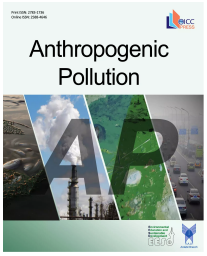


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# Investigating the role of origami algorithm in facades of high-rise buildings to reduce visual pollution and improve urban landscape quality

Tabbasom Tabasi[1], Amir Farajolahi Rod[2]*, Vahid Ahmadi[1], Hamid Reza Shoaei[3]

[1]*Department of Architecture, Islamic Azad University, Mashhad Branch, Mashhad, Iran.*
[2]*Faculty of Art and Architecture, Tarbiat Modares University, Tehran, Iran.*
[3]*Department of Architecture, Islamic Azad University, Shahrood Branch, Shahrood, Iran.*

***Corresponding author**: amirfrod@modares.ac.ir

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**Abstract:**
The present study was conducted to identify and prioritize origami components affecting facades of high-rise buildings to explain the role of origami algorithm in improving urban landscape quality and reducing visual pollution. The research had an exploratory nature, and used the method of descriptive-survey data analysis. The research design was carried out in three steps, documentary analysis, Delphi survey and semiotic analysis. A panel of experts (n = 15) was considered as specialists in urban planning, architecture and urban design. Data were analyzed by statistical tests, SPSS-22 software and MAXQDA 2020 software. A hypothetical model of high-rise building made in RHINO software using Grasshopper plugin was applied for simulation. The results of the questionnaires revealed the effects of 18 components on the facade of high-rise buildings and also 12 components on the improvement of urban landscape quality. The findings indicated a correlation between overall dimensions of origami algorithm and urban landscape quality, and showed that the components of "repetition", "details", "geometry" and "rhythm" were most related to the origami algorithm, thereby highlighting the strong impact of the origami algorithm on improving urban landscape quality. According to the simulation results, among the components affecting urban landscape quality, "View composition" had the largest contribution with the correlation coefficient of 130, followed by "Color" and "Balance and symmetry" with the coefficients of 120. The end of this classification included the component "position of openings" with the coefficient of 2.

**Keywords:** Origami algorithm; High-rise buildings; Visual pollution; Urban landscape quality

## 1. Introduction

Building facade plays an essential role in controlling the environmental conditions of indoor spaces. It is also important from an aesthetic point of view, so that it can have a significant impact on improving urban landscape quality (Abasi et al. 2015). Today, building design and architecture has become a complex and multifaceted issue, so that designers try to simultaneously balance diverse and contrasting parameters and components (Pilehchiha 2019). The aesthetics of the visual fields of the city and the physical elements of its architecture, such as the building facade, are effective in people's perceptions and preferences and are among the factors that contribute to the pleasantness of the space and attracting people to urban spaces (Onal et al. 2015). However, the influence of high-rise buildings on the immediate urban environments cannot be conditioned only by building form. The high-rise building affects and changes the city extensively and comprehensively (Ebrahimzadeh and Ghadermarzi 2014). Therefore, it should be noted that any physical change in a phenomenon called a high-rise building affects various dimensions of the city, not all of which are known to the project designer or architect (Rollings et al. 2017). Since the urban landscape is the first and most effective factor influencing the observer, and the way the buildings are placed have a great influence on how it looks,

**Figure 1.** Location of sampling stations on the map.

high-rise building and its high facades with its special perspective are considered among the most important factors influencing any viewer in the city (Bokharaee 2017).

One of the basic issues in solving architectural problems is the form finding process. In recent years, experts have proven that one of the effective solutions is to take help from other fields of science such as mathematical, computational and computer laws. One of the examples of the use of mathematical language in architecture is the application of origami as a source of inspiration in spatial form finding (Balkanlou et al. 2019). The studies around the application of origami in architecture is considered an interdisciplinary approach, which takes help from mathematical perspectives and practical creativity to investigate the relationship between structure, architecture and building form in folded structure, and tries to find new ways to solve structural and aesthetic problems based on origami logic (Sahebsara et al. 2019; Zaefizadeh et al. 2011).

The current research attempted to achieve a comprehensive view regarding the improvement of urban landscape quality and the reduction of visual pollution in high-rise buildings by examining the components affecting the origami algorithm.

The research questions were:

1. What are the effects of using the origami algorithm on the aesthetic perception of the facade of high-rise residential buildings on the urban landscape?
2. What is the opinion of architectural experts about the impact of using the origami algorithm on the aesthetic perception of the facade of high-rise residential buildings on the urban landscape?

In the current era, there is a need for high-rise buildings for various reasons, including economic, functional and environmental issues. The industrial revolution in Europe and subsequent developments in the 18$^{th}$ and 19$^{th}$ centuries changed people's lifestyles, and this process accelerated following numerous inventions and discoveries (Qin and Dai 2013). These changes led to the formation of new cities and the expansion of existing cities. Issues, including population explosion, the demand for housing more people in cities, the need to use more land in the densely populated centers of cities, the need for reconstruction and renovation in urban areas, the demand for living or working in city centers, and the need to reduce costs due to the horizontal expansion of cities, all caused the emergence of high-rise buildings as one of the solutions for urban development (Pilehchiha 2019; Saghafi et al. 2015). The role of high-rise buildings in the urban landscape, as well as the positive and negative aspects of their presence in the city, has repeatedly been the focus of researchers (Sardari et al. 2019). High-rise buildings are divided into three categories: Tall, Supertall, and Megatall Buildings.

• Tall buildings have an average height of 50 to 300 meters, which includes 90% of the tallest buildings in the world, such as Beijing TV Center and Comcast Center in Philadelphia.

• Supertall buildings have an average height of 300 to 600 meters, accounting for 10% of all tall buildings worldwide.

• Megatall buildings are more than 600 meters high, which comprise less than 0.05% of the total tall buildings in the world (Zhang et al. 2016).

Building facade is one of the main components of the street landscape and urban environment (Dong and Qin 2017). Building facades are combined with other outdoor elements to form the streetscape. The exterior appearance of high-rise buildings is considered the most important dimension in terms of social and identity dimensions of these buildings (Sardari et al. 2019). Not every space can be considered an urban space. One of the necessary conditions for turning an empty space into an urban space is to pay attention to the principles of aesthetics (Saghafi et al. 2015). In the simplest definition, aesthetics can be defined as the harmonious combination of mass and space in such a way that details and the whole design are in harmony and proportion (Zarghami et al. 2020). Based on this definition, if the aesthetic concept of the urban space lies in the connection and coordination of the components, then the urban space can be defined as a whole, and its components as its walls and details (Zhang and Zhang 2017). In fact, it can be claimed that high-rise buildings are considered an invasion of urban space, because they have the potential to fundamentally change their immediate artificial and natural environment (Salehi et al. 2014). Therefore, it is argued that the impact of high-rise buildings is not only restricted to the limited area around them, but they can also affect the present and future of the city due to their unusual scale and size (Vaid and Evans 2016).

The art of origami is based on a kind of geometric thinking, and an important part of its aesthetic values lies in the geometric appearance of these structures. The penetration and expansion of this art in the West started with the Bauhaus School of architecture and design. The works developed

**Table 1.** Factors affecting the facades of high-rise buildings extracted from the literature using MAXODA software (Source: authors).

| Codes | Components | Codes | Components |
|---|---|---|---|
| 0 | Building form | 9 | Equilibrium |
| 1 | Dimensions and proportions | 10 | Natural geometry |
| 2 | Balance | 11 | Composition |
| 3 | Symmetry | 12 | Type of components |
| 4 | Rhythm | 13 | Complexity |
| 5 | Repetition | 14 | Patterns |
| 6 | Discipline | 15 | Openings |
| 7 | Texture | 16 | Curvature |
| 8 | Details | 17 | Combination |

based on the art of origami bring a novel visual and aesthetic understanding to the audience due to multiple escape points (Borzouei et al. 2021). Some of the reasons that draw the attention of engineers and designers to origami-based structures today are:

• Origami can be used under different conditions.
• These structures have high tolerance against the loads imposed on the building.
• Origami has the capacity and ability to be used in folded structures and roofs (Dehghani and Moosavian 2015).

A look at the presented theoretical foundations indicates that origami graphics are geometric patterns that can be used repeatedly (Zhakypov and Paik 2018). Classic origami is usually used for facades of buildings and things that do not need to bear loads. Three-dimensional origami patterns, such as the magic ball (Figure 1), can also be used in building materials for retrofitting (Biyik et al. 2017).

By enabling the diversity and dispersion of light and shadow, the folded plates increase the flexibility of the space and the architectural cover (Firouzeh and Paik 2015). Folded sheets based on origami patterns have been found to have greater strength and load-bearing capacity than flat sheets. Accordingly, in addition to covering the architecture, these patterns also have the ability to bear the load and can act as a part of the structure (Krimm et al. 2016). Origami is used as a design tool to solve structural and aesthetic problems in architectural design. Making origami models through experiments using light and texture promotes creativity (Nematipour et al. 2021).

## 2. Materials and methods

The present research was exploratory in nature and descriptive-survey in terms of data collection method. In the first and second steps of this research, an attempt was made to extract the factors involved in the impact of high-rise building facades on urban landscape quality through the study of sources, documents and interviews. Therefore, Tehran, the capital of Iran, was considered as the pilot city of the research. In the third step, data was analyzed through semiotic analysis using specialized software. Hence, the research design was defined in three steps, including (1) document content analysis, (2) Delphi survey and (3) semiotic analysis (Webster and Jones 2010).

The results obtained from these three steps can lead to the development of the tool for surveying the mental model of experts during the fourth step. According to research standards, since 10 to 15 experts in homogeneous groups are enough for a survey (Rahmani 2019), the present research used a panel of 15 experts as specialists in urban planning, architecture and urban design. Then, the researcher-made questionnaire, approved by 5 experts, containing open questions was provided to the panel members electronically. Finally, the responses were collected. The first round of Delphi consisted of in-depth and unstructured interviews, and the second round consisted of open-ended interviews

**Table 2.** Identified components effective in improving urban landscape quality using MAXODA software (Source: authors).

| Codes | Components | Codes | Components |
|---|---|---|---|
| 1 | Color | 7 | Balance and symmetry |
| 2 | Material texture | 8 | Simplicity |
| 3 | Harmony with context | 9 | Details |
| 4 | Material type | 10 | Decorations |
| 5 | View composition | 11 | Repetition |
| 6 | Position of openings | 12 | Discipline |

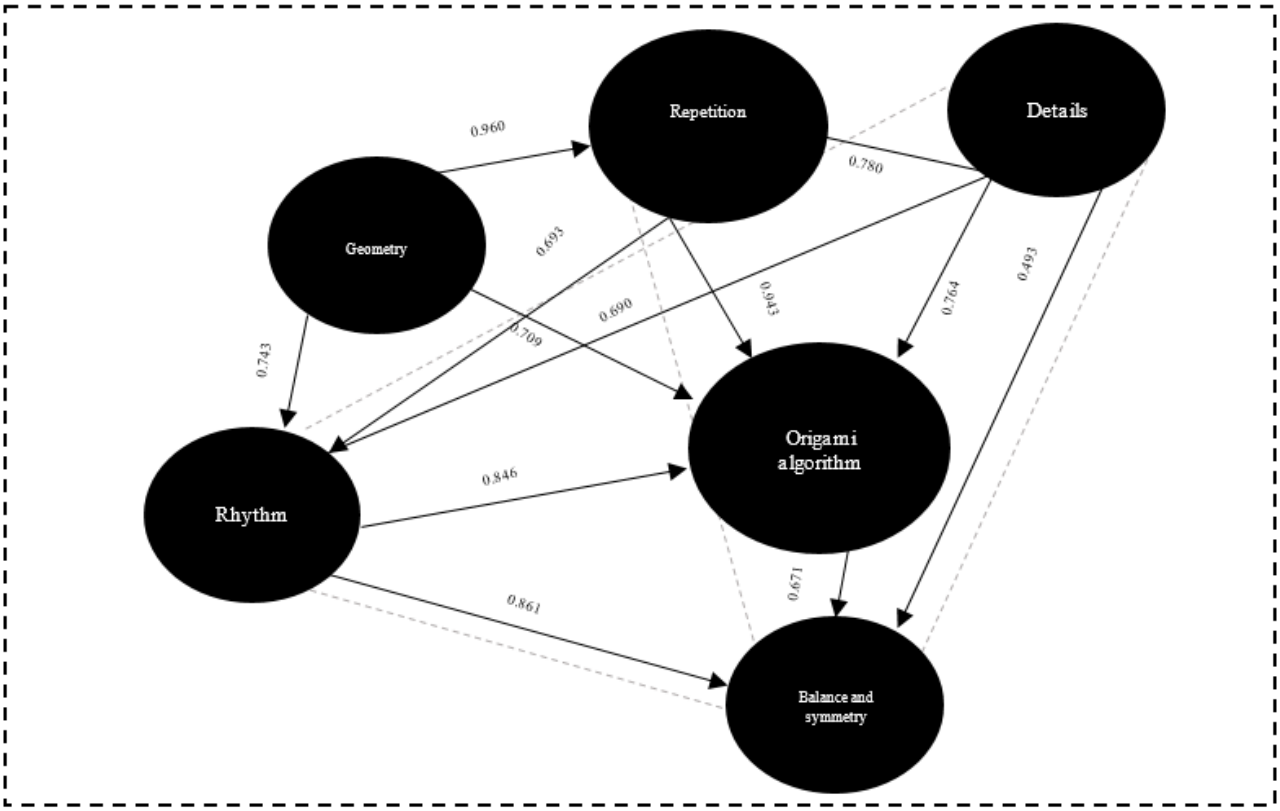


**Figure 2.** The model of structural relationships between the effective components of the origami algorithm on improving urban landscape quality (Source: authors).

and responses based on general concepts.

In this research, the internal consistency method or Cronbach's alpha was used to evaluate the reliability of the research tools. Statistical analysis was done for the questionnaire data by SPSS-22 software using Pearson's test to check the normality of the data and correlation coefficient to check the correlation between the variables. Finally, the data were analyzed using MAXQDA 2020 software. The simulation was done based on a hypothetical model of a high-rise building in RHINO software, which was parametrically created by the Grasshopper plugin. Thus, first a high-rise building with a glass facade was considered and then this glass facade was redesigned using effective origami components.

## 3. Results

In the first step, 18 effective components on high-rise building facades were extracted through the review of written sources, documents and research records (Table 1).

Then, the components affecting the improvement of urban landscape quality were extracted by examining the theoretical foundations and using MAXODA software, which included 12 items as shown in Table 2.

In the next section, the data collected from the questionnaires that were distributed in order to identify and investigate the impact of the origami algorithm on the improvement of urban landscape quality, were subjected to statistical analysis. In this research, Cronbach's alpha coefficient was determined to be 0.861, which was more than 0.7, which meant the reliability of the questionnaire for the purpose of subsequent analysis.

Pearson's correlation coefficient was used to reveal the correlation between the components of the origami algorithm and the improvement of urban landscape quality. According to Table 3, there was a correlation between overall dimensions of origami algorithm and urban landscape quality. The results showed $r = 0.764$ and $P < 0.01$ between origami algorithm and "Details"; therefore, with a 90% confidence interval, it could be said that there was a direct and strong correlation between the origami algorithm and "Details" ($r = 0.764$). In other words, the use of origami algorithm can lead to the increase of "Details" in the design of high-rise building facades, and vice versa, neglecting this system can cause the reduction of "Details" in high-rise building facades. Accordingly, the origami algorithm had a significant correlation with other components listed in Table 3, so that the correlation coefficients for the components of "Repetition", "Rhythm", "Geometry" and "Balance and symmetry" were 0.943, 0.846, 0.709 and 0.671, respectively. In addition, the findings of the research showed a direct and significant correlation between the components of "Geometry" and "Details" ($r = 0.822$). Moreover, there was a direct, significant and strong correlation between the components of "Geometry" and "Repetition" ($r = 0.960$); and the "Geometry" component had a direct, significant and strong correlation ($r = 0.786$) with the "Balance and symmetry" component, as well as the "Geometry" component had a direct, significant and high correlation ($r = 0.846$) with the "Rhythm" component. These results highlighted

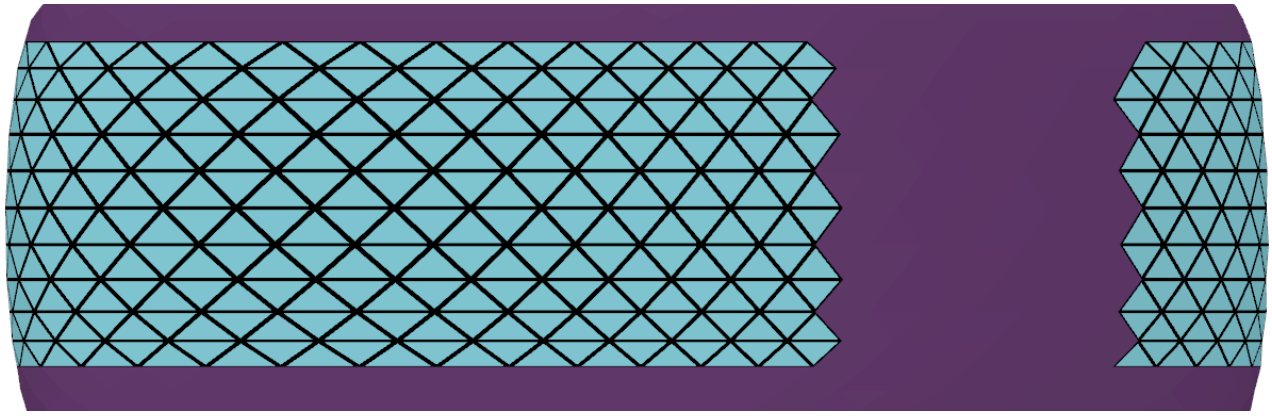

**Figure 3.** Model of a building with a glass facade (Source: authors).

the prominent role of criteria such as details, repetition and geometry in the design of high-rise building facades using the origami algorithm.

As shown in the model of structural relationships in Figure 2, the components of "Repetition", "Details", "Geometry" and "Rhythm" had the highest correlation with the origami algorithm, underlining the strong impact of the origami algorithm on improving urban landscape quality.

The final step, according to the mentioned contents and the investigation of the origami geometric form, was the parametric simulation of the facade of a high-rise residential building in Tehran. In the meantime, according to the scope of the research that included building facades, to compare the origami pattern in high-rise building facades and its effect on improving urban landscape quality, a building with a glass facade was first considered (Figure 3), and then the components obtained from the interview with the expert were checked using the origami pattern.

In the following, according to Figure 4, the mentioned model was parametrically built in RHINO software by means of Grasshopper plugin. The proposed components were investigated in the design model and the use of a shell using the folded pattern of the origami algorithm.

As stated in the analysis of components extracted from experts' interviews, the use of "Repetition", "Geometry", "Rhythm", "Balance and Symmetry" and "Details" patterns in building facades can improve urban landscape quality. Accordingly, the origami algorithm can be a suitable model for facade construction of high-rise urban buildings by putting together all the mentioned components. Figure 5 shows the layout of the shell designed by the folded pattern of the origami algorithm.

According to the results of high-rise building facade simulation through software, among the components affecting urban landscape quality, "View composition" had the largest contribution with the correlation coefficient of 130, followed by "Color" and "Balance and symmetry" components with the coefficients of 120. The end of this classification included the component "Position of openings" with the coefficient of 2 (Figure 6).

## 4. Discussion

An architect's point of view regarding the design components of the facade shows his/her role and duties in the direction of the quality of the urban landscape. The current research has sought to identify the effective factors on the improvement of urban landscape quality using origami algorithm and repeatable geometry in high-rise building facades and categorizing the views of architectural specialists in this field. Based on the findings of the factor analysis of the experts' questionnaire, five patterns with a statistically significant influence were identified, which were divided into two categories, "partially oriented" and "holistically oriented" in the overall classification. The holistically oriented components included "Repetition", "Details" and the partially oriented components included "Symmetry", "Rhythm"

**Table 3.** Pearson's correlation coefficient to investigate the relationship between the effective components of the origami algorithm and the improvement of urban landscape quality (Source: authors).

| Effective components of origami algorithm | Origami algorithm | Details | Repetition | Geometry | Rhythm | Balance and symmetry |
|---|---|---|---|---|---|---|
| Origami algorithm | 1 | | | | | |
| Details | 0.764 | 1 | | | | |
| Repetition | 0.943 | 0.780 | 1 | | | |
| Geometry | 0.709 | 0.822 | 0.960 | 1 | | |
| Rhythm | 0.846 | 0.690 | 0.903 | 0.743 | 1 | |
| Balance and symmetry | 0.671 | 0.493 | 0.692 | 0.786 | 0.861 | 1 |

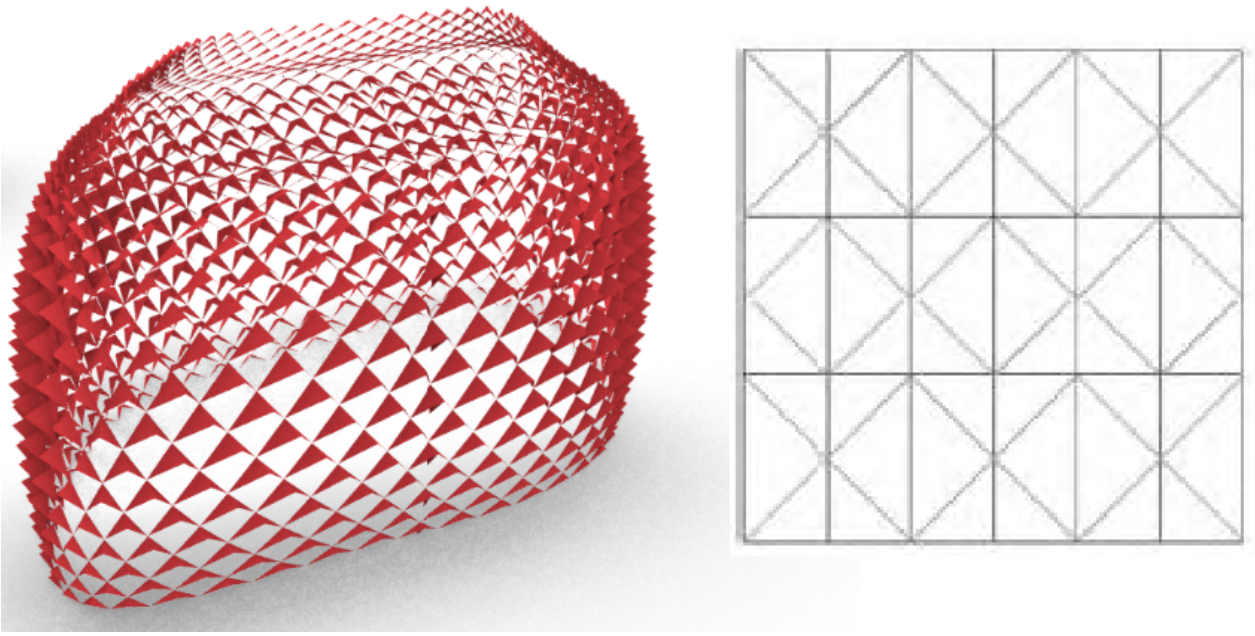

**Figure 4.** Application of a folded pattern as the second shell of the building (Source: authors).

and "Geometry". As the design of the shell of the building showed, the origami algorithm by putting together all the mentioned components could fully create the criteria proposed by the specialist. As in previous researches, facades of high-rise buildings play a significant role in urban landscape quality (Heydari et al. 2019; Lindal and Hartig 2013). The high-rise building facade is the most important part of the building in the aesthetic dimension, which of course, according to the extracted evaluation criteria, cannot be reduced to just the design and form of the facade. Nowadays, efforts are being made to take advantage of new design trends in the field of beautification and improvement of urban landscape quality (Turan et al. 2021). By using origami algorithms, according to the use of each building, a fundamental step can be taken to improve urban landscape quality, and it is possible to move to a great extent in the direction of reducing the use of heavy materials and replacing light shells, which, apart from beautifying the landscape, are also effective in reducing the internal energy consumption of buildings.

## 5. Conclusion

In the aesthetic dimension, the present study introduced and explained the impact of high-rise buildings on the improvement of urban landscape quality, form criteria, height and human scale, light and landscape, proportion and harmony, color and windows and openings. The facade of any high-rise building is not a separate and independent element, and as a part of the walls and windows of other buildings in the city, it forms the overall view and urban landscape. However, the exterior of high-rise buildings is not a marginal element with limited influence due to their size, scale and visibility. It can be boldly said that high-rise building facades, compared to other urban buildings, form the most important part of the overall urban landscape and have a much greater scope of influence on the aesthetic dimension of the urban landscape. Similar to the functional dimensions of high-rise buildings, the criteria for evaluating the aesthetic impact of high-rise buildings on the urban landscape should be carefully studied by engineers in

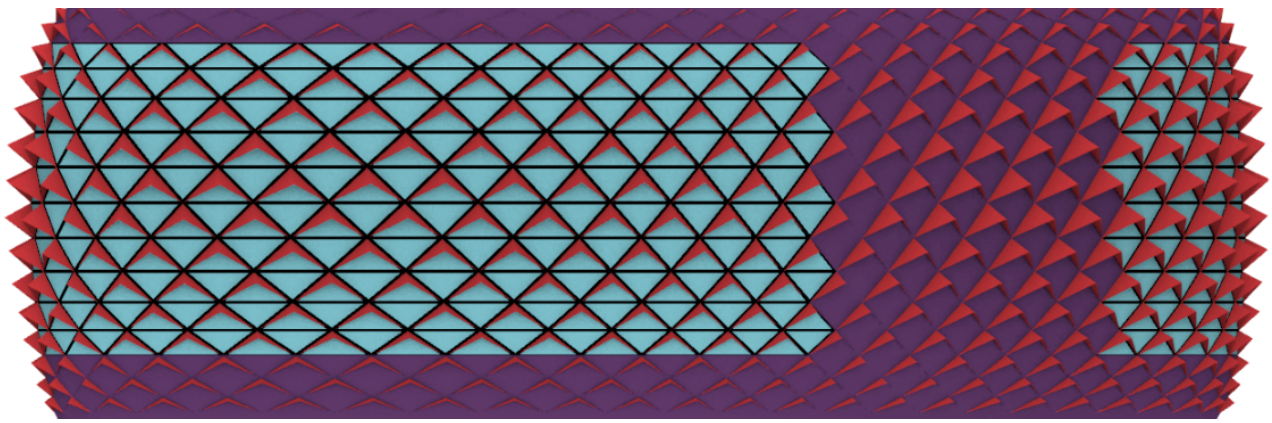

**Figure 5.** Placement of the folded pattern as the second shell of the building (Source: authors).

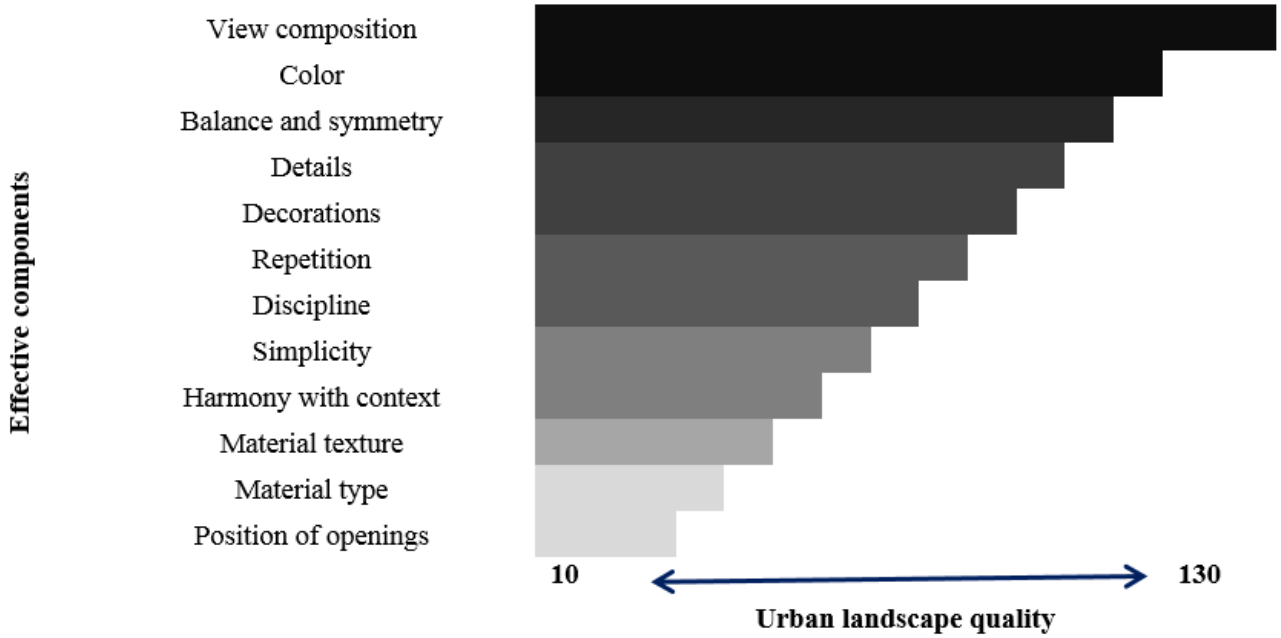


**Figure 6.** Comparative diagram of the impact factor of the components affecting urban landscape quality from the aesthetic point of view.

the design process, because every high-rise building can greatly affect the beauty of the urban landscape and have irreparable effects on the lived experience of city residents. The high-rise building facade is the most important part of the building in terms of aesthetics, which of course, according to the extracted evaluation criteria, cannot be reduced to just the design and form of the facade. Therefore, it seems more logical to use the word "exterior appearance" because it includes factors such as form, human scale, and landscape light, compared to the word "facade" which is often used only to refer to the final covering of the building. In other words, the aesthetic dimensions of the high-rise building in relation to the urban landscape examines the way of interaction, combination and entanglement of the exterior appearance of high-rise buildings with other urban buildings, and based on the extracted criteria, efforts are being made to create a harmonious and systematic composition in order to reduce the negative effect of high-rise buildings on the urban landscape and to devise measures so that these buildings can improve the beauty of the environment and the urban space by increasing the density in addition to reducing and alleviating the housing crisis in Iran.

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