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NEW WAVE OF CHINESE ARCHITECTURE AND CONSTRUCTION. REVIEW OF THE CPR MOST OUTSTANDING BUILDINGS

The most outstanding buildings of the Chinese People's Republic for the last decade are observed. The contemporary projecting and construction techniques with the use of steel structures are analyzed for large-scale projects.

Keywords: *Chinese building megaprojects, construction, large-span steel structures*

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НОВА ХВИЛЯ КИТАЙСЬКОЇ АРХІТЕКТУРИ ТА БУДІВНИЦТВА. ОГЛЯД НАЙВИДАТНІШИХ СПОРУД КНР

Розглянуто найвидатніші споруди Китайської Народної Республіки останнього десятиліття. Проаналізовано сучасні методики проектування та будівництва великомасштабних об'єктів із застосуванням металевих конструкцій

Ключові слова: *будівельні мегапроекти КНР, будівництво, великопролітні металеві конструкції.*

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НОВАЯ ВОЛНА КИТАЙСКОЙ АРХИТЕКТУРЫ И СТРОИТЕЛЬСТВА. ОБЗОР НАИБОЛЕЕ ВЫДАЮЩИХСЯ СООРУЖЕНИЙ КНР

Рассмотрены наиболее выдающиеся сооружения Китайской Народной Республики последнего десятилетия. Проанализированы современные методики проектирования и строительства крупномасштабных объектов с применением металлических конструкций.

Ключевые слова: *строительные мегапроекты КНР, строительство, большепролетные металлические конструкции.*

Introduction. The Chinese People's Republic is the most populated country of the world, moreover it's a great dynamic state, which continuously grows and develops.

With the globalization of architectural practices, foreign architects and associations are vastly involved in the Chinese urbanization process. The construction scale provides a platform for architects in China and abroad, making visionary architecture and imaginary ideas possible to come true.

Survey of the last researches and publications. The Chinese large scale structures and the most striking features of its projecting and construction have been considered in publications of Zhong-Yi Zhu, Chang-Hua Ke, Kai Qin and Yi Wang [14], T. Michael Toole [1], and Ethel Baraona Pohl and others [2], [15].

Target definition. The main aim of this article is to review the most outstanding buildings of the Chinese People's Republic for the last decade and to analyze modern design and construction techniques with the usage of steel structures.

Base material and results. Nowadays, megaprojects in China have drawn international attention. In recent years China has been one of the central areas of the world's construction industry. By the end of 2010, four out of world's twenty most expensive infrastructure projects in progress were in China, according to the Associate Press (2010) [1].

We have briefly paid our attention on the most outstanding of them, considering building structures of the last decade. Three of them were built for the Olympic Games in 2008, such as the National Aquatics center, the National Indoor Stadium and the National Stadium "Bird's Nest" and two constructed along with them: the China Central Television Headquarters and Terminal 3 at Beijing Capital International Airport.

1.The Beijing National Aquatics Center also colloquially known as the Water Cube is an aquatics center that was built alongside Beijing National Stadium in the Olympic Green for the swimming competitions of the 2008 Summer Olympics. Despite its nickname, the building is not an actual cube, but a cuboid (a rectangular box). It measures 177 m x 177 m in plan and has a height of 30.5m. It houses five swimming pools and seating for 17,000 spectators.

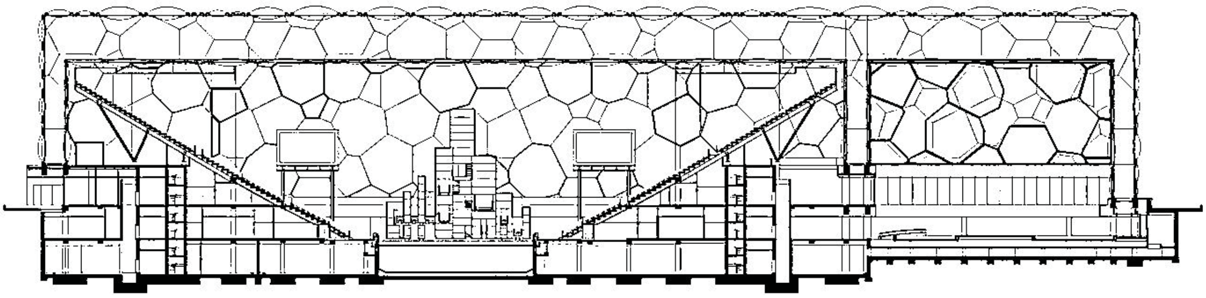


Figure 1 – The Beijing National Aquatic Center cross section

The scheme and design for the 100 million dollars project was elaborated by the consortium of Ove Arup, Australian architectural firm PTW, the CSCEC (China State Construction and Engineering Corporation) and the CSCEC Shenzhen Design Institute. The project had been handed over to a team in Beijing, who created documentation for the Water Cube. The early stages of developing the design concept involved looking and discussing diverse materials (for example water images in numerous forms), producing rough conceptual sketches and models and testing the concepts against functional planning arrangements, to ensure that the architectural idea could be developed into a working Olympic venue [2].

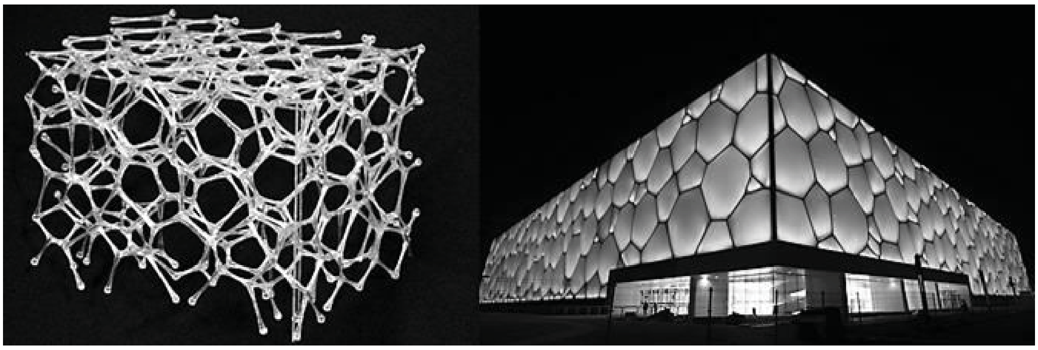


Figure 2 – The Water Cube from 3D concept to real structure

This structure looks like as a something imponderable, however it weights about 65000 tons. The Water Cube it's a majestic achievement in the sphere of modern technologies and design [4].

2. The Beijing National Indoor Stadium is an indoor arena, which hosts artistic gymnastics, tramlining and handball events.

Beijing Urban Engineering Design and Research Institute, which assumed part of the design work of the building, adopted the idea of a wavy roof looking like an unfolded Chinese fan. This creative design, besides paying tribute to Chinese aesthetics, improves the consistency of all the Olympic buildings.

However, the fan-like design of the 81,000-square-meter stadium posed a serious technical challenge to its constructors and design team, which included architects from China Steel Construction Society and a consultation panel from the Beijing Municipal Government.

All the functions of the National Indoor Stadium, the large circular main arena and the smaller circular arena adjoining it had been incorporated together under one large roof.

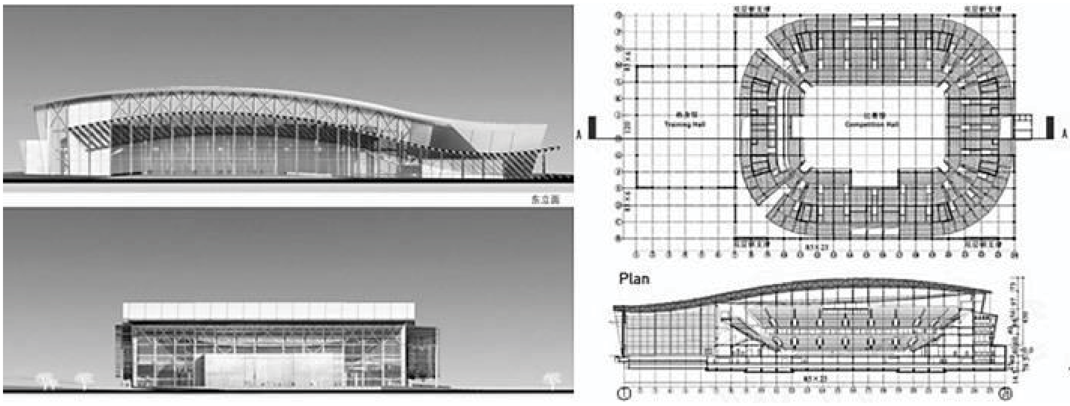


Figure 3 – Plan, section and facades of The National Indoor Stadium, that were designed by Glöckner Architektur und Städtebau with Beijing Institute of Architectural Design

The steel roof trusses of the National Indoor Stadium stretch 144 meters high and 114 meters wide. The frame is composed of 14 steel beams weighing a total of 2,800 tons, this is the longest-spanning indoor, bi-directional truss string structure in China at present, which is made of a multi-layer laminated metal composite material that is strong and with light weight.

The steel roof trusses were installed using nine robots. The construction workers relied on the robots to move and join the steel truss beams.

This modern 140 million dollars structure meets structural design elements in terms of aesthetics, safety, reliability in bearing weight, and cost [5].

Figure 4 – Steel roof trusses of the National Indoor Stadium, Beijing

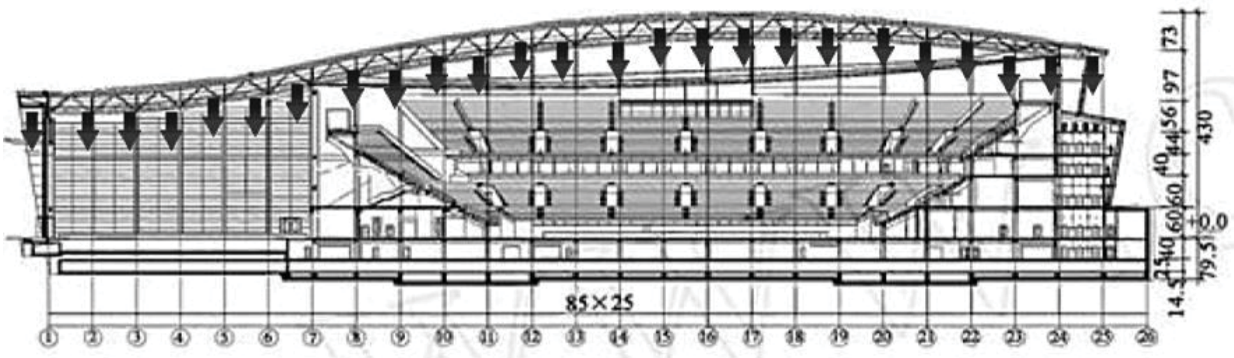


Figure 5 – Transferring of roof trusses loads to the ground through a frame consisting of 437 beams and 78 columns of steel reinforced concrete.

The venue, one of the best sports facilities in Beijing, can be used for sports competition, cultural and entertaining purposes, and will serve as a multifunctional exercise center, also the stadium, which includes Wukesong Indoor Stadium, Wukesong Baseball Fields, and sports and commercial facilities, will be able to meet the needs of local residents.

3. The National Stadium, commonly called “Bird’s Nest” was the main stadium for 2008 Beijing Olympic Games, designed by Swiss architects Jacques Herzog and Pierre de Meuron, the laureates of the 2001 Pritzker Architecture Prize. Choosing these two prominent international architects reveals the ambitions among territorial elites in China to demonstrate the country’s rise as an eminent economic and political power on the world stage.

Swiss architects Herzog & de Meuron collaborated with ArupSport and China Architectural Design & Research Group (which supervised the local construction) to win the worldwide design competition in 2002 for this Stadium, the proposed budget for the "bird's nest" was 500 million U.S. dollars [6].

Newly built National Stadium consists of an inner bowl of concrete seating surrounded by a façade of twisted steel, with a public concourse area sandwiched between the two. The elliptical building footprint is dictated by "the constraints of seating 100 000 people around an athletics track and field." In all, the structure encloses a volume approximately 333 meters long by 284 meters wide and 69 meters tall.

The building's distinctive façade was conceived in order to disguise the large parallel steel girders required to support the retractable roof that was specified in the original design program. The geometry of the seemingly random elements was defined using the geometrical constraints dictated by the usage and capacity of the structure and formalized using modeling software designed by Arupsport [7].

It should be noted that the 258,000 m^2 (gross floor area) stadium is built with 36 km of unwrapped steel. As constructed the roof structure consists of 42,000 tons of steel, while the structure as a whole contains 110,000 tons of it. The stadium has been built at a cost of about $423 million.

Chaotic as it appears, the stadium is really quite elementary in its structural design, consisting of primary, secondary, and tertiary steel members. The 24 columns that form the primary system are arranged at regular intervals around the perimeter of the building, forming an ellipse and carrying the bulk of the loads.

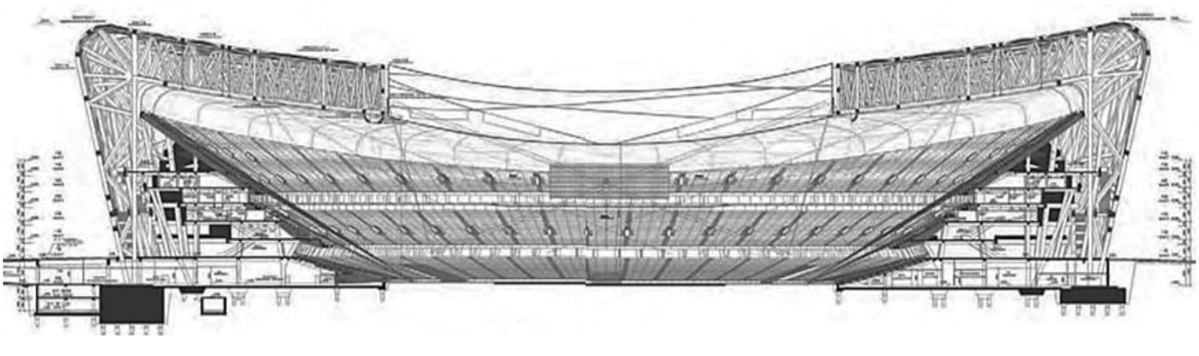
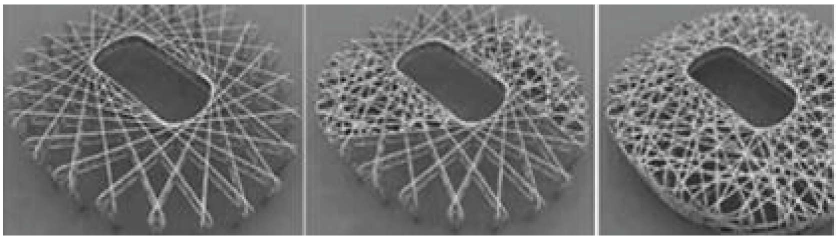


Figure 6 – Bird's Nest cross-section

These main columns define the plane of the facade, which is not strictly vertical but rather leans outward at and approximate angle of 13 degrees as it rises, lending the building its distinctive saddle shape. These mega columns rise to the full height of the stadium to join 12 m deep horizontal trusses that span the roof. The mega column has three main booms–one vertical and two inclined, they are tied together by diagonal elements forming a three dimensional truss system. The roof truss is composed of top and bottom booms with diagonal struts. Depth of the bottom chords reduces towards the center of the stadium from 1.2m to 0.8m The main elements for the columns and trusses are 1.2 by 1.2m box sections, fabricated with thickness varying from 15mm to 60mm. The 10m deep roof trusses follow a diagonal path criss-crossing each other and leaving an opening above the athletic field in the center. During a design review, the originally planned retractable roof was eliminated, increasing the opening in the roof and reducing the amount of required steel by 30%. Thus the columns and trusses form a series of interlocking portal frames, efficiently distributing loads to the foundation. A series of struts transfer axial loads from the curving members of the truss to the vertical columns. The joints where the beams transmit their loads to the columns are critical and 100 mm thick plates are used in the box sections at these locations [8,9].



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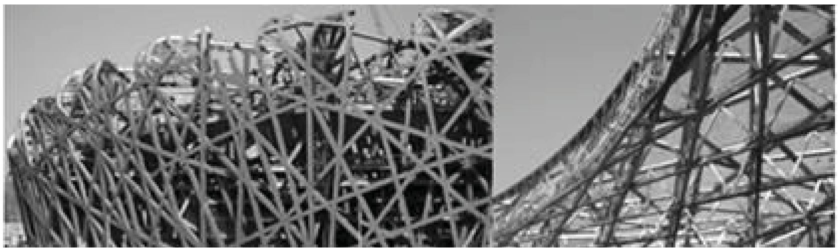

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Figure 7 – A model of Bird's Nest stadium by M/s Arup showing the primary load carrying elements and the secondary and tertiary members (a). The Beijing National Stadium under construction (b).

In conclusion, the National Olympic stadium in Beijing is an innovative building in terms of its design and the way it functions through its use of biomimicry.

4. China Central Television (CCTV), the country's state broadcaster, was planning to expand from 18 to 200 channels and compete globally in the coming years. To accommodate this expansion, they organized an international design competition early in 2002 to design a new headquarters building [10].

CCTV selected its design through an international competition. The design team consisted of the Dutch architectes Rem Koolhaas and Ole Scheeren of OMA (Office for Metropolitan Architecture) and ECADI (East China Architecture & Design Institute), Shanghai, while Ove Arup & Partners (Arup) provided the complex engineering design. It's an audacious monolith that looks like two drunken high-rise towers leaning over and holding each other up at the shoulders.

The skyscraper is 234.7 m tall and has 51 floors. The building has been called an “angular marvel”. Because of its radical shape, it has acquired nicknames such as “Big Shorts”, and “twisted doughnut”.

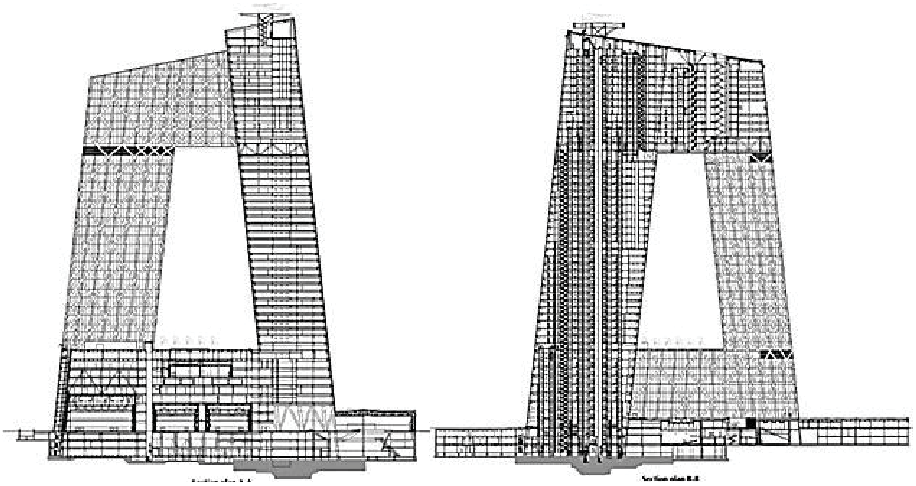

Figure 8 – CCTV Headquarters cross sections

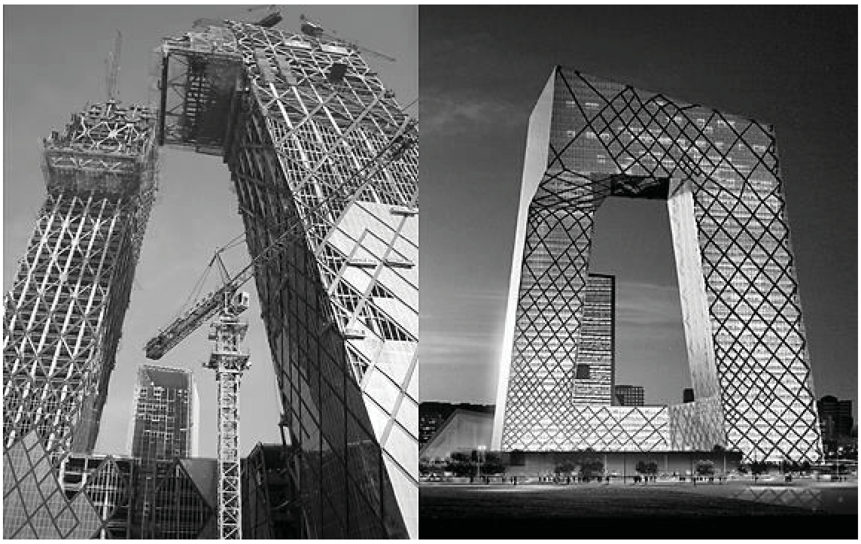

Figure 9 – View on CCTV Tower under construction (left) and the façade design of completed building (right)

The building includes broadcasting studios, program production facilities, digital cinemas and is the second largest office building in the world, after the Pentagon outside Washington. The total development is 540,000m², consisting of two main buildings: the CCTV building (381,000 m^2) and the Television Cultural Centre (TVCC). The total construction cost has been estimated at $750million.

The new CCTV building is not a traditional skyscraper, but in the form of a three-dimensional continuous cranked loop formed by a 9-storey podium at the bottom, joining two high leaning towers (40m x 60m, and 42m x 52 m size, leaning about 6^o from vertical), which are again linked at the top via a 13-storey cantilevered “70m overhang” structure at 36 stores above the ground (see Figure 9).

The building was built in two sections that were joined to complete the loop in 2007. In order not to lock in structural differentials this connection was completed at the last minute [8].

The innovative and iconic shape of the building is capitalized upon to provide its main structural support and stability system. The form warranted a primarily structural steel building, for a “light-weight” solution and enhanced seismic performance. As such, all the structural support elements in the building are of structural steel, except some external columns are steel-reinforced concrete columns due to the magnitude of loads they are designed to carry. The floors are composite slabs on steel beams.

The looping form of the building, combined with the sloping external faces and the need for large open internal spaces for studios and facilities, lead to the introduction of transfer trusses at strategic locations in the building.

At 36 stores above the ground, the two leaning towers crank horizontally and cantilever 75 m outwards in the air to join together forming the continuous loop defining the building shape. This 75 m cantilever structure encompasses 13 stores and is known as the “overhang”. The overhang floors are supported by columns landing on transfer trusses. These trusses span the bottom two stores of the overhang in two directions connecting back to the external tube structure. Thus the overall overhang structure is ultimately supported off the external tube structure. Major transfer trusses are also located in the base (podium) part of the building. These trusses span over the major studios to support the columns and floors above them in the building [11].

In total, 41 882 steel elements with a combined weight of 125 000 tons, including connections, were erected over the 26 months, at a peak rate of 8000 tons per month. During the design it was thought that some high-grade steel elements would need to be imported, but in the end all the steel came from China, reflecting the rapid advances of the country’s steelwork industry. The project demonstrated that a building with many complex technical challenges could be delivered successfully within a tight program [10].

5. The futuristic steel-glass and aluminum construction of **Beijing Airport Terminal 3** represents one of the most significant highlights of the city’s new architecture. The almost four kilometers long and nearly 800 meters wide passenger hall aims at conveying an image of modern China to the arriving passenger. Apart from the impressive space of about 1.3 million square meters – the Chinese authorities proudly call it the “the world’s largest building” [12].

It was designed by a consortium of NACO (Netherlands Airport Consultants B.V), UK Architect Foster and Partners and Arup. They built an integrated, cohesive terminal building without having to accommodate any existing buildings on site [8].

The construction of new terminal 3 buildings started on March , 2004, finished on December, 2007, and became fully operated on March, 2008. The gross loor area is 986,000 m^2, with a designed passenger capacity of 43 million per year, and the total investment is $2.82 billion [13].

Figure 10 – Overall view of Terminal 3 at Beijing capital International Airport during construction and after its completion

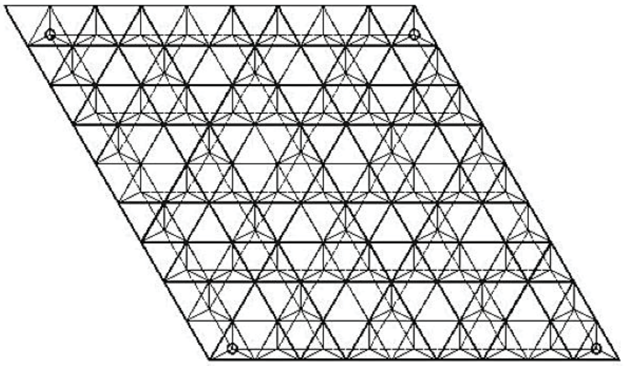

Figure 11 – Basic cell of space frame

The building plan of T3A display "person" word pattern, the length between north and south is about 950 meters, the width between east and west is about 750 meters, the highest light of the roof is about 45 meters. The main body structure of the T3A is the reinforced concrete frame construction, the roof is the space frame structure, and hang the glass curtain wall all around outside, the roof is supported by the variable cross-section steel pipe column which extend to the building surface or peripheral inclines to outside. The contour of T3A becomes an entire flight body.

The variable thickness hyperboloid space frame structures adopted in the roof, the exhaust broach I mode space frame is mainly used, and the part exhaust space frame is adopted in the stem and main body wing part.

In order to coordinate the peripheral curtain wall arrangement, space truss is established in the boundary of roof, at the same time the space truss also play the role of strengthening the space frame structure. The space frame structure is the bottom boom strut; support the column crest which extends to the building surface or peripheral inclines to outside. The column net of the supporting column is an equilateral triangle which the side length is about 41.6 meters. The

T3A roof is supported by 136 steel pipe columns. According to its distributing position, steel pipe columns can be divided into four parts.

The former part is located in the south side of navigation station building, have 22 erect steel pipe columns, 10 steel pipe columns are the taper columns, other 20 ones are the shuttle mold columns. The second part is located in the outside of the navigation station building east, west two sides, have 52 shuttle mold steel pipe columns which incline angle is about 14.5 to outside. The third part is located in the main body structure, have 40 erect taper column steel pipe columns, the anchor is fixed at the highest concrete floor position, so each steel pipe column is anchored in the different floor and elevation place. The latter part is located in the porch, have 42 erect taper columns. The diameter of the steel pipe column capital is changed at the range of 800 mm to 1450 mm, the height of the column cantilever section is changed from 8429 to 33262 mm [14].

The construction of the third terminal building in Beijing Capital International Airport has met the air traffic requirement for Beijing Olympics and the rapid traffic growth through the airport in the short term. Advanced technology and energy efficient design has been integrated into the new terminal building [13].

Conclusion. Thus, considered objects are of great interest for the further researches and also have a lot of benefits. The main of them have unlimited creative and energy efficient design in combination with innovative and iconic shapes and diversity of environment-friendly building materials.

An emphasis had been made on green building and advanced technologies. Moreover, during construction had been applied modern technics (including robots) and innovative modeling software. As a result erecting of column-free structure with span of 120 m, huge retractable roof (nearly 258,000 m 2) and three-dimensional continuous cranked loop of two towers, which lean about 6^{o} from vertical axis became possible.

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