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D.A. Zhegalova[1], S.Sh. Sadykova [2]*

[1,2] L.N. Gumilyov Eurasian National University,
Nur-Sultan, Republic of Kazakhstan

Information about authors:
Sadykova Sara Shangereevna – Candidate of Architecture, Professor of the Department «Architecture» of the Eurasian National University L.N. Gumilyov, Nur-Sultan, Kazakhstan.
https://orcid.org/0000-0002-2777-1556, e-mail: sara.arch@mail.ru
Zhegalova Darya – undergraduate of the Department of Architecture, L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan.
https://orcid.org/0000-0002-7497-6669, e-mail: dasha_7g_95@mail.ru

DEVELOPMENT OF LARGE-SPAN CONSTRUCTIONS IN THE ARCHITECTURE OF THE MID-19TH AND EARLY 20TH CENTURIES

Abstract. *The article reveals the issues of the development of large-span structures in the architecture of the mid-19th and early 20th centuries. Structural systems used in the construction of these structures are considered and analyzed on the example of the unique objects of the first world exhibitions, as well as large shopping passages. This confirms that the use of large-span structures affects the rapid development of the architecture of unique buildings and structures.*

Keywords: *architecture, large-span structures, reinforced concrete structures, metal structures, spatial structures, overlapping, shape, dimensions.*

Introduction

Technological revolution and the Industrial Revolution from the mid-19th and early 20th centuries provided a powerful boost to the development of construction equipment and the emergence of new building structures. Building Science developed along the path of finding the most rational engineering solutions and a clear constructions scheme. A number of outstanding works in this area have opened the way to widespread dissemination of not only linear bar structures, but also statically indeterminate structural systems such as three-articulated arches and frames. The impetus in the development of large-span structures was the invention in 1856 of the Bessemer converter and the development in 1860 of the Martin Steel Method. The end of the 19th century was marked the beginning of industrial production of various light aluminum-based alloys, and in 1913, stainless steel was invented [1].

Materials and methods

Among the architectural structures of different purposes, a group of architectural objects stands out, in which the compositional core is a large hall, it is also the functional basis of the entire structure, which has an area free from intermediate supports and overlapped structures of a large span. These objects (civil, industrial, public) exhibit unique diversity of shapes and dimensions. Such structures include covered markets, exhibition pavilions, various types of auditoriums and gyms, which are united by the characteristics of large-span buildings. Indicative, from the point of view of the development of large-span structures, is the period of mid-19th and early 20th centuries. This is a time of rapid development of scientific progress in the field of building structures and materials, as well as revolutionary construction technologies and theories for calculating structural systems. For example, in the middle of the 19th century, reinforced concrete structural systems were created, the appearance of which is associated with the name of Joseph Monier, who invented reinforced concrete. And at the same time, the development of metal structures associated with the appearance of the first open-hearth furnaces for steel melting. And from that time the era of large-span structures begins [2].

Large-span structures are considered to be coverings with a span of more than 36 meters. Researcher P.G. Eremeev defines them in this way: «These are spatial structures – continuous and rod-type sheathings; domes; hanging, cable-stayed, sheet (membrane) and awning coverings; rod-type spatial structures; cross systems; as well as traditional designs of large spans – trusses, beams, etc.» [3].

Large-span structures are very different in appearance. Of particular importance is the exact choice of one or another structure to overlap the building. Therefore, the choice of coverage is carried out, firstly, from the architectural and artistic tasks to be solved, and secondly, from the size of the overlapped space and the capabilities of the structural system.

There are many classifications of large-span structures. In general, they are divided into three main groups:

- supporting structures operating in one plane;
- supporting structures operating in two planes – cross;
- supporting structures of the spatial system, when calculating the forces in three planes.

Unique buildings and structures with large-span structures include objects including the following:

- spans over 100 meters, with design solutions that have been successfully tested in the practice of design, construction and operation;
- spans over 60 meters using the latest design solutions [3].

Results and disscusion

The development of large-span structures of the period under consideration can be most clearly traced in the architecture of unique buildings and structures. The beginning of active construction of unique structures using metal structures covering large spans falls on the middle of the 19th century. This is the time of the first world exhibitions. One of the main goals of the World International Exhibitions was to demonstrate the latest technical achievements. The first such International Exhibition of Achievements in science, industry, art and trade, held in London's Hyde Park from May 1 to October 15 in 1851, became an important stage in the dissemination of new building technologies and structural systems, especially large-span ones. Its symbol was the large-span building of the Crystal Palace, built under the leadership of Joseph Paxton (Fig. 1).

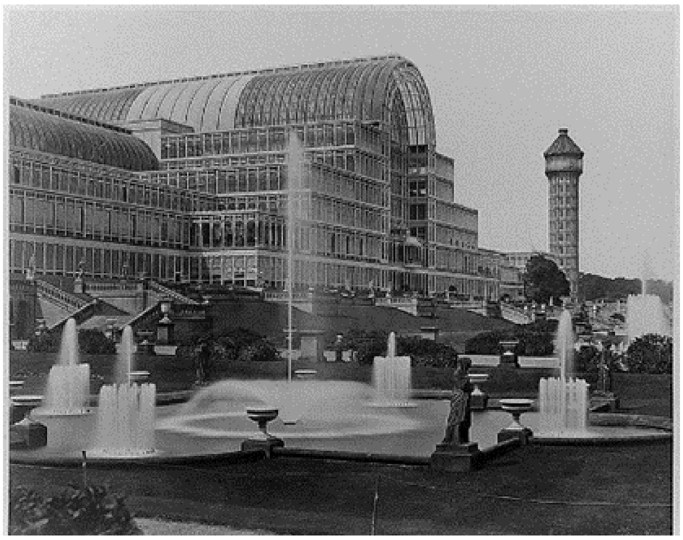

Figure 1 – Crystal Palace, arch. Joseph Paxton, UK, mid-19th century. General view.
A Dorling Kindersley book. Architecture. 1999 [4]

The structural frame elements of the Crystal Palace were prefabricated and consisted of: cast iron supporting legs, steel lattice girders and wooden arches, and frames. This solution was mainly of low cost, and the structure could be removed immediately after the end of the exhibition, since the building was completely prefabricated. The exhibition space had a total area of more than 90,000 square meters, the length was 564 meters, the width was 124 meters, and the height was up to 33 meters. The palace could accommodate up to 14,000 visitors. The rationality of the construction was ahead of its time, but artistically, the Crystal Palace was considered obsolete: triple nave and transverse transept, as in medieval Gothic cathedrals. Architect-decorator Owen Jones used a bright variety of colors inside and disguised the supporting structure with Corinthian capitals. The interior of the palace was decorated with marble statues, a fountain and old trees, which further emphasized the dissonance between the new structures and the general architectural solution.

The large-span structure of the unique Crystal Palace was a cylindrical vault that completely covered the central transept. Under the roof were raised huge elms of Hyde Park - the pavilion was constructed directly above them. In the building rebuilt at Sydenham, the wooden vaults were replaced with metal ones. For the glazing of the roof and the upper tiers of the walls, huge for that time glass sheets 120 * 25 cm, inserted into wooden frames, were used.

The fittings inside the building were painted in the same colors as the trusses. Graceful interior frame and pane of glass allowed into the building maximum natural light, saving money on artificial lighting. The decorative elements were used only for external decoration. Arches and round windows, sharp-pointed towers and roofing grills emphasized rhythm and symmetry of the facades [4].

Thus, an analysis of the architectural and structural solutions of the Crystal Palace showed that innovative building materials and technologies were used here – for the first time a large-span metal cylindrical vault structure, a unified supporting frame of racks and beams, as well as large-format glass vault cover sheets were used (Fig. 2).

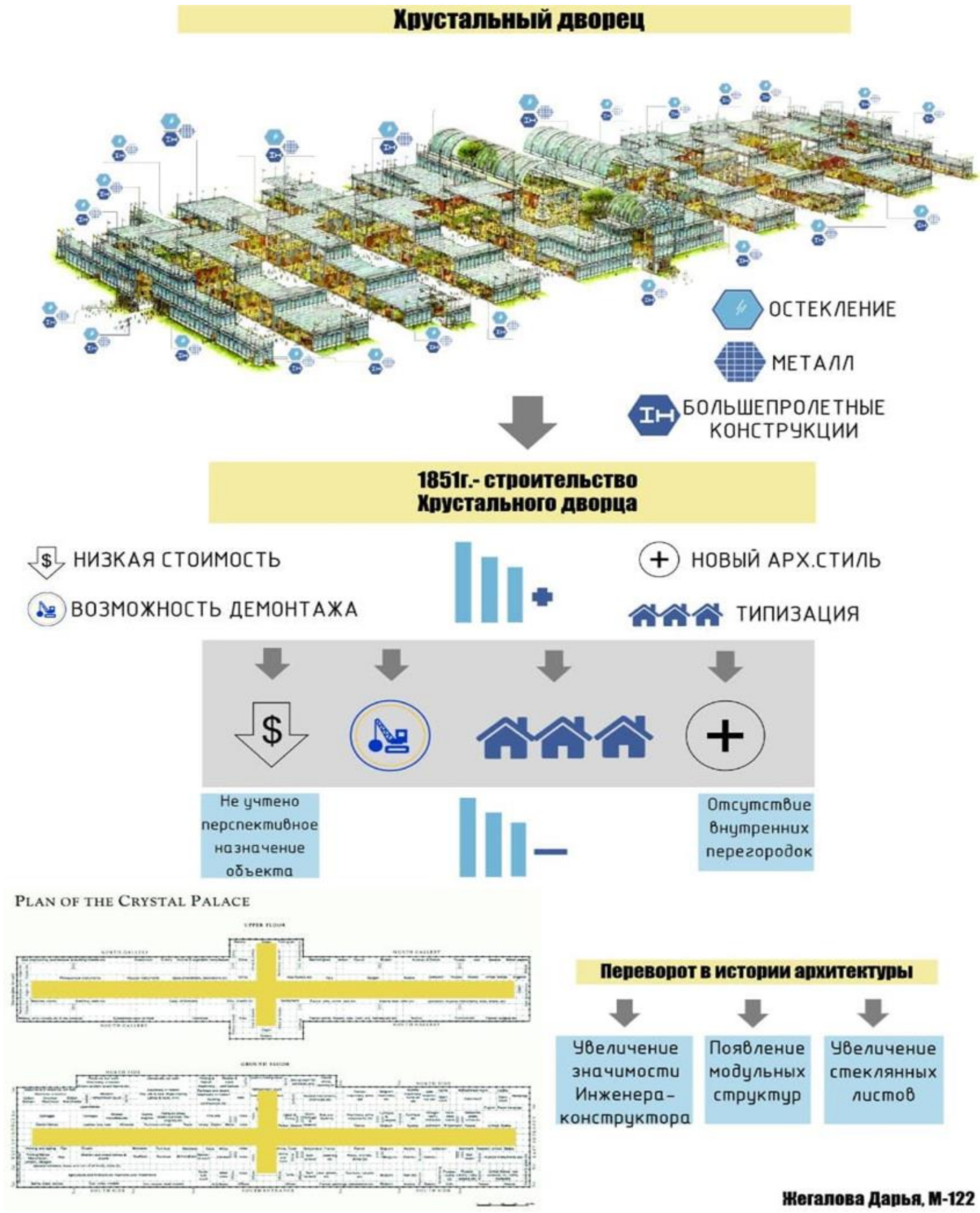

Figure 2 – Scheme of the architectural, planning and structural analysis of the Crystal Palace in London [author's materials]

The next most important stage in the development of large-span building metal structures was the World Exhibition of 1889 in Paris. The sensation of the exhibition was the mechanical engineering pavilion – «Gallery of machines», built by the architect Ferdinand Düter and engineer M. Kotansen (Fig. 3). The gallery formed a hall of metal and glass with an area of 115 by 420 meters, the height was more than 48 meters. The structure had no internal supports. The frame consisted of twenty steel trusses. The gallery's trusses and pillars were connected to form three-articulated steel arches, each of which was composed of two L-shaped elements. The trusses at the base were small and larger at the top, light and narrow. Such proportions of the structure were unfamiliar to people accustomed to heavy stone vaults. The bearing and carrying parts of the Gallery of Machines were structurally separate; this circumstance was emphasized by the architectural interpretation of the details. In the new structure, all parts of the structure worked together and seamlessly passed into each other. In addition, if in the previous structures the vertical supports were made more powerful in the lower part, then in this project, on the contrary, they became thinner downwards. The new constructive forms of the Machine Gallery created a revolution in the architectural aesthetics of the time (Fig. 4). It should be noted that the largest vaulted building of the mid-19th century was the St. Pancras railway station, its span was 73 meters. The gallery had a span of 115 meters, thus the Gallery of Machines span became the largest among those built by that time in the whole world. At the same time, this building, as a giant exhibit of the exhibition, demonstrated revolutionary innovations in the development of architectural structures, the great potential of new building materials, first of all, such as steel and cast iron. The large glass surfaces of the Machine Gallery coverings gave a great opportunity to create light and well-insolated architectural spaces (Fig. 5) [3].

Figure 3 – Gallery of Machines, arch. Duther, Eng. Cotansen, Paris, France, 1889.
View of the interior space
Electronic resource: https://www.pinterest.com/

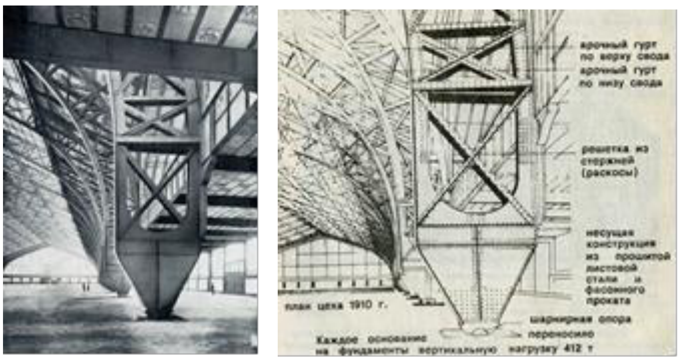

Figure 4 – Structural units of the Gallery of Machines. Fragments of the pivoting bearing
Electronic resource: http://snip1.ru/arhitectura/arxitektura/arxitekturnye-formy/xix-vek/opory,
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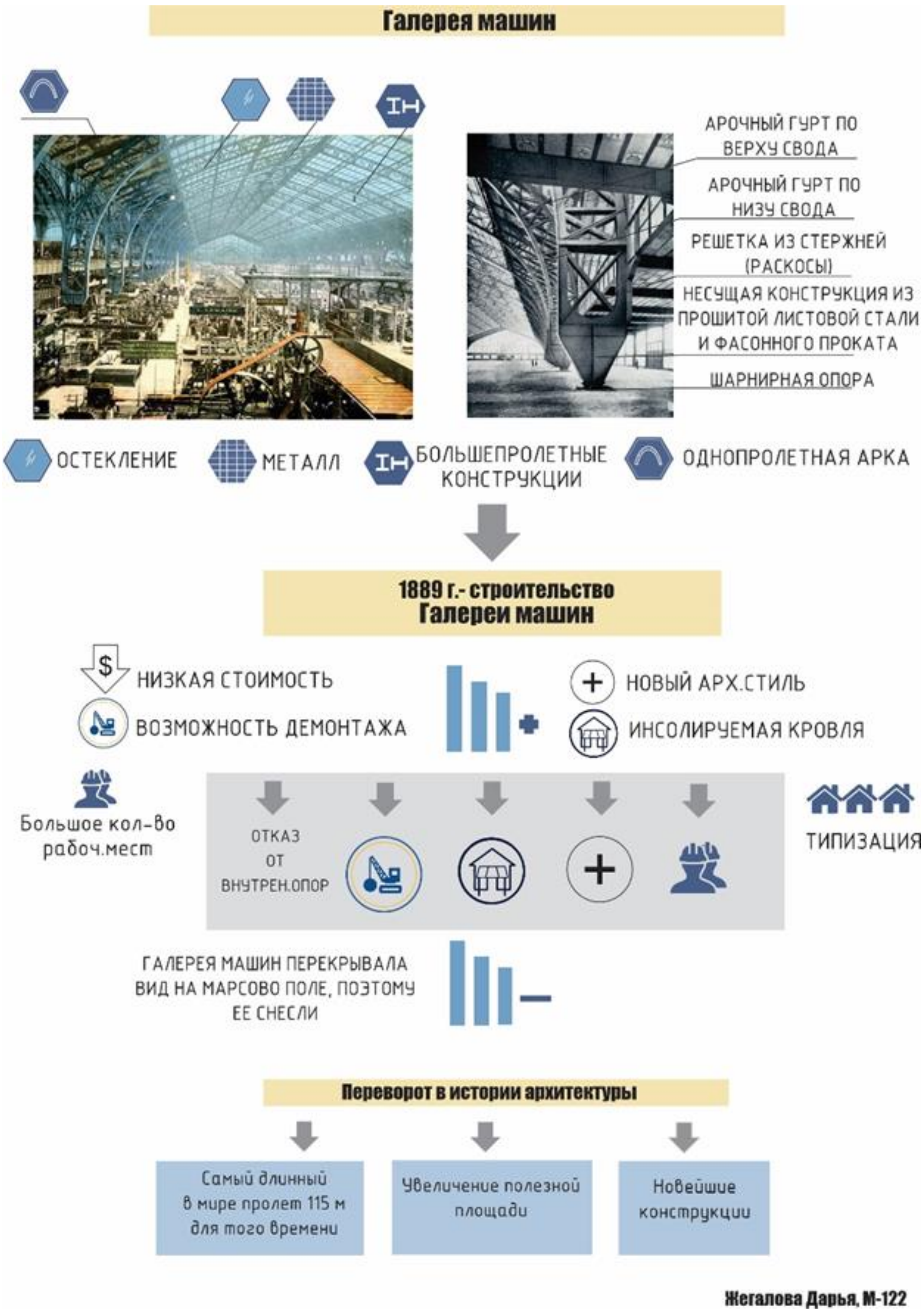

Figure 5 – Scheme of architectural, planning and structural analysis
of the Gallery of Machines [3]

Reinforced concrete structures were important for the development of large-role structures in the second half of 19th century. For unique large-span structures, the most reliable from the point of view of exploitation is the use of reinforced concrete structures, among which the advantages are durability; low cost; fire, chemical and biological resistance; manufacturability (when concreting it is easy to get any form of structure); high resistance to static and dynamic loads. The use of reinforced concrete became possible at the end of the 19th century, after it was patented by Joseph Monier in 1867. Already at the beginning of the 20th century, reinforced concrete became the most common material in the construction of structures with large spans in the form of trusses, arches, vaults, beams and played a significant role in the development of various architectural trends. Further, the improvement of reinforced concrete structures led to the appearance of thin-walled spatial structures: sheathes, folds, domes. New theories for the calculation and construction of thin-walled coatings have appeared.

One of the outstanding examples of the development of large-span reinforced concrete structures is the unique structure of the Upper Trading Rows (now known as the Moscow GUM), built by the architect A.N. Pomerantsev, the engineer-designer of reinforced concrete structures was A.F. Lawlet, who subsequently created the main provisions of the modern theory of reinforced concrete (Fig. 6).

Figure 6 – Upper Trading Rows in Moscow, late 19th century. General view
Electronic resource: https://gum.ru/history/

Upper Trading Rows were conceived not only as a shopping mall, but also as a global getaway to stroll around and enjoy concert art. The composition of the grandiose building includes three parallel passageways connected by three transverse passages covered with cylindrical vaults.

The object had to accommodate a large number of people at the same time, while working daily throughout the year, that is, it had to be built and covered with something reliable and unique, which A.N. Pomerantsev and A.F. Lolleith did (Fig. 7). The large-span structure of the Upper Trading Rows in Moscow was a light cylindrical vault, the stability of which was ensured by diagonal braces penetrating the space inside the vault, but almost invisible from below (Fig. 8).

Figure 7 – Upper Trading Rows in Moscow, late 19th century. View of large-span structures
Electronic resource: https//yandex.kz/images/

At the beginning of the 20th century, with the emergence of the aviation and automotive industry, it became necessary to build new types of structures requiring the overlap of large spans (airports, hangars, train stations, automobile factories, etc.), which served as an impetus for further improvement that arose once in mid-19th century constructions.

Conclusion

Thus, the research of various aspects of the development of large-span structures in the architecture of unique structures of the mid-19th and early 20th centuries led to the following conclusions:

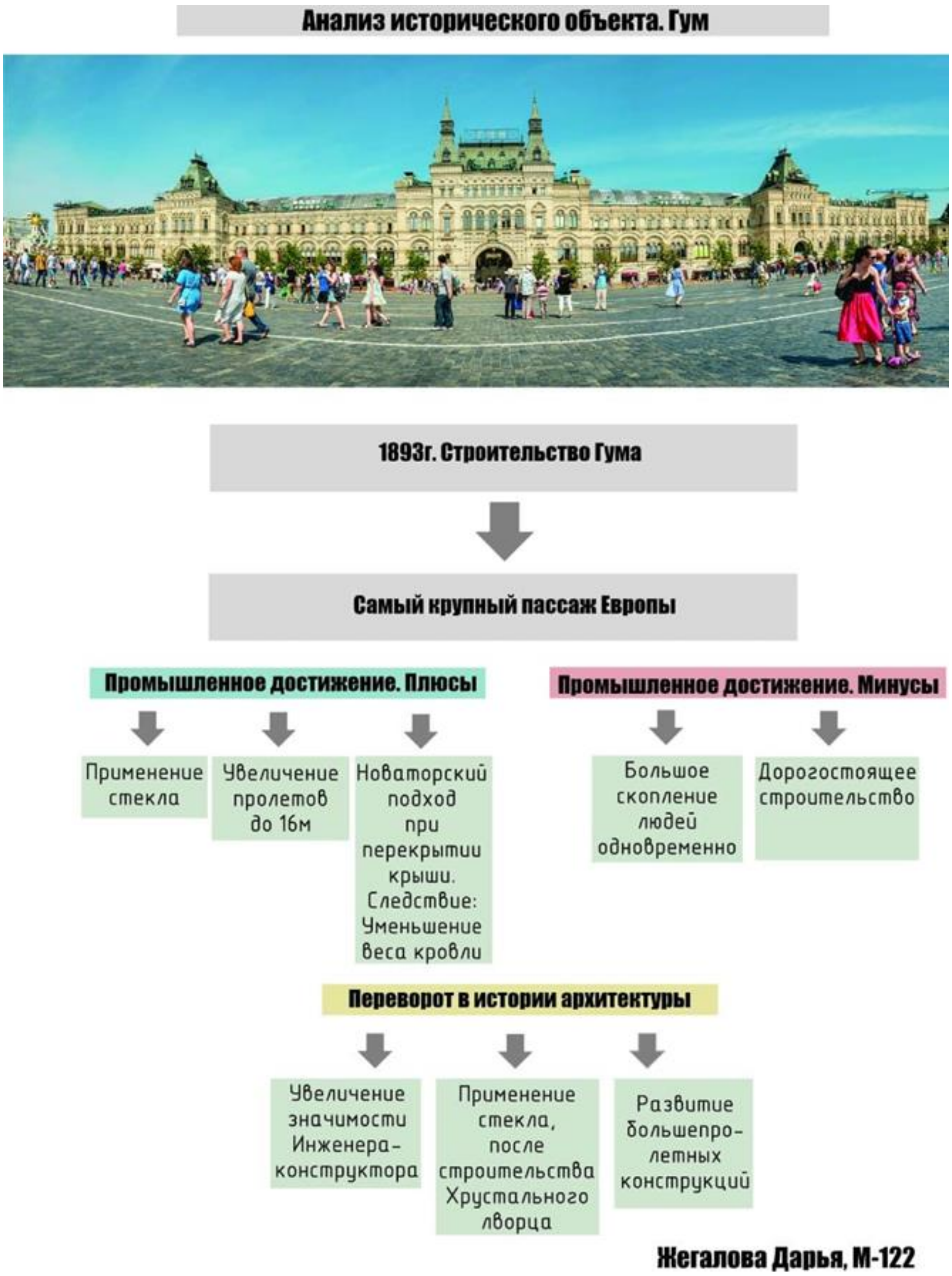

Figure 8 – Scheme of the architectural, planning and constructive e analysis
of the Upper Trading Rows [author's materials]

- The 19th century brought outstanding achievements in the development of metal and reinforced concrete structures, which made it possible to solve the problem of the need for large spans for the construction of unique buildings and structures (outstanding buildings of the first World Exhibitions);
- The development of industry and new technologies directly influenced the development of new types of buildings and structures requiring the overlap of large spaces, which in turn contributed to the emergence of new large-span structures (metal and reinforced concrete trusses, arches, vaults, domes and beams);
- The development of large-span structures and the emergence of new building materials and construction technologies form a new architecture and, together with it, radically change the architectural appearance of cities.

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С.Ш. Садыкова[1], Д.А. Жегалова[2]*

[1,2] Евразийский национальный университет им. Л.Н. Гумилёва, Нур-Султан, Казахстан

Информация об авторах:
Садыкова Сара Шангереевна – кандидат архитектуры, профессор кафедры «Архитектура» Евразийского Национального университета им. Л.Н. Гумилёва, г. Нур-Султан, Казахстан.
https://orcid.org/0000-0002-2777-1556, e-mail: sara.arch@mail.ru
Жегалова Дарья Александровна – магистрант кафедры «Архитектура» Евразийского Национального университета им. Л.Н. Гумилёва, г. Нур-Султан, Казахстан.
https://orcid.org/0000-0002-7497-6669, e-mail: dasha_7g_95@mail.ru

РАЗВИТИЕ БОЛЬШЕПРОЛЕТНЫХ КОНСТРУКЦИЙ СЕРЕДИНЫ XIX – НАЧАЛА XX ВВ.

Аннотация. *В статье раскрываются вопросы развития большепролетных конструкций в архитектуре середины XIX – начала XX вв. На примере уникальных объектов первых всемирных выставок, а также крупных торговых пассажей рассмотрены и проанализированы конструктивные системы, использованные в строительстве этих сооружений. Это подтверждает, что использование большепролетных конструкций влияет на стремительное развитие архитектуры уникальных зданий и сооружений.*

Ключевые слова: *архитектура, большепролетные сооружения, железобетонные конструкции, металлические конструкции, пространственные конструкции, перекрытие, форма, размеры.*

Авторлар жайлы ақпарат:
Садыкова Сара Шангереевна – сәулет ғылымдарының кандидаты, Л.Н. Гумилёв атындағы Еуразия ұлттық университеті «Сәулет» кафедрасының профессоры, Нұр-Сұлтан, Қазақстан.
https://orcid.org/0000-0002-2777-1556, e-mail: sara.arch@mail.ru
Жегалова Дарья Александровна – Л.Н. Гумилёв атындағы Еуразия ұлттық университеті «Сәулет» кафедрасының профессоры, Нұр-Сұлтан, Қазақстан.
https://orcid.org/0000-0002-7497-6669, e-mail: dasha_7g_95@mail.ru

С.Ш. Садыкова [1], Д.А. Жегалова [2]*

[1,2] Л.Н. Гумилёв атындағы Еуразия ұлттық университеті, Нұр-Сұлтан, Қазақстан

XIX ҒАСЫРДЫҢ ОРТАСЫНАН – XX ҒАСЫРДЫҢ БАСЫНА ДЕЙІНГІ ҮЛКЕНАРАЛЫҚ КОНСТРУКЦИЯЛАРДЫҢ ДАМУЫ

Аңдатпа. *Мақалада XIX ғасырдың ортасынан бастап, XX ғасырдың басындағы сәулет өнеріндегі ауқымды құрылымдардың даму мәселелері зерттелген. Осы бірегей құрылымдардың салуында қолданылатын құрылымдық жүйелер ең алғашқы дүниежүзілік көрмелермен, сондай-ақ ірі сауда орындарының мысалында қарастырылып, талданды. Бұл үлкен аралық құрылымдарды пайдалану бірегей ғимараттар мен құрылыстардың сәулетінің қарқынды дамуына әсер ететінін растайды.*
Түйін сөздер: *сәулет, ауқымды құрылымдар, темірбетондық құрылымдар, кеңістіктік құрылымдар, қабаттастық, пішін, өлшемдер.*