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The engineering legacy of the FIFA World Cup Qatar 2022™: Stadium 974 – reuse as driving force for sustainability

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Stadium 974, located on the east shore of the Doha Bay in the municipality of Ras Abu Aboud, is the first fully demountable, transportable and reusable stadium of its kind. Modular systems in construction have a long track record in the industry, but developing and delivering an entire scheme for such a complex venue under the requirements of a FIFA World Cup stadium had never been achieved before. The basis of the innovative concept of a temporary venue is to create a highly repetitive grid of identical structural frames, supporting standardised components: bleachers, concourse slabs and modules carrying containers pre-equipped with all required functions. The venue can then be easily demounted after the event and completely re-installed in another location or repurposed into many small stadia at different locations. All individual elements can be dismantled and transported within the certified shipping containers to the next destination. This enables efficient reuse of the material and hence results in a reduced lifetime carbon dioxide footprint due to less construction material and reduced waste. This pioneering scheme posed significant challenges and constraints for the structural design, and required a comprehensive approach, from the development of suitable structural concepts to the implementation in the structural detailing. This paper describes some of those challenges and the design solutions adopted.

Keywords: buildings, structures & design/light weight/modular construction/stadium/steel structures/sustainability

1. Introduction

The climate crisis poses a major challenge for the buildings design community, considering that the built environment is responsible for about 40% of greenhouse gas emissions (UN Environment and International Energy Agency, 2017). Bold and innovative solutions are, nowadays more than ever, required to help reducing the carbon dioxide (CO_2) footprint of every building, old and new. Large events like the FIFA World Cup or the Olympic Games require, every 4 years, a significant amount of new infrastructure to be built in the host countries. Depending on the legacy concept by the operator or the host city some of the newly and specifically built infrastructure for such large-scale events (e.g. stadiums) end up under-utilised in the years following the event. Typical legacy issues include the size/capacity of the stadiums (i.e. too large to be used outside the main event), less than expected economic and/or social legacy due to insufficient or lack of prior planning for legacy and operational creativity for the venue after the event (Alm *et al*., 2016). Therefore, careful planning of the legacy of the venue is required beforehand to ensure that utilisation is maximized after the main event (Ermolaeva and Lind, 2021; Talavera *et al*., 2019).

Using technology to provide flexibility for the use of existing infrastructure has proved to be extremely effective in reducing the carbon dioxide footprint when compared to new construction. The National Aquatics Centre in Beijing, China is one example, as it was equipped with the technology to enable it to be switched from the ‘Water Cube’ in Beijing 2008 to the ‘ICE Cube’ in Beijing 2022 winter games without re-configuring the structure itself. However, reductions could be achieved by developing structures that are conceived right from the start to be fully re-used/re-purposed or re-configured after the event (Francis *et al*., 2023; Jakimovska, 2007; Wergeland and Hognestad, 2021). This could be achieved by means of extensive use of modular construction concepts as well as careful interdisciplinary planning. Several attempts in this regard have been recently implemented, for instance, for the Rio 2016 Olympics aquatics and handball venues. Developing and delivering such a scheme for a complete stadium under the complex and very demanding requirements of a FIFA World Cup, had never been accomplished before.

Stadium 974, one of the FIFA World Cup Qatar 2022 stadiums located on the east shore of Doha Bay, Qatar, has a net capacity of 40 000 spectators and is the first fully demountable, transportable and reusable stadium of its kind (Figure 1). Kucukvar *et al.* (2021) and Al-Hamrani *et al.* (2021) presented a comprehensive analysis of the social sustainability and legacy aspects of the FIFA World Cup organisation, with Stadium 974 as a case study. Setterwall (2021) presented a greenhouse gas accounting report for the FIFA World Cup 2022. This report presents the full construction emissions for stadium 974 in accordance with the ISO 14040 (ISO, 2006) life cycle assessment standard, as well as an estimate of the emissions related to dismantling the stadium.

The aim of this paper is to present the technical aspects considered during the design, planning and construction, to deliver the first fully demountable stadium for this type of event.

2. The concept: a plug-and-play stadium

Every 4 years, expensive cutting-edge design stadiums are built for the World Cup, an exciting month-long event culminating in the final match and a spectacular closing ceremony. The future of such new stadiums, however, has long been the subject of debate when legacy planning for events of such stature. Unfortunately, the reality is that most of these stadiums remain underused throughout the following years, struggling to make their financial case sustainable in the long run. A much better outcome would be the conversion of the original green-field site into an urbanised site with a boosted value ready to be developed supporting regeneration, economic development and job creation – without the stadium. This purpose can only be achieved with a demountable and transportable structure that is only used for the month-long tournament.

The innovative concept of stadium 974 is based on a simple principle: to create a temporary venue that is fully fabricated off-site, transported and installed on-site, and can then be easily

Figure 1. Exterior rendering of the stadium from the harbour

demounted after the event to be completely re-installed in another location or repurposed into other different venues at different locations (SBP, 2019). Once the World Cup event ends, the stadium components will be dismantled into pieces and stored in containers for later shipment to another location. The stadium can be moved as a whole to a different location. Equally, the components can be moved separately to make different sport venues (Figure 2). For all legacy strategies some additional works may be required such as re-foundation, rebranding and mechanical, electrical and plumbing (MEP) re-adaptation. Furthermore, a structural design verification taking into account the new site-specific loading condition (wind, seismic, snow, etc.) and final legacy building arrangements is required.

To achieve this, the principles of modular construction are implemented in a highly repetitive grid of identical structural frames, supporting standardised components: bleachers, concourse slabs and modules carrying containers pre-equipped with all required functions.

The 'kit-of-parts' (Figure 3) can be dismantled in several parts so it can be easily reconfigured in many other facilities. The design intent was to retain the same modular design that had been considered in the current stadium design in the future legacy buildings. Modular elements in 'blocks' show how the elements can be reused in different configuration designs. The individual 'blocks' are either separated by the expansion joints in the original stadium or separated by a bolted splice at the different floors. The structural elements located on the main gridline of the expansion joint will belong to the corner sector when the stadium is demounted and reused. For straight sectors, additional elements on the expansion joint, such as columns, rakers and beams, will be needed to build an independent structure.

To optimise the different elements used in the design, the stadium is divided into different zones. This separation is reflected not only in plan but also in section, so that different facilities can be created with the same modules. As the stadium gridlines are symmetrical, the modular elements can be easily implemented in future legacy buildings. In section there are two areas that can be easily converted in the different legacy proposed buildings (the lower and upper tiers). In plan, the zones correspond with construction areas and are separated by expansion joints. Joints are located between the curved and straight sections, resulting in eight different zones. The combination of zones and tiers produce a total of 16 'block' segments/modules. The containers and slabs maintain their relative position within each zone and section. All structural elements maintain the position in their zone and section. This 'kit-pf-parts', together with the steel roof truss, can be mixed and matched to create other sport venues or even other types of buildings.

There is a wide range of options in which the stadium can be configured, however, the legacy design focused on five of the possible options to reuse all the different block modules, as explained above. These five options were:

- option B1: 5 K athletics stadium
- option B2: 20 K football stadium
- option B3: 7.5 K swimming pool complex
- option B4: 7.5 K multipurpose pavilion
- option B5: 5 K athletics stadium

In this paper, more detail will be provided for options B2 (20 K football stadium) and B4 (7.5 K multipurpose pavilion) to provide some detail to the reader. The configurations for the other options follow a similar trend.

Option B2. The 20 000 capacity stadium is created using the lower tier of the original 40 K bowl structure. In order to provide certain roof cover, the roof trusses of east and west

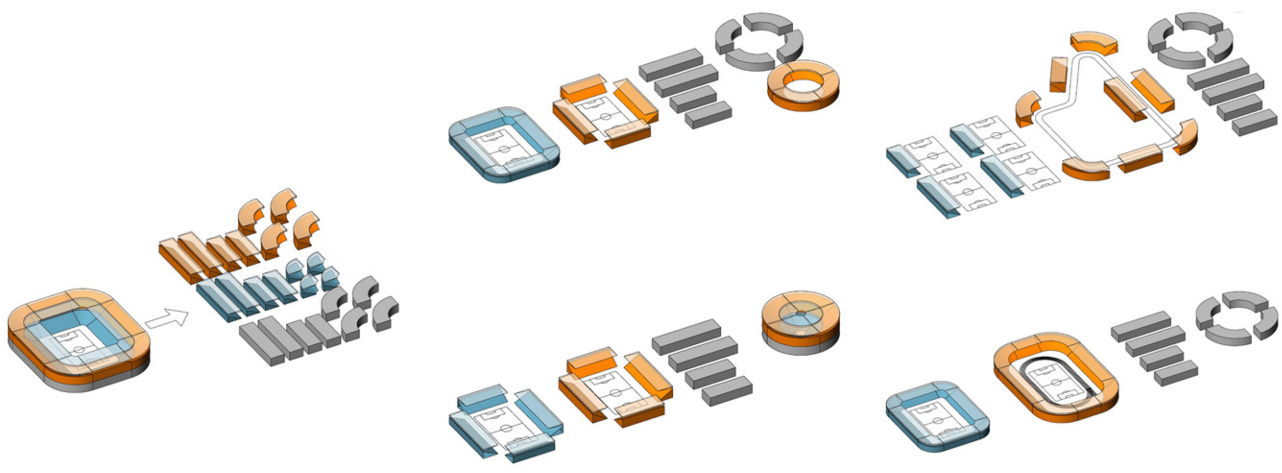


Figure 2. Transformation of the stadium into several different smaller venues

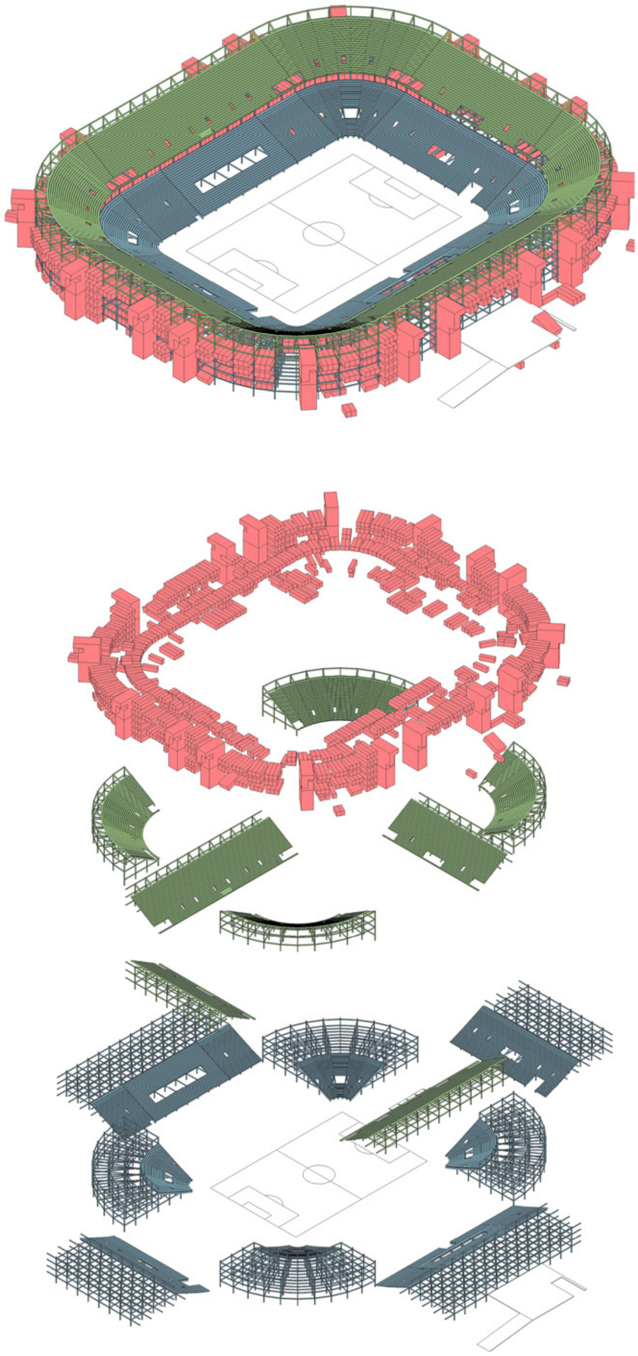


Figure 3. Stadium 'kit-of-parts'

sectors are used. The staircase towers will only be partly used to access the new most upper floor. The tier is assembled at ground floor height with the same original container and slab configuration. The stadium will keep its lower tier with hardly any modification and only some adjustments on the roof to connect this one to the lower tier and not to the upper one. The whole lower tier keeps the same structural integrity and no new elements are needed for the new use of the stadium. Bearing in mind that the roof only runs on the long straight sectors in this configuration, both sides will need to be adjusted to this new condition as they cannot be attached to the main corner bay where the expansion joint was located in the original design.

Option B4. The corners of the upper tier of the original stadium can be dismounted and reused for a new multipurpose arena of approximately 7500 spectators. The corner roof trusses of the zones 2, 4, 6 and 8 can be reassembled to form the circular roof for this proposed legacy venue. This new rearrangement will need to maintain the expansion joint location and provide a gap between sectors to guarantee enough room for the primary elements that were on the main grids (Figure 4).

It should be noted that the MEP services, for the original stadium as well as for all the legacy options, have been designed in a modular arrangement with reuse and flexibility in mind. However, depending on the new locations these options may require some power, heating and cooling adjustments.

All the elements of stadium 974 are fully demountable and consist of members that allow for simple dismantling and transportation in standard shipping containers (Figure 5) as detailed below.

- All bowl structural elements are less than 12 m long and fit in regular shipping containers for transportation.

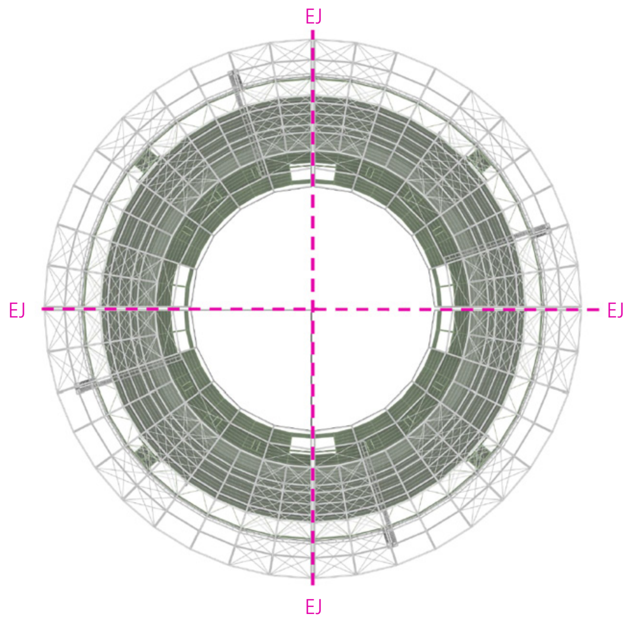


Figure 4. Expansion joints for legacy option B4 for stadium 974

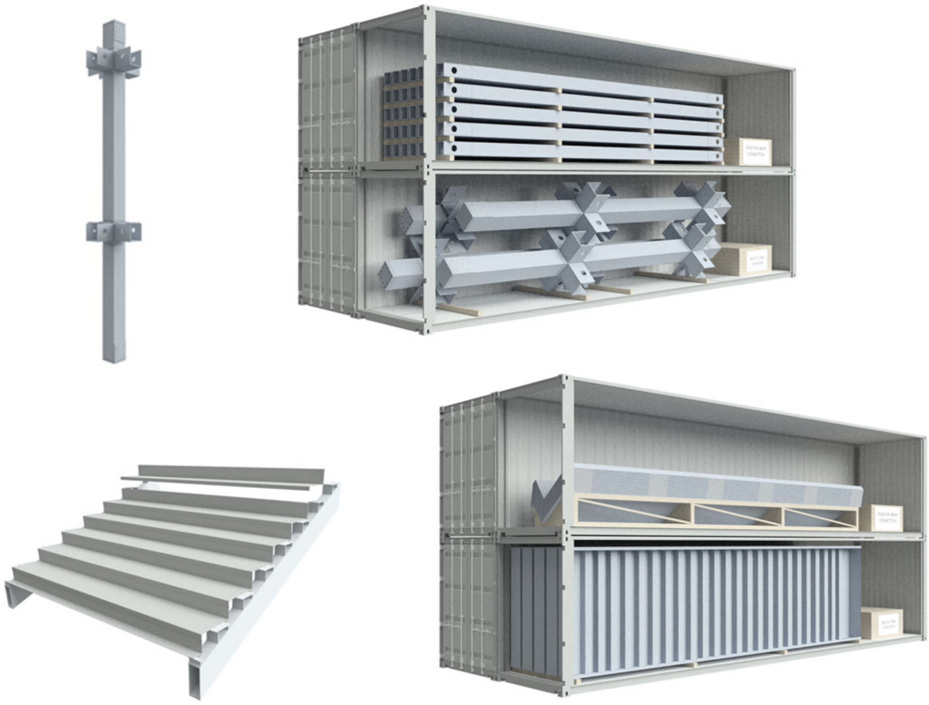


Figure 5. Elements of the structure designed to fit inside standard shipping containers

- All roof purlins, bracings are less than 12 m long and therefore fit in a regular shipping container.
- The roof backstays are in total nearly 39 m long; however, they are composed of four segments, giving a maximum segment length of <12 m, and thus transportation in a container is possible.
- The outer roof V-struts are <12 m long and thus fit in a container.
- The total length of the inner V-struts exceeds 12 m; however, the element is composed of two segments and thus the segments fit in a container.
- Only the long roof trusses exceed 12 m. They can be either transported outside containers/on the deck of a ship or spliced down to individual members with a maximum 12 m length.

This concept poses significant challenges for the design and implementation: modular construction principles deviate significantly from normal practices that govern the construction of stadiums. The construction industry, in general, does not adopt major changes easily and therefore the development and implementation of a modular construction for a large stadium required a challenging process of breaking the traditional thinking and changing the mindset of all the parties involved in this project. From the purely technical perspective, some well-established practices in the design of stadium structures needed to be reconsidered, taking into consideration the constraints imposed by the need for demountability and full reusability of the structure.

3. The structural system

3.1 The bowl frame

The 974 stadium bowl structure followed three guiding design principles; simplicity, regularity and repetition. These were implemented by designing a structure with high flexibility and a structural system that could be easily manipulated for further legacy use. With these principles in mind, a suitable structural system for the bowl was chosen as follows.

- A simple and regular hinged frame is the main load-bearing structure for the bowl, using bracings to deliver the required stiffness and rigidity. For easy installation and later dismantling, all tangential and radial beams are hinge connected to the bending stiff columns.
- The column segments are spliced by means of bending stiff bolted connections. No site welding is required to guarantee flexibility and demountability for reuse.
- There is a high level of repetition of standardised elements (e.g. only three outer column sections with varying wall thicknesses).
- Radial and tangential girders with standardized dimensions are used.
- The length of elements makes them easily transportable.
- Floor elements are prefabricated.

The stadium occupies an area of 212 m × 200 m in plan and a maximum height of 46.9 m above ground level. The structure of the bowl and roof is divided into eight sectors: four straight sectors and four corner sectors, separated by expansion joints. The main steel grid of the bowl (Figure 6) is based on a column and girder spacing of 9 m in the radial direction and 8.5 m in the tangential direction. On this steel grid, prefabricated slab elements will be placed to provide spectator areas and spaces for facilities. Containers are installed at all levels to provide all required services. The bottoms of the containers were used as slabs as well, such that no additional slab elements were needed below the containers. The structure of the four straight sectors consists of a series of modular steel frames forming a regular grid of 8.50 m × 9.0 m (in the tangential and radial direction, respectively) of square welded columns with modular external dimensions of 300 × 300 mm, 400 × 400 mm or 500 × 500 mm, varying from inner to outer columns, with varied plates thicknesses according to the load demand. The structure of the corner sectors is arranged in a radial grid, maintaining the radial distance of 9.0 m between tangential axes, using the same modular column dimensions. Owing to the geometrical constraints, the expansion joints of the bowl and roof do not feature a double support (i.e. double radial frame), as would typically be considered in a standard building. As such, the last bay of tangential beams and purlins of the straight sectors features a sliding connection to the first radial frame of the corner sectors, allowing only vertical forces to be transferred to the adjacent corner frame.

Each column, which is hinged at the base level, is connected at each intermediate level to the adjacent columns through a series of radial and tangential beams. Both tangential and radial beams, with standardised rectangular box sections, are connected to the columns by means of pinned connections. Horizontal diaphragm floors are created on each level by means of a series of tension rods connecting the opposite nodes of the grid diagonally, thereby making it possible to avoid using the floor system as part of the horizontal lateral system.

Tangential beams are standardised and shaped to receive and support either the modular slab elements that form the concourse levels of the stadium, a container or cluster of up to three containers, by means of a standard clamping system.

Concrete cores for staircases and elevator shafts are normally considered to provide stability to the system and are key components for the lateral resisting system of a typical stadium bowl. In the case of stadium 974, the staircases are considered as separate modules, completely independent from the bowl structure, for maximum flexibility of reuse in the legacy mode. To provide the adequate stiffness for the lateral resistant system, each sector includes a series of vertical bracing systems comprising circular hollow sections in both radial and tangential directions, which, together with the inclined raker beam, form the complete three-dimensional (3D) frame of the lateral resistant system (Figure 7).

Special care in the detailing of the connections of the different elements of the bowl was specified, aiming to achieve the maximum repetition and modularity, taking into consideration the requirements for demountability. All the connections were designed and specified to be fully demountable, avoiding any possible plastic deformation. Every structural element of the bowl (i.e. columns, beams, diagonal bracing, modular slabs, raker beams and bleachers) was designed to fit inside a

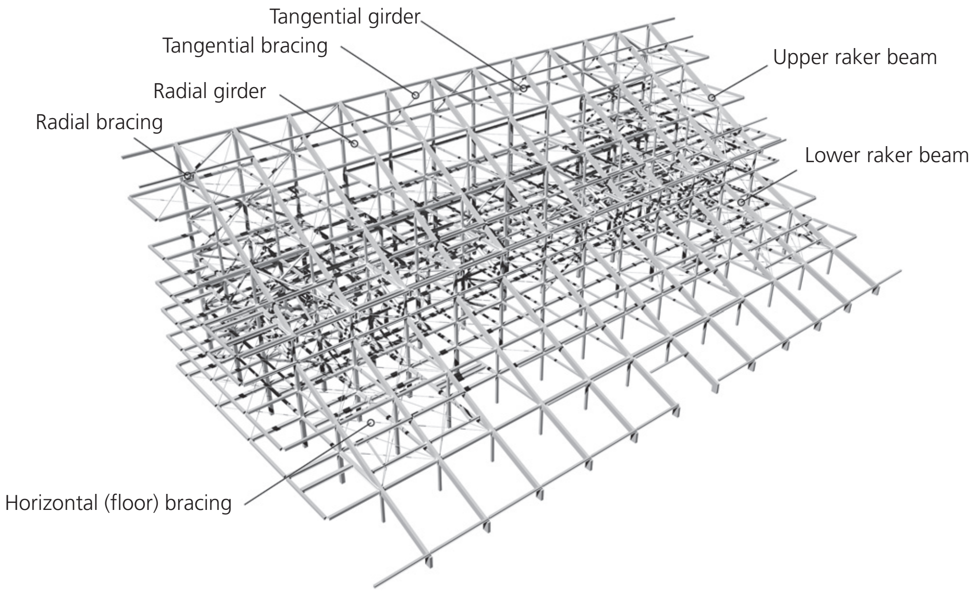


Figure 6. Steel bowl frame for stadium 974

Figure 7. Bowl modular steel frame during construction

standard shipping container, therefore all the elements longer that 12.0 m (basically columns and raker beams) required a series of bolted splices, to comply with this requirement.

The steel of all the components of the bowl structure (plates for built-up sections and profiles) was in general S355 JR/J0/J2 according to EN 10025-2 (CEN, 2004a), depending on the plate thicknesses, in compliance with the requirements of EN 1993-1-10 (CEN, 2005a). The tension rods are of steel grade S460N in accordance with EN 10025-3 (CEN, 2004b). All pinned connections are made of grade 34 CrNiMo 6 + QT according to EN 10343 (CEN, 2009).

3.2 The roof

The roof structure is also organised following the regular grid of the bowl and consists of a series of radial main trusses supported on the outer perimeter columns by means of V-shaped supports, cantilevering from 27.0 m in the north and south stands to 54.0 m in the east and west stands. The large front cantilever is counterbalanced with backstays connecting the back of the roof main trusses and outer V-struts to the foundation level; therefore, the vertical component of the roof forces is transferred to the bowl perimeter columns, while the radial component of the roof forces is introduced to the bowl radial frame system through the raker beams.

The roofing consists of trapezoidal sheet spanning 4.50 m in the radial direction over tangential purlins. The purlins are rigidly connected to the bottom chords of the main radial trusses, providing out-of-plane stability to those elements. Horizontal bracing of the bottom chord by means of tension rods is provided every other bay, while out-of-plane bracing of the V-struts is provided on every bay. V-struts, top and bottom chord and backstays consist of rectangular welded hollow sections, while the main truss diagonals and tangential purlins are made of standard HEA/HEB sections. The roof is sloped towards the outer perimeter, where the rainwater is drained through a perimeter gutter.

Structurally, in case of loads downwards (e.g. dead load, wind pressure) the V-struts are compressed while the backstay is in tension. In case of loads upwards (e.g. wind suction) the V-struts are in tension while the backstay is in compression. The lower chord of the roof truss is stabilised about the weak axis by the purlins and bracings. The upper chord is stabilised in the tangential direction by frames which consist of the purlins and the diagonals.

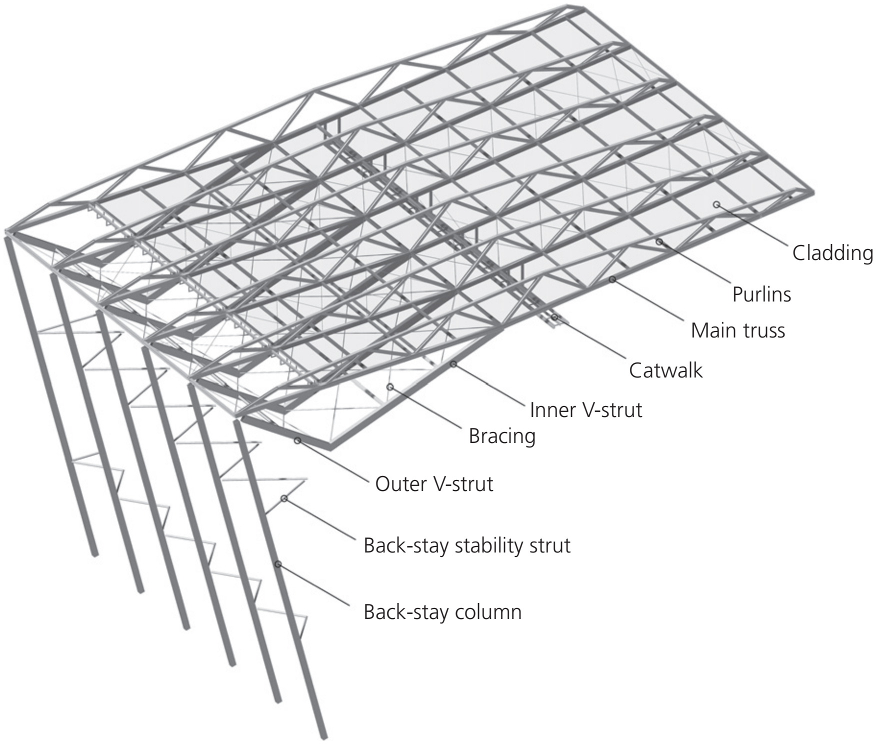


Figure 8. Struts stabilising the backstays

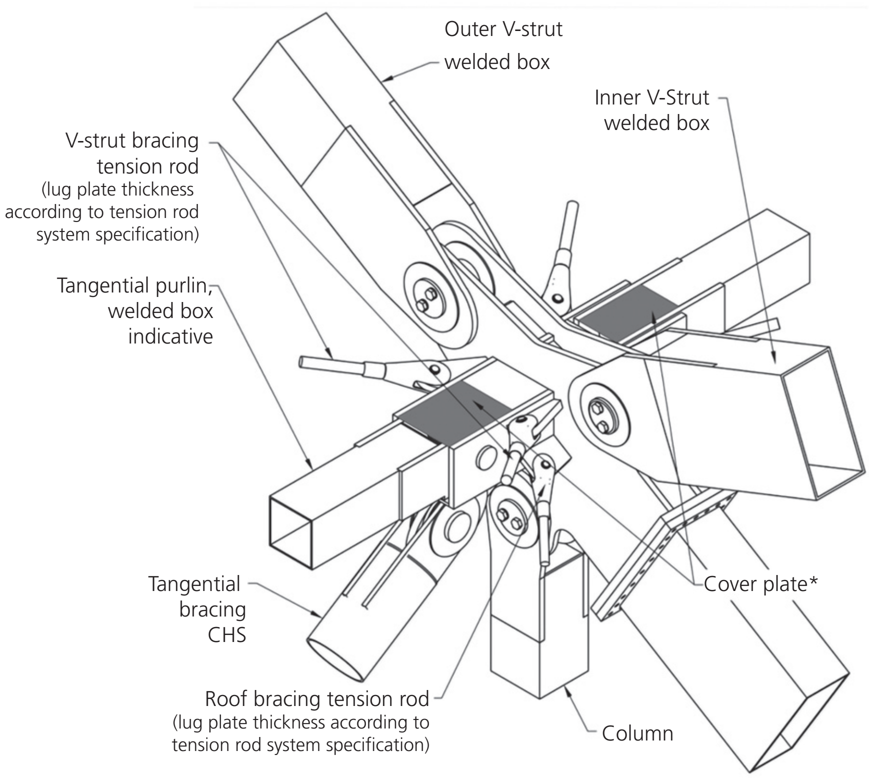


Figure 9. Modular detail of outermost columns supporting roof and raker beams (CHS, circular hollow section)

The wind suction load case may develop compression forces in the backstays. Therefore, stabilisation struts connecting the bowl and backstays on two different levels were added (Figure 8).

Corrugated steel metal deck is used for the roof cladding. The metal deck spans radially, supported by purlins which span tangentially. The corrugated steel does not have any insulation and the structural metal deck works as both a structural element and as a waterproofing element.

In order to reduce the number of connecting elements as well as to keep a clean visual appearance of the stadium roof, the upper chord of the main trusses has no out-of-plane bracing elements. The out-of-plane stability of the truss upper chord is therefore achieved through rigid connections of the purlins to the lower chord and the out-of-plane stiffness of the truss diagonals (Figure 9). The main principles of demountability and modularity have also been applied for the design of the roof elements and connections, but larger segments were considered for the main trusses. Figure 10 shows the roof structure during construction.

The steel of all the components of the roof structure (plates for built-up sections and profiles) was in general S355 JR/J0/J2 according to EN 10025-2 (CEN, 2004a), depending on the plate thicknesses, in compliance with the requirements of EN 1993-1-10 (CEN, 2005a). The tension rods are of steel grade S460N in accordance with EN 10025-3 (CEN, 2004b) while all pinned connections are made of grade 34 CrNiMo 6 + QT according to EN 10343 (CEN, 2009).

3.3 Secondary modular systems

An extremely lightweight (weighing less than 100 kg/m^2) and fully reusable modular slab system was developed, composed of thin gauge orthotropic steel plates, to reduce to a minimum the required means for installation and dismantling. The slab system could withstand 5.0 kN/m^2 live load and spanned up to 9 m. Similarly, the bleacher elements were conceived as a single folded steel plate, bolted together with the adjacent elements and to the raker beams, resulting in a very efficient and lightweight system to resist the grandstand live loads, with adequate stiffness to comply with the stringent vibration requirements in serviceability limit states.

A total of 974 specially modified containers were used to allocate all the required functional spaces of the stadium. In some cases, clusters of up to three containers with different dimensions were designed to achieve the required functional area, considering a large number of variants for the analysis, depending on the geometry (e.g. partial/complete removal of some of the container's

Figure 10. Roof structure during installation

structurally bearing walls) and load requirements (e.g. different superimposed loads and live loads, depending on the usage).

3.4 Foundations

For the foundation of the stadium (the only non-reusable elements of the structure) relatively small shallow foundations (i.e. isolated concrete pads) were designed to facilitate the future reuse and repurposing of the plot after the World Cup. This could be achieved because the proposed innovative modular lightweight stadium resulted in a significant reduction of the loads on the foundations compared to a traditionally built stadium. In addition to that, the presence of a relatively thick layer of a low- to medium-strength limestone – the so-called Simsima limestone, typically found in the Qatari peninsula – close to the surface, made it possible to avoid deep excavations and working below the groundwater level.

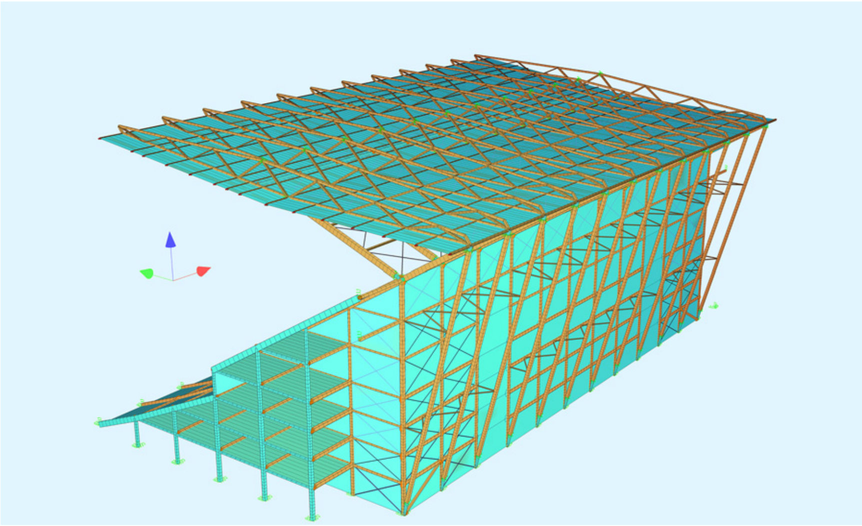


Figure 11. Finite-element method model of a complete sector

Figure 12. A 1 : 300 scale model of the stadium in a wind tunnel

4. Structural analysis

The analysis of the main structure was performed by means of independent models for the different sectors (i.e. straight long sectors, straight short sectors and corner sectors), including the main bowl framing and the complete roof for each sector (Figure 11). To provide maximum flexibility for the legacy mode, each sector was designed to work completely independently from other sectors. The only exceptions were the most extreme bays of the straight sectors, which are vertically supported on the corner sectors. Three-dimensional beam finite-element method models developed in the general-purpose finite-element program Sofistik, were used for the analyses, not only for the final configuration of the structure in service, but also for the full staged construction. Owing to the unusual structural system and load application, a stage for the installation of each element of the bowl was considered, analysed and checked for strength and stability during the complete installation process.

The effect of the wind loads and their interaction with the structure are critical for any large span roof design and require a careful consideration. In the case of stadium 974 these were especially critical due to the location in the shoreline and the special characteristics of the structure, where the roof is fully supported on the bowl structure, resulting in a high interaction between roof and bowl structural response. The complete stadium model was tested in a wind tunnel (Figure 12) in order to determine the appropriate pressure coefficients and dynamic amplification factors for the different elements of the roof and the elements of the bowl exposed to wind (e.g. containers,

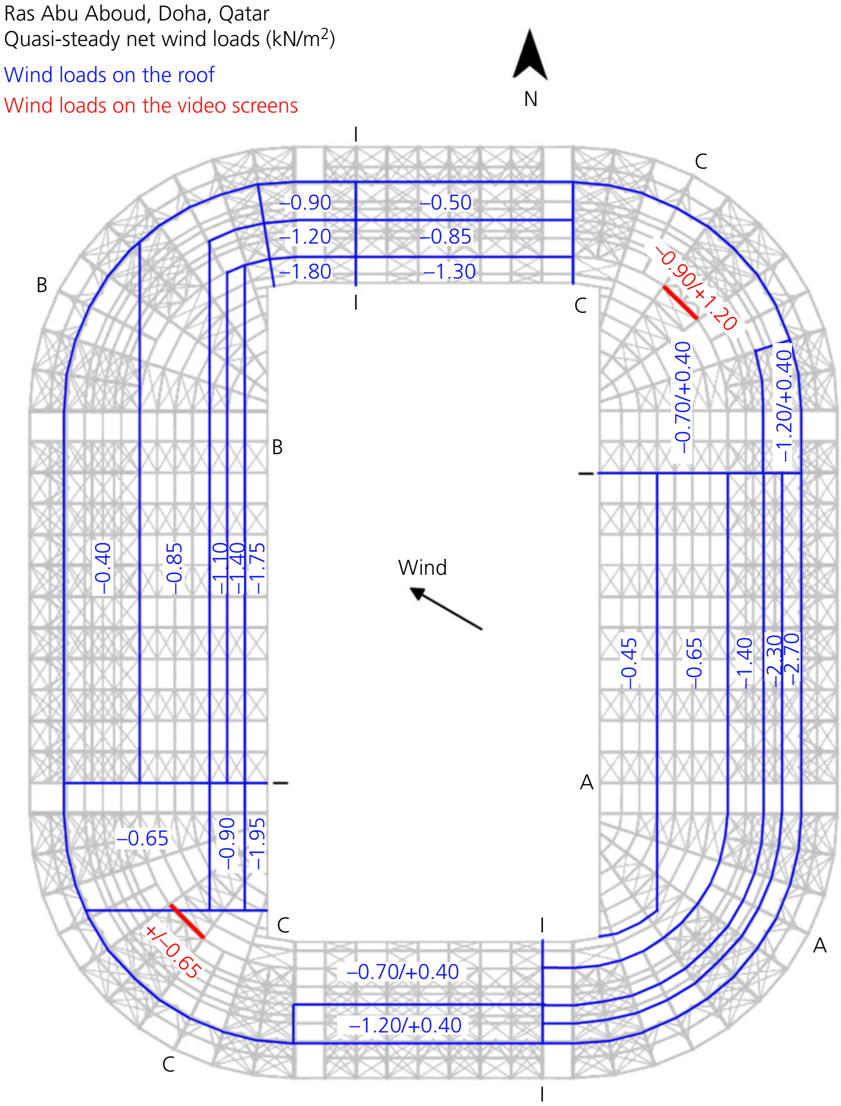


Figure 13. Sample of quasi-steady net wind load pattern for the main supporting structure of the stadium in kN/m^2 for an angle of 30° with respect to the stadium main axis

staircases, etc.), based on the rules of EN 1991-1-4 (CEN, 2005b) and considering the basic wind speed at the stadium location given by the local construction specification QCS (2014). As a result, wind pressure patters for the structure and cladding elements were provided for different wind directions, every 30° (Figure 13).

The main structure was analysed and verified according to the local regulations following EN 1993-1-1 (CEN, 2005c) incorporating initial global imperfections, as well local imperfections at the element level. All the cross-sections were verified (considered as Class 3 according to EN 1993-1-1 (CEN, 2005c) to ensure no plastic strains occur in the ultimate limit state.

Individual detailed analysis models were created for the different components, namely the single lightweight slab panels, bleachers, the different arrangements of individual or cluster of containers and the modular staircases. The analysis of all plated structures was performed in accordance with EN 1993-1-5 (CEN, 2005d) and the recommendations included in Annex C. Each element was individually verified for compliance, not only for the ultimate limit state, but also with respect to the strict stadium requirements in terms of serviceability limit states of vibrations, following the criteria presented in the Institution of Structural Engineers (IStructE) guideline 'Dynamic performance requirements for permanent grandstands subject to crowd action' (IStructE, 2008). The acceptance criteria adopted were based on the most stringent case for stadium grandstands by limiting the lower vertical frequency to 6.0 Hz, not only for the grandstands (i.e. bleachers and raker beams), but also for the concourse slabs, which was extremely demanding for such a lightweight system. In order to ensure that this was achieved, the structure was analysed in a detailed finite-element model in Sofistik, considering a series of bleachers and its bolted connections, between two consecutive bleacher panels, and between bleacher and raker beam (Figure 14).

Structural models were also developed for the different containers (Figure 15) that were used in the stadium, taking into account the length of the containers and whether (or not) longitudinal side walls were present. Gravitational and temperature loads were considered in these analyses. Different load configurations during transportation, handling, stacking and due to wind loads in specific locations were developed by the specialist subcontractors.

5. Detailing

The requirements for demountability of the structure posed a major challenge for the detailing of the structure. On one hand, each connection of the bowl frame, roof and secondary systems (i.e. slabs, bleachers and containers) needed be analysed in detail within a 3D/building information management environment, to ensure proper access for installation and dismantling, including the presence of the MEP and architectural elements as required, and considering the specific installation/dismantling sequence. On the other hand, all the connections were simplified to the minimum number of elements and a series of standard connections was defined. All the bowl frame connections were therefore designed with a single pin. To ensure demountability and full reusability of the connections, plastic strains were not allowed in the design. The connections were designed in accordance with EN 1993-1-8 (CEN, 2005e).

6. Construction

The fabrication of the steel structure according to EN 1090-2 (CEN, 2010), considering Execution Class 3 (EXC3) according to the referred code, was performed completely off-site in a workshop in Vietnam and shipped later to the site. Careful workshop planning was required to ensure a proper and smooth on-site

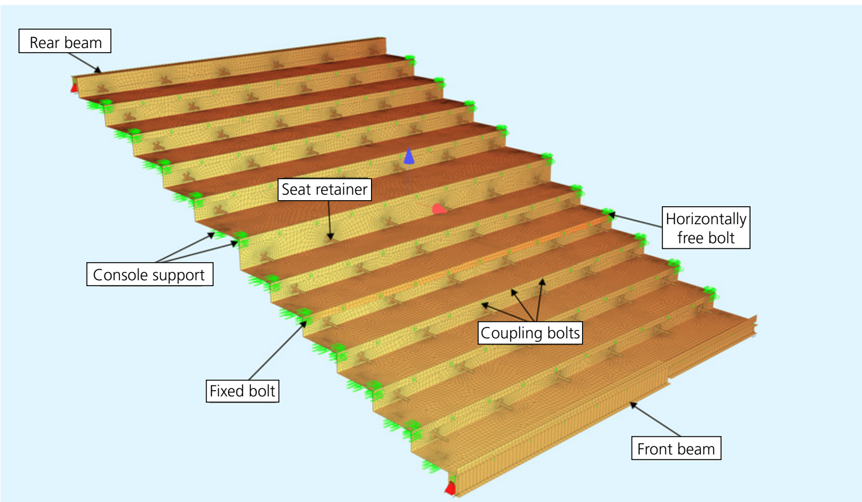


Figure 14. Detailed finite-element model used for the vibration analysis of a group of bleachers

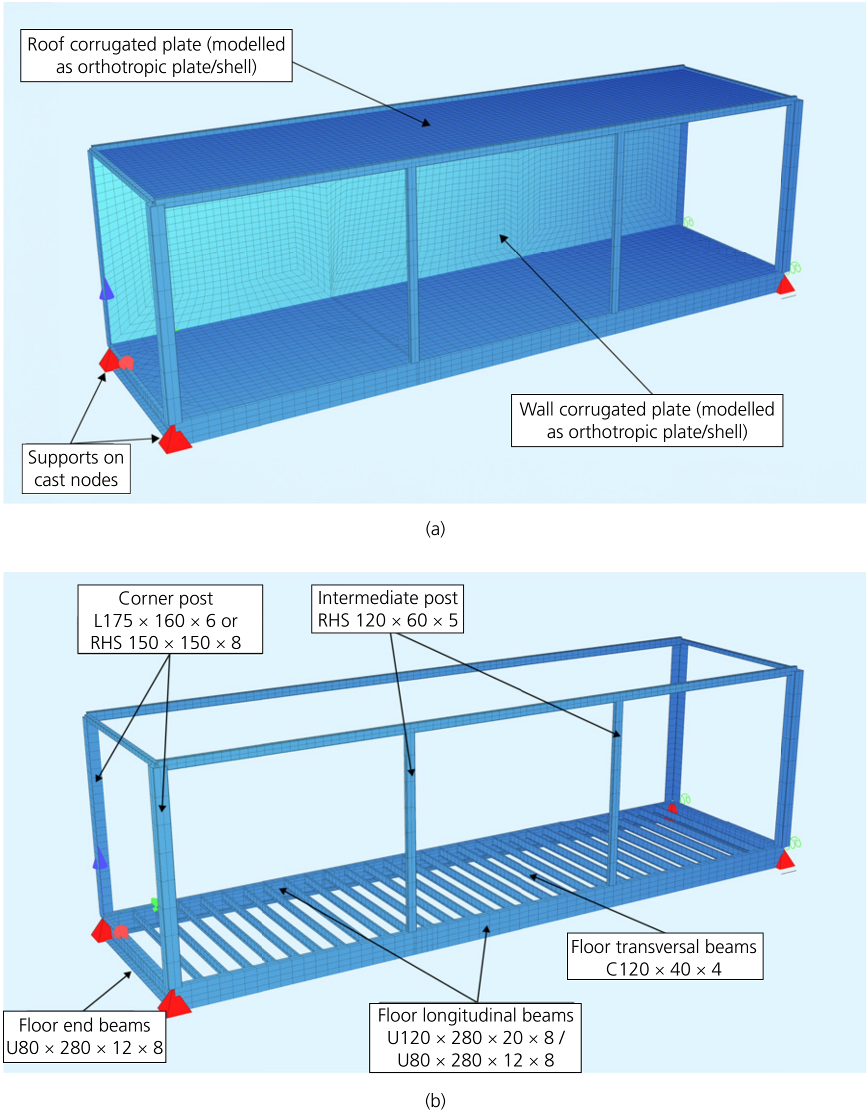


Figure 15. Detailed structural finite-element method models of the containers

installation. The tight tolerances imposed by the pinned connections, allowing a maximum deviation of 3 mm, required a trial assembly of large segments of the bowl frame and roof segments in the workshop, before shipment to the site. To account for possible differences in the installation conditions (e.g. difference in the temperature between fabrication and installation on site), additional connections allowing for installation adjustments were provided in the bowl frame and roof, by means of head plate bolted connections.

A 'temporary stages' analysis document of all the bowl elements was developed in which the erection sequence to be followed by the construction team was fully simulated (including the lifting plans). The erection of the structure required careful geometric control to ensure compliance with the tight tolerances specified. A continuous survey of the structure after each erection stage and a twin 3D model for geometry control was implemented to identify any deviation from the theoretical geometry and adopt any required correction procedures, if required.

7. Pre-camber strategy

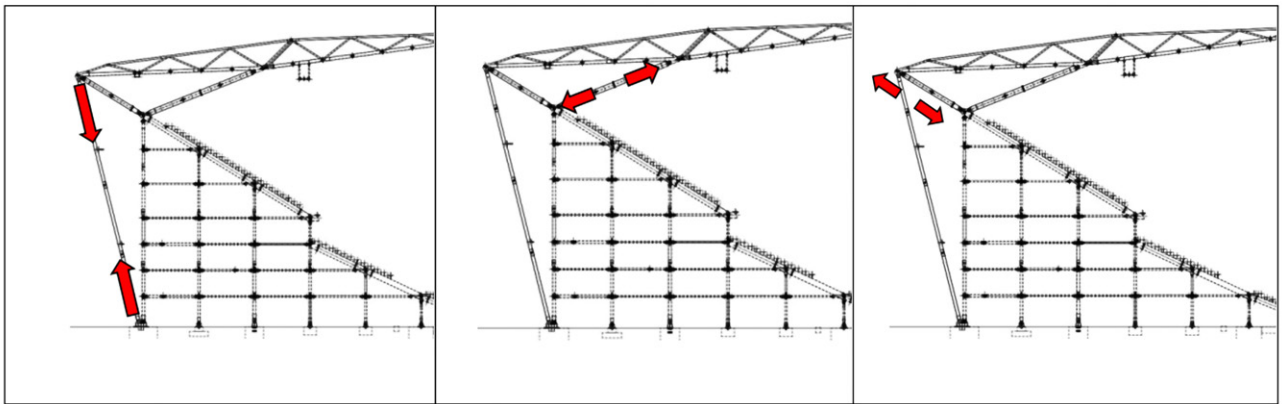
The pre-camber strategy adopted was developed with the aim to reach the target geometry at the end of the construction, considering the actual displacements according to the site survey, and also considering the displacement that will occur after the application of the permanent loads.

In the design phase, splice joints on the backstay and V-struts elements were developed to allow for any required adjustment by adding/removing shim plates (Figure 16).

After installation of the roof truss segment, a final survey was done and the data collected enabled a detailed assessment of the displacements in all three directions (vertical, radial, and tangential) of the tip of the roof (aided by a 3D finite-element method model) and a final report was generated identifying the location and number of shim plates to be added/removed if required (Figure 17).

8. Conclusions

Stadium 974 in Qatar is a pioneering project in the field of sports venues. The visionary concept to have a modular kit of parts for the structure and pre-equipped containers with all required building services allowed the stadium to be demounted after the FIFA World Cup Qatar 2022 and to be re-erected at other locations. The individual components and details of the



Shortening of backstay column	Lengthening of inner V-strut	Lengthening of outer V-strut

Figure 16. Roof backstay and V-struts adjustment scheme detail

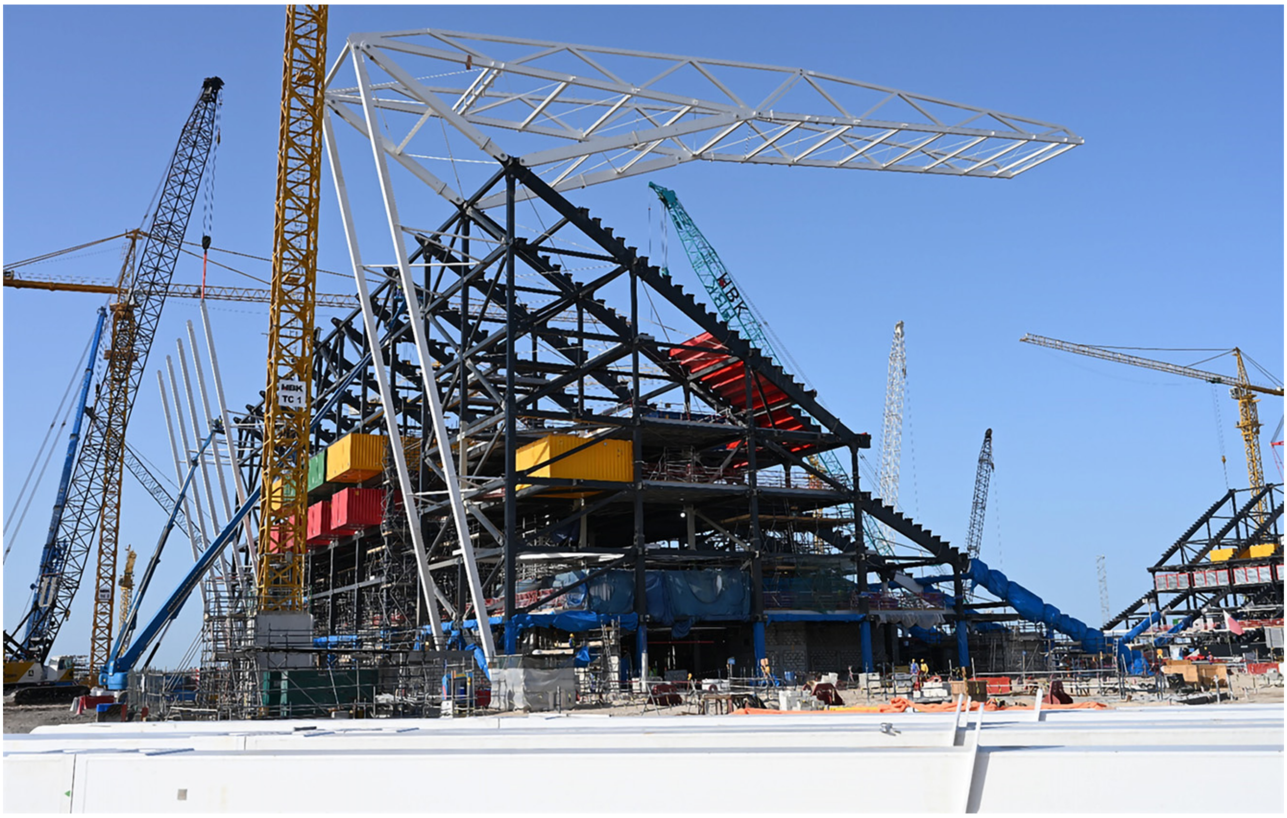


Figure 17. Installation of west stand structure and roof

stadium were designed such that the initial 40 000 capacity stadium could be configured to a variety of other possible usage options ranging from an ordinary size reduction to even a modified overall geometry – transforming the football stadium into other sports stadiums or individual components for smaller sport and entertainment venues. The modular elements and the corresponding details are designed to allow for simple and fast transportation, installation and dismantling. The visionary scheme resulted from a holistic approach with close collaboration between all the consultants, together with the client. Stadium 974 is not only an example of modern sport architecture, but it is also one of the most sustainable sports venues: the more often the individual components of the stadium are reconfigured and re-used at other sites, the smaller the overall carbon footprint of the venues becomes.

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