Expanding Underground. Knowledge and Passion to Make a Positive Impact on the World – Anagnostou, Benardos & Marinos (Eds)

Sustainable and resilient city: The case study of a hypogeum stadium in a desert area

P. Lunardi
Lunardi Geo-Engineering, Milan, Italy

G. Lunardi, G. Cassani, M. Gatti & C.L. Zenti
Rocksoil S.p.A., Milan, Italy

ABSTRACT: As cities have grown denser, it seemed only natural to extend skywards. However, the sky is not the limit: Cities need to start looking downwards to adapt to new circumstances and reach the next level of existence. Earth is our only home and that humankind faces enormous challenges. To overcome these challenges we need to focus on how spaces underground can contribute to more sustainable and resilient cities. At the same time we need to break out of our existing paradigms and transition to new ways for space use. The aim of paper is to describe a case study presenting the project of a Hypogeum stadium located into a desert area. The authors, through this project try to reply to above mentioned requirements.

1 INTRODUCTION

Rapid urbanization is a global phenomenon. In 2008, for the first time in human history, there were more urban dwellers than rural, and the trends show that this is not going to be reversed. The United Nations estimates that by 2030, over 60% of the global population of will be living in "megacities" (10+ million), large (5-10 million), medium (1-5 million), and smaller cities and peri-urban communities, increasingly concentrated in Asia, Africa, and Latin America. This fraction could rise to two thirds by 2050. The recent Intergovernmental Panel on Climate Change (IPCC) report on Human Settlements, Infrastructure and Spatial planning states that the expansion of urban areas (urban centres and suburbs) is on average twice as fast as the urban population growth, and that the anticipated growth in the first three decades of the 21st Century will be larger than the cumulative urban expansion in all of human history. (Lunardi et al., 2018).

In 1950 about 65% of the population worldwide lived in rural settlements and 35% in cities and this number will be reversed by 2050, where 70% will be urban and 30% rural. Almost 6 billion people will be living in urban areas by 2050. Figure 1 shows share of populations living in urban areas.

The cities contribute to approximately 70% of global energy use and greenhouse gas emissions but only occupy 5% of the earth's landmass. This is accompanied by the unprecedented increase in demand need for water, land, building material, food, pollution control measures and waste management from urban areas. Therefore, cities are constantly under pressure to provide better quality services, promote local economic competitiveness, improve service delivery, increase efficiency and reduce costs, increase effectiveness and productivity, address congestion and environmental issues. These pressures are motivating cities to turn to sustainable and resilient solutions and experiment with various structure and infrastructure applications. The objective of such a new "city model" is a complex process involving deep-rooted innovation with regard to: tangible and intangible infrastructures, the lifestyles of citizens; the

DOI: 10.1201/9781003348030-15

regeneration and design of public spaces, strategies and tools to develop the economy and the handling of complexities.

Public administration on its own cannot transform the city, but it does have the task of creating a favourable environment where the best and blue-chip players within its area work successfully towards common and shared goals.

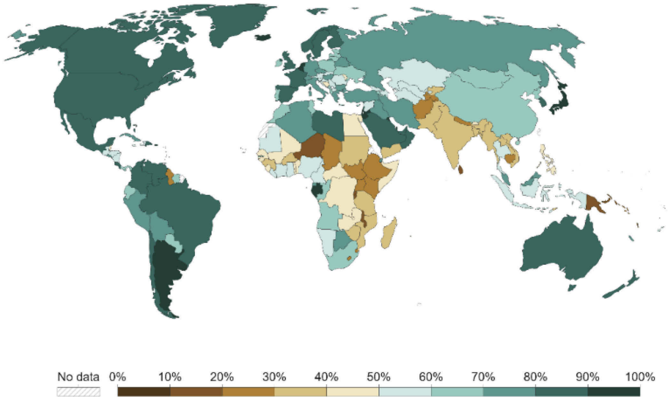

Figure 1. Share of people living in urban areas, 2020 (Source Our World in Data, https://ourworldindata.org/urbanization).

2 SUSTAINABLE AND RESILIENT CITY

2.1 *Definition*

There is no standardized, commonly accepted set of terminologies or definitions, which would help to aptly describe sustainable and resilient city. From a general point of view:

- sustainable city is one designed to address social, environmental and economic impact through urban planning and city management.
- resilient city is one that have the ability to absorb, recover and prepare for future shocks (economic, environmental, social & institutional)

Good urban governance and sustainable development are closely interlinked. As such, urban resilience is viewed as an important outcome of good urban governance. Good urban governance is a multidimensional concept that focuses on the improvement of the quality of living conditions of local citizens. Cities face various adversities and challenges, such as unsustainable use of natural resources, rapid urbanization, disasters and effects of climate change. City resilience is an inclusive process that refers to a city's ability to sustainably manage unexpected and expected risk-related events. In addition, it includes a city's capacity to adapt to future challenges from a strategic and spatial perspective. Figure 2a represents a macro perspective of the requirements needed to ensure city sustainability and resilience.

The term 'resilient' means possessing inner strength and resolve. Thus, a resilient city takes into consideration appropriate built form and physical infrastructure to be more resilient to the physical, social and economic challenges. For cities, resilience is enhanced by knowledge of risks and tools and resources available to confront threats and build on opportunities.

Public works programmes may contribute to adaptation and disaster risk reduction through the construction of community assets that enhance resilience through better natural resource management and adaptation.

The three ovals in Figure 2b highlights how resilience is also increasingly used as a "programmatic bridge" to help along the integration of short-term responsive intervention with longer-term development programmes. Understood in a linear way, the framework below suggests that managing for resilience requires directing a system in a way that promotes resistance in a period of small disturbance, adaptation in a time of greater disturbance, and transformability when conditions are becoming unviable or unsustainable (Benè et al., 2018).

2.2 *Desert condition*

Despite the environmental implications, man's dependence on non-renewable energy resources continues to increase. In most developed countries the equivalent of some three tons of oil per person is expended in a single year, some 40% of this energy is consumed for heating, cooling, and making buildings habitable. When the energy costs of building construction and materials, on the one hand, and urban transportation, on the other, are added to this basic load, it becomes clear that most of society's energy use is influenced by architects, engineers and planners.

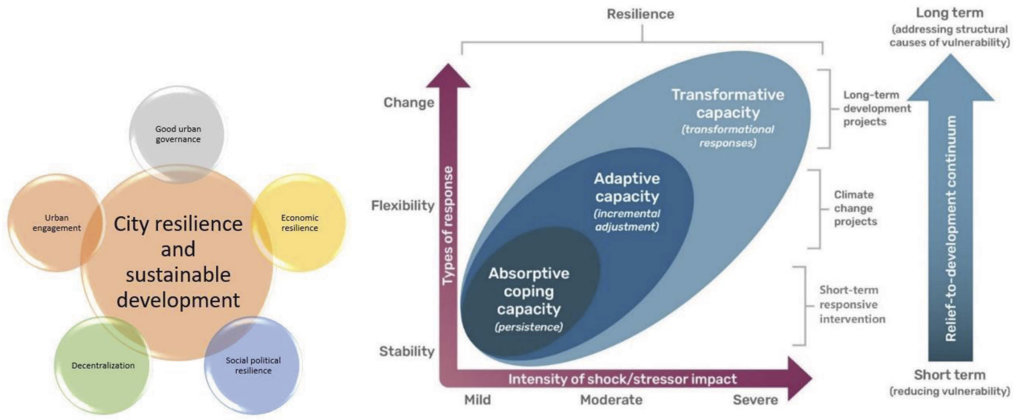

Figure 2. a) Factors leading to city resilience and sustainable development; b) The long-term vision for resilience (figure modified from Benè et al., 2018).

The burden of resource use in buildings or urban settings can be minimized in many ways, and the first requirement is a basic understanding of climate and local conditions. This "bioclimatic" approach may be applied in the desert as elsewhere, and its pertinence is in fact amplified:

- Often characterized as an "extreme" environment, the desert makes considerable inputs of natural resources, such as water and energy, necessary to provide acceptable levels of human comfort.
- The opportunities for utilizing "natural energies"- solar radiation, night ventilation, evaporation, or nocturnal sky radiation - are among the many passive systems and design strategies whose effectiveness is especially pronounced in an arid climate.

With sparse population and low rates of development, arid regions have typically received little attention from planning professionals. This means that standard building methods are predominantly adapted for non-desert conditions. However, overcrowding in the heavily populated centers of many countries is causing intense pressure for the development of "peripheral" regions such as deserts - and accomplishing this in a sustainable manner is an imminent challenge.

3 THE CASE STUDY OF A HYPOGEUM STADIUM IN A DESERT AREA

As cities have grown denser, it seemed only natural to extend skywards. However, the sky is not the limit: cities need to start looking downwards to adapt to new circumstances and reach the next level of existence. Earth is our only home and that humankind faces enormous challenges. To overcome these challenges, we need to focus on how spaces underground can contribute to more sustainable and resilient cities (Broere, 2016). At the same time, we need to break out of our existing paradigms and transition to new ways for space use (Lunardi et al., 2019). Figure 3 summarizes underground use advantages.

Large structures for sport competitions, such as football stadiums, are generally built on surface. Such condition determines some advantages, but also several disadvantages, which importance can vary considerably, depending on geographical location of the works.

Other than occupation of public land areas that would be devoted to less environmental impacting uses, surface location exposes the structures and spectators to climatic conditions that could be very adverse. This disadvantage can be considered particularly relevant in desert area, where it is common to cope with large variations in temperature, various kinds of storms and aggressive atmosphere. The idea of a completely underground structure came up from such considerations.

The fully underground location would allow to realize:

- facility suitable for all seasons, (control of internal temperature and humidity);
- structure characterized by manufacturing costs significantly lower than those of realized on surface, especially in good ground conditions;
- construction not exposed to aggressive weather conditions (structure durability increase);
- a sport facility which security/safety aspects are easier to be managed compared to similar surface-one;
- a suitable link with the existing underground transportation system, such as sub-way and underground parking system.

UNDERGROUND USE ADVANTAGES		Environmental Benefits			Safety Benefits			Economic Benefits		
		LAND CONSERVATION	AIR POLLUTION	NOISE POLLUTION	EXPLOSION, FIRE & SABOTAGE	METEOROLOGY PHENOMENA	SEISMIC EVENTS	CONSTRUCTION	OPERATION	MAINTENANCE
METRO LINE	LINE STATION DEPOT WORKSHOP	NOTICEABLE	NOTICEABLE	NOTICEABLE	MINOR	NOTICEABLE	MINOR		MINOR	MINOR
RAILWAY	LINE STATION DEPOT WORKSHOP	NOTICEABLE	MINOR	MINOR	MINOR	NOTICEABLE	MINOR		MINOR	MINOR
DISTRIBUTION NETWORK	OIL&GAS ELECTRICAL THERMAL COMPUTING	MINOR	NOTICEABLE	MINOR	CONSIDERABLE	CONSIDERABLE	MINOR		MINOR	CONSIDERABLE
INFRASTRUCTURES	SPORTS FACILITIES SHOPPING CENTRES RECREATION CENTERS LIBRARY&MUSEUM	NOTICEABLE		MINOR	MINOR	MINOR	MINOR		MINOR	CONSIDERABLE
DEPOTS	LIQUID RESOURCES GASEOUS RESOURCES FOOD RESOURCES FUEL RESOURCES	MINOR	MINOR	MINOR	CONSIDERABLE	CONSIDERABLE	NOTICEABLE	MINOR	NOTICEABLE	CONSIDERABLE
WASTE STORES	MUNICIPAL INDUSTRIAL CHEMICAL RADIOACTIVE	NOTICEABLE	CONSIDERABLE	MINOR	MINOR	NOTICEABLE	NOTICEABLE	MINOR	CONSIDERABLE	CONSIDERABLE
POWER PLANTS	HYDROELECTRIC THERMAL NUCLEAR	NOTICEABLE	CONSIDERABLE	MINOR	CONSIDERABLE	CONSIDERABLE	CONSIDERABLE	NOTICEABLE	CONSIDERABLE	CONSIDERABLE
MILITARY FACILITIES	HEADQUARTERS SHELTERS BASES DEPOT	CONSIDERABLE	MINOR	NOTICEABLE	CONSIDERABLE	CONSIDERABLE	CONSIDERABLE	MINOR	CONSIDERABLE	CONSIDERABLE
	ADVANTAGES	MINOR	NOTICEABLE	CONSIDERABLE	MINOR	NOTICEABLE	CONSIDERABLE	MINOR	NOTICEABLE	CONSIDERABLE

Figure 3. Underground use advantages.

The case study presents the project of a Hypogeum Stadium located into a desert area. The project represents an example of a sustainable development of a resilient city infrastructure in a desert area.

3.1 *The case*

The aim of the case study is presenting how the development of strategies, supported by engineering technology, can integrate the use of underground space into the fabric of urban development. The objectives are:

- to optimize use of spatial resources in urban development for buildings, services and transport;
- to integrate use of facilities in spatial form;

- to provide sustainable development with minimal environmental impact;
- to develop technologies to enhance opportunities for planning the use of underground space (e.g. underground mapping)
- to develop engineering technologies for implementing the development of underground space for buildings, service facilitation and transport.

It's clear that the project of hypogeum stadium must be fitted in a general view through which the underground space became an integral part of urbanization process. Underground high-speed transportation connects the city, end-to-end, making travel simple and stress-free. By this way roads and streets above the ground are replaced by piazzas and walkable boulevards filled with parks and green spaces (see Figure 4). Subway and underground parking will be integrated with the hypogeum stadium.

3.2 *The project*

The Hypogeum Stadium (Figure 5), designed to last over time through the ages as part of the history, is characterized by some indisputable advantages:

- control of temperature & humidity (aspect particularly relevant in case of desert area)
- control of security
- savings over surface-built solutions
- low maintenance costs
- high energy savings

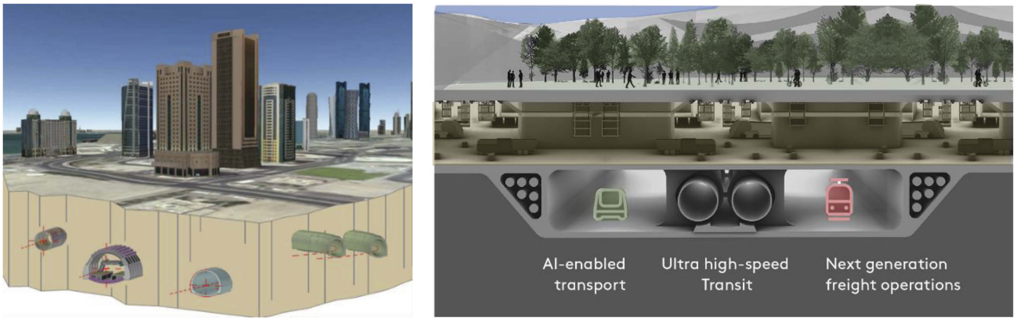

Figure 4. Integrate use of underground space into the urban development.

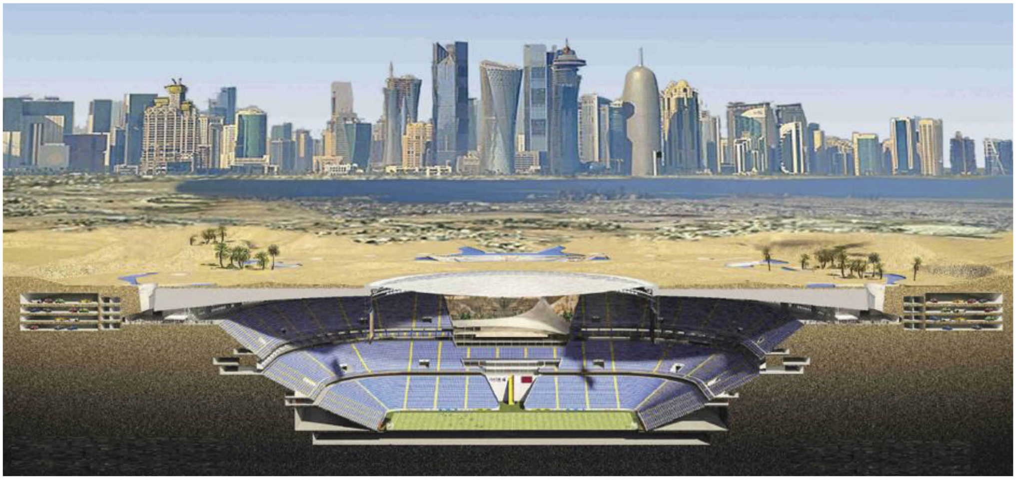

Figure 5. Rendering of the Hypogeum Stadium.

The stadium, totally underground (quarry-like), provides suitable dimensions in order to accommodate a football yard with 45’000÷67’000 seated spectators, with grandstands and bleachers completely laying on the sound-ground, properly shaped according to the stadium design geometry. Entrances to the stadium are excavated from the surface, by shafts and tunnels directly connected to underground transport system, car-parking, road and highway system (Figures 6 and 7).

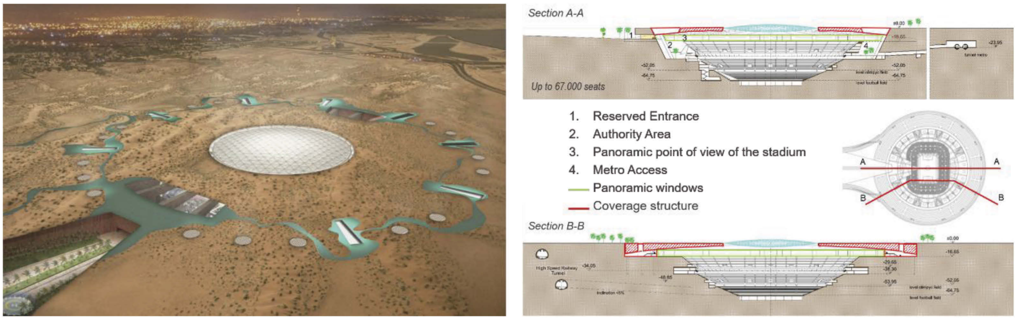

Figure 6. Hypogeum Stadium perspective view & general sections.

The ceiling is constituted by a truss-structure simply resting on consolidated foundation ground, along the outer upper perimeter of the stadium. The ceiling, arranged with a central opening, gives light to the yard allowing exhausted air circulation thanks to convective motions; at the same time, during inactivity of the structure the central opening may be closed by a portion of sliding cover.

3.3 *Stadium level & zones descriptions*

There are mainly nine level within the stadium. Three are principally accessible by the public and the others are the domain of private membership or reserved entrance (Figure 7).

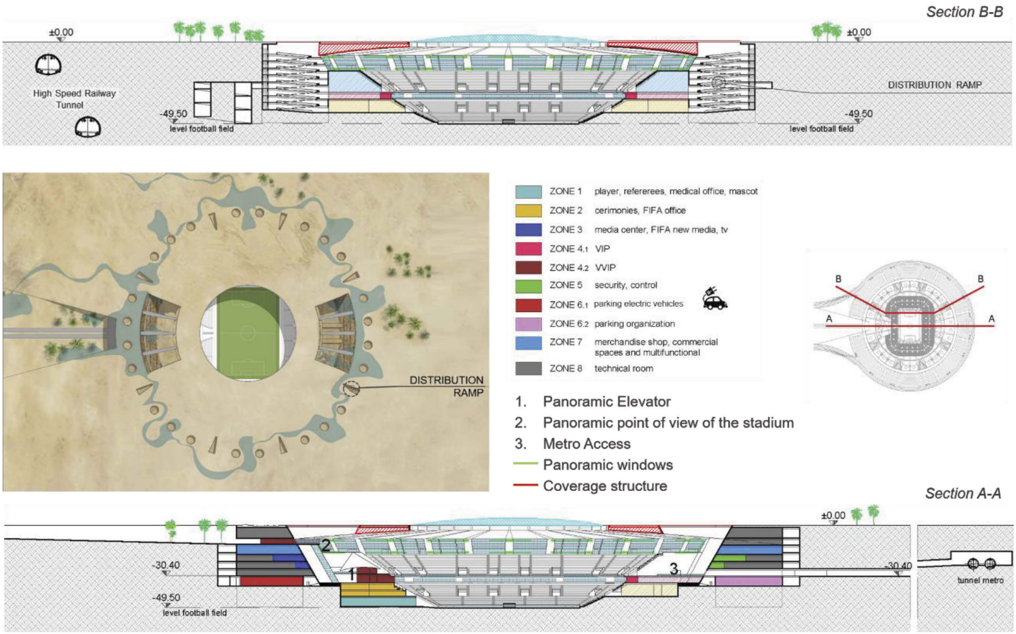

Figure 7. Hypogeum Stadium ground level view & functional sections.

Metro access level (Figure 7, bullet 3) and electric vehicles parking (Figure 7, zone 6.1) are the primary public entrance to the facility accommodating the public concourse and circulation areas. At the same level there is also the panoramic elevator (Figure 7, bullet 1) to stadium panoramic point of view (Figure 7, bullet 1). Only after the security control (Figure 7, zone 5) the public will have access to the stadium, merchandise shop, commercial shop, bar & restaurants (Figure 7, zone 7).

The bottom levels are reserved to player, referees, medical office, FIFA office and cerimonies location. (Figure 7, zone 1 & 2). The upper levels are set out to house level media center (Figure 7, zone 3) and authority reserved area (Figure 7, zone 4.1 & 4.2). The authorities have a private area (Figure 8).

Figure 9 shows Business area floor plan and Figure 10 shows Football field floor plan.

3.4 *The roof element and construction method*

The roof is made by means of a reticular system, with a main steel frame, placed in a radial direction, and "truss" plates resting on the main structure. The covered part also provides for the laying of a corrugated steel sheet and a concrete slab, in order to support a filling load, consisting of sand and gravel, so as to reconstitute the surrounding environment at ground level. The central part, which allows the entry of light, will be made of a double pneumatic membrane reinforced with a steel mesh.

The excavation will be executed by drill&blast system if the works are located in rock-mass conditions (sound rock or weak-rock); if the stadium is located in poor soil, retaining structures, such as reinforced concrete diaphragm or piles, must be provided to guarantee stable condition during excavation. The retaining structure will be used to support the internal structures too. Prefabricated system will be preferred, in order to speed up the construction process, both for bearing structures as well as for steps. If groundwater is present, waterproofing system will be placed by PVC membrane and geotextile; in poor soil the water pressure will be supported by the retaining system to avoid any seepage effect with the risk of dragging materials. Otherwise, in rock-mass condition, a drainage system will be studied in order to collect water and to use it for washing and cooling needs. These are general consideration, which should be addressed in detail with reference to the real conditions of the jobsites.

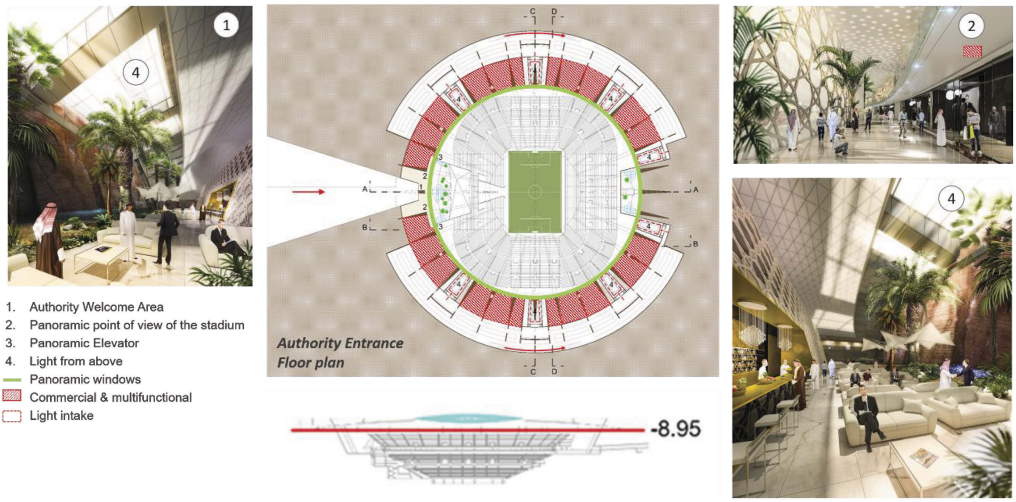

Figure 8. Authority entrance floor plan & rendering of internal view.

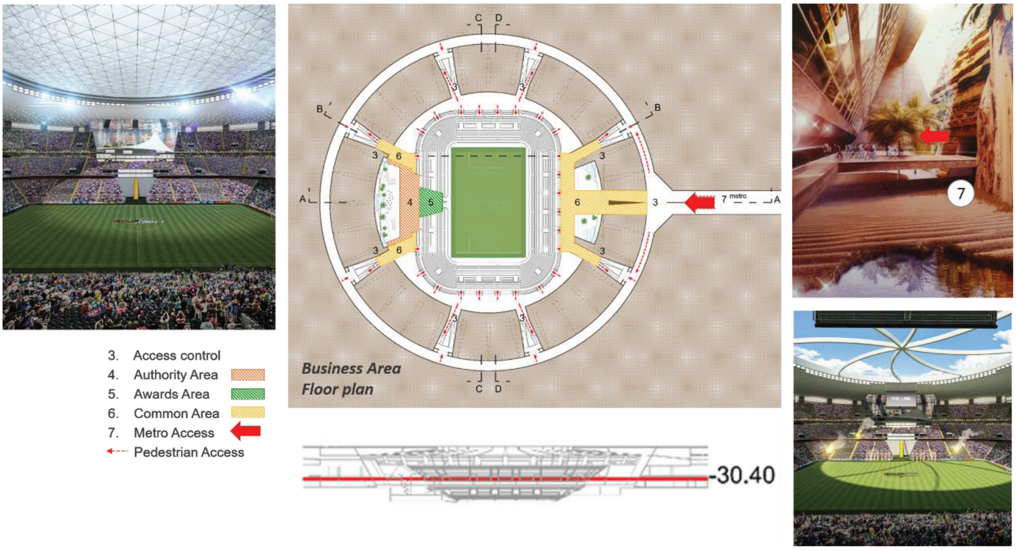

Figure 9. Business Area floor plan & rendering of internal view.

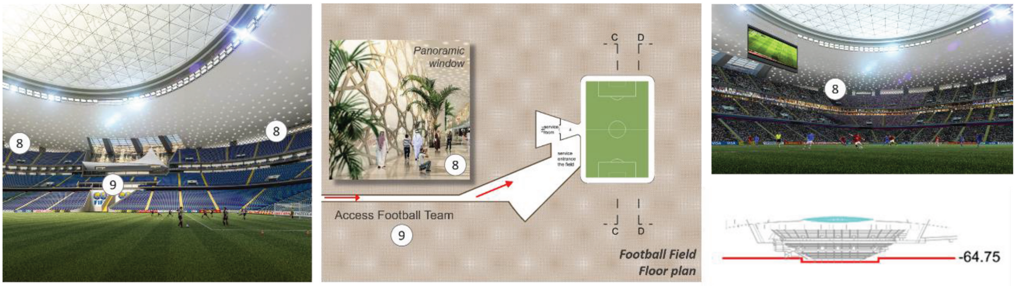

Figure 10. Football field floor plan & rendering of internal view.

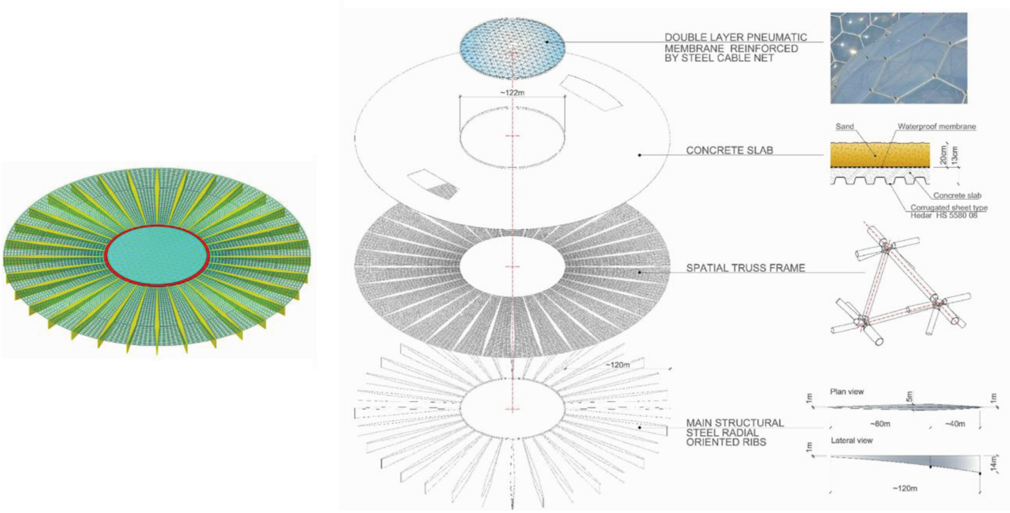

Figure 11. Roof element: 3D view and structure details.

4 CONCLUSION

While finding ways to help the planet is essential to sustainability, reducing costs and creating a vibrant culture for citizens are equally important.The paper explores how city's structure and infrastructure play a fundamental role: the system itself must be sustainable and resilient, but it must also support economic, environmental and societal sustainability and resilience. All aspects of a nation's economy, environment and society are enabled, either directly or indirectly, by structure and infrastructure. The ones with low sustainability and resilience jeopardises the short-term realization of all national strategic objectives and risks initiating a long-term downward spiral in which the cumulative impacts undermine the quality of life, reduce productivity and GDP, damage industry and investor confidence. System that is not sustainable and resilient is susceptible of damage with greater frequency, on a larger scale, with higher intensity, for longer durations and at a greater cost than its more sus-tainable and resilient counterparts, yet not all strategic challenges and hazards are known (such as natural disasters) or are easily predictable (such as climate change), making preparedness of infrastructure systems a potentially uncertain and expensive undertaking. For this reason, it is necessary to expand the concept of urbanization that provides for the use of underground space not limited to transport but as an integral part of a community social space. The authors, through the project of a Hypogeum Stadium, try to reply to above mentioned requirements.

REFERENCES

Béné, C., Cornelius, A. &, Howland, F. 2018. Bridging humanitarian responses and long-term development through transformative changes-some initial reflections from the World Bank's adaptive social protection program in the Sahel. *Sustainability (Switzerland)*, 10(6):1697.

Broere, W. 2016. Urban underground space: Solving the problems of today's cities. *Tunnelling and Underground Space Technology*, 55: 245–248.

Lunardi, G., Cassani, G., Gatti, M. & Zenti, C.L. 2018. The role of underground transportation inside Milano's Smart City perspective. In *Proceedings in USB*, World Tunnel *Congress 2018*, April 2018, Dubai, UAE

Lunardi, G., Cassani, G., Gatti, M., Spigarelli, B. & Zenti, C.L. 2019. Resilient city: The case of Bisagno diversion tunnel. In Peila, Viggiani & Celestino (Eds), *Proceedings of ITA-AITES World Tunnel Congress WTC 2019*, *Naples, Italy*, *2019*, *3rd – 9th May. Tunnels and Underground Cities: Engineering and Innovation meet Archaeology, Architecture and Art*. Taylor & Francis Group, London, pp. 5159–5169. ISBN 978-1-138-38865-9.