Interiority, 2024, Vol. 7, No. 2, 175–198
DOI: 10.7454/in/v7i2.351
ISSN 2615-3386 (online)
ISSN 2614-6584 (print)

Assessing Relations Among Visual Variables in Hotel Lobbies Using Deep Learning

Taraneh Saniei, Mansoureh Kianersi, Shervan Fekri-Ershad

Islamic Azad University
Iran

Abstract

To understand the relationships between cognitive variables like visual complexity, coherence, and colour contrast in interior spaces, direct numerical analysis is crucial. Conventional approaches are limited due to the brain's struggle to process visual information without cognitive manipulation. However, advancements in artificial intelligence enable direct examinations. This study used a convolutional neural network to assess the intensity of colour contrasts in images of 5-star hotel lobby interiors with high levels of coherence and complexity. The results indicated that visually complex lobby interiors have less warm-cool and dark-light contrast but more pronounced complementary contrast than coherent lobby interiors. Additionally, a negative correlation was identified between complementary and warm-cool contrasts across all perspectives. These results underscore the potential influence of specific colour contrast types on the cognitive experience of interiority.

Keywords: coherence, complexity, colour contrast, lobby interior design, deep learning

Correspondence Address: Taraneh Saniei, Faculty of Art and Architecture, Islamic Azad University, Najafabad, Isfahan, Iran. E-mail: taraneh.san74@gmail.com

Introduction

The theory of preference matrix, proposed by Kaplan et al. (1998), is a widely recognised psychological theory that plays a significant role in creating a positive impression through interior design. These theory's visual variables are effectively employed in interior designs where creating a positive impression is a priority. Hotel lobbies are a prime example of such spaces because their visual appearance significantly shapes customer's initial perception (Naqshbandi & Munir, 2011). Consequently, complexity and coherence, two specific variables from the preference matrix theory, form the foundations of hotel lobby interior designs. These variables are cognitive aspects of the interiority that are perceived in the first interaction with the space (Kaplan et al., 1998). By controlling these variables, the overall quality of the spatial experience can be improved, eliciting positive emotions. This study focuses on the analysis of complexity and coherence as two-dimensional variables using two-dimensional data (Zhang et al., 2021).

Complexity stimulates curiosity and the desire to learn. It is also associated with increased arousal (Paxton, 2006; Xylakis et al., 2021). However, the positive impact of complexity on emotion construction and preference is ensured only with the application of suitable levels of coherence (Zhang et al., 2021), as extreme complexity with low coherence is associated with anxiety and reduced cognitive ability (Tang et al., 2017). The perception of complexity and coherence depends on visual cues in the interior space, such as size, shape, texture, colour, and object position (Manav, 2013). Colour, in particular, has been studied extensively for over 100 years, showing the significance of the impact of this visual cue on perception and cognition (Witzel & Gegenfurtner, 2018).

Colour contrast can contribute to complexity when highly noticeable (with high intensity) (Kwallek et al., 2007) and may provide coherence in some regulated levels and compositions (Kaplan & Kaplan, 1989). However, there are no studies regarding the measurement of colour contrast intensity in complex and coherent interiors, possibly due to the complexity of the visual perception process in the human brain when encountering spatial compositions that communicate too many impactful factors. Individuals are unable to accurately report the exact intensity of specific visual features of the detailed interior compositions, such as colour contrasts (Bakhtiari et al., 2020). Therefore, relying solely on descriptions from individuals who view interior spaces may not provide accurate and reliable evaluations regarding visual principles such as colour contrast as an important and influential aspect of the interiority of space (Cho & Suh, 2020; Kraus, 2019). However, emerging artificial intelligence (AI) technology allows for direct and precise analysis of visual features (Demir et al., 2021).

In the domain of artificial intelligence, the utilisation of machine learning (ML), specifically deep learning (DL) employing Convolutional Neural Networks (CNNs), has been widely prevalent in both research and practical implementations. The application of CNNs has been proven efficacious in the numerical examination of visual attributes like colours (Alfa et al., 2023; Alzubaidi et al., 2021; Elavarthi et al., 2023). However, there is a lack of research exploring the intensity of specific colour combinations in interior spatial design views to understand their relations to the significant cognitive factors of interiority, complexity and coherence, especially in hotel lobbies where the creation of positive interiority conveyed through visual variables is crucial for establishing favourable first impressions (Naqshbandi & Munir, 2011), employing CNNs. This study aims to reveal the hidden visual structures communicating the interiority using a simple structured CNN model, focusing on colour contrasts' relationship with preference matrix variables in hotel lobby designs.

An Overview of the Preference Matrix Theory

The preference matrix theory states that the environment people prefer should have the properties to transmit information of coherence and legibility for understanding. It also needs to transmit complexity and mystery to meet the need for exploration (Zhang et al., 2021). Legibility and mystery are inferred from a 3D perspective and refer to the ease of orientation and availability of information for further exploration. On the other hand, complexity and coherence are based on the direct perception of scenes as 2D images, making them immediately perceptible (Zhang et al., 2021).

Complexity, coherence, and association with emotions

Visual complexity, which refers to visual stimuli's diversity or information rate, influences first impressions, emotions, and aesthetic preferences (Jang et al., 2018). Complexity provides content to think about, but simpler scenes are generally preferred over highly complex ones (Rezakolai et al., 2015). Extreme complexity in a space can make the interior confusing and difficult to analyse, leading to negative emotions (Rezakolai et al., 2015). According to a study by Zhang et al. (2021), highly complex spatial scenes are associated with positive emotional responses and preferences only when represented in highly coherent settings.

By applying coherence, the complex setting becomes systematised by integrating identical groups achieved through repetition, unity, and grouping of spatial visual information (Kaplan & Kaplan, 1989). Coherence provides predictability for the environment and impacts people psychologically, leading to positive emotional responses such as calmness by applying simplicity and clarity (Kaplan & Kaplan, 1989; Kaplan et al., 1998).

Complexity without appropriate levels of coherence is defined by extreme variety and contrast (Von Meiss, 2013). However, coherence and complexity do not oppose each other (Kaplan et al., 1998). Some visual principles that contribute to the perception of complexity can also contribute to the perception of coherence. One obvious visual feature that plays an influential role in the application of complexity and coherence is contrast, as it not only provides diversity but also helps identify specific groups (Kaplan & Kaplan, 1989).

Colour and perceptual manipulation

"One way to apply contrast is to use substantially different colours" (White, 2011, p. 4). The intensity of colour contrast must also be considered, as "human colour perception is spatially low pass at very low colour contrast near the threshold" and becomes "edge-sensitive," or spatially-tuned, at higher colour contrast when colour patterns are clearly visible (Shapley et al., 2019, p. 11). Furthermore, different colour attributes used in creating a colour contrast composition elicit diverse spectrums of significance and focus (Wilms & Oberfeld, 2018; Zadra & Clore, 2011).

Colour, a vital attribute in visual perception, influences emotional connections with environments (Gaudiot & Pernão, 2020). As Wilms and Oberfeld (2018) and Zadra and Clore (2011) note, emotional arousal from colours intensifies, progressing from blue and green to red. Saturated and bright colours signify higher arousal, carrying information about object value. Therefore, objects presented in colours associated with high arousal receive significantly more attention than surfaces and objects presented in colours such as green and blue, impacting the perception of the interior composition and the formation of the cognitive-emotional responses to the interiority of space. This capacity of colour has attracted interior designers and researchers who work and research on the environmental design for service industries, known as the 'servicescape,' as it significantly influences customer perceptions and interactions (Minah & Nemcsics, 2015). Hence, designed servicescapes offer valuable interior compositional frameworks for analysing colour as a crucial factor linked to cognitive variables of the interiority of space (Julmi, 2022; Kumar et al., 2023).

Colour in Hotel Lobby Interior as a Servicescape

Among the recognised servicescapes, the hotel lobby holds significance as a critical service space that prioritises visual design. This area serves as the initial environment guests encounter before they commit to their stay, making a positive first impression crucial in shaping their expectations (Countryman & Jang, 2006). Investigating the impactful variables for providing a positive impression, many researchers have demonstrated that visual complexity is one of the most influential variables used in the interior design of service environments. Visual complexity affects observer interest and information processing, which are linked to evaluations of stimuli (Jang et al., 2018). But, before complexity, coherence needs to be considered in servicescapes as individuals first interpret contextual effects to make sense of their environments. The contextual effect refers to the phenomenon whereby individual groups process information together to form a unified picture and make it easier to understand (Lin, 2004). Based on these theories, hotel lobby interior designs represent distinguishable levels for both preference matrix 2D variables, providing a suitable context for examining these cognitive attributes.

In the analysis and evaluation of complexity and coherence in interior designs of hotel lobbies, there are underlying atmospheric elements that are most influential, including style, layout, colours, lighting, and furnishings (Naqshbandi & Munir, 2011). In the study by Naqshbandi and Munir (2011), lighting was found to be a considerable important dimension for the case studies of convention hotels and boutique hotels. However, shaping understanding by colour contrast is often more effective than by illuminance contrast, and "colour has the most significant impact on the perception of the hotel lobby atmosphere" (Geng et al., 2023, p. 5).

Choosing the right colour in hotel design has long gone beyond what looks vibrant or pretty. Colour and surface design will help to attract more clients and send a message to the hotel owners who wish to attract and make loyal customers (Agnes & Dsouza, 2019). "Colour strongly impacts consumers's visual comfort, emotion, value perception, and behaviour" (Geng et al., 2023, p. 5). Positive moods and emotions bias attention toward positively valued stimuli (Zadra & Clore, 2011).

Regarding the preference for colour combination in service environments such as hotel lobbies, Deng et al. (2010) explained a preference for monochromatic colour combination as the visual principle for enhancement of coherence, based on the Gestalt principle of similarity and coherence. In another relevant study by Cho and Lee (2017), it is also stated that a "high-luxury colour combination is dark brown and brown," which are similar in hue, while a "low-luxury combination has orange and green," which are complementary in the colour wheel (p. 13). Nevertheless, neither this particular study nor the additional pertinent research endeavours conducted a direct and accurate numerical analysis of the colour schemes within hotel lobby interiors to suggest dependable results that can facilitate the initiation of more rigorous investigations. Deep learning (DL) networks offer comprehensive techniques for such examinations (Alfa et al., 2023; Alzubaidi et al., 2021; Guo et al., 2016), which will become the main approach of this study.

Convolutional Neural Networks as the Optimal Tools for Revealing Hidden Facets of the Interiority

The Convolutional Neural Network (CNN) is one of the most remarkable DL approaches with multiple robustly trained layers. It has been found highly effective in various research areas and is most commonly used in diverse computer vision applications (Guo et al., 2016). Visual features and principles, including colour features, have been measured by CNN models in multiple research. Training CNN models on datasets featuring specific visual patterns enables them to categorise novel input data based on the level of presence of these patterns, generating prediction numbers as scores that quantify the intensity of such visual patterns (Alfa et al., 2023; Elavarthi et al., 2023).

By utilising CNNs to analyse interior space perception, a more profound comprehension of the concealed facets of spatial interiority can be uncovered. The scrutiny of visual components like colour contrast by CNNs can reveal the intricate correlation between these visual indicators and cognitive parameters. In contrast to conventional approaches dependent on participant feedback, which might be restricted by the intricacy of spatial interiority, CNN scrutiny provides a more objective viewpoint (Bakhtiari et al., 2020; Demir et al., 2021). Cognitive parameters such as complexity and coherence are pivotal in forming emotional responses, fundamentally influencing the comprehensive perception of a view. The sentiments elicited by a spatial view can subsequently influence ensuing cognitive processes, shaping favourable or non-favourable perceptions (Barrett, 2017; Shiau et al., 2021). Additionally, colour carries substantial cognitive-emotive significance as a fundamental constituent in shaping these cognitive parameters (Gaudiot & Pernão, 2020; Shapley et al., 2019; Wilms & Oberfeld, 2018). Hence, the intricate interaction between visual characteristics and affective reactions underscores the intricacy of human perception and cognition. However, CNN models excel in detecting and comprehending precise visual structures, like colour arrangements, devoid of the prejudices of cognitive-emotional impacts (Elavarthi et al., 2023; Guo et al., 2016). This impartial scrutiny aids in elucidating the direct association between colour arrangements and the establishment of spatial interiority, presenting valuable insights into how visual components contribute to the communication of space.

Method

Following the relevant literature, to measure the intensity of colour contrasts accurately in visual compositions of interior design, the human brain needs to be assisted by robust, customised machine learning models to omit the interference of cognitive-emotional impact. Machine learning models can also produce numerical results for abstract variables directly and promptly. Therefore, one of the aims of this study is to introduce a new method to examine the variables of interiority of space by machine learning (artificial intelligence) and all of the stages of the method support this intention.

To begin, over 1,500 photos of the hotel lobbies (or a zone dedicated to a lobby lounge) were collected, 90% of which were sourced from the main websites of famous hotels worldwide. In the selection procedure, the criteria that were not related to visual design in the interior design of the lobbies, such as the age of the building, type of building, location of the building, differences unrelated to the visual design, or minor differences in facilities and services were not considered. Afterwards, 200 photos of various hotel brands were excerpted. Then, two categories, each dedicated to one of the preference variables (50 photos for coherence and 50 photos for complexity), were extracted from the 200 photos by two of the authors as design specialists. For each category, we examined the photos that show the considered variable as clearly as possible regarding the original definitions adopted from Kaplan and Kaplan (1989). For instance, all the photos for complexity have been chosen to illustrate visual diversity as much as possible. Nevertheless, it is important to note that the presence of complexity in the considered photos does not necessarily imply a lack of coherence, and vice versa.

In the next stage, 10 experts, including seven people with doctoral degrees in architecture and three people with master's degrees in architecture who have had successful experiences in the field of the interior design of the hotel lobby, were asked to give a rating to the final 100 photos (50 photos for coherence and 50 photos for complexity) regarding the descriptive sentences for each preference variable (Table 1). The rating used 5-point scales where 1 represents "not at all," 5 represents "very much," and 2, 3, and 4 for degrees in between. After the rating process by experts, the scores were analysed using a Friedman Test, with significant result for complexity (p = .000) and non-significant result for coherence (p = .903). A set of photos containing eight photos with the highest mean ranks for each of the complexity and coherence variables were excerpted. The final 16 images in their exact visual quality are accessible through the direct links in the references in Annex. The mean ranks for all images are presented by *f* in Table 3 and Table 4, and the examples of the selected images for complexity and coherence are illustrated in Figure 2 and Figure 3 respectively.

In the next step, the colour contrasts were measured and analysed for each of the images by the DL model, and a specific score was defined for each type of colour contrast in each photo. After interpreting the result scores, to examine the relations between colour contrasts in each of the two categories, the grouped scores were analysed by a Friedman test to make the comparisons and further interpretations. in Thailand.

Table 1
The descriptive sentences for complexity and coherence (Adapted from Farboud & Shahhoseini, 2020)

Variable	Definition
Complexity	The scene has too many distractions, making it confusing.
	The scene does not contain enough components to interest me.
	The scene contains a good variety of components that keep me involved.
	I feel drawn in by the variety of information or components the scene offers.
Coherence	It is clear when I can go in.
	It is easy to get around every part.
	It does not take much time to figure out the way of moving around.
	I can always figure out where I am.

Data collection

In this study, we use the images of 5-star hotels because they have the highest range of variation regarding the dimensions of interior design (e.g., style, layout, colours, lighting, and furnishings). For studies of this sort, it is necessary to consider all of these dimensions due to an interfering variable of taste and style to minimise the potential bias. Furthermore, various interior design dimensions need to be involved in the lobby composition because this study is not focused on any specific dimension aside from colour combination. To achieve a general conclusion, this study must consider the variables of interest in all possible types of interior compositions. Although various interior compositions are also found in lobbies of hotels with less than five stars, the importance of the quality of design in 5-star hotels has forced the designers to be more creative in this area, designing interior compositions for lobbies that are unique and certainly different from one another (Beka & Cenko, 2019; Huang & Tsaih, 2022). For these reasons, 5-star hotel lobbies make the most suitable context for this study.

In general, 5-star hotels are placed in various categories, and many famous hotels worldwide are subsets of two specific groups in relation to the style of design: distinctive and classic. In addition, there are four groups for hotels considering their service environments and range of standards: Luxury, Premium, Select, and Longer Stays. The images considered in this research are from the hotels dedicated to the Luxury and Premium groups because the hotels of the other groups are usually not included in the category of 5-star hotels or, more precisely, 4.3 stars and above.

The technical criteria for image selection

The selection of suitable images for this study, consisting of the views of the lobbies and service spaces dedicated to lobby lounges, was not limited to specific styles, colour combinations, furnishing, layouts, locations, and size. However, the final images were selected regarding the following two criteria to prevent possible interruptions and misunderstandings. First, there must be no human or animal figures featured in the images, and second, the images should show variation regarding colour combinations and styles.

Analysis of selected photos using a CNN model

To analyse the selected images by the DL network, a customised CNN model was designed in Python 3, Anaconda with Keras, and TensorFlow (tf) frameworks. The model was subsequently trained and tested using precise datasets. Following verification of the network's accuracy and efficiency in quantifying the specified visual parameters, each of the 16 chosen images was analysed by the model.

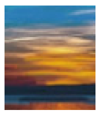
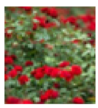
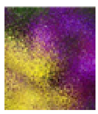
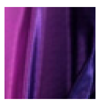
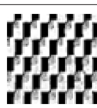
Dataset: Contrast-Unity-Proportion (CUP)

To detect and measure the intensity of colour contrast in this study, it was necessary to specify specific sub-variants to compare the results and achieve reliable outcomes. Therefore, we made the selection from the primitive types of colour contrast based on Itten's (1970) famous book *The Elements of Colour*. In this study, complementary, warm-cold, and dark-light contrasts are chosen to be analysed numerically for the first time.

For this purpose, we introduce Contrast-Unity-Proportion (CUP), a publicly available dataset for the analysis of visual principles and sub-visual principles, including the three types of colour contrasts, i.e., complementary, warm-cool, and dark-light (Saniei, 2024). The dataset for colour contrasts contains 2,846 photos in total. In the analysis of colour contrast, the subject is less important as colour contrasts could be detected and measured in photos of various subjects. Therefore, we did not limit the datasets to a particular area, and the dataset images included various subjects such as nature, decoration, food, and even digital illustrations.

Our dataset includes images representing the types of colour contrasts considered in this study in the most obvious way. To train a CNN model accurately, we split the datasets regarding the diversity of the colour combinations that make complementary, warm-cold, and dark-light contrasts. For the complementary contrast, three categories of colour combinations were defined and used, and for the warm-cool contrast, two categories or classes were included (Table 2).

Table 2
Samples from the CUP dataset

Class number	Colour contrast	Sample	Quantity
1	Complementary contrast (blue-orange)		562
2	Complementary contrast (green-red)		482
3	Complementary contrast (purple-yellow)		483
4	Warm/cold contrast (purple-red)		410
5	Warm/cold contrast (green-yellow)		376
6	Light/dark contrast		533

Note: Images are taken from public domain and augmented digitally by author (Saniei, 2024)

All the images were labelled manually by two architecture specialists, one experienced interior and visual design researcher and another specialising in image processing. In the training process, 80% of the dataset was employed for training and 20% of it was used for testing. All images were cropped to 300 x 300 pixels and categorised into six classes.

The dataset images contain various ranges of saturation and brightness. Therefore, the network trained by this dataset is able to detect colour contrasts that are saturated and brightened differently. The warm-cool datasets contain colour combinations that show subtle differences, concentrating on the movement of colours from coolness to warmness or vice versa (purple to red and green to yellow). Complementary colours are also warm-cool colour combinations by nature of colours, but they make more noticeable contrasts. The dark-light combination is also considered a high-noticeable contrast.

The Architecture of the Designed Network

The CNN model used in this study is an image classification network trained on the required sections from the provided dataset (CUP). It is a simple CNN structure that measures the intensity of the presence of colour contrasts in images, producing prediction scores for each type of contrast (ranging from 0 to 1).

The considered CNN model is chosen to act as the basic model for an introduction in architecture and interior design. The objective of this section is to propose a new approach for analysing visual principles that communicate interiority, not to advance machine learning. Machine learning is just used as a tool for analysis. The CNN architecture chosen has undergone comparison with VGG16 (Qassim et al., 2018), ResNet50 (Mascarenhas & Agarwal, 2021), and MobileNet (Phiphiphatphaisit & Surinta, 2020) structures, all with the same specified input shape and dataset. The outcomes derived from the aforementioned CNN architectures have demonstrated a sufficient level of proximity, indicating that these alternate configurations are viable candidates for mutual substitution.

The layers of the CNN model

A simple structured CNN model which is capable of running for classification and prediction of 2D data containing colour variations is as follows:

```
model=tf.keras.Sequential([
    1. tf.keras.layers.Conv2D(32, (3,3), activation='relu', input_
       shape=(300,300,3)),
    2. tf.keras.layers.MaxPooling2D(2,2),
    3. tf.keras.layers.Conv2D(64,(3,3), activation='relu'),
    4. tf.keras.layers.MaxPooling2D(2,2),
    5. tf.keras.layers.Flatten(), #image to vector
    6. tf.keras.layers.Dense(128, activation=tf.nn.relu),
    7. tf.keras.layers.Dense(6, activation=tf.nn.softmax)
])
```

Adam optimiser was used to compile the model. The number of samples used in each training iteration (batch size) was 32. Batch normalisation has been used for regularisation. The model was trained and tested using the specified dataset, with 80% allocated for training and 20% for testing or validation. The training and validation procedures were conducted over eight epochs (Figure 1).

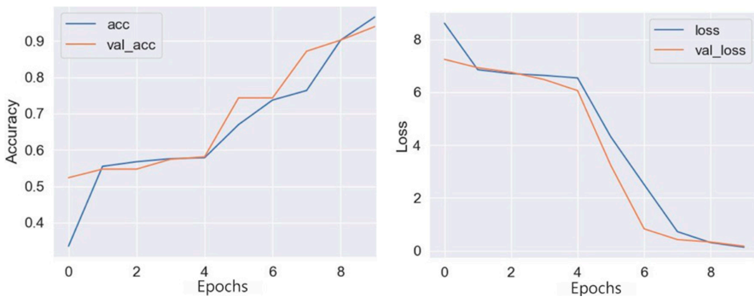


Figure 1
The plots of the model's accuracy and loss over the training epochs (Image by authors)

Figure 2
An example of hotel lobby image with high complexity: Photo no. 7 (Photograph by Marriott International, Inc.)

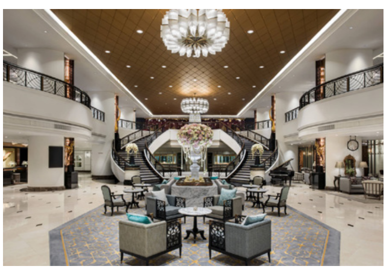


Figure 3
An example of hotel lobby image with high coherence: Photo no. 14 (Photograph by Marriott International, Inc.)

No	Hotels and service spaces	Mean rank (*f*)	Colour contrasts (by class number)					
			Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
1	The Ritz-Carlton, Hong Kong; The Lounge and Bar	40.33	0.571	0.0945	0.290	0.0102	0.0334	0.0373
2	The St. Regis Florence; The Winter Garden Restaurant	39.42	0.472	0.513	0.0128	0.000131	0.000728	0.00000 00619
3	Le Meridien, Dubai; Hotel & Conference Centre	39.00	0.00444	0.162	0.171	0.000174	0.661	0.000179
4	Four Seasons Hotel, Hong Kong; Lobby	37.08	0.217	0.499	0.183	0.00747	0.0915	0.00444
5	The Ritz-Carlton, Moscow; Lobby	36.58	0.0558	0.259	0.344	0.00280	0.336	0.0313
6	Hotel Danieli, Luxury Collection Hotel, Venice; Lobby	36.33	0.809	0.138	0.0498	0.000554	0.000826	0.000000 000477
7	W Hotels-W Amman; Lobby Seating Area	36.00	0.976	0.0216	0.00183	0.0000573	0.000130	0.000000 0707
8	Four Seasons Hotel Kuwait; Lobby	35.75	0.657	0.0272	0.241	0.0171	0.0560	0.326

Table 3
The complexity and the colour contrast's intensity of the selected lobby interior spaces

No	Hotels and service spaces	Mean rank (*f*)	Colour contrasts (by class number)					
			Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
9	Marriott Hotel Al Jaddaf, Dubai; Lobby	35.50	0.210	0.788	0.000724	0.000243	0.000128	0.00000 205
10	Le Meridien, Hyderabad; Latitude-The Hub	35.10	0.0650	0.138	0.448	0.0292	0.318	0.0271
11	The Ritz-Carlton, Xi'an; Lobby Lounge	35.10	0.0459	0.107	0.581	0.0182	0.246	0.0565
12	Park Hyatt Milan; La Cupola-Entrance	34.90	0.0123	0.173	0.192	0.00249	0.618	0.00136
13	Izmir Marriott Hotel; Lobby	32.70	0.00289	0.142	0.138	0.000530	0.715	0.00173
14	The Athenee Hotel, Luxury Collection Hotel, Bangkok; Main Lobby	31.70	0.0175	0.138	0.273	0.00256	0.567	0.187
15	Sheraton La Caleta Resort & Spa, Costa Adeje, Tenerife; Servicescape	31.30	0.0212	0.200	0.234	0.00451	0.539	0.000184
16	The Ritz-Carlton, Chicago; Lobby	30.60	0.657	0.0272	0.241	0.0171	0.0560	0.326

Table 4
The coherence and the colour contrast's intensity of the selected lobby interior spaces

Before the final stage of data analysis, sums were provided for complementary and warm-cool contrast to define a single score for each colour contrast group. Classes such as blue-orange, green-red, and purple-yellow were created for the desired accuracy in the CNN model's operation, and the three classes collectively explain the complementary contrast. Therefore, each scene acquired a total score of complementary contrasts. Sums were also given for the colour contrast groups of warm-cool and dark-light contrast. The results in Table 5 and Table 6 showed that as complementary contrast increases, warm-cool contrast decreased in all views.

Table 5
Final scores for colour contrast in complex hotel lobby interiors

No	Complexity	Complementary contrast	Warm-cool contrast	Dark-light contrast
1	40.33	0.9555	0.0436	0.0373
2	39.42	0.9978	0.000859	0.0000000619
3	39.00	0.33744	0.661174	0.000179
4	37.08	0.899	0.09897	0.00444
5	36.58	0.6588	0.3388	0.0313
6	36.33	0.9968	0.00138	0.000000000477
7	36.00	0.99943	0.0001873	0.0000000707
8	35.75	0.4206	0.577467	0.0186

Table 6
Final scores for colour contrast in coherent hotel lobby interiors

No	Coherence	Complementary contrast	Warm-cool contrast	Dark-light contrast
9	35.50	0.998724	0.000371	0.00000205
10	35.10	0.651	0.3472	0.0271
11	35.10	0.7339	0.2642	0.0565
12	34.90	0.3773	0.62049	0.00136
13	32.70	0.28289	0.71553	0.00173
14	31.70	0.4285	0.56956	0.187
15	31.30	0.4552	0.54351	0.000184
16	30.60	0.9252	0.0731	0.326

To analyse the relationships between the different variables regarding the prediction scores, a Friedman Test was performed to compare the groups of scores. The Friedman test for complexity scores in Table 7 and coherence scores in Table 8 both indicate a statistically significant difference between the related groups in the dataset. The results in Table 7 and Table 8 showed that the intensity of complementary contrast was higher than the other contrasts, the warm-cool intensity was the next highest, and the dark-light had the least intensity in both coherent and complex hotel lobbies. Besides, the complex lobbies contained a higher level of intensity merely for the complementary contrast. Conversely, the coherent scenes showed higher intensity for both warm-cool and dark-light contrasts. The intensities associated with each colour contrast in both coherent and complex lobbies exhibited notable proximity.

Discussion: Colour Contrast as a Hidden Aspect of Interiority

According to the basic definitions, complexity is defined by variety and contrast, especially more noticeable contrasts, according to Kwallek et al. (2007). However, the outcomes of this study showed that the dark-light contrast (high-noticeable contrast) was the least effective in complex hotel lobbies showing almost the score 0. This outcome demonstrates that there is a very low level of reliance on dark-light contrast when designers tend to enhance complexity. Furthermore, complex scenes contained both complementary and warm-cool contrast, but when the complementary contrast (high-noticeable contrast) was high, the warm-cool contrast (low-noticeable contrast) was low and vice-versa, demonstrating that; although colour variety can be applied by employing low different and high different colours simultaneously, the highest levels of complexity in the interior design of 5-star hotel lobbies were not implemented by just variety of colours. Most of the complex lobbies had high-intensity complementary colour combinations and low warm-cool contrast.

Table 7
The output of the test for complexity

Contrast types	Mean rank	Friedman Test result		
		Chi-square	*df*	Asymp. Sig.
Complementary	2.75	13.000	2	.002
Warm-cool	2.25			
Dark-light	1.00			

Table 8
The output of the test for coherence

Contrast types	Mean rank	Friedman Test result		
		Chi-square	*df*	Asymp. Sig.
Complementary	2.50	9.250	2	.010
Warm-cool	2.38			
Dark-light	1.13			

According to the studies concerning informational variables, coherence is enhanced by colour repetition and contrast helps with the grouping (regarding the Gestalt principles). However, there was no indication of the hue of the colours or the type of colour contrast. In this study, we achieved different scores related to colour contrasts for coherent lobby interior scenes. Although the scores for colour contrast were believed to be lower for coherent interiors as the colour repetition was considered more important in such visual compositions, the results showed that warm-cool and dark-light contrast intensity were higher compared with complex lobbies. The intensity of complementary contrast was also recognisable but lower than the score for complexity.

Based on the studies by Wilms and Oberfeld (2018) and Zadra and Clore (2011), various colours activate different emotions and some specific colours (such as red, pink, and orange) bring enhanced attention, making elements of the composition appear more recognisable that might manipulate the perception process toward more complexity or coherency. In this study, we measured different colour combinations (blue-orange, green-red, and purple-yellow as complementary colours, purple-red and green-yellow as warm-cool combinations and, black-white as the dark-light contrast) but, we found no correlation between specific colours and perceived coherent or complex 5-star hotel lobbies.

However, the view with the highest score for coherence (f = 35.50) had the highest intensity of green-red contrast. The two views with the same score in the coherence category (f = 35.10) had the same proportions of colour contrast. The most complex lobby (f = 40.33) showed a high intensity of blue-orange contrast. The view with high complexity (f = 39.42) featured high and close intensities for blue-orange and green-red contrasts. There were also two complex views (f = 36.33 and f = 36.00) with very close ranges of complexity showing great scores for blue-orange contrast, while the scores for other kinds of contrasts were surprisingly low (almost 0). These outcomes indicate that there might be correlations between specific colours and coherence or complexity in interior design and more investigations with a focus on this area are needed.

A study by Cho and Lee (2017) mentioned that in servicescapes, monochromatic colour combinations or compositions with similar hues are preferable due to the desire for cohesion and are mostly used in high-luxury environments, while spatial compositions represented in colour contrasts in interior designs are considered less luxurious. In this study, we examined the most coherent 5-star hotel lobbies and found various ranges of colour contrasts. Therefore, it cannot be concluded that colour contrasts make low-coherent and low-luxury service environments.

This study's results indicate the importance of utilising numerical analysis to explore visual features like colour combinations, revealing underlying truths about the ultimate interiority of space. It is evident that these findings diverge from previous conclusions in several aspects as they are significantly more realistic and accurate to be relayed for further accurate investigations. These results shed light on hidden aspects of the interiority of hotel lobbies as the cognitive-emotional quality conveyed through experience of the interior view created by visual elements of design and perceived by the influence of each specific combination of them through cognitive variables. The results suggest that each specific colour contrast composition considered in this study in specified intensities can potentially manipulate the cognitive and emotional communications of interior design through the perception of complexity and coherence. The complexity and coherence are cognitive variables of interiority providing specific emotional responses.

Conclusion

This study aimed to explore the relationship between cognitive variables of interiority proposed by the preference matrix and colour contrasts in 5-star hotel lobbies. We utilised data from expert ratings and a visual dataset for CNN training to analyse the intensity of colour contrasts in both coherent and complex scenes. Our study revealed the following findings. First, complementary contrast and warm-cool contrast showed a negative correlation in both lobbies groups. Second, complementary contrast exhibited the highest intensity among the colour contrasts, followed by warm-cool contrast and dark-light contrast, which had the least intensity in both coherent and complex hotel lobbies. Third, in complex scenes, the intensity of warm-cool and dark-light contrasts was lower compared to coherent lobbies. However, complementary contrast was more visible in this type of composition.

This paper contributes to visual design, interior design, and scenography regarding the effects of colour contrasts on perceived coherence and complexity as the cognitive variables of interiority. As coherence and complexity bring positive cognitive-emotional impressions together, being aware of the effects of different colour contrasts would be advantageous, especially in projects with restrictions regarding lighting, colour repetition, style, furnishing, and layout. For instance, interior designers can add complementary colours to a coherent scene and make it perceived as more complex. This implementation can apply complexity more easily than adding warm-cool or dark-light contrasts. Regarding coherence, designers can employ warm-cool colour combinations (the subtle movement from warm to cool colour) in complex compositions (which are to be made by variety in form, texture, patterns, etc.) and create an interior design that is coherent and complex at the same time.

The purpose of this study is not to assess the effect of specific hues. However, we found some photos of lobbies showing similarities in terms of coherence-complexity score and colour contrast intensities dedicated to specific hues, indicating that more investigations with a focus on hues and perception of informational variables in interior design are needed.

Through the method section, we introduced the Contrast, Unity, and Proportion (CUP) dataset that can be used to train CNN models for any visual annotations such as photography, painting, urban, facade, and interior design. Moreover, we have put forth a simplistic CNN architecture adaptable to diverse 2D datasets, serving as a foundational model for the precise examination of visual data to uncover latent dimensions of interiority across various scenarios. The findings of this research underscore the significance of employing DL networks for precise scrutiny of visual attributes that influence the intricate facets of interiority, as evidenced by markedly more authentic and precise data compared to earlier relevant studies which employed traditional methods of examination, which can be leveraged and further expanded upon by future investigations.

Acknowledgements

This paper has been extracted from a master's thesis in the field of interior design at The Department of Architecture and Urban Planning Research Centre, Najafabad, Islamic Azad University. The training dataset was provided by Taraneh Saniei. Codes for the designed CNN have been initially written by Ghazal Shamsipour, a researcher at the Faculty of Computer Engineering and Information Technology, Najafabad, Islamic Azad University, and edited by Taraneh Saniei. The authors would like to appreciate the permission granted by W Hotels–W Amman and The Athenee Hotel, a Luxury Collection Hotel in Bangkok, for the use of their lobby space photos, specifically, photos presented in Figure 2 and Figure 3 in this paper.

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Annex: Sources of Photographs of Service Spaces

Photograph no.	Source of photographs
1	Marriott International. (n.d.). *The lounge and bar* [Photograph]. The Ritz-Carlton, Hong Kong. https://cache.marriott.com/is/image/marriotts7prod/hkgkw-lounge-bar-50069532:Square?wid=570&fit=constrain
2	Marriott International. (n.d.). *The winter garden restaurant* [Photograph]. The St. Regis Florence. https://cache.marriott.com/content/dam/marriott-renditions/FLRXR/flrxr-restaurant-0303-hor-wide.jpg?output-quality=70&interpolation=progressive-bilinear&downsize=1336px:*
3	Marriott International. (n.d.). *Lobby* [Photograph]. Le Meridian Dubai Hotel & Conference Centre. https://cache.marriott.com/content/dam/marriott-renditions/DXBMD/dxbmd-meridien-hub-9558-hor-wide.jpg?output-quality=70&interpolation=progressive-bilinear&downsize=1336px:*
4	Four Seasons Hotels & Resorts. (n.d.). *Lobby* [Photograph]. Four Seasons Hotel Hong Kong. https://www.fourseasons.com/alt/img-opt/~70.1530.0,0000-241,5765-2998,1569-1686,4633/publish/content/dam/fourseasons/images/web/HKG/HKG_2445_original.jpg
5	The Travel Magazine. (n.d.). *Lobby* [Photograph]. The Ritz-Carlton, Moscow. https://www.thetravelmagazine.net/wp-content/uploads/Lobby-2.jpg
6	Hotel Danieli. (n.d.). *Lobby* [Photograph]. Hotel Danieli, Venice. https://www.hoteldanieli.com/alt/img-opt/~70.1530.467,0000-0,0000-933,0000-933,0000/publish/content/dam/danieli/images/web/3_Lobby_1400x933.jpg
7	Marriott International. (n.d.). *Lobby seating area* [Photograph]. W Hotels-W Amman. https://cache.marriott.com/content/dam/marriott-renditions/AMMWI/ammwi-living-room-9632-hor-wide.jpg?output-quality=70&interpolation=progressive-bilinear&downsize=1336px:*
8	Four Seasons Hotel & Resorts. (n.d.). *Lobby* [Photograph]. Four Seasons Hotel Kuwait. https://www.fourseasons.com/alt/img-opt/~80.930.87,5556-0,0000-2824,8889-1589,0000/publish/content/dam/fourseasons/images/web/KUW/KUW_274_original.jpg
9	Travel Triangle. (n.d.). *Lobby* [Photograph]. Marriott Hotel Al Jaddaf, Dubai. https://img.traveltriangle.com/cms/attachments/pictures/948915/original/3.jpg
10	Marriott International. (n.d.). *Latitude-the hub* [Photograph]. Le Meridien, Hyderabad. https://cache.marriott.com/content/dam/marriott-renditions/HYDMD/hydmd-latitude-hub-6677-hor-wide.jpg?output-quality=70&interpolation=progressive-bilinear&downsize=1336px:*
11	Marriott International. (n.d.). *The lobby lounge* [Photograph]. The Ritz-Carlton, Xi'an. https://cache.marriott.com/is/image/marriotts7prod/50619232-xiyrz-lobby-lounge_overall:Classic-Hor?wid=1300&fit=constrain
12	Perrier-Jouët. (2019). *La Cupola-Entrance* [Photograph]. Park Hyatt Milan. https://www.perrier-jouet.com/sites/default/files/2019-10/park-hyatt-milan-lacupola-entrance.jpg
13	Ostrovok. (n.d.). *Lobby* [Photograph]. Izmir Marriott Hotel. https://ostrovok.ru/hotel/turkey/izmir/mid9846731/izmir_marriott_hotel/?popup=photos_hotel&photoNum=1
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16	Fodor's Travel Guides. (n.d.). *Lobby* [Photograph]. The Ritz-Carlton, Chicago. https://cimg2.ibsrv.net/cimg/www.fodors.com/2000x2000_60-1/778/5a78a4e2f2de0-314778.jpg