IDP2 Project Brief: Retractable Stadium Roof

1. Background

Demands for stadia and large buildings equipped with a retractable roof structure are significantly increasing. Such a structure prevents games and events to be cancelled or rescheduled due to unexpected weather conditions. They also attract more attendance. First retractable roof structures can be traced back to ancient Roman civilization (see Figure 1). They developed covered buildings which intended to be used for various public events such as circus and theatre. Foldable covering wings made from wooden beams, canvas and ropes were used as a simple retractable roof which could be unfolded above the roof stands to protect people from severe weather conditions.

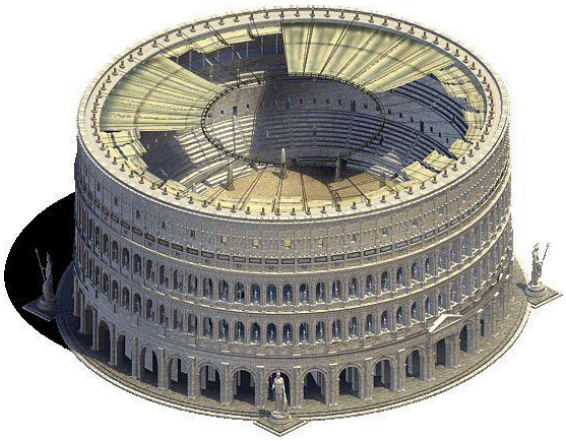

Figure 1 Roman retractable roof for colosseum [1]

From ancient Roman era to recent modern stadia, the main purpose of retractable roof structure is to allow to use the building in various weather conditions and makes sports and other events independent of the local weather. In addition, it is desired for many sport events to retain outdoor conditions such as natural lighting and ventilation. This increases the demand for stadiums with retractable roof structure. The roof usually remains opened by default whilst the weather condition is favourable. However, the roof structure is required to be closed/opened in just a few minutes [1].

First generations of large modern retractable roofs were reintroduced in the 1950's. Since then many ideas and concepts have been proposed and a variety of systems and structures have been built. The first retractable roof structures employed crane technology to solve the problem. This followed by folding membranes and telescopic structures. In modern retractable roof structures the movement technology and the main structure design are based on the heavy weight and large dimension structures such as transhipment containers in ports and oil drilling rigs. Building's architectural design, user safety, interior design and other engineering characteristics are significantly influenced by movement of the roof structure. Sports buildings and stadiums with retractable roof have both fixed and movable roof properties and demand different design structures [2].

Figure 2 Wembley Stadium in London with the capacity of 90,000 people

The biggest stadium in the UK is Wembley in London which uses retractable roof structure with 90,000 seating capacity. It is used for a variety of sports and events such as national/international football matches including FA Cup final, Rugby Challenge Cup and musical events. The total area of the roof is 40,000 m^2, of which 13,722 m^2 can be retracted. The main purpose of the movable roof is to expose the pitch to direct sunlight to grow grass

effectively while protecting the attendees from undesired weather condition when needed [3].

2. Design Guidance

You have been requested to design a retractable stadium roof. The challenge in this project will be to develop your knowledge and expand your team working and technical abilities. You need to decide about the specification of the stadium such as capacity and location. In designing the roof, structural design, power train, load analysis and energy supply are the main areas to focus. The design will comprise of a conceptual design for the whole roof structure including its support structure and analysis of the design in detail.

There are various working principles to design retractable roofs. Typical designs consist of several panels which are rolled on motorized steel wheels over the steel rail. The wheels are commonly powered by DC motors using long cables. Operational opening and/or retracting time varies between 7 to 20 minutes based on design. Figures 3 and 4 exhibit examples of modern design considerations.

Your conceptual design will include the supporting structure, retractable roof structure, drive system and power train, and energy supply system throughout. Design considerations include structure (, loading), load analysis engineering (dynamic loads, gravity, wind loads, tension, compression, bending moments), drive and power train (actuator selection, power train design and motion mechanism, dynamical considerations), power supply (type and supply system), and roof safety analysis. Detailed numerical calculations are not required for the conceptual design. You should focus your efforts on elements your group deem most important and differentiate your design from others.

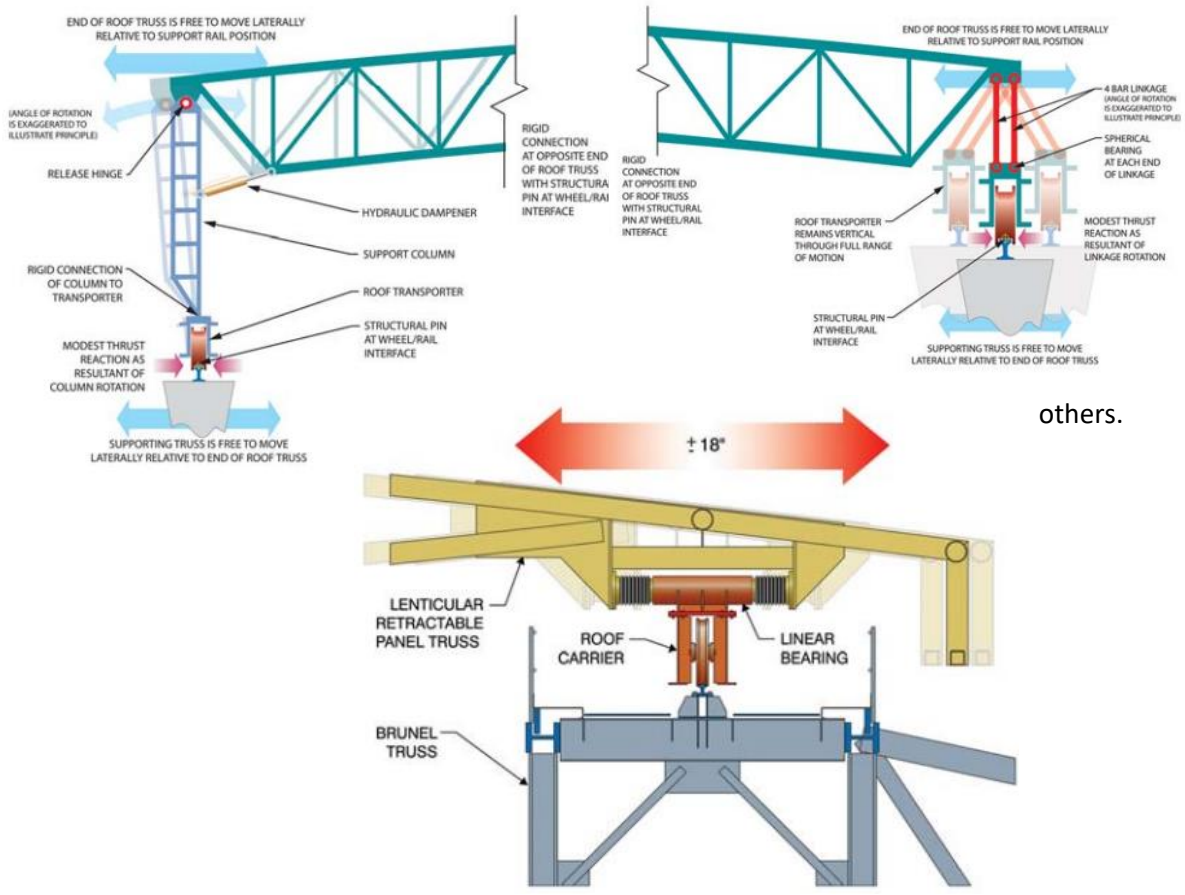

Figure 3 Thrust release mechanisms [6]

In addition to conceptual design you should consider effective pitch size, seating capacity, sun exposure to the pitch, wind/ air flow / ventilation, flexibility, stability, material selections, methods of assembly, manufacturability and cost. The design factor seminars will help you to determine their impact; evidence of their consideration must be provided in the final design.

The detailed designs are individual activities specific to your individual discipline. Civil Engineers should focus on designing the trust and the roof with load calculations. Electrical Engineers should focus on the power supply and power distribution system using model-based simulation and design optimisation techniques for energy and suggestions for energy efficiency. Mechanical Engineers should focus on actuator and drive selection, power train design and analysis, finite element analysis, and use SolidWorks software as a design-assisted CAD package. The software can also be used to model the moving roof operation to analyse the dynamics of the operation.

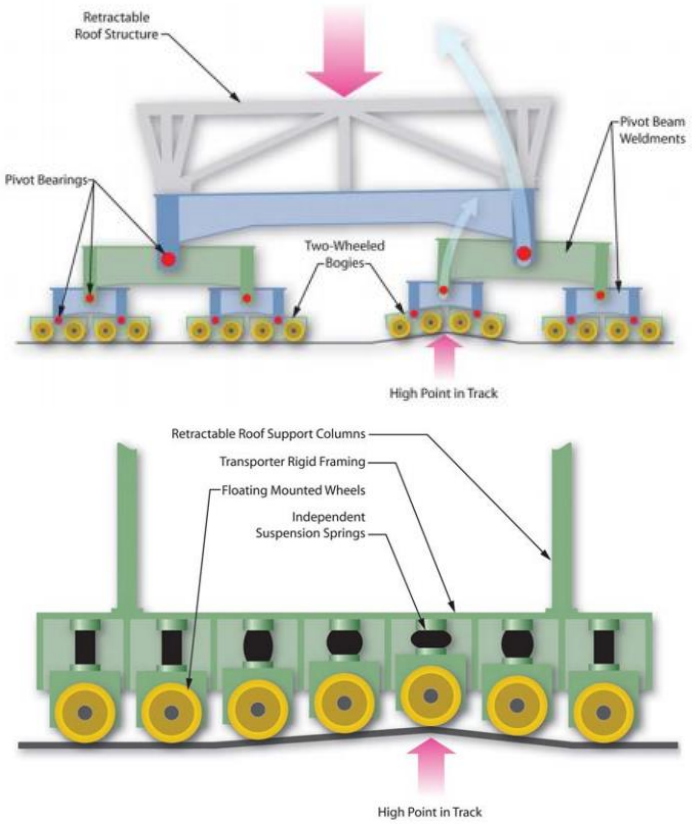

Figure4 Wheel suspensions and load distributions [6]

To encourage creativity, the design requirements have been left open ended. Consequently, as a group you are required to determine suitable values to produce a winner. These include the capacity of the stadium, design creativity, the structural stability, energy consumption, reliability and cost-benefit analysis. However, there are certain requirements that are fixed. These are the climate type (either Tropical, Moderate, Continental, Polar or Dry) and energy sources (local energy providers in UK). Each group is allocated a unique combination of these two requirements to ensure that your design should have unique characteristics. You are, however, allowed to choose the exact location of the stadium for any sport you like!

3. Comments from Industry: Arup

Many more retractable roofs are designed than are built: a significant number are casualties of ‘value engineering’ when the full cost of building a new stadium (normally a must have) with a moving roof (often a nice to have) becomes apparent. The obvious challenge of where the roof goes when it is open significantly influences the architectural and structural engineering concepts of the whole stadium. Whilst you are not required to design the stadium, just the roof, you must have a plausible concept for the stadium as the two are completely interdependent. If your roof is to survive the value engineering stage it must complement the stadium design, be affordable and mechanically reliable. Movable roofs are mechanically complex structures, avoid the temptation to

be overly innovative in this aspect of your design – cost and complexity in the mechanisms could give your client cold feet. And don't forget the basics: where does all the rain water go? Depending on size and location, there could be a lot of it!

4. Support

You are expected to gather resources and information on existing Retractable roof designs from internet sources and case studies. A canvas discussion forum is available for general queries regarding this challenge. The forum will be monitored by Dr Mozafar Saadat.

References:

[1] Andrej Mahovic, Typology of Retractable Roof Structures in Stadiums and Sports Halls, *Theory and Practice of Spatial Planning*, 2015; 3: 90-99

[2] P. E. Kassabian, and Z. You, Retractable roof structures, *Proc. Instn Civ. Engrs Structs & Bldgs*, 1999; 134: 45-56

[3] http://www.wembleystadium.com/

[4] Kassabian, P. E., Z. You, and S. Pellegrino. "RETRACTABLE ROOF STRUCTURES." Proceedings of the Institution of Civil Engineers-Structures and Buildings 134.1 (1999): 45-56.

[5] Frazer, Andrew H. Design considerations for retractable-roof stadia. Diss. Massachusetts Institute of Technology, 2005.

[6] Riberich, Barton L. "Retractable stadium roofs and flooring." Structures Congress 2008: Crossing Borders. 2008.