Standardization and Diversification of Precast Concrete Facade Panel

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Abstract. Standardization is a major feature of the performance of fabricated building facades, which can achieve high-efficiency construction, reduce costs, and simplify production and construction difficulties. However, excessive standardization restricts the diversification of facades. Through a comparative study of Chinese and foreign completed cases, we seek a balance between standardization and diversification, avoid the limitation on facade diversification of standardization, explore performance potential of precast concrete facade panel in China, and achieve the integration of standardization and diversification of precast concrete facade panel.

1. Introduction
Prefabricated buildings have been in full swing in China in recent years. In 2017, the Ministry of Housing and Urban-Rural Development identified 30 demonstration cities, including Beijing and 195 industrial bases including Beijing Residence Group Co., Ltd. And set the corresponding target task. At present, the domestic design, production, and construction enterprises have initially formed a system, the industrial chain has gradually matured and improved, and the market prospect is promising. More than 90% of the demonstration cities have completed the 2018 annual target. Twenty-seven demonstration cities have achieved their work goals. The proportion of prefabricated buildings in 7 cities including Shanghai and Shenyang has exceeded 30%.

Figure 1. The distribution of demonstration cities and the initial formation of industrial cluster effects.
An enclosure system is an overall unity, composed of building facade, roof, exterior doors, windows and other components, used to separate the interior and exterior environment of a building. After the industrial revolution, the application of the frame structure system separated the enclosure system from the structural system, and modernist architecture began to have what Corbusier called “free facade”. The rise of dry hanging buildings in facade installation made it possible to dismantle a single component, which not only facilitates the recycling of components, but also meets the requirements of sustainable use.

The precast concrete facade panel is the most commonly used component in an enclosure system, which is installed on the main structure as a non-bearing external wall plate for enclosure and decoration. The high plasticity and diversified surface treatment effects of precast concrete facade panel can generate huge performance tension and enrich architectural semantic expression. In addition, with stable performance, not easy to change color, mottle or crack, precast concrete facade panel gains more and more favour from architectural designers and production plants.

The design of precast concrete facade panel of prefabricated buildings is restricted by many factors, including standardized design, factory prefabrication, site construction, etc. [1]. The emergence of standardization makes large-scale industrial construction possible, while the diversified design is a further exploration of industrial product design based on standardization [2]. In the 1970s, monotonous building components restricted the flexibility of architectural modeling, and stereotyped square box buildings of international style sprung up all over the world, much criticized because of lacking individual and regional characteristics, which prompted architects to reflect on the dialectical relationship between standardization and diversification. In sole consideration of component variation, a contradiction exists between standardization and diversification. Through balancing opposition between the two, avoiding limitation imposed on facade performance by standardization, exploring performance potential of precast concrete facade panel and design creativity of architects and promoting the application of digital technology, more possibilities are provided for facade modeling of prefabricated buildings [3]. A crucial task in developing enclosure system of prefabricated building in China is to explore standardized and diversified design methods of precast concrete facade panel suitable for China, in order to reduce cost, simplify production and construction difficulty, and improve quality, efficiency and benefits, through research on precast concrete facade panel at home and abroad [4].

2. Development of Precast Concrete Facade Panel at China and Abroad
After the third industrial revolution, prefabricated buildings came to the stage of history. Market-oriented and socialized, the development of precast concrete facade panel and other components abroad has complete standards and specifications, with a high degree of standardization, serialization, and generalization. The principle of separation on component production and construction is generally carried out. With the establishment of a general technical system, a general product catalog was formed to promote large-scale applications, reduce costs and improve efficiency. The software of “constructive logic system” was developed to provide architects with a series of components and combination rules, assist design and quickly provide project cost [5]. The precast concrete facade panel components pursue individuality, diversification and fine design. Meanwhile, as manufacturing technology has reached a professional level, the continuous optimization and improvement of construction technology and machinery have created objective conditions for the diversified design of architects.

Because of low industry concentration and small enterprise scales of precast concrete facade panel in China, it is challenging to form standardized and large-scale production, which brings about low level of mass production and “high cost”. The waste on time, labor and mould because of diversified customization caused increased production cost and longer production cycle [6]. The existing domestic precast concrete facade panels mostly adhere to changes in the appearance of a single module while lacking exploration of diversified design.
3. Analysis on the main influencing factors in the design of precast concrete facade panel

The comparison and selection of architectural facade design schemes is a multi-objective and comprehensive decision-making problem with many uncertain factors. Based on the AHP method, the weights of each evaluation index are determined by constructing pairwise judgment matrix, and on the basis of evaluation index system, through a combination of qualitative study and quantitative study, complicated problems are stratified, qualitative problems are quantified and hierarchy and weight of the evaluation index system are constructed. The production and construction period, application of industrial technique, adaptability of technology, construction cost, aesthetics, and other indicators of precast concrete facade panel constitute the main influencing factors in the facade design of prefabricated buildings [7], as shown in figure 2.

![Figure 2. Weight of influencing factors in facade design based on AHP.](image)

4. Standardized and Diversified Design Strategy Based on Individual Precast Concrete Facade Panel

Based on comprehensive consideration of precast concrete production, construction period, cost, aesthetics, and other factors, a combination of standardization and diversification is to be explored as the design strategy for precast concrete facade panel.

4.1. Surface Treatment of Concrete

The uniqueness of concrete that differentiates itself from other materials lies in its on-site forming ability, plasticity during process and integrity of the results, which brings diversity to its surface texture, quality, color, etc., as shown in figure 3. Surface treatment after the component is poured and formed has no influence on its standardization, and the process is simple. Patterns or textures can be produced by using several different surface treatments.

![Figure 3. Surface texture of concrete.](image)
4.2. Component Diversity Realized by Variable Moulds and Combined Moulds

Variable moulds can save mould cost by producing many different components in one mould. Changes in openings are the most common type of variable mold strategies, because it is possible to use variable moulds for components with the same outer dimension and different inner openings, as shown in figure 4.

![Figure 4. Component diversity created by variable moulds.](image)

4.3. Diversity of Surface Texture Realized by Mould Plate

The surface texture of precast components can be produced by plates placed on the mould. The components with the same shape but different texture can be produced by placing different plates in the same mould. The processing technology in the mechanical age and information age, adding to the plasticity of concrete different from other materials, makes the surface texture of precast concrete components highly changeable. The main processing methods are as follows:

- rubbings of different natural wood textures and patterns with certain style or different scales cut on the surface of wooden formworks;
- based on CNC machinery, digital grid image and vectorization method, design pattern is sprayed on membrane material with concrete retarder, and the concrete surface is washed with high-pressure water gun after the pattern membrane is torn off, to form pattern-decorated concrete;
- pour negative images of basic textures and patterns on surface of plastic and rubber formworks, and after removing the formworks of precast concrete façade panel, relief patterns with a certain concave depth and distinct effect will show up.

4.4. Numerical Control Technology Strategy

Digital technology is quietly changing production and installation of precast components. Laser scanning and cutting technology, computer digital control technology, rapid prototyping and other technologies brought by computer-aided design (CAD) and manufacturing (CAM) are leading design trend in the field of architecture.

The combination of precast concrete and numerical control technology is mainly reflected in mould [8], because plasticity of concrete can almost adapt to all kinds of moulds, while numerical control technology can manufacture moulds more complicated and finer than traditional moulds, as shown in figure 5. The use of CNC engraving machine can also properly deal with a small amount of precast concrete surface, but too much engraving will lead to longer engraving time and lower efficiency than direct use of complicated mould pouring. With the aid of BIM Technology, numerical control technology can assist fine management to realize non-linear and scientific architectural performance, which is of great value to the exploration on modern design and construction methods [9].

5. Design Strategy Based on Group Combination of Precast Concrete Facade Panels

The arrangement and combination of various components is a major source of facade diversification. The logic of permutation and combination can be varied, for example, different components join together to form group order, correspond to different internal spaces and different degrees of shading requirements, constitute virtual-real contrast, etc. Parametric design creates more opportunities for
arrangement and combination of components. The facade composed of a large number of components can be quickly arranged through computer program, and thus form richer and more diversified effects. The transformation is gradually taking place from pursuit of shape changes to digitalization. Without changing building shapes, replication and array of precast concrete facade panels will not only retain originality and uniqueness, but also reproduce shape authenticity.

![Digital modeling and construction.](image1)

**Figure 5.** Digital modeling and construction.

### 5.1. Change of Installation Methods
Using different installation methods for the same kind of components is a strategy that can produce changes without increasing component types. With 90° rotation, components of square or other central symmetry shapes can still be installed in the original module grid.

In a project of China Construction Technology, all four types of component A, B, C and D enriched facade diversity through rotation, each accounting for 20%, 22.5%, 30% and 27.5% respectively, which effectively ensured the reuse rate of the four types of formworks, as shown in figure 6.

![Facade diversity produced by varied installation methods of precast concrete facade panels of an office building project in Chengdu, China.](image2)

**Figure 6.** Facade diversity produced by varied installation methods of precast concrete facade panels of an office building project in Chengdu, China.

Meanwhile, turning upside down is also a rather common method of rotating installation, because after 180° rotation the frequently used rectangular components can still be arranged together with the non-rotating components, whose height are related to floor height. Thus, turned upside down, the components still conform to the floor height, and through mixed arrangement of rotating and non-rotating components, two kinds of performance of components can be obtained. The layout of the facade panels of Mannheim Nohein Community Center is realized by upside down components. The seemingly random and irregular precast concrete facade panel components was actually produced by using only two sets of basic moulds, with really high efficiency, as shown in figure 7.

![Facade panels of Mannheim-Nohein Community Center](image3)
5.2. Component Repetition

Originated from “abstract composition” principle of Cubism Aesthetics, materials and parts are arranged according to geometric constructing law to form a flat or three-dimensional overall interface pattern clear in shape with organization laws simple and easy to follow.

Repeatability can bring rhythmic beauty, enhance linear impact of architecture, and strengthen tension of architecture art. In Chengdu Construction Project, the repetition rate of component A, B and C in the main facade accounted for 25%, 16% and 59% respectively, as shown in figure 8. The precast concrete facade panels of Science Complex of Florida International University was uniformly made in moulds, and rotated by 15 ° anticlockwise during installation, thus producing a facade rich in levels and light and shade relation, which not only saved cost, but also avoided simple array replication. With rich design techniques and experience, the architect effectively eliminated contradiction between standardization and diversity, as shown in figure 9.

5.3. Module Repetition

Module is a basic scale unit as well as a standard coefficient. The architectural texture formed by reconstructing and arranging precast components under unified module is an effective way to enrich facade effects and control costs.
In the office building of Chengdu Chengtou Yuanda Industrial Building Material R & D and Production Base, the width of standard precast facade panel determined by the arc length corresponding to the center angle of 3.6° was adopted to form a module for the facade design, as shown in figure 10.

5.4. Gradual Change of Components
Gradual change means regular change, which forms interface patterns with rich organic shapes and relatively complex organization rules that still presents a clear sense of order, abiding by composition rules such as topological geometry and fractal geometry. With the development of precast technology, random generation experiments of computer software broke the static and solidification mode, and formed overall control processing with parametric design.

Gradual design can ensure unity of overall shape and break homogeneous texture. As precast technology develops, architectural design ideas are no longer limited to linear thinking, and the continuous and weak gaps between components under unified parameters come true. The difficulty and cost changes of mass production of precast repetitive components and precast differentiated components will tend to be consistent in NC manufacturing, as shown in figure 11. Parametric design and digital construction not only make building forms more expressive, but also show strong gradual characteristics due to weak gaps between components.

The precast concrete facade panels of John Lewis Department Store in the UK was designed parametrically assisted by three-dimensional software, and panel components of different sizes formed the gradually changing facade effect. The size of the precast concrete facade panels was combined with the maximum transport size of professional transport flat cars. The biggest panel is 4m in length and 14T in weight.

On the basis of digital analysis, precast concrete facade panels with hexagon as component unit were adopted in Sinosteel Tower. To meet the needs of indoor lighting and realization, hexagon honeycomb components were divided into five types by size of openings, and digital analysis was adopted for precast and installation.

6. Design of Precast Concrete Facade Panel Based on Concept of Sustainable Development
Since the 1970s, increasing energy crisis and environmental crisis have gradually awakened ecological consciousness of human beings, promoted gradual implementation of “sustainable development”
concept in architectural design, impelled us to reduce negative impact of buildings on natural environment in the whole life cycle, besides designing buildings which can create a comfortable and pleasant microclimate environment, in order to seek harmonious coexistence of human and nature.

The form, material, scale, shape, color and location of repeated energy-saving components used on building facades should be considered comprehensively, and the design should be carried out combining environmental conditions.

By planting herbs or traditional climbing plants and combining them with components of different forms, a compound of vegetation and material performance is formed. The material performance of vegetation covering includes comprehensive content of ecological performance, morphological aesthetic performance and emotional performance, as shown in figure 12. The sun shading and heat insulation system is formed by combining different material components with vertical greening planting, in which the texture composition of points, lines and surfaces of material is presented.

Figure 12. Vertical Living Gallery in Bangkok, Thailand & Green Wall Design of a project in Chengdu, China.

7. Conclusion
As a relatively independent single construction system in the whole building lifecycle, precast concrete facade panel has its own assembly rate which contributes a lot in improving quality and reducing construction period throughout the whole construction period. At present, precast concrete facade panel in China has realized precast and batch production and mechanized installation, which improved wall construction efficiency, and reduced risks on construction sites. However, the production technology in China is relatively backward compared to cases abroad. Limited by construction technique and precision, the facade language is comparatively regular and monotonous, product structure is relatively homogeneous, and there is still a certain gap at industrialization and mechanization level.

While designing facades of prefabricated buildings, architects should fully understand component characteristics, combine production and construction technology, make best use of advantages and bypass disadvantages, show artistic aesthetics, give consideration to production possibility and cost rationality, and avoid simple repetition.

The current digital construction system has been on the way of exploring a balance between standardization and diversification, and architectural science and technology can already meet personalized needs of designers. However, to realize low cost of precast components and popularity of development, architects need further exploration in practice.

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