The Parametric Architecture Tall Buildings Implementation Aspects

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Abstract. The presented article discusses the design of the high-rise buildings, created on the parametric architecture basis. The relevance of the topic is due not only to the identification of new directions in shaping high-rise buildings, but also to defining the parametric architecture main aspects implementation that has become possible in the digital technologies’ development conditions in the field of design and construction. On the basis of a comprehensive analysis of the experience in the design and construction of the parametric architecture high-rise buildings, the main areas of innovative technologies and materials application have been determined. On the conducted research basis, the main aspects of the high-rise buildings’ parametric architecture implementation that meet the sustainable development requirements are identified.

Introduction

Today, when creating a high-rise building image, the architect is inspired by new curvilinear, dynamic, organic forms. Freedom in the design of parametric architecture became available since the computer programs were developed, such as: Grasshopper, Rhinoceros. They make it possible to simulate, find the optimal solution of the problem in automatic mode, which greatly expands the possibilities for creating complex structures and forms. The question of the architectural image came to the fore, as the engineers and designers’ arsenal expanded significantly, it became possible to implement the most complex non-linear forms. Here, in addition to modern computer programs the following features stand out: advanced construction equipment and the latest construction materials.

Creating an optimal high-rise building project in architectural and structural terms is a multidisciplinary work due to the large number of design parameters. The architectural parameters include: shaping, functional zoning, provision of auxiliary and technical spaces, taking into account the features of structural systems, engineering communications, sustainable technologies in the creation of the required number of storeys of the building.

Based on the experience analysis in the high-rise buildings design and construction, it was revealed that the main building systems in the high-rise buildings design are the mechanical systems, the main supporting structures, cladding, and the operational building suitability. These parameters directly depend on the design idea, the shape of the unique building outer shell, the courage and skill of the architect.

This study examines the parametric architecture implementation aspects of the high-rise buildings based on the use of computational design, modern engineering and technical means and materials, taking into account these objects operation safety.
The aim of the work is to identify the high-rise buildings parametric architecture implementation aspects.

In accordance with the goal it is necessary to solve the following main tasks:
1. To determine the current trends in the development of the parametric architecture in conjunction with digital technologies.
2. To conduct a comprehensive analysis of experience in designing, building and operating high-rise buildings based on parametric architecture.
3. To identify the main directions of the parametric architecture application in the high-rise buildings design in order to implement the sustainable development parameters.
4. To determine the high-rise buildings main parametric architecture implementation aspects.

The parametric architecture high-rise buildings architectural formation concept

Parametric architecture is a steadily developing direction in modern digital or digital architecture. This direction has been developed over the past 15 years. The idea of parametric modeling originated with the advent of CAD (the 70s of the 20th century), but for a long time could not be embodied due to insufficient computer performance.

In practical architecture, the parametric design principles are widely used. Due to the ability to automate changes in the building model and working documentation, it has greater efficiency. Design using digital technology takes into account the relationship between the building, the environment and the human factor. It also allows to create in the lattice structures and stained-glass windows of the facade shell protruding and falling planes, calculated individually for each filling element and its frame with its nonlinear geometry [1].

The parametric modeling use makes it possible to introduce the latest technological tools and materials during the curvilinear shell facades shaping. Such forms can be realized using aluminum and zinc-titanium panels. The sheets from which the panels are made have good flexibility and plasticity, therefore they can be bent at an angle of 180 degrees. Consequently, it allows to veneer the facades of complex shapes, decorate arches, and make smooth bends. These materials and technologies make it possible to ensure a long service life, a high class of fire safety, resistance to corrosion and temperature differences, and compliance with the requirements for modern finishing materials. An example of such panels use is the residential complex Reflections in Singapore (Figure 1a) [2], consisting of six high-rise buildings from 24 to 41 floors (up to 160 m high) and eleven 6 and 8 storey apartment buildings. Due to the rounded shapes and variable number of floors, the complex harmoniously fits into the landscape. The complex facades decoration is made of anodized aluminum panels, with the help of which it became possible to create a bending effect of a skyscraper with sloping roofs topped with gardens.

In objects that have a large span overlap without the installation of additional supports, solid polymers replace glass, one of them is ETFE. Its weight is only one percent of the glass weight, but at the same time it can withstand heavy objects, melts at a temperature of more than 130 degrees and does not ignite. This ETFE film was used in the unique Khan Shatyr eco-creation in Kazakhstan [3]. The building has the giant tent shape with a height of 150 m, constructed from a network of steel cables on which a transparent ETFE polymer coating is fixed. Due to its special chemical composition, it has protective properties against sudden temperature changes and creates a comfortable microclimate inside the complex (Figure 1b).
Figure 1. a. [2] Residential complex Reflections, Singapore, b. [3] Khan Shatyr, Kazakhstan, c. [4] Ardmore Residence, Singapore.

Modern technology of concrete, reinforced with fiberglass - also helps to create a multi-faceted curving shape of a unique object, with unlimited possibilities of creating a form. Such material was used in the 36-storey skyscraper “Residence Ardmore” in Singapore, developed by the Dutch company UNStudio in the bio-tech style, with smooth curves. To create the building facade clear lines, the panel parts made of glass fiber reinforced concrete were attached to prefabricated wall panels, and the entire surface was textured with silicon, which completely smooths out any walls’ prominences (Figure 1c) [4].

The high-rise complex “ICT mixed use Complex” (Figure 2a), designed by the architectural bureau Dewan Architects & Engineers, is a unique composition of three different-height towers, differing in volume but united by a single texture and detail [5]. Plastic undulating forms of high-altitude volumes are placed on a single stylobate. The development was carried out in the environmental conservation and sustainable development direction, with the maximum use of local materials.

The Strata Tower in Abu Dhabi, UAE has a spectacular appearance thanks to its external cantilever frame. This 40-storey apartment building designed by architects Hani Rashid and Lise Anne Couture has a height of 160 meters. The spinning tower with a bionic appearance was created using the computer programs (Figure 2b) [6].
The design experience analysis shown that high-rise buildings use a combination of parametric architecture, digital technologies, and sustainable systems and materials.

It is revealed that the engineering equipment in such buildings is very different from the engineering systems in ordinary buildings. Unlike the latter, special requirements for power, durability and reliability are applied to it. Altitude determines the presence of special systems in the equipment, as well as the use of energy-saving technologies.

Energy saving. Nowadays, energy-efficient buildings erected with built-in wind turbines can reduce energy use by up to 60%, i.e. buildings that use wind energy.

The use of wind generators in high-rise buildings is facilitated by free wind flows, which are not hampered by other structures and obstacles.

In many countries, high-rise buildings are being developed in several areas of power generation. In the work of V.V. Elistratova, D.M. Bobrova [7] provides a classification of the possible options for installing wind generators in buildings:
- on the roof of a building with a horizontal axis of rotation in the upper part of a high-rise building, which does not depend on the shape and plastic of the skyscraper itself, and is essentially an independent architectural form on the roof;
- wind installation with a vertical rotation axis on the roof, but giving a lower performance;
- wind installation in “hollows-cutouts” with a vertical rotation axis, requiring calculations for the planes’ formation [8];
- vertically located windmills along the side facade, to which wind flows, resulting from the volumes and surfaces plastics;
- generators located on an independent frame between the buildings high-rise.

Figure 2. a [5] ICT Mixed Use Complex, Abu Dhabi, UAE, b [6] Strata Tower in Abu Dhabi, UAE

Figure 3. a [9] World Trade Center Building in Bahrain, b. [10] Pearl River Tower, China
Among this type of building, it is interesting to note the World Trade Center building in Manama (Bahrain) with a height of 240 meters, which was created by the construction company Atkins (Fig. 3a) [9]. The uniqueness of this object is emphasized by the installation of three wind turbine bridges connecting skyscrapers, the turbines of which are oriented to the Persian Gulf: the side with the prevailing wind. The shape in the ovoid bridges cross-section is dictated by the aerodynamics conditions, and the structures are complicated by the action of vibration from the turbines. The grand structure model was studied on a test bench, to account for the effects of all loads.

The most characteristic example of a breakthrough in ecological construction is the 71-storey office building with a height of 309.7 meters in China (Fig. 3b) [10]. Architects Skidmore, Owings & Merrill (SOM) created a structure with a smooth aerodynamic shape, in the openings of the technical floors of which the wind turbines are located. All the utilized facilities contribute to the building energy efficiency: solar panels, double glazing, air conditioning and ventilation systems, a decrease in insolation, and most importantly, the building form itself. For its energy independence and maximum efficiency in the wind and solar energy use, the building was given the status “green”.

The studies have shown that when designing high-rise buildings of a parametric architecture, special attention is paid to compliance and security.

Fire safety. To ensure the high-rise buildings safety, modern forecasting methods are used, which allow to calculate:
- the fires (fire, smoke) dangerous factors spread possibility for the alarm devices and fire extinguishing optimal location;
- to divide the floor plans, as well as the high-rise blocks into fire zones and compartments, including according to their functional characteristics, ensuring the correct location of the fire barriers;
- to simulate the human flows movement during their emergency evacuation,
- develop algorithms for phased combined evacuation from floors (using elevators),
- to design the traffic safety of people at the exits of buildings and complexes, calculating pedestrian paths at the stage of project documentation taking into account the existing buildings [11].

In modern construction practice, in the complex implementation, unique objects, in order to ensure safety, it became possible to use monitoring systems.

**Monitoring**

The former large strength reserves in the high-rise buildings load-bearing structures calculations do not make it possible to develop the structures upwards, to twist, incline, bend, connect them. To reduce the high-rise buildings destruction risk, both in the construction process and during its operation are assigned to monitoring systems, i.e. emergency warning systems. The monitoring systems include: construction quality control, making forecasts of the state of both the facilities themselves and those adjacent to all possible man-made and climatic impacts, when deviations from specified values are detected, operational technical and technological solutions development for their elimination [12].

Buildings of modified forms are more complicated, “problematic”, and they are the subject for the increased requirements in order to prevent any possible emergency or emergency situations. Monitoring systems allow to comprehensively solve security problems based on the use of automated systems. With the help of computer simulation, the monitoring systems include identifying the main responsible places in the design systems in which the sensors are located. Sensors transmit the changes taking place; on the basis of the data obtained, it becomes possible to warn and prevent the emergency situations. Buildings monitoring provides security, both during construction and during the operation of high-rise buildings.

Thus, on the basis of the research and the experience analysis in designing high-rise buildings of a parametric architecture, the main aspects of such buildings’ implementation were identified:
1. The use of computational architectural design based on digital technologies and computer programs that allow to create a parametric high-rise architecture.
2. To form a figurative solution of a high-rise building based on curvilinear shapes.
3. The use of innovative materials and technologies to implement parametric architecture in high-rise buildings.
4. The introduction of sustainable and energy-saving technologies that meet the high-rise construction modern requirements.
5. To ensure the safety of high-rise buildings created on the parametric architecture basis.

The computational design use, digital technologies and innovative materials made it possible to implement the parametric objects in high-rise construction, providing not only the beauty of plastic forms, but also the introduction of a dynamically developing architecture [13] that meets the sustainable construction requirements.

Summary
The practical value of the work is as follows:
These studies can be the basis for the high-rise buildings’ architectural projects further development, based on the parametric architecture principles, allowing to implement the individual creative design of the architect in combination with modern technologies and materials. The high-rise buildings parametric architecture implementation formulated aspects accounting and application will provide an integrated approach to high-rise construction, which combines computational architectural design, digital technologies and modern materials that make it possible to implement the most incredible imaginative solutions and at the same time to solve the sustainable development tasks.

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