Tectonic Methodology on the Façade Composition Pattern of Prefabricated Building Enclosure Wallboards

Chao WANG1, Fanrong LI2*, Jingyi ZHANG1, Jinzhe GUO1, Shengcai LI1

1 School of Architectural Science and Engineering, Yangzhou University, Huayang Ave. 198, Yangzhou, 225127, China
2 Department of Civil Engineering & Computer Science, University Rome “Tor Vergata”, Via Politecnico 1, 00133 Rome, Italy
fanrong.li@students.uniroma2.eu

Abstract. Building industrialization have been becoming mainstream in China. But the challenge to balance the diversity and standardization on the form of prefabricated building seems to be hardly overcame. The methodology for facade design related to prefabricated buildings is discussed in this paper. Enclosure walls were divided into a few modular panels based on the distance between columns, floor height, windowsill’s heights, and so on. Then, the panels were assigned different function according to their position on the building elevation. Some of the panels were combined with solar photovoltaic cell, some were designed into polyhedral wall panels with cavity embedded building service equipment and pipelines. The panels were assembled in terms of aesthetic principles and their roles. Possible composition pattern has been probed and corresponding suggestion have been offered. Nantong Dongsheng international business centre has been taken as an example to verify the operability of the methodology on the facade composition pattern in design process.

1. Introduction
Prefabricated building technology is becoming an important approach to contemporary construction with the feature of high quality, speedy erection, shorter construction period. In 2004, the British construction department promoted prefabricated buildings and applied assembly technology to the design of local residential buildings, promoting the development of prefabricated buildings [1]. As the introduction of prefabricated technology into China, the process of building industrialization in China was accelerated, especially in densely populated areas such as Beijing and Shanghai where prefabricated buildings have been developing to meet the needs of living [2]. Building wallboard components are prefabricated in the factory, and then transported to construction site and assembled to the main structure in terms of design drawing. This will impact the overall appearance of a building. The fabricated wallboard can speed up the construction progress, guarantee the quality of a building and reduce the waste of resources [2][3]. However, due to the lack of corresponding guidance, most factories often have little concern with aesthetic design of the wallboard while considering the construction and production costs of the wallboard. This situation has led to many buildings with boring facades. As the medium between the internal space and the external environment, the external wall plays important role in guaranteeing internal function and the external aesthetic expression. So, the facade design of the building with prefabricated wallboard is particularly important [4].
As for the research of facade design with prefabricated building wallboard, most academic papers focus on the production and construction technology of wall panels. The research on facade modeling of prefabricated building wall panels is still insufficient. Previously, Karhu, a Finnish scholar, proposed a method of product model. On the basis of data requirements, he developed a product data model of facade, which makes the overall design and construction of exterior walls more efficient [5]. And now specific digital tools are developed to support specific appearance products [6]. Prefabricated building facade composition pattern and tectonic approaches should be probed so that corresponding academic achievements could support the development of prefabricated building.

2. Methodology on the tectonic of façade composition pattern

2.1. Idea on façade composition
The design principle of prefabricated building wallboard is based on the concept of modularization. Façade elements should conform to the characteristics of large-scale production of assembly buildings and people's aesthetic habits. In the process of investigation, it is coincident that the composition principles of the De Stijl paintings in the early 20th century are quite useful to form characteristics of prefabricated buildings. Related works from the early 20th century emphasize that art needs abstraction and simplification, and against baroque art forms in mathematical structure [7]. For example, Peter Mondrian's lattice painting, The composition with red, yellow and blue colours, fits well with the idea of assembly building and combines the simplest geometric forms to make the plane abstract into a rhythmic and dynamic picture. This abstract plane composition is conducive to the modularization of wallboard facades. Components obtained by proportional adjustment and module division can be manufactured in large quantities in factories, meeting the production requirements of rapid construction of assembly buildings. At the same time, it can solve the contradiction between the aesthetic needs and the concept of rational structure [8]. Therefore, the composition principles of De Stijl paintings in the early 20th century could be applied to coordinate the facade elements of prefabricated building.

2.2. Formative approach
Based on the idea of modularization, a method of applying stylistic principles to facade design of assembled buildings is put forward. It integrates the concept of plane composition into the module division of a building.

2.2.1. Procedure of Façade analysis. Firstly, the beam-column frame is taken as the structural relationship so as to obtain controlling parameters of building façade. Secondly, controlling grid sizes are determined according to the function of wallboard and related requirement of modulus. Thirdly, the appropriate style art works are taken as references so as to regulate the controlling grid, and adjust the appropriate proportion to make them conform to the specific modulus size of the elevation grid, to complete the elevation of the perceptual. Fourthly, drawing the composition diagram and structure

![Fig 1. De Stijl pattern](image-url)
proportion in the works, the vertical and horizontal lines in the works are translated and reproduced in the control grid, and the geometric structure elements with different sizes. Restructuring structural elements to form a rich and rhythmic composition.

2.2.2. **Prefabricated wallboard module.** The division of prefabricated wallboard modules follows the same logic as described above. Firstly, the dimensions of grid elements are determined by considering the spacing of column network, floor height, beam height, windowsill’s height and material behavior. Then the wall panel elements are divided into a set of reference grids, and the scale of style works of art is matched with the grid size. Later, according to the composition of the lines in the painting, grids are divided into different sizes, and the standard modular units with the effect of Constructivism sculpture are obtained. Finally, on the basis of meeting the requirements of window-to-wall ratio and window-to-ground ratio, windows can be randomly opened on the mesh texture of elevation modules so as to form a rich and orderly arrangement of windows. The rest can be fitted with layers of other materials that could enrich the facade.

2.3. **Requirements to wallboard module**
Window dimensions must result from a careful process and be part of an integral design process, considering multiple aspects at the same time [1]. For example, window-to-wall ratio (WWR) is a crucial building envelope element that decides the indoor luminous and thermal environments [9], and window-to-floor ratio is a common index for estimating indoor natural light level. Therefore, a set of formulas is designed to restrict and regulate the random opening of windows in prefabricated wallboard modules.

The dimension of assembled wallboard module is usually determined by the spacing between columns and the height of layer. The splitting of prefabricated wallboard also follows the above rule. The ratio of window to wall and the ratio of window to floor are the maximum and minimum limiting factors of window area respectively.

The spacing of the building column network is defined as $L_1$. The height of the building standard floor is defined as $h$. That is, the area of the single wall panel is $S_t=L_1*h$; Defining the opening of the building room as $L_2$, and the depth of the room is $d$, you can get the room area $S_h=L_2*d$. According to the splitting principle of the wallboard in 2.2, the prefabricated wallboard generates $n$ rectangular frames with different sizes. And the areas are recorded as $a_1, a_2, a_3...a_n$. Now randomly take the $P$ rectangular frames to open the window hole, and the total window area is $S_w$. The program is designed as following.

$$K_i=1 \text{ or } 0; \quad P = \sum_{i=1}^{n} K_i, P \in (1, n); \quad S_w = \sum_{i=1}^{n} K_i * a_i$$

Therefore, according to the requirements of local regulations, the minimum window opening area is determined in terms of the window ratio, and the minimum window opening area is determined in terms of the window ratio. The requirement could be met when $S_w$ is in the both ranges.

3. **Case study**
Nantong Dongsheng International Business Centre is located in the new urban area of Rudong County, Nantong City. It is a commercial complex that integrates accommodation, shopping, entertainment, catering and other functions. The facade design of the project is conducted with above methodology.

3.1. **Facade formulating**
The contradiction and conflict between standardized components and architectural personality runs through the developing progress. In the design process of this project, perceptual abstract works of art has also been rationalized into the design of architectural facades. The hotel tower is selected for in-depth analysis and interpretation as following.

Firstly, the beam-column frame of the building facade is abstracted to obtain the structural relationship of four spans and twenty-four stories, and on this basis, the control grid of 8x25 elevation
is refined and segmented according to the modular relationship. Under the grid layout, the special splitting method is an innovation that distinguishes the facade of the building from other traditional facades. Theo van Doesburg’s *Composition in Gray* strips away all the representational features of traditional architecture and combines the most basic geometric units to form a rich and rhythmic composition. This individualized, abstract and reasonable rule of art form coincides with the idea of mesh division. Therefore, the composing graph method of *Composition in Gray* is used for reference in elevation division. The work is regularized in the control grid and adjusted appropriately to fit the length-width relationship of 25/8. At the same time, in order to get closer to the true composition proportion of the work, the grid is further refined to form the third-level control grid. The ultimate division of various rectangular structural units in the facade forms the unity of the individual and the whole, and achieves an order and balance (Fig. 2).

3.2. **Wallboard module**

3.2.1. *The form of windows.* The use of the same logic technique makes the design more rational and precise, while ensuring the harmony and unity of facades. Therefore, the artistic rationality conveyed in early De Stijli works has been consistently applied to the partition design of prefabricated wallboard. Therefore, the artistic rationality conveyed in early De Stijli works has been consistently applied to the splitting design of prefabricated wallboard. In order to realize the combination of modularization and functionalization, the project uses solar thin film batteries with their own “modularity” enriching the elevation level.

In the design of the wallboard modules, Mondrian's abstract painting *Composition in Red, Yellow, Blue and Black* is taken as a reference. The horizontal and vertical lines control the geometric colour blocks with different sizes. Division and combination make the plane be more rhythmic. Precise proportion highlights the balance and order of the whole picture. The principles here can be applied to the division of wallboard module. The size of prefabricated wallboard modules in this project is determined by the structural components of the building, which is 8.4m long and 3.5m wide. Firstly, 700 mm x 700 mm is chosen as the smallest grid element based on many factors. Because the length and width of prefabricated wallboard meet the multiple relationship of 700 mm, and also meet the size requirements of solar thin film battery installation. Then, the wallboard modules are divided into 5x12 reference grids, and the dimension ratio of the Mondrian abstract drawing is adjusted to match the reference grids. According to the composition of the lines in the drawing, the basic grid is retranslated, and a standard module is divided into 20 rectangular structure elements separated by the horizontal and vertical lines, which makes it present a rational beauty with artistic flavour (Fig. 3)

![Fig 2. Splitting and restructuring of enclosure wall module](image-url)
3.2.2. Window orientation. After splitting the prefabricated modules, according to building codes, the prefabricated wall panels monomers with the same size but different surface texture can be created by randomly opening windows or installing solar thin film cells on the grid texture of the elevation units, which has strong variability and operability.

In order to facilitate the design, the grasshopper program is designed for the random opening of the window (Fig. 4). The specific ideas are as follows: According to the 20 rectangles formed by the previous division of the single wall panel, the number of them is given in turn. Grasshopper software is used to pick up 20 faces in turn, list all the combinations of all the blocks, and classify them according to single block, two block combinations, three block combinations and so on. Then input the total window area (the sum of the selected square area) to screen the total data column, and finally list the serial number of the blocks that meet the requirements. According to this set of results, the possibility of all elevation pattern can be obtained with the permission of the normative requirements. (Fig. 5)
3.3. Modulation
Based on the adaptability of De Stijl works to modularization and standardization of prefabricated buildings, this paper uses modular grid to retranslate the paintings and incorporates its plane composition into the overall elevation division and the design of window openings. The formulas are designed to define the logic of the form generation of wallboard, and to restrict the scope of the formulas according to the restrictive factors such as window-wall ratio and window-to-ground ratio, so that the generated wallboard components meet the specifications of the project site. Finally, a set of methods of applying De Stijl Paintings to facade design of prefabricated building is summarized. To further verify the applicability of the facade construction model in the actual design process, the project of Nantong Dongsheng International Business Centre is taken as a design practice under the mode of assembled building, and various forms of facade of prefabricated building wall board are explored. The wall and window holes are divided according to the composition diagram and structure proportion in Composition in Gray and Composition in Red, Yellow, Blue and Black. This project combines the style school works with the facade design, satisfies the expression of architectural form, and provides a useful reference for the design and construction of prefabricated building.

4. Conclusion and future work
The tectonic method of façade composition pattern discussed in this paper could be applied to improve the monotonous appearance of building façade. The modules of wallboard components could be uniform and the size proportion could be controlled in different level, which can meet the requirements of standardization and mass production of prefabricated buildings. The advantage of this method is that it has certain typicality and strong applicability. In the process of facade design, the composition principle from De Stijl works are recommended to design the façade with prefabricated enclosure wallboard. Unique architectural elevation could be created with the tectonic method. The elevation composition pattern is not affected by the local topography and climate, and has a wide range of applications. However, the paper focuses on the facade composition pattern. More research work on construction detail should be conducted in the future so that the tectonic method could play important and practical role.

Acknowledgements
The work has been supported by the Innovation Cultivation Fund of Yangzhou University (Grant No.201811117031Z), Science Research Program of (Xinhua) Rural Revitalization Research Institute
of Yangzhou University (Grant No. XH2018102), Construction Science and Technology Research Program of Yangzhou (Grant No. 201904, 201804), International Cooperation Research Program of Yangzhou (Grant No. YZ2019148).

References
[1] C. Ochoa; M. Aries; E. van Loenen and J. Hensen (2012). Considerations on design optimization criteria for windows providing low energy consumption and high visual comfort. Applied Energy, 95, pp.238-245.
[2] X. Cao; X. Li; Y. Zhu and Z. Zhang (2015). A comparative study of environmental performance between prefabricated and traditional residential buildings in China. Journal of Cleaner Production, 109, pp.131-143.
[3] A. Lacey; W. Chen; H Hao. and K. Bi (2018). Structural response of modular buildings – An overview. Journal of Building Engineering, 16, pp.45-56.
[4] J. Montali; M. Sauchelli; Q. Jin and M. Overend. (2019). Knowledge-rich optimisation of prefabricated façades to support conceptual design. Automation in Construction, 97, pp.192-204.
[5] V. Karhu,(1997). Product model based design of precast facades Electron. J. Inf. Technol. Constr., 2
[6] T. Henriksen, S. Lo, U. Knaack (2016). The impact of a new mould system as part of a novel manufacturing process for complex geometry thin-walled GFRC. Archit. Eng. Des. Manag., 12, pp. 231-249.
[7] E. Xue (1989). Dutch style and Schroeder residence. World Architecture, 03, pp.27-29. (In Chinese)
[8] Q. A. Yang (2010). preliminary study of the Dutch style. Architecture and Culture, 05, pp.89-91. (In Chinese)
[9] P. Xue, Q. Li, J. Xie, M. Zhao and J. Liu (2019). Optimization of window-to-wall ratio with sunshades in China low latitude region considering daylighting and energy saving requirements. Applied Energy, 233-234, pp.62-70.