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Identification of approaches to architectural and structural solutions in the design of sports buildings

Identificación de enfoques de soluciones arquitectónicas y estructurales en el diseño de edificios deportivos

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ABSTRACT

In the modern world, sports facilities are multifunctional complexes that not only meet the needs of the sports infrastructure but also serve as recreational facilities. Sports buildings and facilities are constructed using large-span structures and require significant urban areas for their erection. The paper discusses the results of research carried out by the Moscow State University of Civil Engineering, which provides for the efficient use of the building area of sports facilities and the reduction of the cost of facilities through the use of space within the large-span structures for the placement of a large number of sports infrastructure facilities. The key issue in solving the problem of compactness of the developed area is the use of large-span structures of intermediate floors. Based on the selected cases, the authors classify approaches in the design of sports buildings, based on the use of three types of large-span floor structures: steel-reinforced concrete floor slab, load-bearing floor, and building-bridge. The authors conclude that these approaches can be used in the design of various types of sports facilities: from the municipal level of sports and recreation complexes to facilities designed for major international competitions.

Keywords: multifunctional facilities; sports infrastructure; large-span steel-reinforced concrete slab structures.

RESUMEN

En el mundo moderno, las instalaciones deportivas son complejos multifuncionales que no solo satisfacen las necesidades de la infraestructura deportiva sino que también sirven como instalaciones recreativas. Los edificios e instalaciones deportivas se construyen utilizando estructuras de gran envergadura y requieren importantes áreas urbanas para su erección. El artículo analiza los resultados de la investigación realizada por la Universidad Estatal de Ingeniería Civil de Moscú, que prevé el uso eficiente del área de construcción de las instalaciones deportivas y la reducción del costo de las instalaciones mediante el uso del espacio dentro de las estructuras de gran envergadura para la colocación de un gran número de instalaciones de infraestructuras deportivas. El tema clave para resolver el problema de la compacidad del área desarrollada es el uso de estructuras de pisos intermedios de gran envergadura. Con base en los casos seleccionados, los autores clasifican los enfoques en el diseño de edificios deportivos, basados en el uso de tres tipos de estructuras de piso de gran envergadura: losa de piso de concreto reforzado con acero, piso de carga y edificio-puente. Los autores concluyen que estos enfoques pueden utilizarse en el diseño de varios tipos de

instalaciones deportivas: desde complejos deportivos y recreativos a nivel municipal hasta instalaciones diseñadas para grandes competiciones internacionales.

Palabras claves: instalaciones multifuncionales; infraestructura deportiva; estructuras de losa de hormigón armado de gran envergadura.

1. INTRODUCTION

Sports occupy a large place in the life of modern people. Sports facilities are some of the most popular public buildings. People do sports both professionally and for their personal health. A particularly important direction in the development of sports buildings is to provide a sports environment for the younger generation. The typology of sports buildings is quite extensive (Wirschillo, Brzuchowski, Weichert, 1968).

Sports buildings are traditionally divided into physical education, sports, and recreational facilities. However, nowadays, in all countries of the world, more often than not, sports buildings provide a multifunctional environment (Chepeleva, Tomeian, 2013). For example, the under-stand spaces in stadiums are used for sports halls for different purposes. A sports building can be used for practice by professional athletes, people who improve their health, and children, i.e. the volumetric-planning solutions are universal for different population groups. These buildings are simultaneously used, for example, as entertainment venues, not only for sports competitions but also for a wide variety of musical public events, which automatically turns them into leisure facilities. Thus, a multifunctional sports building often becomes an object of citywide or district significance. In large cities, there is a shortage of available land, especially in developed residential areas, and sports facilities tend to take up a significant amount of building area.

The purpose of the paper is to identify the main approaches to architectural and structural solutions in the design and construction of sports facilities.

2. METHODS

The paper presents examples of buildings in which various types of large-span floor structures are used.

The research was conducted at the Scientific-Research Moscow State University of Civil Engineering from 2021 to 2022. The case study method was chosen as the main research method.

The objects selected for the study are:

- Gazprom Arena (Saint Petersburg),

- Multifunctional sports complex “Ice Palace” (Moscow),

- The Bolshoi Ice Palace (Sochi),

- Building-bridge near Nagatinskaya floodplain (Moscow),

- Building-bridge made up of cubic volumes (Nizhny Novgorod),

- Building-platform with the bearing floor above the railroad tracks (Moscow).

Based on the chosen cases, an analysis of the use of various large-span floor structures was conducted in order to identify the primary approaches, as well as the optimal design solutions, for the construction of sports facilities.

3. RESULTS

The most technologically advanced and appropriate to the climatic conditions of Russia sliding roof solution was implemented for the Gazprom Arena stadium in Saint Petersburg (Figure 1).

Figure 1. Gazprom Arena in Saint Petersburg

To solve such exceptional and grandiose problems, free territories were found that allowed for the erection of such facilities. However, with the expansion of cities and the increasing density of construction, the problem of allocating free space in them is growing ever more acute. This especially applies to large cities and megapolises.

In this respect, there are two fundamentally novel solutions that could be attributed to modern trends in solving the issues of the lack of space for such large-scale objects. The first solution is the erection of large two-tier facilities, in which the soccer field itself as the largest part of the building, is located at ground level and the parts smaller in size, such as training fields, swimming pools, and gyms, are placed either above the field, or, conversely, under it.

"Steel-reinforced concrete floor slab"

This solution is illustrated by a project proposal for a multifunctional sports complex in Moscow, which provides for the placement of swimming pools and sports halls on the second level above the ice arena on a load-bearing steel membrane (Figure 2).

The membrane is a reinforced concrete slab about 10 cm thick with anchored longitudinal and transverse through ribs made of steel profiles or reinforcing bars. This type of construction for a span of 20 meters has a building height of 1 meter and a width of 2 meters. Increasing the spans of steel-reinforced concrete structures for strength requires increasing their structural height, leading to room volume loss or an increase in the height of the floor and the house. In this case, an excessive volume of space is created in the structural height of the slab. Therefore, increasing the span and structural height of steel-reinforced concrete slabs becomes inexpedient, which raises the need to shift to fundamentally new structural solutions to increase the span covered.

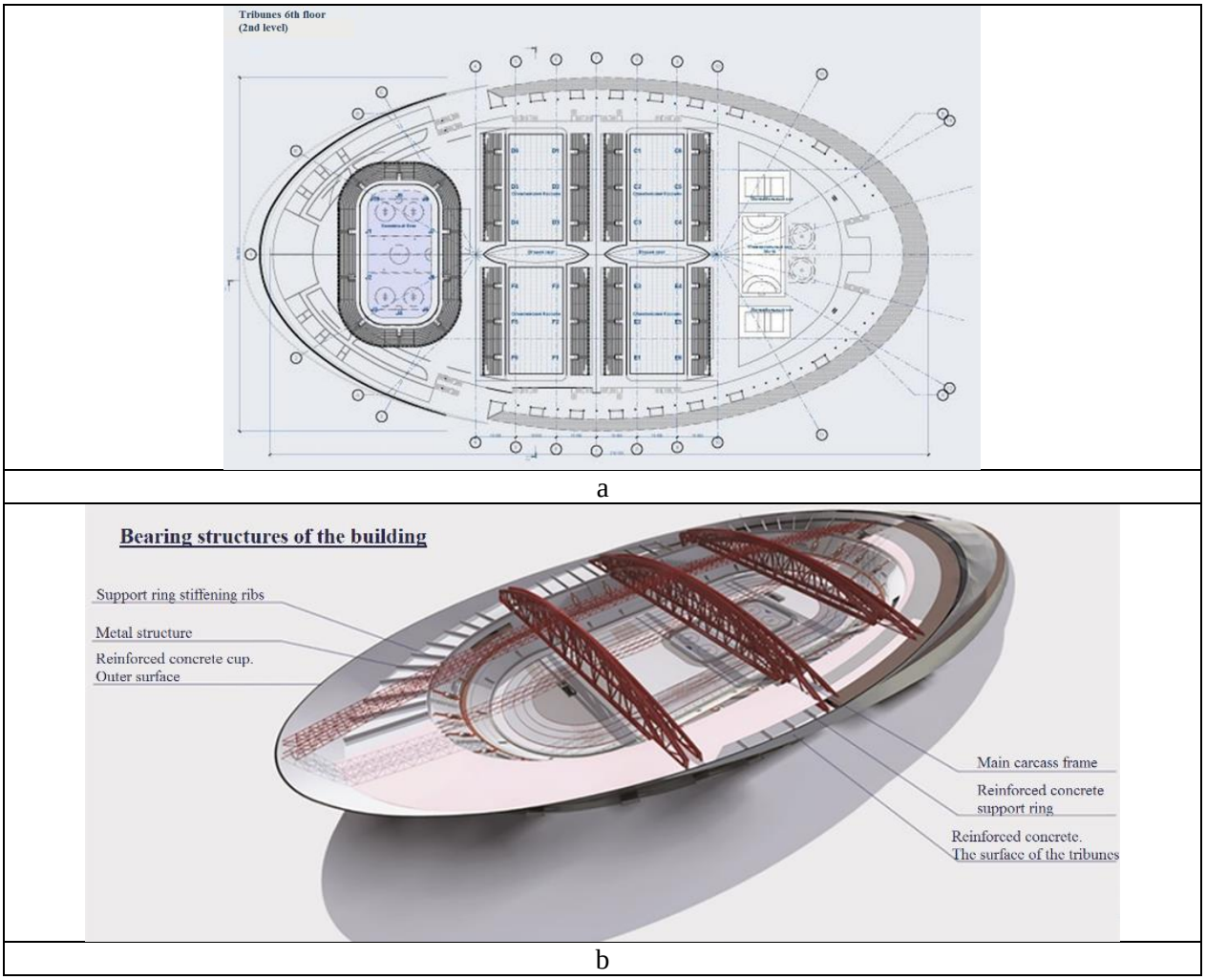


Figure 2. Multifunctional sports complex "Ice Palace" near Kaluzhskoe highway in Moscow with the placement of sports facilities at two levels with the use of a steel membrane as a ceiling at the lower level: *a – plan of the 6th floor with pool tribunes on the second level; b – scheme with trusses supporting the membrane and the shell of the cover*

The development area is determined by the size of the oval ice arena with stands for the classic speed skating competitions. Inside the oval with a skating track, there is an area for short track competitions and a warm-up lap. The building simultaneously hosts many other sports facilities placed on the second level on the membrane, which saves a lot of the territory of the city. At the level of the second floor, the longitudinal direction of the oval is divided into four parts by three steel trusses, to which the steel membrane supporting the interfloor slab is suspended. The middle of the spans between the trusses has the maximum sag of the membrane, allowing placing above them swimming pools of required depth. The presence of large sags itself reduces stresses in the membrane and thus allows for a reduction in its thickness, cutting metal consumption by up to 30%. In general, the building is designed according to the second version, the structural system of a bearing floor. Here, a steel membrane is used in the lower slab instead of steel-reinforced concrete slabs.

Whereas in the previous example, a steel membrane was used as a slab, in the following example, a multi-level solution is created with a structural system of a bearing floor (Zabalueva, Zakharov, 2013), the upper and lower slabs of which are steel-reinforced concrete slabs. This structure presents a spatial large-span box, the area and height of one floor, with a large number of bulkheads serving as interior walls, firmly connected

to the lower and upper floor slabs. The bearing floor rests on the outer walls, forming a space beneath it, free of supports, called the "free floor", in this case – a large sports arena.

The use of the bearing floor structure

In a design proposal for the city of Sochi (Figure 3), a bearing floor design was used to divide the interior space by levels, which made it possible to combine several sports facilities located at different levels in one building (Biriukov, Zakharov, Zabalueva, 2011). The lower level, the free floor, houses the ice arena; on the second level, training halls and auxiliary rooms are built into the structure of the load-bearing floor, which covers the ice field; and on the third level, there are three training rinks with locker rooms.

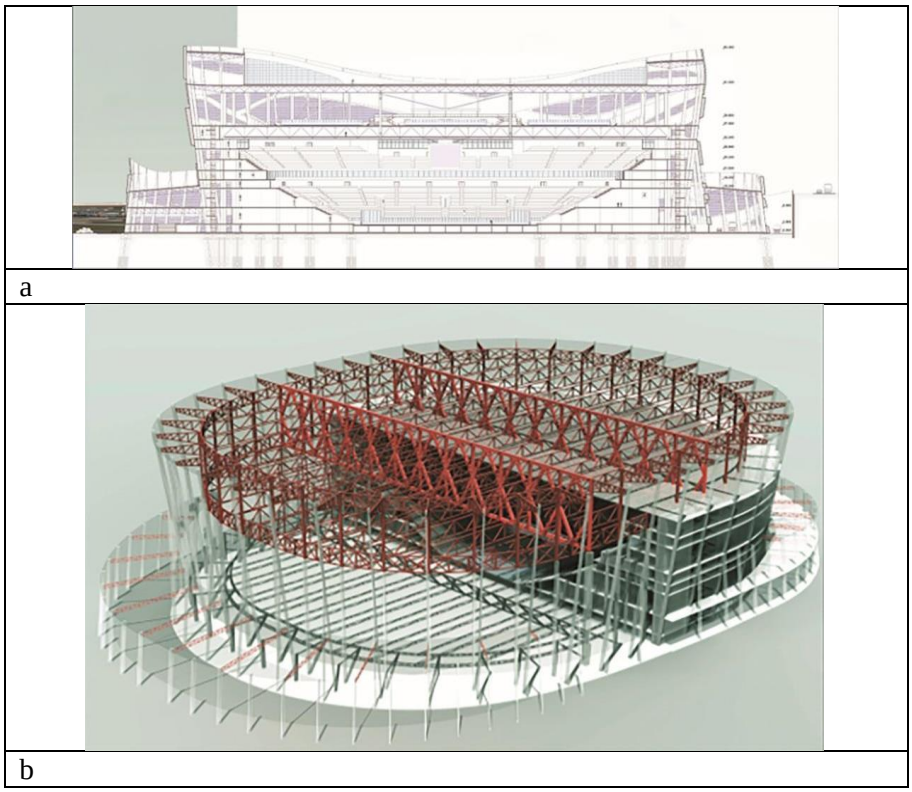


Figure 3. The Bolshoi Ice Palace for the city of Sochi with a bearing floor: a – cross-section of the Ice Palace with a bearing floor; b – 3d diagram of the bearing structures of the Ice Palace.

Another trend in the development of approaches to the construction of modern sports facilities is the placement of these facilities in building-bridges and building-platforms, which are currently a novel type of elevated large-span buildings (Zabalueva, Zakharov, 2012). These buildings are raised above the already occupied areas at ground level, which can be railroads, highways, or industrial areas. These objects can "step over" rivers, ravines, other nuances in the landscape, etc. (Kocheshkova, 2013).

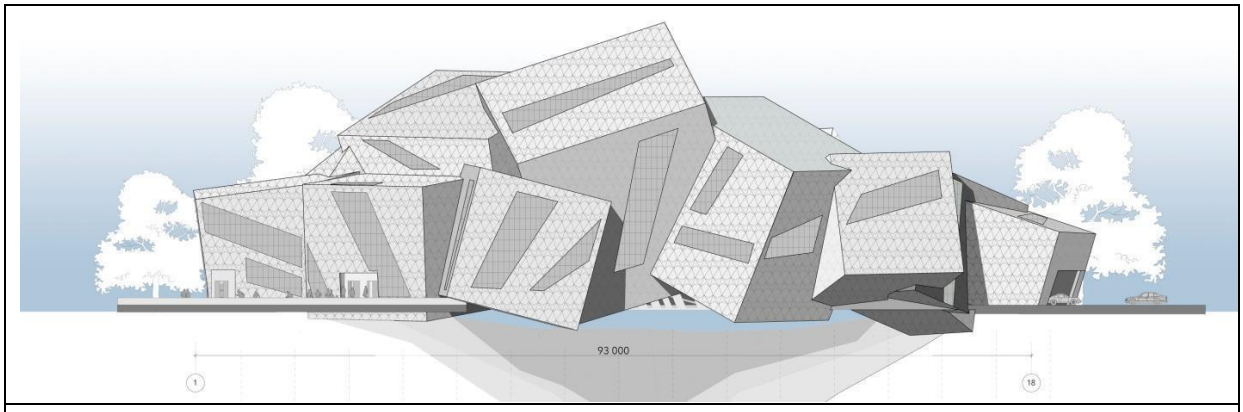
Building-bridges

Building-bridges are span structures, the construction space of which has premises of different purposes inside it (Zabalueva, Fleishman, 2018). In our case, these functional fillings may be sports facilities (Kaisarova, Zabalueva, 2021).

Bridge buildings can have a variety of large-span structures from 20 to 100 or more meters. In this case, structural solutions can vary, as well as, respectively, the filling with rooms of different purposes.
One of the project proposals suggests placing a complex of gyms for various purposes in the arched building-bridge in the Nogatinskaya floodplain of the Moscow River (Figure 4).

Figure 4. Building-bridge in the Nogatinskaya floodplain of the Moscow River with sports halls for various purposes. Structure: steel-reinforced concrete ceilings suspended from two-bracket supports.

The designed building-bridge with a complex of wrestling halls for the city of Nizhny Novgorod is a composition of cubic volumes blocking the ravine that is an insurmountable obstacle to the passage of cars (Figure 5a).



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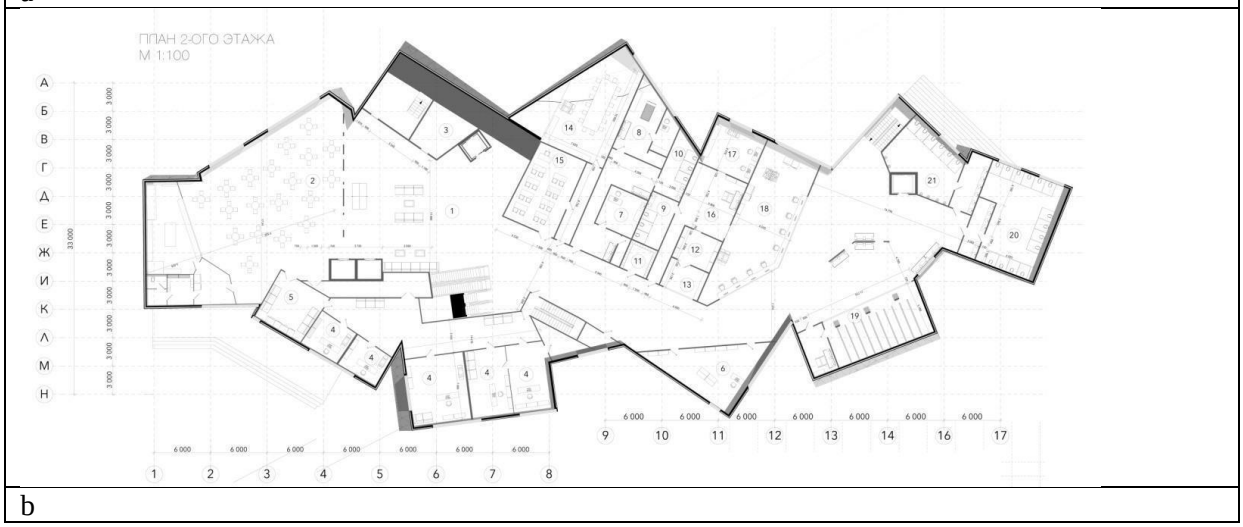

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Figure 5. Building-bridge of cubic volumes with halls for martial arts in Nizhny Novgorod: a – facade of the building-bridge; b – plan of the second floor.

Building-bridges allow a wide variety of spaces to be accommodated within their design solution, as presented above. The choice of sports functional purpose depends on the design of the building. However, the most low-cost and suitable for the needs of the population to use them within walking distance are small-span building-bridges. The study of the possibility of placement of sports halls for various purposes in small-span building-bridges, in which the main span overlapped by steel-reinforced concrete slabs is 20-25 m, shows that the set of such halls is wide enough. Such small-span buildings can accommodate rooms for martial arts, wrestling, weightlifting, volleyball, badminton, deck tennis, etc. The larger the span of the building-bridge, up to 50 meters, the more diverse the functional purpose of sports facilities inside it can be (Kaisarova, Zabalueva, 2021). More spacious building-bridges can accommodate fencing grounds, ice rinks, swimming pools, etc.

Building-platforms

Among the new types of elevated large-span objects are building-platforms (Kharkovskaia, Zabalueva, 2017). A building-platform is a large-scale structure covering considerable territory on the surface of the ground that is already used for certain needs. Building-platforms can cover developed railway sidings, marshalling yards, industrial areas, multi-level road junctions, etc. These objects can be either single-story or multi-story. Almost any sports facility can be easily accommodated inside these buildings, which can be operated by means of artificial supply and exhaust ventilation.

One of the proposals for the placement of sports facilities in a building-platform is the insertion of a large track and field manege in the building-platform located above the railroad tracks near Leninsky Prospekt metro station in Moscow (Figure 6).

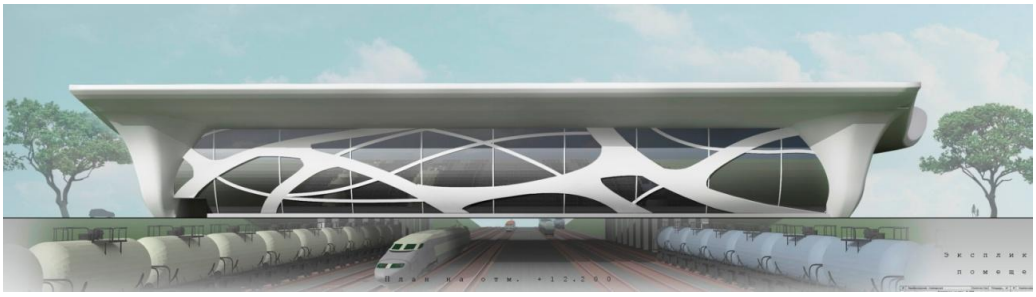
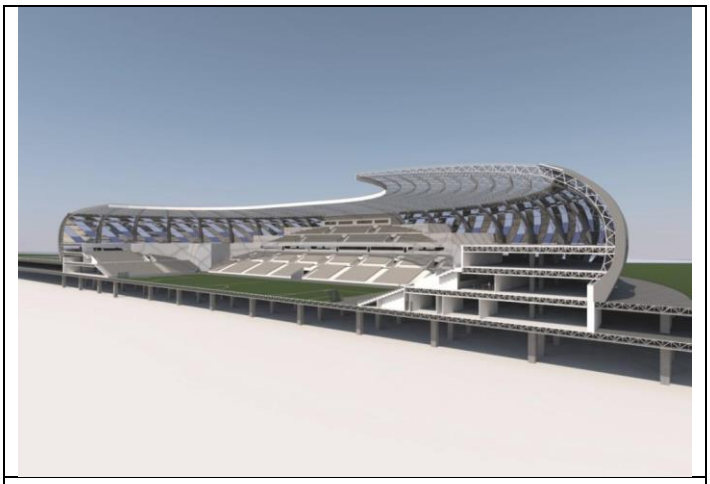


Figure 6. Building-platform with a load-bearing floor above the railroad tracks near Leninsky Prospekt metro station in Moscow with a track-and-field arena from various angles

In addition to the placement of sports facilities inside the building-platforms, such facilities can be placed on their upper level. One example of such a solution could be the project of a soccer stadium for 25,000 spectators on the upper level of the building-platform over the Riga railway junction and the Riga Station Square in Moscow. It is a full-fledged stadium that meets UEFA requirements. The surface of the platform allows for 4,200 individual parking slots and 300 parking slots for buses in accordance with the standards. In this proposal, parking spaces are placed in the body of the platform, which frees up space for park plants that improve the city's environmental profile. The presented solution involves placing the playing field itself at a level below the surface of the platform, which allows visually reducing the height of the entire structure towering above the surface of the platform and the grandiosity of the object in an urban environment (Figure 7).



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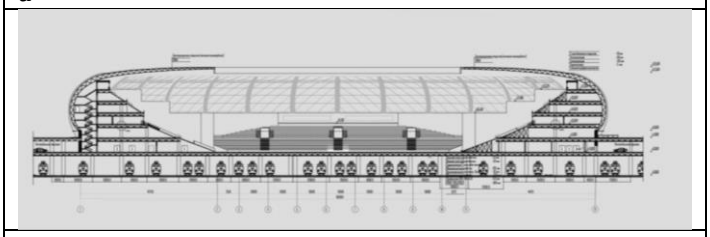

b

Figure 7. Soccer stadium for 25,000 spectators on the upper level of the building-platform over the Riga railway junction and the Riga station square in Moscow: a – general bird's-eye view; b – 3d section; c – cross-section of the entire building together with the building-platform over the tracks of the Riga railway junction. Construction with steel-reinforced concrete slabs.

4. DISCUSSION

Research and experimental design at the Scientific-Research Moscow State University of Civil Engineering suggest some ways to reduce the development area of sports facilities through the use of progressive design solutions that contribute to the sustainable development of the architecture of these facilities.

Sports facilities in small towns are much more modest in size, but perform the same set of functions. The closest to the population for purely non-professional and recreational sports are health and fitness complexes built directly into residential buildings (Lasprilla, 2020; Padilla Llano, 2020). As a rule, they are constructed for the population of all ages within walking distance of their places of residence. For these facilities, it is very important to reduce the cost of the object. New structural solutions with the use of a load-bearing floor reduce the cost of such facilities by half.

When considering trends in the construction of modern sports facilities, we must turn to the soccer stadiums built across the country in time for 2018. New approaches to the design of major sports facilities are most evident in the creation of 12 international stadiums in Russia based on the requirements of UEFA for the FIFA World Cup. The requirements primarily boiled down to an open soccer field. This problem was solved mostly by not covering the field itself and simultaneously overhanging the roof over the tribunes. The climatic conditions of the country were taken into account, which resulted in quite striking design solutions to cover these stadiums with retractable roofs in the summer and closing the roofs in the winter, which was a new approach to the design of the coverings of large-span stadiums (Shaidurova et al., 2021; Zhang et al., 2020).

Computational pre-design studies carried out as part of the designs of sports buildings examined in this paper show the limits of their implementation with the following parameters of the structural solutions considered, which lead to the following conclusions:

- Steel-reinforced concrete floor slabs with through ribs for a span of 20 meters can be used with a grid of 6x20 meter columns without restrictions on the area of development and number of stories of the building;

- Steel-reinforced concrete slabs according to clause 1 can be unified for the device of cross-spans of load-bearing floors and building-bridges.

- Technically feasible structural ratios of building heights to spans of load-bearing floors lie between 1/15 and 1/10, the economically feasible − between 1/5 and 1/3. Technically feasible ratios of building heights to spans of bridge buildings lie in the range of 1/10 – 1/7, the economically feasible – between 1/4 and 1/2.

5. CONCLUSION

Thus, it can be said that today the sports facilities themselves have a wide range of functions combined in one facility. In addition to freestanding buildings with at least two working levels, they can be located in such structures as building-bridges and building-platforms, which allow for the secondary use of urban areas and thus compensate for the lack of space for construction together with ensuring the economic efficiency of the construction of these objects.

The conducted computational research reveals that the designs of the considered building projects allow for a wide range of sports facilities ranging from municipal-level health and fitness complexes to objects intended for major international competitions.

All of the proposed design materials change the view on the design of sports facilities and their placement in the urban environment.

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