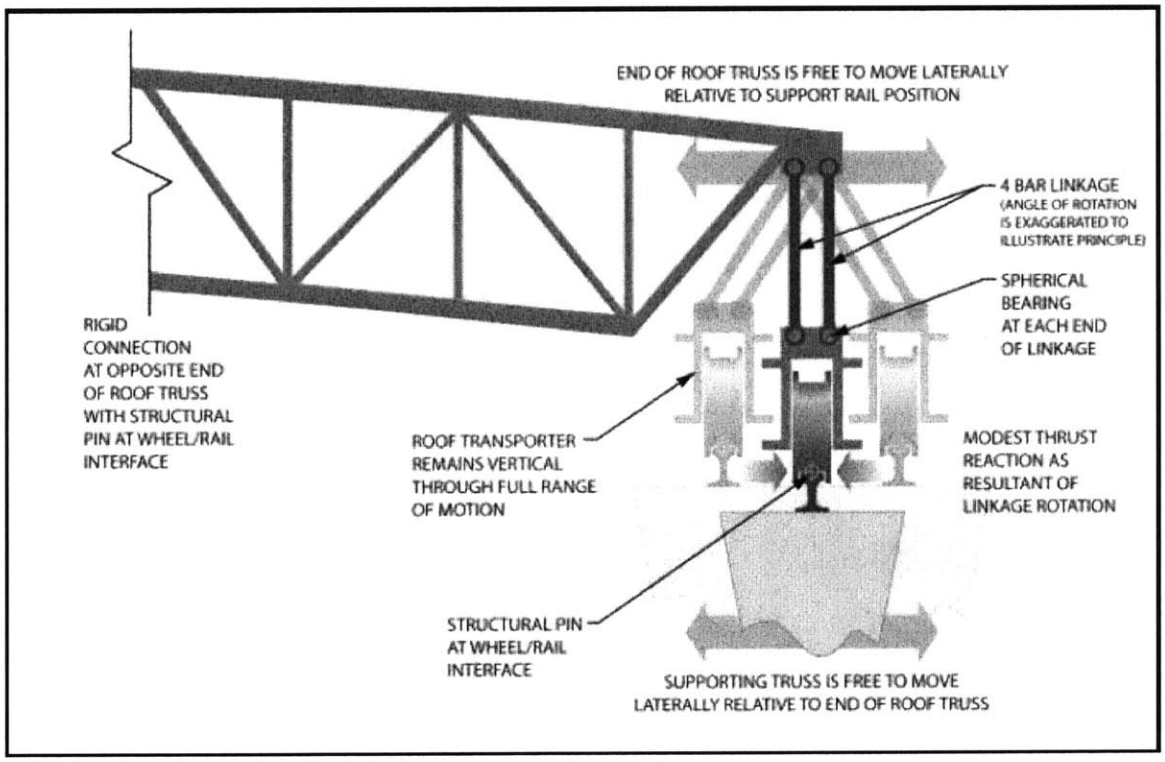

Figure 28: 4-bar linkage

Bowl XXXVIII. At a total cost of $417 million, $48 million of which for the roof, its designers and engineers saved considerable amounts in material cost with original

solutions, although the project cost is somewhat higher than others of its kind. Nevertheless, as the first retractable-roof stadium used for professional football, it has build upon existing precedents and demonstrated the success of new possibilities with this building type.

4.0 Case Studies of New Retractable-roof Stadia

Today, there are 5 new retractable-roof projects for professional sports during construction or in negotiation. This analysis looks at the preliminary designs of these new stadia, outlines the funding processes, and looks for similarities between these new structures and their predecessors.

4.1 Cardinals Stadium

In 2000, a government proposal in Maricopa County, Arizona, called Proposition 302 was initiated to fund the construction of a new multipurpose football stadium. However, the anti-tax nature of the Arizona government and the lack of recent success of the local team, the Arizona Cardinals of the National Football League, potentially discouraged voters from approving the ballot. Finally, with the correct funding mechanism using taxes on visitor spending, Proposition 302 passed a public vote by a slim margin and guaranteed new stadium construction for the area.

Scheduled to open in 2006 in Glendale, Arizona, Cardinals Stadium will host NFL home games, the Tostitos Fiesta Bowl of college football, and future Super Bowls

Figure 29: Cardinals Stadium (roof open)

as well as various trade shows and conventions. Indirectly, the project is meant to bolster state tourism and strengthen local Cactus League baseball. As a retractable-roof stadium in the progression of others before it, this structure emulates Reliant Stadium in some design features and pushes the limits of moving parts in such a building.

Designed by Peter Eisenman Architects, the shape of Cardinals Stadium is meant to resemble a barrel cactus, indigenous to the local area, and creates a rounded, rectangular appearance to the building (Figure 29). As a result, the roof system follows this form and is supported by two enormous arched trusses called "Brunels," which span 700 feet and are 87 feet deep in the center. Along these Brunels are two moving panels, which bi-part at midfield and measure 270 feet by 180 feet long.

The curved shape of the roof complicates the design of the rolling mechanism. A flat retractable roof is generally pulled along two rails by motorized cables and rests in an open position held with brakes or clamps. Nearby, at Bank One Ballpark, the cables for each roof panel undergo different levels of tension and must be closely controlled to open them at the correct speeds. In Cardinals Stadium, however, gravity is always trying to pull the panels off the top of the structure, and the brakes used in other similar stadiums are not designed to resist such high forces.

Therefore, the panels in this roof system are opened and closed by 16 independent drums, using 1.5-inch steel cables in constant tension. With winds at the height of the structure, the panels could be moving as fast as 29 miles per hour while opening, but the taut cables would always be in control of them; 8 special rail clamps are also included secure the roof in case of uplift. This way, the system has redundancy in holding the roof in place and simplicity of design and operation.

In designing Cardinals Stadium, the roof engineers at Walter P. Moore and Associates certainly had Reliant Stadium in mind. The roof panels in both stadiums bi-part at midfield and have aspect ratios close to 1.5. Both roof coverings are also made of a similar lightweight, translucent, expensive material that lightens the weight of the roof, promotes natural grass growth, and warrants some design against uplift. The roof support structure in Cardinals Stadium resembles the four-legged table system used in Reliant Stadium. The long steel Brunels are supported by 171-foot tall concrete supercolumns, and all six elements together could stand separately from the rest of the building.

To release lateral loads on the roof structure, engineers at Uni-Systems, LLC, designed a small, unique mechanism within the transport assembly itself. Rather than using a release-hinge or 4-bar linkage system, the roof trusses at Cardinals Stadium attach to the transporters on the west side with linear bearings, which act as horizontal dampers

and can withstand up to 18 inches of movement in either direction (Figure 30). By actually resolving the design issue of lateral release inside the transporter assembly, this solution allows roof sections to be fabricated more efficiently and thus simplifies construction of the stadium.

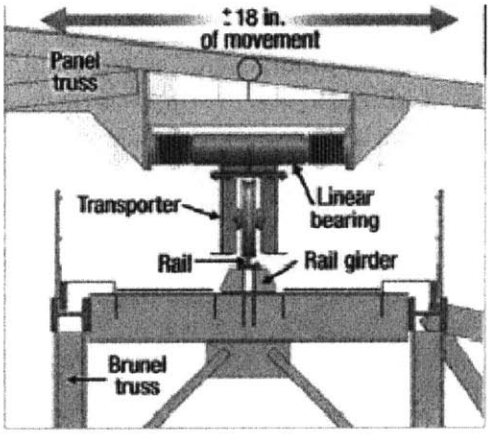

Figure 30: Linear bearing release system

Perhaps the most interesting and innovative feature of Cardinals Stadium is the movable field. In considering how to move the 16.9-million-pound turf reliably, there were three main options. First, the field could be pulled or pushed along bearing pads or rails underneath, but the force required to overcome friction would be unreasonably high. Next, the turf could be floated on a film of pressurized water or air; however, the equipment required for this system is very expensive and difficult to maintain and repair. Finally, a wheel-and-rail system, similar to that on which retractable roofs are moved, would provide a quiet, low-power, reliable method of moving the field if properly designed (Figure 31).

The entire moving turf system in Cardinals Stadium is about 30 to 35 inches deep and can travel from its position inside the stadium to a location beside it in a little under an hour. The structural frame and shell, known as the pan, includes all drainage and sprinkler systems, and the wheels on which the field moves are made of hardened steel and bolted directly to the pan. Rails must be placed every 20 to 30 feet to spread out the enormous load, and one row of wheels must be double-flanged for horizontal guidance in the case of any unexpected lateral loads.

The total cost for Cardinals Stadium was approximately $375 million, $75 million of which for the roof and $2.5 million for the field mechanism. Public funding was

agreed to stop at $266.6 million, and the Cardinals organization will share the remainder of the price as well as any additional costs. Since several features of this structure's

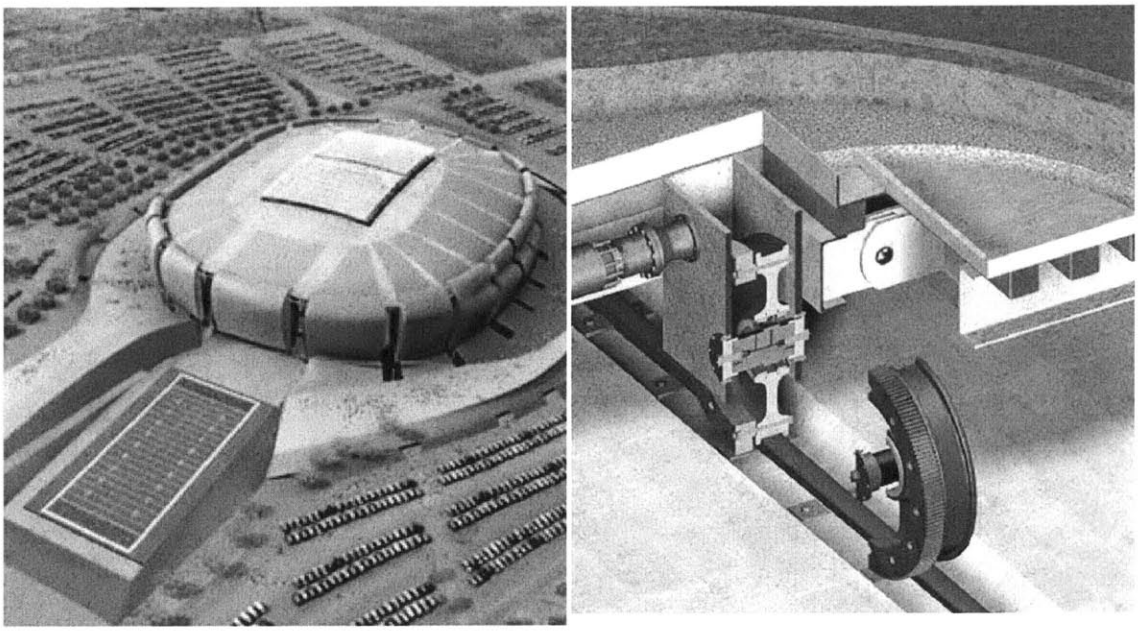

Figure 31: Movable field (left) outside stadium and cross-section of field (right)

design are original to its building type, cost-efficiency was a driving factor in determining simple solutions to these issues. These financial figures may be comparable to those of Bank One Ballpark, built 7 years ago, but do not indicate the advances in technology since then. With a seating capacity over 70,000, this structure is building upon several aspects of Reliant Stadium specifically and will likely be a successful multipurpose stadium in the future.

4.2 Marlins Stadium

Since 1993, the Florida Marlins of Major League Baseball have played their homes games at Pro Player Stadium, which they share with the Miami Dolphins for the National Football League. The shape of this stadium is not perfectly suited for viewing baseball games, and due to the volatile summer climate of south Florida, rain is often a threat to game delays or cancellations and can drive fans away. Although average attendance has been increasing recently, it is still one of the lowest figures among the other 29 franchises. After the team's world championship season in 2003, the Marlins

organization and government of Miami-Dade County announced plans for a new ballpark, initially conceived with a retractable roof.

Scheduled to open in 2008, Marlins Stadium is yet to begin construction and already has a number of design concerns. From preliminary concepts, the roof system will resemble that of Minute Maid Park in Houston, Texas, and open in 3 panels, 2 of which will slide and store under a larger one (Figure 32). Since this type of structure has existed for almost 15 years, architect HOK Sport is listening to the desires of the local residents and planning a more contoured roof shape than the stiff, flat panels of other retractable-roof stadia (Figure 33). Additionally, the ends of these panels will not reveal the ugly trusses which support the panels but instead be concealed by cantilevered bulkheads which conform to the rest of the roof.

The frequent incidence of hurricanes in the Miami area creates wind pressures that could be twice as severe as that of Houston, site of two stadia with moving roofs. A retractable roof on a Miami stadium would virtually act as a giant sail and have to bend and flex significantly to distribute these winds loads down through the rest of the

Figure 32: Concept of Marlins Stadium (roof open)

structure. Such a lateral release system could require great amounts of steel or concrete and, thus, increase the cost and complexity associated with the project. Additionally, the bulkheads on the end of each roof section will put added stress on the wheels nearest to them and possibly redistribute the roof load along the rest of the wheels in an unknown

manner. This feature could potentially call for a new type wheel suspension system and further increase the cost of the structure.

Up to today, the funding process for Marlins Stadium has taken a number of controversial twists and turns. Shortly after the announcement for new stadium construction, the city of Miami proposed a location directly adjacent to the existing Orange Bowl, and county officials agreed to fund their portion of the cost of the new venue. At the end 2004, the Marlins were notified that they would no longer be able to play in Pro Player Stadium after 2009 and consequently began a strong push to complete a definite funding proposal to keep the team playing in Miami. Just three months later, county officials publicized plans for a $420 million project including a retractable-roof stadium and parking garage at the originally chosen location.

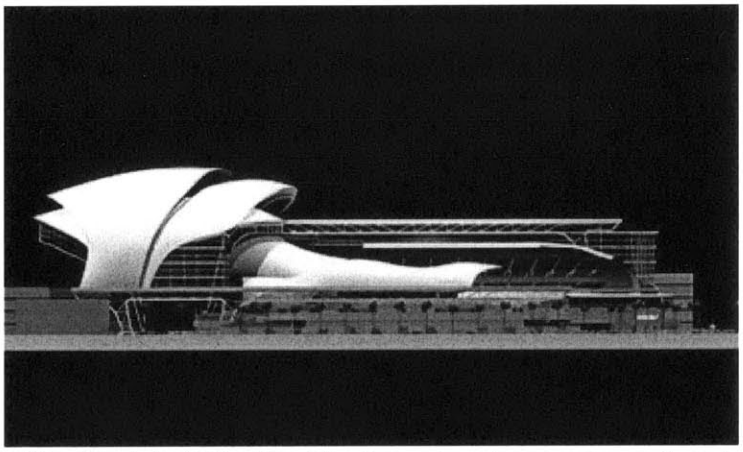

Figure 33: Model of Marlins Stadium showing contoured roof panels

The proposal stated that Miami-Dade County and the city of Miami would contribute $166 million, $138 from sports facility and hotel taxes and $28 from tourism development taxes. The Marlins would pay $30 million in design and construction expenses and $162 million in rent payments, for a total of $192 million, as well as absorb any cost overruns. With $60 million unaccounted for in this plan, neither party has been willing to pay its share, and the matter has been taken up in the Florida legislature.

With the latest of almost 1000 failures on May 5, 2005, all proposals to subsidize this amount have been voted down by the Senate and House of Representatives in a state that rarely gives tax breaks to sports stadiums. Clearly, further design and construction plans cannot be carried out until an agreement is made, but the Marlins seem to have a leveraging point in threatening to move the team to a new city. Las Vegas has expressed

its interest in a professional sports team for years and could put up the money for new stadium construction if a franchise such as the Marlins were interested in the playing there. Considering this possibility and the short time remaining to form an agreement, perhaps the people of south Florida will persuade their legislators to subsidize the extra $60 million and keep the team in Miami.

The combination of structural and financial issues with Marlins Stadium makes it an interesting case to observe in the future. If it is completed within the specified time frame, the new moving structure will be able to operate in a very unstable climate and answer new design challenges for this building type. If a deal cannot be reached and the team leaves the city, the conflict between motivations and cost associated with retractable-roof stadia will be evident in the sports world.

4.3 Colts Stadium

The Indianapolis Colts of the National Football League relocated to this city two decades ago for the RCA Dome. While this stadium was once sizeable for its time, it has been surpassed by modern structures with greater capacities. In fact, its capacity of 55,506 is the smallest of any NFL stadium. To increase stadium revenues and to play on a natural grass surface, team owner Jim Irsay approached the local government about a new home for the Colts. The result was the largest funding bill for sports facilities in history, and the future benefits to the local area should be numerous.

According to Colts president Bill Polian, the team has been at a disadvantage for years as other franchises are putting up larger, more sophisticated stadiums (Reference 28). High-profile free agent players are often lured to new teams by signing bonuses, which are paid for by stadium revenue. This revenue is, of course, directly related to a venue's size, and thus teams with larger stadiums are more competitive in the league. If the Colts cannot be competitive in Indianapolis, team officials had discussed moving the team to another city which would commit to new stadium construction.

Indianapolis Mayor Bart Peterson did not want to lose the Colts during his administration and began negotiations with team officials during the 2004 season. Additionally, the National Collegiate Athletics Association headquarters is located in

Indianapolis, where postseason college basketball games are played every year. These events carry traditional value and are another important source of revenue for the city; therefore, replacing the RCA Dome would warrant a new venue for basketball as well.

On January 4, 2005, Irsay announced the proposal for a project which includes the new Colts Stadium and an expansion of the Indiana Convention Center. The stadium will be located just south of the RCA Dome and have a retractable roof, similar to that of Reliant Stadium, to harvest natural grass but also to host NCAA postseason and Final Four games on a standard four-year cycle (Figure 34). While it had sometimes been seen as cramped, the expanded convention center will be able to compete for more events.

With completion set for 2008, the total cost of the project is daunting at $900 million. After a number of arguments and failed proposals, an elaborate funding plan was finally created four months later, when Governor Mitch Daniels approved the bill calling for $50 million in bond payments and interest for 30 years. Tax increases will be imposed on food and beverage (in 7 counties surrounding Indianapolis), hotels, rental cars, and sales and income (within the city only). A state-appointed committee will also be formed to manage construction of the project and control any cost overruns.

Figure 34: Model of Colts Stadium near downtown Indianapolis

Although many legislators and Indiana residents are in favor of the new Colts Stadium, dissidents reside all over the state and feel that taxpayers are being forced to pay

too heavily. Successful sports teams can often leverage new stadiums from city governments by threatening to relocate in a city that is willing to spend on new construction. These stadiums are nearly always funded by tax increases, and to keep a franchise, the home city might pay more than its potential market competitors.

In the NFL, general ticket revenue is shared among all teams to create a competitive balance, but revenue from luxury boxes is kept entirely by the team owner. While the RCA Dome has only 104 of these suites, Colts Stadium will have an estimated 200 and thus potentially double this source of income for Irsay. Fans can view these design features as selfish exploitation of public funding, and since the team considered moving in 2002, local polls have indicated that residents are not willing to pay for new stadium construction.

The popularity of the retractable-roof stadium as the most advanced sports venue today is creating controversy between cities with aging facilities and their teams. The all-in-one combination of convention center and stadium is an appealing but very expensive solution to a multifaceted problem. The city of Indianapolis will keep the Colts for the next 30 years, but at what price? If the funding plan for this project is upheld, the scenario sets an ugly precedent for public exploitation. Now that this building type has been proven successful by structures in Houston and Arizona, namely, it has entered a new phase of development and become the preferred choice for all future stadium construction.

4.4 Cowboys Stadium

For over 30 years, the Dallas Cowboys of the National Football League have been playing in Texas Stadium, a unique structure with a permanent roof opening and a synthetic turf field. However, the emerging technology in sports venues and the team's desire for a natural grass playing surface were persuasive arguments for the owner of the Cowboys, Jerry Jones, to consider new stadium construction. In the last few years, funding has been secured for a new retractable-roof stadium in Arlington, Texas, but there are a number of issues surrounding this project even before it gets underway.

In early 2004, the Cowboys announced plans for a new stadium and first approached Dallas County with a plan for a $650-million stadium, of which $425 would be publicly funded. A preliminary concept shown in Figure X depicts an innovative roof system with two semi-circular panels which cover the entire structure and open by rotating and sliding around the perimeter (Figure 35). Keeping in mind the success of Houston's Reliant Stadium, which was funded 75% publicly, the Cowboys felt this was a

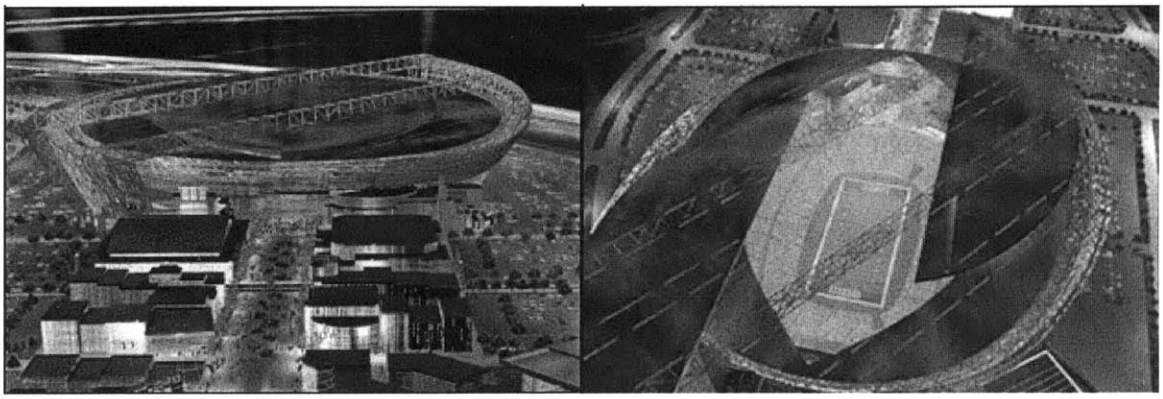

Figure 35: Concept of Cowboys Stadium with roof closed (left) and open (right)

fair offer. Dallas residents, however, were surprised at this figure, and legislators sought to restructure the funding allocation.

Two other parties, with different motivations, became factors in the negotiations for this project. First, the committee from the SBC Cotton Bowl, a semi-major college football game played in Dallas annually, wanted the stadium deal to be reached as soon as possible because a new state-of-the-art venue might help it become a premiere college bowl game. Also, the American Airlines Center, which hosts professional basketball and hockey games in Dallas, has an agreement with the city that no other such arenas can be built in the city, for fear of competition with securing concerts and other events.

In June of 2004, the Cowboys openly considered other locations for the stadium, such as Arlington, Grapevine, Las Colinas, and Tarrant County. Of those, Arlington already had an established franchise and stadium in the Texas Rangers of Major League Baseball and Ameriquest Field, respectively. The next month, the Cowboys met with government officials in Arlington and offered them a "50-50 deal," half public and half private funding for the stadium. Finally, in early 2005, an agreement was reached between the Cowboys and Arlington, which would pay the lesser of $325 million and half of the stadium cost and would also receive an annual $2 million lease payment.

The site chosen for the new stadium is also a source of controversy. In May 2005, the Cowboys revealed that they would build on residential and commercial land near Ameriquest Field. Upon this announcement, residents of the targeted area were very upset, and some have refused to move despite the Cowboys proposed buyout. The dispute is currently being resolved, but the Cowboys are prepared to force these residents to leave to begin construction in the spring of 2006.

Scheduled to open in 2009, Cowboys Stadium will cost an estimated $650 million, $250 million of which for the roof. This cost is quite extravagant compared to that of existing retractable-roof stadia and must be justified in some way. Cowboys vice president and chief operating officer Stephen Jones has described the importance to the city of being able to host other events but does not refer to any specific sources of revenue (Reference 25). For example, Reliant Stadium was built with the explicit intent of hosting the Houston Livestock Show and Rodeo and home games for the Houston Texans.

The Cowboys intended to use the stadium for home games and would benefit by playing on a natural surface, giving their fans a climate-controlled environment, and paying only a portion of the project cost. During the rest of the year, the city would be responsible for bringing in other events as additional sources of revenue to pay for the stadium. Thus, the Cowboys could play in a more sophisticated structure for roughly the same cost as an open-air stadium at the city's expense.

4.5 Jets Stadium

New York City is a candidate city for the 2012 Olympic Summer Games, and new stadium construction plans are an important part of its bid to secure the event. Meanwhile, the New York Jets of the National Football League, who currently share Giants Stadium in New Jersey, saw this initiative as an opportunity to play in a new state-of-the-art venue closer to the city. Land in the form of a rail yard on the West Side of Manhattan has been secured for construction, but there remains a great deal of opposition, both public and private, to the plan.

With a convention center included in the project, Jets Stadium has been designed with a seating capacity of 75,000 and a unique retractable roof. It could potentially host the opening and closing ceremonies, as well as track and field events, during the Olympics, and home games for the Jets beginning the following year. During the two weeks of the Games, this structure will ensure a timely schedule of events, uninterrupted by weather, and impress spectators with the latest sports-venue technology.

As seen in concept drawings, the roof system will cover a rectangular field and bi-part longitudinally, unlike the roof at Reliant Stadium in Houston, which separates above the 50-yard line. Although they reveal more of field area to the sky, the panels at Jets Stadium will measure roughly 300 by 1000 feet, an aspect ratio of over 3, as opposed to 1.5 in Houston. This geometry could create problems with deflection over the enormous span and thus require sophisticated methods of improving the stiffness while maintaining a lightweight, movable system (Figure 36).

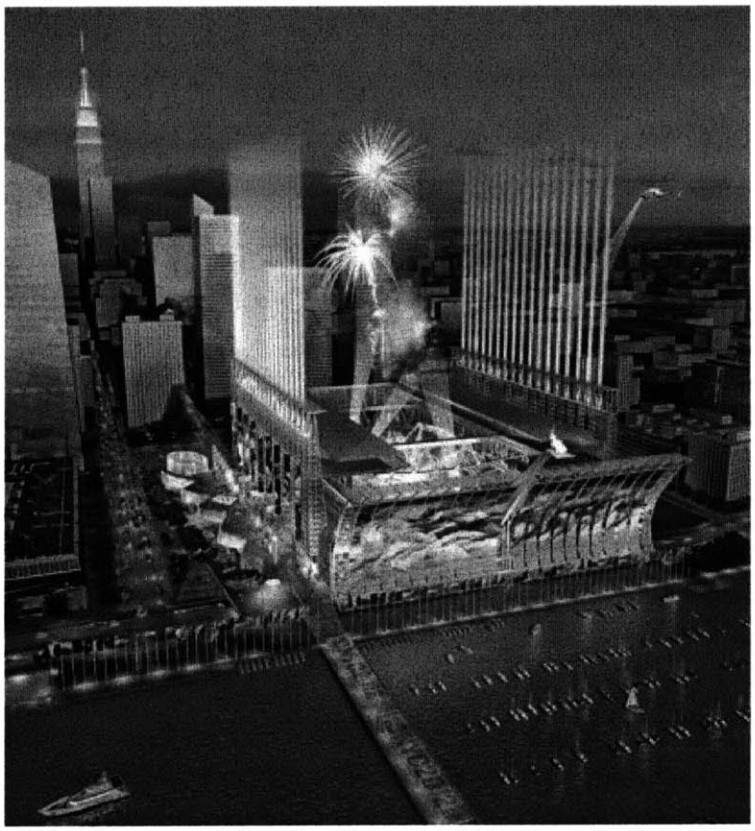

Figure 36: Concept of Jets Stadium at 2012 Olympic Summer Games

The former rail yard established as the site for this project is a vacant area located on the West Side of Manhattan, an underdeveloped section of such a booming area

(Figure 37). For this reason, the land is not very attractive to many developers or commercial businesses. Additionally, the Metropolitan Transportation Authority, which owns the land, needs capital for a new subway line on 2nd Avenue as well as for renovation of existing stations and trains. The Jets organization bought the land from the MTA for a negotiated price and fully intends to build a new stadium there.

Figure 37: Vacant West Side area around Jets Stadium

With the announcement of the location for the 2012 Olympic Summer Games in July 2005, a funding plan for the project would have to be in place soon for the city to garner serious attention from the International Olympic Committee. In fact, New York City is currently seen as unlikely to receive the selection for the Games, but Mayor Michael Bloomberg has been intent on passing a proposal since the beginning of the year. The original financial proposal stated that the Jets organization would completely fund the $800 million stadium and that the city and state of New York would each contribute $300 million to the convention center and the remainder of the project.

The mayor has repeatedly spoken about the number of new and long-lasting jobs which the project will create for the city, but the funding plan could be far more detrimental. While the Jets' portion of the project seems fixed, the total cost has already risen to $2.2 billion, the remainder of which must be covered by the city and state; this extra capital will undoubtedly come from tax increases to state residents, many of whom will most likely never enjoy the stadium. Moreover, if the Olympics are not awarded to

New York City, which is a distinct possibility, the potential funds for the convention center could be diverted to stadium construction, which is a more certain undertaking. If so, in the footsteps of the Marlins and Colts, the Jets will receive a new venue at a fraction of the total cost.

Understandably, there has been and continues to be significant public opposition to the project. Local protesters are pleading for the money devoted to this stadium to be used for new schools, firehouses, and other municipal programs. Other dissenters believe that mayor Bloomberg is using this effort to help his chances for re-election in the fall. In terms of local construction, there is also an issue of priority as the new World Trade Center project, which has been well regarded as an important one, has stagnated and will possibly require additional funding from the city. To many, a new sports stadium pales in comparison to the meaning behind erecting a new tower in downtown Manhattan, and thus funding should be allocated accordingly.

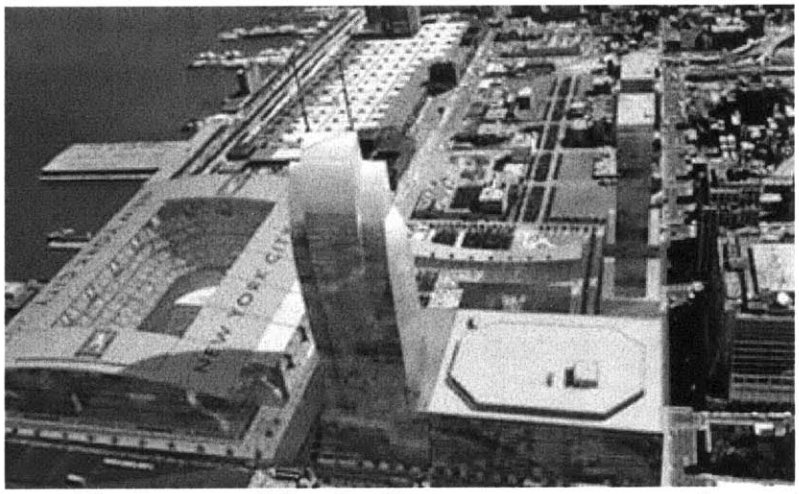

Figure 38: Concept of Jets Stadium next to new convention center

Private opposition has come directly in the form of the owners of Madison Square Garden, a nearby sports arena that would potentially compete with Jets Stadium for sports and entertainment events such as concerts. These owners believe that the bidding procedure for the land in the rail yard was unfair and flawed and have consequently filed a lawsuit to void the Jets' bid to build there.

In perhaps America's richest city, the cost for a convention center and retractable-roof stadium has reached a new height, and if it receives the proper funding and approvals, the project could be a great addition to New York City (Figure 38). However,

the exact need for a moving roof has been somewhat overshadowed by the desire to have a technologically advanced structure. In this sense, this building type has quickly evolved in the last 10 years from one of specific purpose and raw appearance to a symbol of refined sophistication for a city and franchise.

5.0 Recommendations and Future Projects

5.1 Recommendations for continuing progress

The progress of technology associated with retractable-roof stadia has been similar to that of elevators in America. Elevators have been used in this country since the mid-nineteenth century and were prevalent in buildings by the end of that century. However, the first safety code for elevators was not published until 1921, almost 70 years after the first inception of the technology. This gap in time attributes to a phase of tremendous development in understanding power sources, machinery involved, specific dimensions, human requirements, and many other factors in refining an invention.

Before the Rogers Centre was built, there were no retractable-roof stadia in North America, no precedents from which to study and learn. Government agencies or trade organizations could not issue any kind of permit for this type of building, thereby forcing designers to work simultaneously with uncertainty and creativity. Also missing were insurance companies willing to cover financially such an unproven and risky structure. For all these reasons and more, the success of the Rogers Centre to this point is an amazing structural accomplishment in terms of safety, appearance, and functionality, though its financial repercussions have been unfavorable at best.

Beginning in 1998 with Bank One Ballpark, America has seen retractable-roof stadia grow in popularity from a structural anomaly to the standard of excellence in sports-venue technology. Bank One Ballpark met demands of environmental control and seating requirements while incorporating interesting design features used in future facilities. Safeco Field provided a welcome change from Seattle's existing arena with a new earthquake-safe structure that reminds fans of older ballparks. In hurricane country, Minute Maid Park combines moving walls and roofs in a simple yet flexible system that saved the city of Houston millions of dollars. Although Miller Park has a one-of-a-kind fan-shaped roof, its design and construction have shown some of the many complexities and issues that arise without careful analysis and attention to detail. Finally, as an attractive lure for professional sports franchises, Reliant Stadium pushes the limits of

structural material and size, but its success has exemplified the right combination of purpose and expertise in planning a retractable-roof stadium.

In the future of this building type, engineers will be pushed to understand every issue associated with it and to design the most cost-effective solution. In these projects, electrical, mechanical, and structural engineers are working closely on individual but interconnected pieces of a very big puzzle. The more each one understands the role and responsibilities of the other, the more simple and economical their end product will be. But the pressing issue in these stadia is not the mechanism design for the moving roof but rather the unwritten safety standards that must be agreed upon and satisfied.

Before a code of some sort can be written for a retractable-roof stadium, an organization of companies in the trade must first be formed. This association will function as a collaborative to establish fundamental concepts, construction tolerances, dimensions, specifications, and other details useful to a new designer in the field. Since this building type is a relatively narrow specialization, experts in the field should be structural engineers with strong proficiency in electrical and mechanical engineering as well.

As for the stadia themselves, there is the possibility that they are not a long-term solution to modern sports venues. Since they are still buildings, these structures are sometimes incapable of providing an environment for grass to grow throughout the year. Otherwise, replacing the field periodically can become a serious expense. The efficiency of the steel rail system is also in question as the best way to move such a heavy section; track wheels were never intended for a purpose with such a heavy load, and the amount of machinery in the mechanism increases the complexity of the system.

Movable walls are a common design theme in several existing retractable-roof stadia because of the atmosphere they add. Perhaps if these glass walls are enlarged and the stadium geometry changed slightly, they could take the place of a moving roof altogether in bringing in light and air or shielding spectators from the weather. As shown in facilities such as Miller Park, these walls can slide into part of the rest of the structure with limited machinery and operation. Moreover, they amount to only a fraction of the cost of a bulky, multi-panel roof system. Today, retractable-roof stadia have been refined as a building type but can still benefit from valuable additions such as movable walls.

5.2 Potential future retractable-roof projects

There are a variety of characteristics that make a site susceptible to construction of a retractable-roof stadium. As a new building project, such a facility will be attractive in areas where an existing stadium is out-of-date and in need of replacement; typically, an existing stadium is replaced after 30 years or so. Since football is generally played in all conditions, this type of structure will be more popular in baseball locations with potentially uncomfortable weather or climate, so as to protect against cancellations. Cities which also do not currently have a multipurpose outdoor facility might consider this venue because of the variety of options it provides for sports and other events. Finally, and perhaps most importantly, a city that can garner the funds for a new retractable-roof stadium will definitely consider it for its football or baseball team, as this technology is still new and highly desired.

With these attributes in mind, Minnesota is a very good choice for one or two retractable-roof stadia in the future. Home to both MLB and NFL teams in Minneapolis, the Hubert H. Humphrey Metrodome is one of the few domes remaining in either sports league. A stadium with a moving roof could be the perfect solution for protection from Minnesota's northern climate while still harvesting a natural grass playing surface. The challenge for the city and state could be collecting the funds to begin construction for one or both teams.

St. Louis could be building a new retractable-roof stadium very soon. Since 1966, the city's MLB team, the Cardinals, has played in Busch Stadium, a typical 1960's circular stadium that does not afford its spectators great viewing. Fans would benefit from an air-conditioned facility, as St. Louis usually experiences hot and humid weather throughout the summer. Additionally, the city has not undertaken outdoor stadium construction recently and may have already been considering the possibility before moving roofs became popular.

Los Angeles should be a good possibility for one or two retractable-roof stadia in the future. As an exception to the aforementioned characteristics of potential sites, the city does not often suffer from inclement weather or a lack of multipurpose facilities.

However, the Los Angeles Dodgers of Major League Baseball have been in their current stadium for over 40 years, and more importantly, the city has been trying to secure a NFL team for several years. While an open-air stadium would be sufficient for either team, Los Angeles can accumulate the money needed for new retractable-roof stadia, in much the same way New York has. The former might view the image associated with such a new structure as important to the area, considering the other cities that already have these stadia or plans to build them.

6.0 Conclusion

These existing stadia incorporate many successful solutions to structural design problems and act as valuable precedents for future designers. Four different roof systems have been shown to operate smoothly and open the playing fields below to a great deal of sky and sunlight; adding to this outdoor feel are moving walls, which, when combined with an open roof, can greatly increase lighting and create fresh air circulation inside a stadium. In all of these structures, the systems designed for release of lateral loads have combined simplicity of design with effective engineering technology. These forces can potentially damage or destroy a stiff structure, and thus flexibility is essential in resolving them in a safe, controlled manner. Finally, new but proven building materials can give designers additional options in developing an optimal structural solution.

While the retractable-roof stadia of the future will certainly build upon this progress and emerge with fascinating designs, their costs may be growing out of proportion with their technology and financially hurting their home cities. With the exception of the Rogers Centre for good reason, existing venues with moving roofs can certainly control total cost without sacrificing appearance or functionality. For example, Minute Maid Park has a final price tag under $300 million, while Safeco Field exceeds $500 million in total expense. These figures roughly converge around a $400 million average, which agrees with the estimates for Cardinals and Marlins Stadiums in Arizona and Florida, respectively.

However, in Arlington, Texas, and Indianapolis, Indiana, stadia in earlier stages of development are expected to exceed $600 million. Inflation is not enough to justify this quick and dramatic increase in cost, and the preliminary designs do not indicate extravagance that would warrant such additional funding. Therefore, several scenarios are possible.

Sports teams could be seriously leveraging their home cities to pour money into this type of stadium, even if it is not necessary. The building type itself may have achieved an image of technological advancement that is appealing to teams or cities which are willing to pay high prices. Perhaps simultaneous construction with a convention center drives the cost of the stadium up from its original value. In any event,

the $800-million Jets Stadium plan in New York City is the pinnacle to this point, and should it be constructed, organizations in the future may reconsider a retractable-roof stadium as an appropriate option to their needs.

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