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A Method for Evaluation of Streetscapes: Relationship between Visual Entropy and Interesting Streetscape

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ABSTRACT

The present research studies the complexity of urban facades, which is related to the visual diversity and correlation of the components of urban facades. It studies how the complexity of urban facades affects their desirability amongst citizens and what their preferences are when it comes to facade complexity. In addition, it addresses the complexity of urban facades in both quantitative and qualitative forms and investigates the relationship between quantitative and qualitative data and the desirability of using the correlation analysis method in urban facades.

To obtain quantitative data, a survey was conducted on Nowshahr citizens, and the data was analyzed through MATLAB software. The data obtained is the image entropy, which indicates the number of image irregularities. The results indicated that the Nowshahr citizens prefer the second complexity level, then the first complexity level, followed by the third complexity level, and finally the fourth complexity level, respectively.

There is a slight correlation in the results of the quantitative-qualitative data comparison. Therefore, using entropy as a measure of complexity cannot be confirmed in this study, and further research is needed.

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1. Introduction

Living in new cities has become difficult but not impossible, even with the current state of visual disturbance in cities. However, life would be more organized and scenic if it took place in a clearer setting. A city itself is a diagram illustrating the complexity of the society. We could add to its meaning and effect if we strengthen its visual aspect [1]. Streets comprise important components of the city and they are important places for recognizing and experiencing the city's visual landscape [2].

Many researchers and designers are looking for ways to create more beautiful and proportional designs [3, 4]. However, what is important to note here is whether there is a quantitative way to measure the attractiveness of a design.

Researchers have provided different methods to measure the complexity of an image [5, 6] and a large number of researchers have independently concluded that the amount of complexity or visual diversity created in a streetscape is an important variable affecting the individuals' perception of environmental attractiveness [7-10]. Based on experiments, adverse psychological conditions such as anxiety and nightmares are caused [A1] by absolute ignorance of the environment. In addition, human beings are unable to receive and analyze large amounts of information [11], which means that too complex an image would not be easy to comprehend.

The question posed here is that what is the optimal level of information received? And what should be the diversity and complexity of urban facades?

The ultimate goal of this research is to determine how to measure the beauty of urban landscapes and how to use these findings in design, and [A2] to provide a criterion for measuring the attractiveness of urban facades, so that designers can use it to make their designs acceptable.

1.1. Visual Element of the Streetscape

The space between buildings usually consists of the open space of the street, and the elements inside it determine the shape of these spaces [12]. Lynch (1960) discussed in detail the significance of visual perception for a thorough understanding of the purpose of a building with all its visual elements [1].

Elements such as color, texture, and decoration form the visual features of streetscapes [13], each of which can affect the other elements [14]. As a facade, elements can all directly affect the residents' comfort [15-17]. The façade of a building is one part of the streetscape, and there are also other elements such as gardens, walls, trees, and their relationship with the buildings which form the streetscape [18].

The elements can also directly affect the visual complexity of urban facades. Some of these variables play a significantly greater role in creating the alley landscape than others. Therefore, as moderator variables, visual elements include all of the components and elements observed by the viewer.

1.2. Complexity as an Important Visual Feature

During the study, the environment-related visual preference received a lot of attention and accordingly, some theories were developed [19]. One of these theories focuses on information processes [20]. There is a theory based on a psychological model that considers human information processors and attempts to understand variables as a means to affect people's preference for the environment as a source of information.

This theory explains that information is generally essential for all humans gaining experience and the continuation of life [21]. Environmental information is obtained from visual elements and their spatial organization or arrangement [22]. This part of the study mainly includes the information processing aspect of cognition explained by the cognitive theory of perception, where the perception behavior and action is considered independent and different institutions of the theory of embodied cognition [23] and the perception function are considered as two aspects of a single cognitive system [24].

The physical features of the environment can significantly affect the observer's visual preference, such as the effect of tall buildings on the city's horizon line [25]. These physical features may consist of basic design elements like visual elements, or the spatial relationships among components, which would provide the viewer with an understanding of the built environment [1].

The literature considers visual complexity an essential feature in the visual phenomena of the built environment [18, 26].

1.3. Visual Complexity Variables

The complexity of the built environment is a general concept, which includes several observed variables [27]. It is an important and widespread indicator of the aesthetic value of the environment [28].

The perceived complexity level in the built environment significantly affects its preference [10, 29-31]. However, there is almost no agreement on how the complexity level should be measured [32].

Generally, complexity refers to the level of accessibility to environmental information, which refers to the number of elements in a landscape [33]. The diversity of colors, architectural elements, buildings, and activities also affect the landscape complexity [34].

Research on the complexity of a landscape raises three components of evaluation, namely, the number of design elements, changes between them, and ambiguity. Ambiguity pertains to the semantic complexity resulting from physical reality [35].

Understanding visual complexity largely depends on the quantity and diversity of visual objects [36]. Additionally, visual complexity depends on the number of design elements and the similarity or differences between them [37]. The difference between visual elements occurs at both levels of position and color. Thus, this interpretation indicates that visual complexity is related to three variables, namely, the number of design elements, changes in their position, and changes in their color [9, 35, 38].

1.4. Visual Complexity Effect on Preferences

Visual complexity affects people’s reactions most [18]. The most important factor affecting people's reactions is visual complexity [18]. On the one hand, some studies indicate a positive complexity-preference linear relationship [18, 39, 40], and on the other hand, other studies suggest an inverse U-shaped relationship, specifically that samples with a medium complexity level are more preferred to samples with high or low complexity [8, 37].

1.5. Visual Complexity (Entropy)

A simple method for determining visual diversity in the facade of a building was presented by Salingaros [41]. Using a copy of the entropy concept, Salingaros suggested that "temperature" can be used to evaluate the view.

The five analytical categories Salingaros used include the intensity and smallness of the receivable details, separation density, curvedness of lines, color hue intensity, and contrast between color hues. Later this method was developed by Klinger and Salingaros (2000) to provide a measure of "structure" or "complexity" in the abstract virtual arrays [42]. They state that " structuring of visual diversity is based on the shape features of the facade" indicating the effect of the building on the urban environment. Krampen (2013) used a technique known as parsing to calculate visual diversity (or entropy) in a façade of a building [43]. Again, by placing a grid on a picture of a façade, he calculated cases where there was a specific material in a house.

One of the most commonly used methods for analyzing visual features in architecture is the extrapolation of Mandelbrot's box-counting method to determine the fractal dimension [44]. Bovill's main contribution to the box-counting method is primarily his explanation of potential applications in architecture, design, and art. Bovill's interpretation of Mandelbrot's box-counting method was used to analyze the facade of historic and modern buildings including the alley landscape and the horizon line. In this study, visual complexity is important in all situations and quantitative methods that were not previously available are developed [A3].

Stamps (2003) developed an analytical method in which certain components in a building facade are counted [10]. By sequencing certain components, such as a "square window" in an abstract computer-based alley landscape, he was able to determine the entropy value of any hypothetical arrangement. Stamps III then used the image of the alley landscape to trigger human reactions and determine arrangement desirability and was able to relate visual diversity to desirability through computing methods [A4].

In 2009, Mansouri and Matsumoto conducted a comparative study into the cognitive patterns of complexity in the context of the streetscape's visual composition in Algeria and Japan [45]. Based on the results, complexity, disorder, irregularity, and disturbance are often contradictory concepts in urban texture. The streetscapes of the Algiers during the day are balanced, orderly, and regular, and the streetscapes of Japan during the day are unbalanced, seemingly disordered, and bright.

The streetscape of Algiers at night are diverse, rich, and irregular. Japan's streetscapes are more balanced, orderly, and regular. [A5] This research was able to find three main factors, namely: 1) human-made forms, 2) style, and 3) a combination of materials/activities/factors. The number of factors in each visual array indicates its degree of complexity [46].

In order to optimize and evaluate street design, Junwei (2013) proposed a quantitative indicator to measure the visual complexity of the landscape [47]. Junwei defines a commercial sidewalk as follows: A hallway with a rather artificial visualization, with more richness and variety than usual because malls gradually gather there.

In the present study, visual entropy (disorder) is introduced to assess the visual complexity of a commercial sidewalk street, the data of which is calculated using the MATLAB digital image processing module. The data were analyzed in terms of correlation, and an evaluation of the results of a group of interviewees (N = 105) was conducted with SPSS analysis software. The analysis indicated a significant correlation between visual entropy and evaluation results, so visual entropy was used as a quantitative indicator to assess the visual complexity of a commercial sidewalk street [47].

1.5.1. Visual Entropy Calculation Process

One of the most efficient tools for processing digital images is MATLAB software, which has a special toolbox for processing digital images, including a sequence of operational functions of image processing [48, 49].

Based on the bivariate Pearson correlation, the correlation coefficient between visual entropy and visual complexity at the level 0.05 (bilateral) was 0.753, P = 0.012, indicating a significant correlation between visual features in one landscape and individual's indicator for measuring the visual complexity of the landscape. Therefore, it provides a reference for assessing visual order.

An image with larger visual entropy has a higher order and an image with a smaller visual entropy has a lower order. This result does not correspond to the usual manner in which daily life is conducted, thus there is a need for more research to examine the probable principles [47].

In a comparative study, Mansouri and Matsumoto investigated the complexity of streetscape composition, which was a comparative study of complexity, as a multidimensional concept, in the context of streetscape composition in Algeria and Japan. The results indicated that complexity, disorder, irregularity, and disturbance are often contradictory concepts in urban texture [45].

According to Mansouri, complexity is a multidimensional concept. Also, some concepts of complexity, such as disorder, irregularity, and disturbance are often contradictory as revealed through the findings. There is a need for further research to investigate the geometric background and concepts involved in the streetscape complexity composition [45].

1.6. Problems and Their History

There is a large body of studies on the calculation of visual complexity in urban spaces, which include determining the visual diversity using building temperature, box-counting method, entropy, and its difference in day and night; however, few studies measured their correlation with people's opinions and preferences in order to provide quantitative criteria.

In the present study, attempts were made to evaluate the efficiency of visual entropy using color images in addition to comparing the complexity obtained from quantitative methods with qualitative ones to finally determine the desired complexity level of an urban façade.

1.7. Research Question and Aim

The present study introduces a criterion for measuring the complexity of urban facade, i.e. visual entropy, and examining its efficiency. Furthermore, by comparing the computational and quantitative methods of measuring complexity with the qualitative method and the audience's perception of an urban facade (streetscape), we can measure the degree of correlation between them. The desirability of urban facades is also analyzed in terms of complexity, i.e. the present study mainly aims at determining a quantitative criterion for measuring the desired degree of complexity in the urban facades.

The main question addressed in this article is: What is the optimal complexity level in urban facades? There are hypotheses regarding this question: visual entropy can be a measure of the complexity of urban facades. People will be more satisfied if the complexity of urban facades is optimal.

2. Methods and Materials

2.1. Case study: Nowshahr City

Considering the question discussed in the research, Nowshahr City in Mazandaran province, which was formerly a village called Khajak or Khachank, is suitable for a population study because of the special coastal status, harbor capacity, and architectural diversity it provides as an urban environment research setting.

2.2. Data Gathering

2.2.1. Primary Data Type (Photos)

The primary data used in the present study includes digital pictures of the city's streetscapes, taken in the opposite direction as facades. This is because this view provides some of the visual information that can be used to judge human reactions and shows the building-street interaction.

There are several ways to take still pictures of an alleyscape, you can include a central view of the center of the alley in a downward direction with buildings on either side or vertical pictures of the front of each house. Each perspective or approach has its advantages, as both are found in any pedestrian's experience of walking in an alley [50].

The pictures used for the computational analysis in the current study were taken in a standing position in front of the buildings. This means that the pictures mostly taken from a perspective were directly opposite the building facade. A photo taken of a standing position also provides a view closely related to the passers-by's experience of the alley. This position also allowed for photographing a two-story building and buildings with a wide facade. Consequently, several photos were taken in front of the facade of each street, and connecting them provides an integrated picture [27]. See the online supplemental material for further details on image creation.

2.3. Method of Data Collection

In the present study, we collected both quantitative and qualitative data. MATLAB software was employed to obtain quantitative data and computational analysis. A survey was used to obtain qualitative data.

The 12 images (Table **S1**) from the streetscapes were presented to the candidates, and in the questionnaire, they were asked to grade the images from the simplest to the most complex, respectively. They were then asked to select their desired image in terms of complexity. In the relevant literature, as we used color images, the results of the research are highly correlated with the real environment [51-55] [A6].

2.4. MATLAB Software and Visual Entropy

As mentioned, a criterion was set for measuring the complexity of urban facades, namely visual entropy. Two different codes were used to calculate entropy in this study to evaluate the efficiency of each, the results of which were presented as entropy 1 and entropy 2.

In the mid-19th century, Rudolf Clausius proposed the concept of entropy, mainly to describe the degree of disorder in thermodynamics [56]. Later, entropy was employed as an important concept in various systems. Currently, in the field of image processing, researchers have described the abstract measurement of human visual information with visual entropy, which is consistent with human visual features and is easily quantifiable [57].

Visual entropy is theoretically described in accordance with the order of the pixels of a gray image, which indicates the degree of information richness and noise distribution. Entropy cannot state the image details, though it is important to reflect the richness of the images. When there are N important boundary areas or units in a visual object in the landscape, the probability of the occurrence of the i-th region is $\mathrm{Pi}(\mathrm{i}=1,2,3,\mathrm{n})$, and the amount of information is $\mathrm{H}=-\log \mathrm{P_i}$, since a complete visual object contains N regions, its information is $H=-\sum_{i=1}^{n} P_i \log P_i$, indicating the degree of complexity of a visual object. We can call it visual entropy [58].

2.4.1. Computer Analysis Process of Visual Entropy

Visual entropy as an important indicator can reflect the visual complexity and richness of the earth's landscape, though it is still impossible to have a quantifiable measurement, analysis, and calculation from a physical or visual landscape. This is due to the complexity of the landscape and the problem of measurement in geometric parameters.

Using digital photography and photo processing technology, it is possible to conduct visual entropy analysis of digital images from a landscape. This method of landscape assessment with real images has been widely acknowledged by psycho-physical schools for its high validity and reliability [49]. There are more details about the process of computing visual entropy in MATLAB in the online supplemental material, which describes how entropy is calculated.

2.5. Method of Data Analysis

The data obtained from the survey were analyzed through SPSS software and the images were graded. The grading was compared with the entropy values of the images and the correlation among the obtained results was taken into consideration. The images that citizens considered desirable according to complexity were identified. Accordingly, the relationship between complexity and desirability was established and interpreted.

2.6. Determining the Sample Size and Reliability of Questions

Using Cochran's formula, the sample size was calculated. To this end, 20 primary questionnaires were completed to obtain an initial variance. Then, based on the calculated variance in the assumed statistical population of 42,170 people in Nowshahr, according to the statistics of the year 2011 with a 95% confidence level (95% - Z Score = 1.96) and error of 0.77, the sample size of 100 people was obtained.

The study adopted a random convenience sampling method. The convenience method is one of the non-probabilistic or non-random sampling methods.

The study adopted a random convenience sampling method. The convenience method is one of the non-probabilistic or non-random sampling methods. In this method, the researcher studies those who are available, and the interviewer randomly selects and interviews people based on the number and sample size. Regarding the reliability of the questionnaires, it was calculated using Cronbach's alpha statistics, the result of which is as follows (Table **1**):

Table 1: Reliability of questionnaire questions.

Reliability of Statistical Analysis	
Number of items	**Cronbach's alpha**
12	0.779

As seen, the value of this statistic is above 0.70, indicating the reliability of the questionnaire intended for future analysis [59].

In the present research, a total of 100 people were interviewed, of whom males were 43 (43%) and females were 56 (56%). The highest number of respondents were between the ages of 18-35 and the education level of most respondents, i.e. 35%, was Bachelor's. Most of the respondents were residents and inhabitants of the city; 6% of people lived in this city for less than ten years, 3% of them lived for 5-10 years, and 18% lived more than ten years in Nowshahr.

3. Results

3.1. Grading Images Based on the Complexity of Views (Friedman Test / Two-Way Analysis of Variance)

The Friedman test was used for measuring people's preferences and ranking the complexity of each facade from their perspective. This test is utilized when the measurement scale is at least at the level of sequential measurement. The Friedman test is used to analyze two-way variance (for nonparametric data) through ranking, as well as to compare the mean rankings of different groups [60]. See the online supplemental material (including Table **S2**) for further details about the Friedman test.

In addition to investigating the significance of difference or lack of difference of the mean rank of the degree of complexity of each facade in the perspective of the respondents, the Friedman test prioritizes each image from the perspective of individuals. The degree of simplicity and complexity is ranked between numbers 1-12, with 12 as the highest complexity level. To achieve this, we can use the results in the first table (named ranks). The results are listed in Table **2**.

Table 2: Friedman test.

Facade	Mean Rank (Complexity Level)	Facade	Mean Rank (Complexity Level)	Facade	Mean Rank (Complexity Level)
Image No.09	6.80	Image No.05	6.82	Image No.01	7.86
Image No.10	7.23	Image No.06	6.72	Image No.02	4.35
Image No.11	6.89	Image No.07	7.13	Image No.03	4.20
Image No.12	7.18	Image No.08	6.77	Image No.04	6.08

Based on the results of Table **2**, from the respondents' point of view, the complexity level in the facade of Fig. (**1**) is higher than other facades and has a mean rank of 7.86.

After that, facade 10 with a complexity level of 7.23 has the highest rank of complexity among other facades. The simplest facade, from the point of view of the respondents, is facade number 3, with the lowest complexity level with a mean rank of 4.20 compared to other facades.

3.2. T-Test Analysis for the Degree of Complexity

Based on Table **S3**, the mean observed degree of complexity in the façade in Fig. (**1**) is 7.52, which is higher than the expected mean of 6.5. Considering that the significance level of the calculated t-value with a degree of freedom of 99 is lower than 0.05, the difference between the observed mean and the expected mean is significant ($P < 0.05$). Therefore, with 95% confidence, it can be said that the complexity of facade 1 is higher than expected.

The observed degree of complexity in facades 2, 3, and 4 was obtained at 3.35, 3.79, and 5.71, respectively, which is lower than the expected mean of 6.5. As the significance level of the calculated t-value with a degree of freedom of 99 is lower than 0.05, the difference between the observed mean and the expected mean is significant ($P <0.05$). Therefore, with 95% confidence, the complexity of facades 2, 3, and 4 is lower than expected.

The observed mean degree of complexity in facades 5, 6, 8, and 9 is 6.45, 6.29, 6.40, and 6.40, respectively, which is less than the expected mean of 6.5. Since the significance level of the calculated t-value with a degree of freedom of 99 is higher than 0.05, the difference between the observed mean and the expected mean is not significant ($P <0.05$). Therefore, with 95% confidence, the complexity of facade 5 has no significant difference from the expected mean and they are almost equal.

Eventually, the observed degree of complexity in facades 7, 10, 11, and 12 was 6.73, 6.82, 6.52, and 6.52, respectively, which is higher than the expected mean of 6.5. Considering that the significance level of the calculated t-value with a degree of freedom of 99 is higher than 0.05, the difference between the observed mean and the expected mean is not significant ($P <0.05$). Therefore, with 95% confidence, the complexity of facade number 7 is not significantly different from the expected mean as it is almost equal.

3.3. Factor Analysis

The analytical factor is considered the queen of scientific methods due to their strength, elegance, and proximity to the core of scientific goal (Kerlinger, 1986). This method pursues two main objectives: first, identifying the underlying factors of variables. In this regard, the common feature of variables is identified regarding the common variance and then named by the researcher.

The second goal of factor analysis is to identify the relationships between new variables (factors), which, of course, are less considered. Regarding its capability in data analysis, it is impossible to use it in any situation.

The data with sufficient competency deserves factor analysis. To this end, the Bartlett test and the KMO coefficient are used. Factor analysis can be used with confidence if the KMO value is higher than 0.5. The coefficient obtained in this study was 0.884, which is a good figure, so the Bartlett test became significant at the 1% (Sig = 0.000) level (Table **3**).

Having ensured the data appropriateness for factor analysis, the Varimax rotation was used to obtain significant factors. The number of factors is determined in advance based on the specific values.

Table 3: KMO and Bartlett's Test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.580
Bartlett's Test of Sphericity	150.698
df	66
sig	0.000

Each of the above factors consists of several variables. The loading status of the factors after rotation is based on the placement of variables with a factor load greater than 0.5 in Table **4**. In this Table, the variables with a factor load less than 0.5 were removed due to less significance.

Table 4: Factors extracted with special value, percentage of variance, and percentage of cumulative variance.

Factor	Special Value	Percentage of Variance	Percentage of Cumulative Variance
The first factor	1.744	14.529	14.529
The second factor	1.721	14.341	28.870
The third factor	1.535	12.790	41.660
The fourth factor	1.496	12.468	54.128

In the first group, the complexity level is equal to the expected mean: Based on Table **4**, the levels of complexity equal to the expected mean belong to facades 5, 8, and 9, which have a direct and a very strong relationship of the variables constituent of this factor. This factor alone explains 14.529% of the special variance (Table **5**).

Table 5: Variables related to each of the factors and the number of factor loads obtained from the matrix.

Factor	Variable	Load
In the first group, the complexity level is equal to the expected mean	facade 09	0.574
	facade 08	0.736
	facade 05	0.661
In the second group, the complexity level is higher than the expected mean	facade 06	0.684
	facade 11	0.632
The third group, the highest complexity level	facade 01	0.502
	facade 12	0.527
	facade 07	0.571
	facade 10	0.572
The fourth group, the highest level of simplicity	facade 02	0.665
	facade 03	0.798
	facade 04	0.721

In the second group, the complexity level is higher than the expected mean: According to the results of the table, this group explains 14.341% of the total variance. Facades 6 and 11 have a direct and strong relationship with this complexity level.

The third group, the highest complexity level: This group consists of facades 1, 7, 10, and 12, which have the highest complexity level among other facades.

The fourth group, the highest level of simplicity: This group consists of facades 2, 3, and 4, which have the highest level of simplicity among their other facades.

3.4. Comparison of Complexity of Images in MATLAB Test

Analyzing the results of diagram **S1** indicated that according to Friedman's test, image 7 has the highest complexity level followed by image 12. According to the results of entropy, image 12 has the highest complexity level.

3.5. Specifying the Most Desirable Image in Terms of Complexity Level

In order to investigate and determine the most desirable image from the perspective of the respondents, the frequency analysis of the responses was used. See the online supplemental material (diagram **S2**) for further details.

Analyzing the results obtained from studying the frequency level of desirability of images in terms of complexity indicates that from the perspective of respondents, image 9 is the most desirable in terms of complexity, and image 10 had no votes.

3.5.1. Comparison of the Complexity Rank from People's Point of View and the Most Desirable Image and Entropy

Investigating and analyzing the rankings obtained from each test and comparing the correlation between their rankings with each other indicates the similarity and correlation between some images in different tests (Facades with color correlation are color marked). See the online supplemental material (Table **S4**) for further details.

3.6. Comparison of Surveys with MATLAB Software Analysis

Based on the analysis conducted, we compare the data and results obtained from the SPSS analysis in two groups and ranks. In group comparisons, images, and entropies 1 and 2 fall into several groups, and these groups are compared. In rank comparison, however, the images and entropies 1 and 2 are compared individually and placed according to their rankings in the table.

3.6.1. Group Comparison

Based on the factor analysis, the images fall into 4 groups, namely:

The first group: the complexity level is equal to the expected mean

The second group: the complexity level is higher than the expected mean

The third group: the highest complexity level

and *the fourth group:* the highest level of simplicity

This grouping was consistent with the Friedman test ranking, reflecting people's perspective on image ranking. Thus, the results of entropy 1 and 2 can be compared with this grouping.

To facilitate the comparison, we name these 4 groups based on the complexity variable as follows:

The first group: has the second complexity level; the second group: has the third complexity level; the third group: has the fourth complexity level; and the fourth group: has the first complexity level.

Regarding this nomenclature, the grouping of images based on factor analysis, entropy 1 and entropy 2, is as Table **S5**.

As seen in the online supplemental material (Table **S5**), in group comparison, entropy 1 is more consistent with the grouping based on factor analysis and the survey conducted, and therefore closer to the opinions of the respondents In other words, images 7 and 12 are both in the fourth level group of complexity, images 5 and 9 are in the second level group of complexity, and image 4 is in the first level group of image complexity.

3.6.2. Rank Comparison

Table **S3** presents the correlation between Friedman's test ranking (which is based on a survey) and entropy 1 and 2. As seen, in only two cases entropy 1 fully conform to Friedman's test, and in some cases, a significant proximity was observed.

The results show that by conducting this research, it is impossible to accurately attribute the entropy numbers to the ranking obtained from the survey of images, and to this aim, which is the main purpose of the present study, more research is needed. Apparently, better results will be obtained if an algorithm is chosen instead of the Region Growing algorithm that performs the segmentation operation better and more accurately. It is possible to use other segmentation algorithms with higher efficiency proposed in recent years to compare and analyze the results.

3.7. Reviewing the Desirability of Images (City Facade)

The most desirable to the most undesirable image is as seen in the online supplemental material (Table **S6**). Image 9, which is the most desirable image, is in the second-level complexity group followed by image 3 in the first-level group of complexity, image 8 in the second-level complexity group, images 6 in the third-level complexity group, images 12 and 1 in the group of the fourth level complexity; the rest of the images had rather poor desirability.

Thus, in general, in terms of grouping, the second level of complexity followed consecutively by the first level of complexity, the third level of complexity, and the fourth level of complexity of the group were desirable in the view of people.

3.8. Investigating the Grouping of Images According to the Survey

By analyzing the images in this section, the common features of the images of each group and the possible reasons for the placement of these images in their respective groups are investigated.

3.8.1. The Fourth Level of Complexity (common features)

Complex skyline, multiple vertical divisions, a large number of colors and materials, different 3-part horizontal divisions, and disorder (Table **S7**).

3.8.2. The Third Level of Complexity (common features)

The skyline is similar and relatively simple, almost uniform compared to the previous group of horizontal divisions, and few vertical divisions. regarding color composition, it can be said that complementary colors are used to some extent and have relatively good harmony. The left side of the images, which is prioritized over the right, is somewhat simple and uniform, and this simplicity affects the overall composition (Table **S8**).

3.8.3. The Second Level of Complexity (common features)

Uniform, with more purity, less detail, less material, more use of white, and more order (Table **S9**).

3.8.4. The First Level of Complexity (common features):

Simple and uniform skyline, simple surfaces with little details, uniform colors, simple horizontal divisions, no vertical divisions of the index, and solitude (Table **S10**).

4. Discussion

The present study used several quantitative and qualitative tests comparatively to measure the complexity of the urban facade to reduce the final error and to measure the use of entropy as a criterion for measuring the complexity. Then, factor analysis was employed to identify the common features of the variables, and this was never performed in previous studies. There are many studies on the calculation of visual complexity in urban environments, but few studies are measuring the correlation between quantitative methods and people's opinions and preferences, and providing a quantitative criterion for them.

Natural backgrounds, like mountains, can have a significant effect on the complexity of facades and their compositions, the absence of which can be seen in this research. This can be considered a limitation in this research.

In addition, there are components such as vehicles and signs in the images, that in some cases, can act as intervening variables. However, we have tried to reduce this as much as possible. However, their interference in the images has possibly affected the results.

Taking these limitations into account, future research needs the addition of images with natural backgrounds such as mountains, and artificial backgrounds such as urban environments, especially tall buildings. In some research, this method can be employed to measure single tall buildings, because these buildings have a great effect as a significant element in the complexity of the surrounding facades.

5. Conclusion

In this study, attempts were made to measure the complexity of urban facades both quantitatively and qualitatively and use correlation analysis to evaluate the relationship between quantitative and qualitative data, taking into account the desirability of urban facades. These data are the entropies of the images that show their irregularity. quantitative and qualitative data share a slight correlation in the results. Therefore, entropy cannot be confirmed as a measure of complexity in this study, and further research is needed.

Having examined the general features of the images of each group, we examined the features of facade 9 in particular. As mentioned, facade 9 is the most desirable image in the opinion of citizens of Nowshahr, which is in the second level of the complexity group.

Therefore, the features of this facade can be considered significant features in designing or renovating urban facades in the future. Considering the features that facade 9 possesses in design can lead to higher desirability and satisfaction amongst citizens regarding architectural and urban plans.

For facade 9, the feature can be described as a "number of variables", which is described as follows:

The first variable: the purity and simplicity of the surfaces with the diversity created by the trees and green space. The presence of trees in this facade has been considered not because of its natural beauty but because of the visual diversity it creates in urban walls since the beauty variable has been controlled as much as possible in this study.

Therefore, other elements can be used instead of trees and green spaces, of course, in compliance with features such as order at the time of disorder, lack of chaos, and rhythm which is created by green space.

The second variable: The uniform and simple lower levels along the soft and varied skyline create a balanced and eye-catching image that is neither too simple, uniform, nor too complex.

The third variable: Using contrasting colors (green and red) along with the white color of the walls has created a suitable color harmony preventing the facade from being monotonous.

The fourth variable: Using minimums to create a desirable urban facade to avoid vanity and using redundant elements are other features of this facade that makes it easier for the viewer to understand. Generally, the right number and type of components and the correct relationship of these components have created a desirable urban facade. If the value of these variables increases or decreases, it loses its desirability. In this facade, we have accidentally created features that were selected by citizens, and in this way, to some extent, the desired image of the citizens and the desired level of complexity or visual diversity required for them is evident to us. It is essential for the designers to smartly address this issue and to pay closer attention to the needs of citizens.

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SUPPLEMENTARY MATERIAL

This document includes material bearing on 1) Capture images images and related aspects of the methods; 2) the process of computing visual entropy in MATLAB; and 3) Summarizing of the main analyses with their statistical data.

1. Capture Images

All images were captured with the Canon EOS 800D camera from a 15m distance of the facades. All images were controlled in terms of dimensions, resolution and image quality, etc., and were in the same condition with the image pre-processing steps in MATLAB and Photoshop software.

The same approach was used in order to capture each image. The photography was repeated if the image was blocked with a moving object (e.g. a car), and the previous version was discarded. Of course, if the car was still and on an internal scale, it would be accepted as part of the characterization of an alleyscape.

Trees, fences and natural landscapes in front of the house were necessarily part of the alleyscape and were sometimes a significant component of the image. A house with large plant growth could almost completely block the facade of the building, though the qualities and components such as these are often quite desirable for the residents and therefore recorded as it was.

1.2. Image Collecting and Processing

Images were taken from a number of streets in areas of Nowshahr. Complexity is the criterion for selecting streets, and attempts were made to provide facades with varying degrees of complexity. Also, regarding facade style and appearance, diversity was ensured in order to enhance the aesthetic variable and design style. These streets include Enghelab Street, North Ferdowsi, Piroozi, 15 Khordad, Razi and Shahid Kheirian Streets, selected after consulting with 15 experts in urban architecture and design at Bu-Ali Sina university. In some streets, pictures were taken from both sides of the street, and in some the image was divided into two separate samples due to differences in their façade complexity. Eventually, 12 images of streetscapes were recorded (Images 1 to 12). Images were taken on June 7 and 11, 2018 at a specific time and the same lighting conditions.

Using Adobe Photoshop software, individual images of each street were connected to achieve an integrated view of the streetscape to analyze the streetscape in the form of a single image. The length of the streets was controlled and adjusted through the crop tool and the parts of the images that were distorted and incomplete due to the connection of the images, such as vehicles were corrected as much as possible. The image size was set to 1000 pixels because it has adequate details to perform calculations and is small enough to store and process. The next steps in image processing were conducted in MATLAB software.

2. Computing Visual Entropy

In the present study, the process of computing visual entropy in MATLAB is summarized as follows:

2.1. First Code

Reading and graying the image.

Equalizing histogram to improve image contrast.

Image segmentation using REGION GROWING algorithm.

Computing the entropy of each section.

Computing the entropy of the whole image.

Table S1: Final selected images.

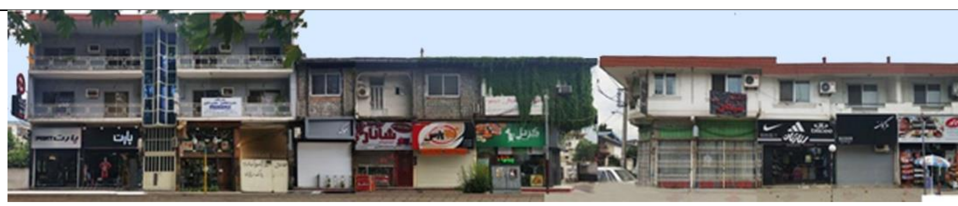
Image No.01	
Image No.02	
Image No.03	
Image No.04	
Image No.05	
Image No.06	
Image No.07	
Image No.08	

Image No.09	
Image No.10	
Image No.11	
Image No.12	

2.1.1. The key Algorithm is as Follows

```
%%
   [M,N]=size(cIM);
   x=initPos(1); y=initPos(2);
   point= [x, y];
   point_list=[point_list; point];
   [J, num_of_ele,I0ut]= regiongrowing(cIM,x,y,0.18);
   % [suit,Y]=unitregiongrow(cIM,M,N,.7,x,y);
   figure, imshow(cIM);
   figure, imshow(cIM+J);
   figure, imshow(J*255);
    J1=J*255;
   J2=J1/255;
   J3=J2.*cIM;
   figure,imagesc(J3)
   I_e=entropy1(J3,num_of_ele)
   I_e1=entropy1(I0ut,length(I0ut))

   decide= input('1: continue, 2:stop    :');
   cIM=cIM+J;
   s_I_e= s_I_e+ I_e;
```

```
    c=c+1;
    if decide==2
        break;
    end
end
Local_Entropy =s_l_e/c;
save point_list_3_3.mat point_list;
% I2 = imcrop(J3,[429 250 1997 936]);
% entropy1(I2,num_of_ele)
% figure,imagesc(I2)
```

Description of the first code for computing entropy in MATLAB:

```
% I = im2double(imread('medtest.png'));
clear all;
clc;
close all;
im= imread('D:\ 3\3.jpg');
cIM=im2double(rgb2gray(im));
[rr,cc]=find(cIM<255);

cIM = histeq(cIM);
E_Without_remove_object = entropy(cIM)
E_with_removed_object = entropy2(cIM,length(rr))

true=1;
s_l_e=0;
c=0;
point_list =[];
while (true)
    close all;
     figure, imshow(cIM), hold all
    %%
    % graphical user input for the initial position
        himage = imshow(cIM, []);
        p = ginput(1);

        % get the pixel position concerning to the current axes coordinates
        if  iscell(get(himage, 'XData'))
            initPos(1) = round(axes2pix(size(cIM, 2), cell2mat(get(himage, 'XData')), p(2)));
        else
            initPos(1) = round(axes2pix(size(cIM, 2), (get(himage, 'XData')), p(2)));
        end
        if iscell(get(himage, 'XData'))
           initPos(2) = round(axes2pix(size(cIM, 1), cell2mat(get(himage, 'YData')), p(1)));
```

```
        else
            initPos(2) = round(axes2pix(size(cIM, 1), (get(himage, 'YData')), p(1)));
        end

    %%
    [M,N]=size(cIM);
    x=initPos(1); y=initPos(2);
    point= [x, y];
    point_list=[point_list; point];
    [J, num_of_ele,I0ut]= regiongrowing(cIM,x,y,0.18);
    % [suit,Y]=unitregiongrow(cIM,M,N,.7,x,y);
    figure, imshow(cIM);
    figure, imshow(cIM+J);
    figure, imshow(J*255);

    J1=J*255;
    J2=J1/255;
    J3=J2.*cIM;
    figure,imagesc(J3)
    l_e=entropy1(J3,num_of_ele)
    l_e1=entropy1(I0ut,length(I0ut))

    decide= input('1: continue, 2:stop    :');
    cIM=cIM+J;
    s_l_e= s_l_e+ l_e;
    c=c+1;
    if decide==2
        break;
    end
end
Local_Entropy =s_l_e/c;
save point_list_3_3.mat point_list;
% I2 = imcrop(J3,[429 250 1997 936]);
% entropy1(I2,num_of_ele)
% figure,imagesc(I2)
```

2.2. Second Code

Reading and graying the image

Equalizing histogram to improve image contrast

Computing the entropy of Color Images (RGB)

Image segmentation using REGION GROWING algorithm

Computing the entropy of the whole image

2.2.1. The Key Algorithm is as Follows

```
%% COMPUTE ENTROPY OF EACH COLOR IN RGB IMAGE
E_Without_remove_object = entropy((I(:,:,1)));
E_Without_remove_object1 = entropy((I(:,:,2)));
E_Without_remove_object2 = entropy((I(:,:,3)));
%% COMPUTE THE ENTROPY OF THE COLOR IMAGE
E_kol_Without_remove_object=
(E_Without_remove_object+E_Without_remove_object1+E_Without_remove_object2)/3;
E_kol_Without_remove_object*PER_,
% INITIALIZED THE PARAMETER FOR COMPUTING LOCAL ENTROPY
true=1;
Sum_Local_Entropy_G=0;
Sum_Local_Entropy=0;
Sum_Local_Entropy1=0;
Sum_Local_Entropy2=0;
c=0;
point_list =[ ];
%%
while (true)
   close all;
   figure, imshow(cIM), hold all
   cIM = histeq(cIM);

  %% DO REGION GROWING IN THE SURROUNDING OF THE CORRENT PIXEL
  [M,N]=size(cIM)
  %% DEFINE X AND Y
  x=initPos(1); y=initPos(2);
  %% DEFINE THE POINT LIST
  point= [x, y];
  point_list=[point_list; point];
  %% DO REGION GROWING IN THE SURROUNDING OF THE CORRENT PIXEL
  [J, num_of_ele,I0ut_G]= regiongrowing(cIM,x,y,0.18);
  %% DO COLOR REGION GROWING IN THE SURROUNDING OF THE CORRENT PIXEL
  [J, num_of_ele,I0ut,I0ut1,I0ut2]= regiongrowing22(I,x,y,0.18);
  % [suit,Y]=unitregiongrow(cIM,M,N,.7,x,y);

%% COMPUTE THE FINAL LOCAL ENTROPY OF Gray IMAGE
Local_Entropy_G =Sum_Local_Entropy_G/c,
%% COMPUTE THE FINAL LOCAL ENTROPY OF COLOR IMAGE
Local_Entropy =Sum_Local_Entropy/c;
Local_Entropy1 =Sum_Local_Entropy1/c;
Local_Entropy2 =Sum_Local_Entropy2/c;
Local_Entropy_KOL = (Local_Entropy2+Local_Entropy1+Local_Entropy)/3
%% Save the point List
save point_list_4_6.mat point_list;
```

Description of the second code for computing entropy in MATLAB:

```
%% CLEAR ALL PART OF MATLAB
clear all;
clc;
close all;
warning off;

%% READ IMAGE
im= imread('D:\4\6.jpg');

%% COPY IMAGE TO I1 and I
I1=im;
I=im;

%% define the size of input image
[row,col,color_]=size(I1);

%% Convert IMAGE TO GRAY IMAGE
gray_=(rgb2gray(im));

%% SHOW THIS IMAGE
figure(19)
imshow(gray_)

%% CONVERT GRAY IMAGE TO BINARY IMAGE
bw= im2bw(gray_,0.7);

%% SHOW THIS IMAGE
figure(20)
imshow(bw)

%% COMPUTE THE CONTRIBUTION OF THE SKY
aaaaa=find(bw==1);
PER_= 1-(length(aaaaa)/(row*col));

%% CONVERT THE RGB INPUT IMAGE TO GRAY
cIM=im2double(rgb2gray(I));

%%

%% APPLY HISTOGRAM EQUALIZED TECKNIQUE
cIM = histeq(cIM);

%% COMPUTE ENTROPY OF GRAY IMAGE
E_Without_remove_object = entropy(cIM)*PER_,
```

```
%% COLOR IMAGE
imshow(I(:,:,2))
I(:,:,1) = histeq(I(:,:,1));
I(:,:,2) = histeq(I(:,:,2));
I(:,:,3) = histeq(I(:,:,3));

%% COMPUTE ENTROPY OF EACH COLOR IN RGB IMAGE

E_Without_remove_object = entropy((I(:,:,1)));
E_Without_remove_object1 = entropy((I(:,:,2)));
E_Without_remove_object2 = entropy((I(:,:,3)));

%% COMPUTE THE ENTROPY OF THE COLOR IMAGE
E_kol_Without_remove_object=
(E_Without_remove_object+E_Without_remove_object1+E_Without_remove_object2)/3;
E_kol_Without_remove_object*PER_,
%%

% INITIALIZED THE PARAMETER FOR COMPUTING LOCAL ENTROPY

%
true=1;
%
Sum_Local_Entropy_G=0;
Sum_Local_Entropy=0;
Sum_Local_Entropy1=0;
Sum_Local_Entropy2=0;
%
c=0;
%
point_list =[ ];
%%
while (true)
    close all;
    figure, imshow(cIM), hold all
    cIM = histeq(cIM);

  %%
  % graphical user input for the initial position
    himage = imshow(cIM, []);
    p = ginput(1);

    % get the pixel position concerning to the current axes coordinates
    if  iscell(get(himage, 'XData'))
       initPos(1) = round(axes2pix(size(cIM, 2), cell2mat(get(himage, 'XData')), p(2)));
    else
       initPos(1) = round(axes2pix(size(cIM, 2), (get(himage, 'XData')), p(2)));
```

```
    end
    if iscell(get(himage, 'XData'))
      initPos(2) = round(axes2pix(size(cIM, 1), cell2mat(get(himage, 'YData')), p(1)));
    else
       initPos(2) = round(axes2pix(size(cIM, 1), (get(himage, 'YData')), p(1)));
    end

  %% DO REGION GROWING IN THE SURROUNDING OF THE CORRENT PIXEL
  [M,N]=size(cIM);

  %% DEFINE X AND Y
  x=initPos(1); y=initPos(2);

  %% DEFINE THE POINT LIST
  point= [x, y];
  point_list=[point_list; point];

  %% DO REGION GROWING IN THE SURROUNDING OF THE CORRENT PIXEL
  [J, num_of_ele,I0ut_G]= regiongrowing(cIM,x,y,0.18);

  %% DO COLOR REGION GROWING IN THE SURROUNDING OF THE CORRENT PIXEL
  [J, num_of_ele,I0ut,I0ut1,I0ut2]= regiongrowing22(I,x,y,0.18);

  % [suit,Y]=unitregiongrow(cIM,M,N,.7,x,y);

  %% SHOW THE RESULTS
  figure, imshow(cIM);
  figure, imshow(cIM+J);
  figure, imshow(J*255);

  J1=J*255;
  J2=J1/255;
  J3=J2.*cIM;

  %% SHOW THE COMBINE RESULT
  figure,imagesc(J3)

%    Local_Entropy=entropy1(J3,num_of_ele)

%% COMPUTE THE LOCAL entropy OF Gray Image
  Local_Entropy_G=entropy1(I0ut_G,length(I0ut_G));

%% COMPUTE THE LOCAL entropy OF color Image
  Local_Entropy=entropy1(I0ut,length(I0ut));
  Local_Entropy1=entropy1(I0ut1,length(I0ut1));
  Local_Entropy2=entropy1(I0ut2,length(I0ut2));
```

```
    %% Decide to CONTINUE OR TO STOP
    Decide= input('1: Continue, 2:Stop  3:Repeat Again    :');
    if Decide==1
      cIM=cIM+J;
      Sum_Local_Entropy_G= Sum_Local_Entropy_G+ Local_Entropy_G;
      Sum_Local_Entropy= Sum_Local_Entropy+ Local_Entropy;
      Sum_Local_Entropy1= Sum_Local_Entropy1+ Local_Entropy1;
      Sum_Local_Entropy2= Sum_Local_Entropy2+ Local_Entropy2;
      c=c+1;

      elseif Decide==2
        cIM=cIM+J;
        Sum_Local_Entropy_G= Sum_Local_Entropy_G+ Local_Entropy_G;
        Sum_Local_Entropy= Sum_Local_Entropy+ Local_Entropy;
        Sum_Local_Entropy1= Sum_Local_Entropy1+ Local_Entropy1;
        Sum_Local_Entropy2= Sum_Local_Entropy2+ Local_Entropy2;
        c=c+1;

        break;
      elseif Decide==3
        continue;
    end

end

%% COMPUTE THE FINAL LOCAL ENTROPY OF Gray IMAGE
Local_Entropy_G =Sum_Local_Entropy_G/c,

%% COMPUTE THE FINAL LOCAL ENTROPY OF COLOR IMAGE
Local_Entropy =Sum_Local_Entropy/c;
Local_Entropy1 =Sum_Local_Entropy1/c;
Local_Entropy2 =Sum_Local_Entropy2/c;
Local_Entropy_KOL = (Local_Entropy2+Local_Entropy1+Local_Entropy)/3
%% Save the point List
save point_list_4_6.mat point_list;
```

2.3. Compute Entropy of Each Color in RGB Image:

Every color image includes 3 main colors: red, green, and blue (RGB). Lines 37 - 41 separately calculate the entropy for each color. Since it is impossible to obtain an entropy of the whole color image, it should be considered as a gray image and each color should be calculated separately, i.e. the blue parts, the red parts and the green parts of the image should be processed individually.

2.4. Region Growing in the Surrounding of the Current Pixel

This section implements the Region Growing algorithm through which the corresponding and similar areas of the image are identified. Region Growing is conducted automatically or manually. Since the automatic method has complex calculations, the manual method is preferred by clicking on different parts of the image. To this aim, by each time clicking on a point in the image, the Region Growing is conducted around that point, i.e. it finds and selects areas similar to that point. This process is repeated until all the intended areas in the image are selected and processed.

In order to identify similar areas in the REGION GROWING algorithm, there is a parameter called reg_maxdist, for which the number 0.2 is defined. When clicking on a point, by checking it, any point where the parameter is greater than 0.2 will be removed, actually measuring the proximity of colors. When implementing the code, the person may change this number. The closer this number is to zero, the higher and more accurate its sensitivity becomes, and the closer it is to 1, the less sensitive it becomes and selects larger numbers with each click.

2.5. How to Calculate Entropy

Each gray image ranges 0 - 255 in terms of color. MATLAB entropy imhist (image histogram) determines the number of color spectrums in the image. In fact, the histogram indicates the frequency of each color. It then defines a P-factor indicating the probability of a particular color in the image and is obtained by dividing the number of colors by the total number of pixels in the image (Valdman, 2016):

p = p ./ num_of_ele;

The entropy formula is as follows (Stamps III, 2004; Zenil, 2020):

E = -sum (p. * Log2 (p))

The P-factor is embedded within this formula and for each color the code is calculated. Eventually, the total codes are calculated and the entropy is obtained.

By computing the mean entropy of the colored sections (RGB), the total entropy is obtained (Wu et al., 2013).

Local_Entropy_KOL = (Local_Entropy2 + Local_Entropy1 + Local_Entropy)

Larger entropy means that the amount of change in that image is greater and the image has more diversity.

3. Summarizing of the Main Analyses

3.1. Friedman Test (Two-Way Analysis of Variance)

When interpreting the results of the Friedman test, we need to use the results of the Table S2 (as Test Statistics) to realize whether the mean difference between the mean votes of the people and the complexity level of the views is significant or not. In this table, based on the Chi-square test (111.433), which is significant at the error level smaller than 0.01, it should be said that statistically the degree of complexity of each facade was significant (significance level: 0.000).

Table S2: Test: Statistics.

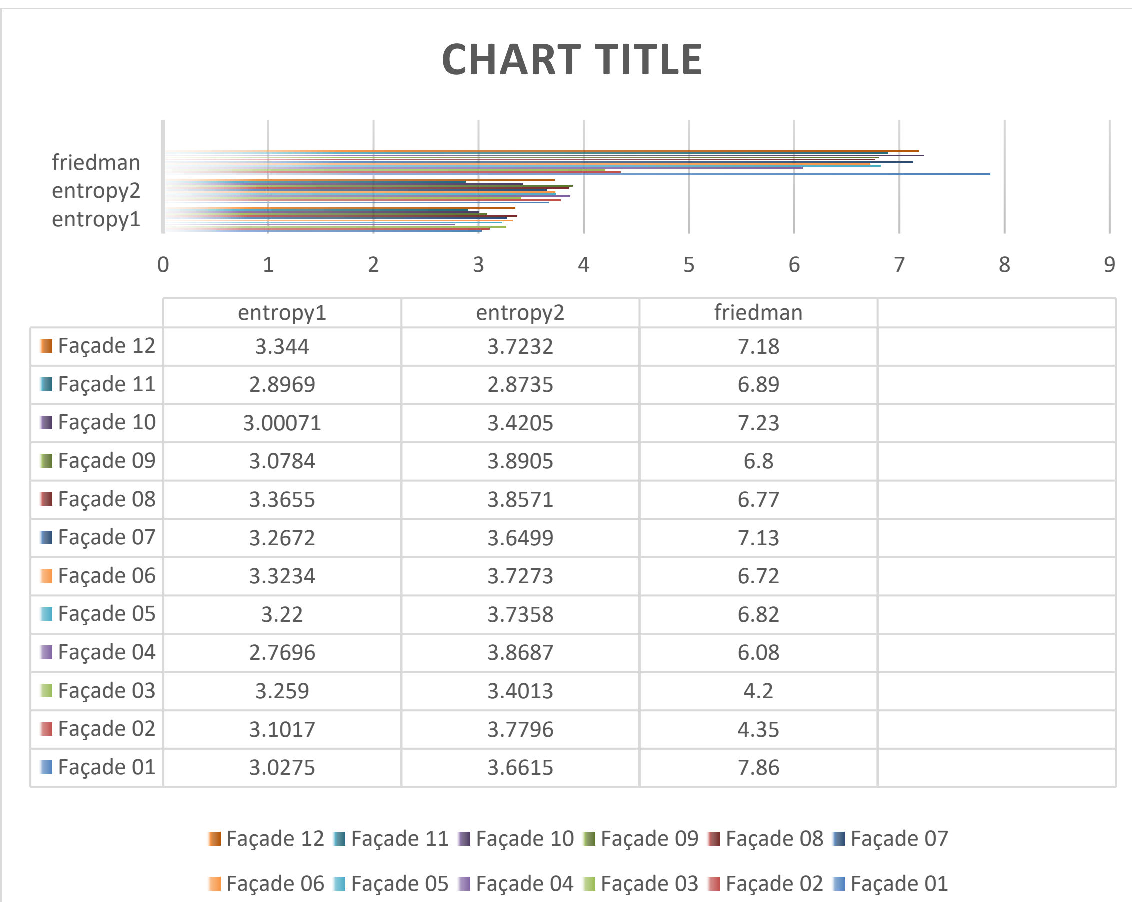
N	100
Chi-Square	111,433
df	11
Asymp. Sig.	0,000
a. **Friedman test**	

3.2. T-Test Analyzes for the Degree of Complexity

Table S3: Summarizing the mean rank and prioritizing the complexity level in the facades based on the results of the single sample t-test.

Image Number	Priority	Significance Level	Degree of Freedom	t-Value	Difference Mean	Expected Mean	Mean Observed Degree
facade 01	1	0.001	99	3.352	1.020	6.5	**7.52**
facade 02	10	0.000	99	-8.325	-2.555	6.5	**3.95**
facade 03	11	0.000	99	-7.448	-2.710	6.5	**3.79**
facade 04	9	0.05	99	-1.951	-0.790	6.5	**5.71**
facade 05	5	0.897	99	-0.130	-0.050	6.5	**6.45**
facade 06	8	0.565	99	-0.575	-0.210	6.5	**6.29**
facade 07	3	0.552	99	0.597	0.230	6.5	**6.73**
facade 08	7	0.779	99	-0.287	0.230	6.5	**6.40**
facade 09	6	0.834	99	-0.211	-0.070	6.5	**6.43**
facade 10	2	0.320	99	0.999	0.320	6.5	**6.82**
facade 11	4	0.063	99	0.950	-0.020	6.5	**6.52**
facade 12	2	0.312	99	1.116	0.320	6.5	**6.82**

3.3. Comparison of Complexity of Images in MATLAB Test



	entropy1	entropy2	friedman	
Façade 12	3.344	3.7232	7.18	
Façade 11	2.8969	2.8735	6.89	
Façade 10	3.00071	3.4205	7.23	
Façade 09	3.0784	3.8905	6.8	
Façade 08	3.3655	3.8571	6.77	
Façade 07	3.2672	3.6499	7.13	
Façade 06	3.3234	3.7273	6.72	
Façade 05	3.22	3.7358	6.82	
Façade 04	2.7696	3.8687	6.08	
Façade 03	3.259	3.4013	4.2	
Façade 02	3.1017	3.7796	4.35	
Façade 01	3.0275	3.6615	7.86	

Diagram S1. Comparison of results obtained from entropy 1 and 2 and results from Friedman test ranking

3.4. Specifying the Most Desirable Image in Terms of Complexity Level

In order to investigate and determine the most desirable image from the perspective of the respondents, the frequency analysis of the responses was used.

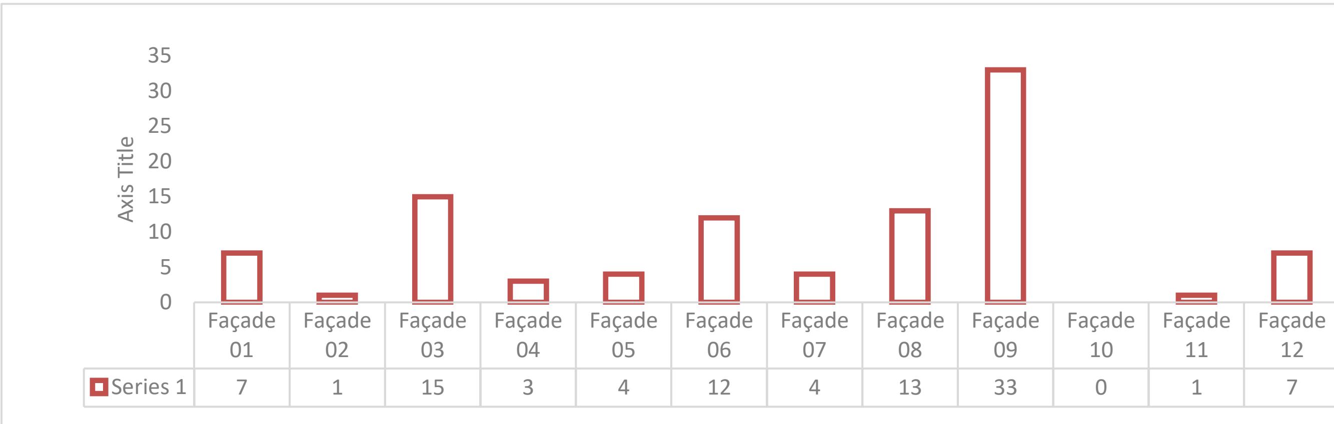


Diagram S2. Comparison of the most desirable images in terms of complexity level

3.4.1. Comparison of the Complexity Rank from People's Point of View and the Most Desirable Image and Entropy

In Table S4, rank 1 was the most complex and rank 12 was the simplest image.

Table S4: Investigating the correlation of ranks in different tests.

Rank	Most Desirable Image	Friedman Test Ranking	T-Test Ranking	Entropy 1	Entropy 2
Rank 1	Image No.09	Image No.01	Image No.01	Image No.08	Image No.09
Rank 2	Image No.03	Image No.10	Image No.10,12	Image No.12	Image No.04
Rank 3	Image No.08	Image No.12	Image No.07	Image No.06	Image No.08
Rank 4	Image No.06	Image No.07	Image No.11	Image No.07	Image No.02
Rank 5	Image No.01,12	Image No.11	Image No.05	Image No.03	Image No.05
Rank 6	Image No.07,05	Image No.05	Image No.09	Image No.05	Image No.06
Rank 7	Image No.04	Image No.09	Image No.08	Image No.02	Image No.12
Rank 8	Image No.02,11	Image No.08	Image No.06	Image No.09	Image No.01
Rank 9	Image No.10	Image No.06	Image No.04	Image No.01	Image No.07
Rank 10	-	Image No.04	Image No.02	Image No.10	Image No.10
Rank 11	-	Image No.02	Image No.03	Image No.11	Image No.03
Rank 12	-	Image No.03	-	Image No.04	Image No.11

3.5. Group Comparison

The grouping of images based on factor analysis, entropy 1 and entropy 2.

Table S5: Grouping images based on factor analysis, entropy 1 and entropy 2.

	Factor Analysis	Entropy 1	Entropy 2
Fourth complexity level	   	   	   
Third complexity level	 	 	 
Second complexity level	  	  	  
First complexity level	  	  	  

3.6. Reviewing the Desirability of Images (City Facade)

The most desirable to the most undesirable image is as See the Online Supplemental Material (Table S6)

Table S6: The relationship between image desirability and ranking in terms of complexity.

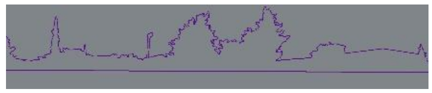
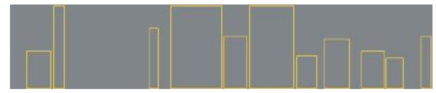
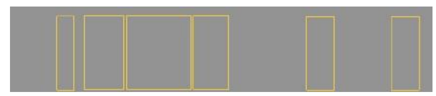
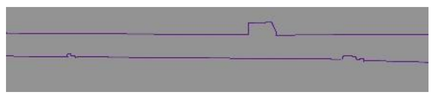
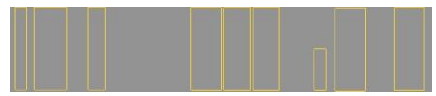
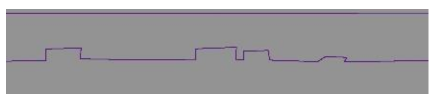
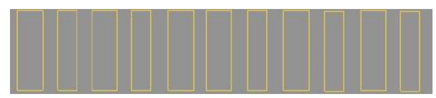
Most Desirable Image	Image Number	Image Ranking in Terms of Complexity
1		rank 7
2		rank 12
3		rank 8
4		rank 9
5	 	rank 3 and 1, respectively
6	 	rank 6 and 4, respectively
7		rank 10
8	 	rank 11 and 5, respectively
9		rank 2

3.7. Investigating the Grouping of Images According to the Survey

By analyzing the images in this section, the common feature to the images of each group and the possible reasons for the placement of these images in a group are investigated.

3.7.1. The Fourth Level of Complexity

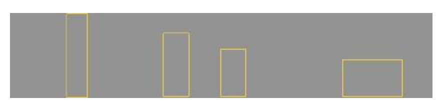
Table S7: The fourth level of complexity.

Original Image	Horizontal Division	Vertical Division
 **No.01**		
 **No.07**		
 **No.10***		
 **No.12**		

* In this image, the horizontal division is more regular and uniform, but the vertical division is more than the above images.

3.7.2. The Third Level of Complexity

Table S8: The third level of complexity.

Original Image	Horizontal Division	Vertical Division
 **No.06**		
 **No.11**		

3.7.3. The Second Level of Complexity

Table S9: The second level of complexity.

Original Image	Horizontal Division	Vertical Division
 No.05*		
 No.08**		
 No.09***		

* Although the lower part has much detail in this image, the upper part is simple and uniform. The skyline is simple and at the same time slightly varied. In general, this image is balanced in terms of complexity.
** In this image, the amount of detail at the top and bottom of the image is balanced and has a uniform composition. The trees create variety in the image so it is generally balanced.
*** The lower part of the image is rather simple, but the upper part is diverse and irregular due to the presence of trees. In general, we witness a picture with balanced complexity.

3.7.4. The First Level of Complexity

Table S10: The first level of complexity.

Original Image	Horizontal Division	Vertical Division
 No.02*		-
 No.03**		-
 No.04***		--

* In the middle part of the image, the second floor of the buildings, a uniform and simple surface can be seen with little details. The lower part also has less details and uniform colors.
** It is rather uniform and the composition of the elements is very simple and regular. There is no index element in the image and the whole image can be divided into 3 horizontal sections.
*** The skyline is a little irregular and varied, but the detail of the image is very small.