

Research Article

# Emotional evaluation of architectural interior forms based on personality differences using virtual reality

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## KEYWORDS

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PAD;  
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Virtual reality

**Abstract** Recent studies have shown that architectural interior forms could impact the affective state of inhabitants. However, the direct relation of specific forms with specific affective states is difficult to determine. In addition, no systematic categorization of architectural forms and their relation to emotional states exists. The investigation of the impact of architectural features on inhabitants' emotions is further complicated by the use of two-dimensional images of forms in laboratory investigations, which cannot perceive real-world architecture. Furthermore, the interior form consists of a combination of different forms rather than only pure forms, which was considered in previous studies. This study aimed to fill these gaps by evaluating interior forms on the basis of clustering different images of built living rooms throughout history as well as their impact on emotions. This study used pleasure, arousal, and dominance ratings with an emphasis on individual differences in personality. Virtual sample rooms were created based on formal clusters of architectural forms. Results showed a relationship between forms and emotional states for different personality traits. This work provided a novel approach on the influence of architecture on emotion by considering systematic form categorization and combinations, personality differences, and a virtual reality setup.

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## 1. Introduction

Knowing the effects of space on users has been an important issue for architects in designing adequate places. Emotional effects are one of the main effects on inhabitants. Moreover, people are emotionally engaged by their surroundings (Gifford, 2007; Manzo, 2003; Reddy et al., 2012), especially interior spaces. Form, lighting, and color are the three main aspects in architectural design, particularly in interior design. Although studies have evaluated the emotional effects of lighting (Shin et al., 2015; Xue et al., 2014) and color (Valdez and Mehrabian, 1994; Wilms and Oberfeld, 2017), no comprehensive research exists on architectural forms and their impact on human emotions.

Several psychological studies have provided evidence on the effects of different forms on emotions. Early investigations have described forms with different adjectives, such as lazy curves and harsh angles (Lundholm, 1921; Poffenberger and Barrows, 1924) or graceful curves and robust angles (Hevner, 1935). Bar and Neta (2006) showed that sharp angles or curved contours can influence people's attitude (Bar and Neta, 2006). Numerous studies have shown a covariation of pleasant feelings associated with curved forms (Bertamini et al., 2016; Cotter et al., 2017; Dazkir and Read, 2011; Madani Nejad, 2007; Silvia and Barona, 2009; Vartanian et al., 2019). Curves, especially the large ones, produce warm- or light-aroused feelings, whereas sharp angles create a perception of roughness (Poffenberger and Barrows, 1924). Recent studies have investigated additional variables beyond simple curves and angles such as differences in distance (Bertamini et al., 2016), straight lines (Bertamini et al., 2016), symmetry and balance (Silvia and Barona, 2009), and upward, downward, and horizontal directions (Poffenberger and Barrows, 1924). Vast studies in this area exist, which have analyzed forms from different views. However, no systematic, comprehensive study exists in the literature.

The investigation of the emotional effects of forms in the field of architecture is likewise not comprehensive. One study showed the relation between the geometric properties of rectangular rooms such as openness, two-room proportion, room area, and balustrade height and emotional experiences by using a semantic differential scaling technique. The study demonstrated the preference for the golden ratio for spatial proportions and several correlations between scene features as well as affective rating categories (Franz et al., 2005). An architectural study on interior furniture form showed the pleasant-unaroused emotions of curved forms (Dazkir and Read, 2011). Additionally, a study on airport design demonstrated that passengers prefer areas with curved rather than rectilinear designs (Van Oel and van den Berkhof, 2013). Although certain studies have investigated the relation of architectural forms and emotional states, no approach has systematically described the different architectural forms and how they relate to emotional states.

Studies on the emotional effects of different forms from architectural and psychological perspectives have shown that four main gaps exist in these fields.

The first gap involves form features. Nearly all previous studies have used curvature and rectangular geometries as form features (Dazkir and Read, 2011). The majority has shown similar emotional effects of curvatures as pleasant (Bertamini et al., 2016; Dazkir and Read, 2011; Madani Nejad, 2007; Silvia and Barona, 2009) and rectangles as harsh (Lundholm, 1921; Poffenberger and Barrows, 1924). Given that geometry is not limited to curves and linearities, other aspects of forms, such as type, angle, scale, and location (Banaei et al., 2017), may also affect emotions, especially in the study of three-dimensional (3D) forms.

The second gap relates to the complexity of architecture. Although certain studies have shown the emotional effects of principle forms, they neglected to consider that architecture, especially interior spaces, does not consist entirely of pure forms. Interior spaces emerge from a combination of different forms in a formal context. Hence, analyzing pure forms cannot help in evaluating complex perceptual and emotional experiences arising from realistic architectural environments. Although several architectural studies have shown the effects of combined forms from 3D places (Franz et al., 2005; Madani Nejad, 2007; Van Oel and van den Berkhof, 2013), they did not emotionally evaluate form features.

The third gap concerns the stimulus type. The majority of previous studies have used two-dimensional (2D) stimuli (Cotter et al., 2017; Silvia and Barona, 2009) or 2D images of 3D stimuli (Dazkir and Read, 2011; Madani Nejad, 2007; Van Oel and van den Berkhof, 2013) to demonstrate forms, whereas the actual forms, especially interior types, are presented in 3D. Given that actual architecture exists in the 3D environment, perceiving forms in 3D is essential. Moreover, a significant difference exists between 2D and 3D displays in perceiving and preferring spaces (Popelka and Brychtova, 2013; Slobounov et al., 2015) and movies (Rooney and Hennessy, 2013).

Aside from the impact of different architectural forms on emotional experience of the environment, personality factors may play a significant role in evaluating and emotionally experiencing architectural design (Gifford, 2007, p. 101). Thus, personality is the fourth gap in this field of study. People show different reactions toward and have different perceptions on the built environment (Küller et al., 2009). Although personality traits can be an important issue in environmental psychology, the majority of previous studies have used factors such as age, the role of participants in the environment, and duration of the relationship with it as the main person–environment features (Giuliani and Scopelliti, 2009). Notably, personality has a preexisting effect on three emotional responses of the model by Mehrabian and Russell (1974), namely, pleasure, arousal, and dominance (PAD). These responses play a mediating role between the built environment and behavior (Gifford, 2007, p. 75; Mehrabian and Russell, 1974).

This study aimed to fill the first and second gaps by using a thorough category of 3D forms from actual built places. Recently, Banaei et al. (2017) released a complete category of 3D forms for interior living rooms on the basis of extracted images. This approach covers different aspects of architectural forms, such as type, geometry, angle, scale, and location (Banaei et al., 2017) and provides relevant

form features. This category was adopted in the present study for the systematic analysis of architectural forms.

We used a head-mounted virtual reality (HMD-VR) gear to fill the third gap and to conduct a realistic investigation of architectural perception as well as the affective changes associated with 3D architectural spaces. The use of VR in psychology has the advantages of improving the effectiveness of experimental control conditions, enhancing experimental realism, controlling the variables of the experiment, facilitating the experimental setup creation, providing new data sources, and performing impossible manipulations (Loomis et al., 1999). Additionally, different personality traits were used in this study to fill the fourth gap. The commonly used personality model, that is, the NEO five-factor inventory (NEO-FFI), with its five personality traits, namely, extraversion, agreeableness, conscientiousness, neuroticism, and openness to experience (Costa and McCrae, 1992), was used in this study.

This study aimed to investigate the impact of architectural interior forms on the affective states of inhabitants by considering personality differences as a mediating factor. We attempted to determine the relation between different form features (i.e., type, geometry, scale, location, and angle) and PAD rates in different personality traits by using a VR setup. The use of a systematic form categorization, personality differences, and a VR setup provided a novel approach to investigate the influence of architecture on emotion.

## 2. Materials and methods

### 2.1. Participants

A total of 40 nonarchitect subjects, with a mean age of 27.6 years ( $\sigma = 4.7$ ), volunteered to participate in this study by using the HMD-VR (Gear VR; Samsung Electronics Co., Ltd.) gear. One participant was removed from the study because of technical issues, and the data from 21 female and 18 male participants were included in the final study design. All the participants provided written informed consent before the experiment, and the study was approved by the local ethics committee.

### 2.2. Experimental design

Data from a previous study were used for the precise analysis of architectural forms (Banaei et al., 2017). In the present study, Banaei et al. clustered the form data of 343 images of interior living rooms from different historic eras with different architectural styles. For this high-dimension data, the Graphical Clustering Toolkit software (Rasmussen and Karypis, 2004) was used for clustering, which involved the use of correlation coefficients and internal similarity among the clusters. The study showed that these forms could be grouped into 25 formal clusters (Banaei et al., 2017). The top five descriptive form features of the 25 formal clusters were used in this study to create virtual rooms. Autodesk's 3DS Max student version (San Francisco, CA) was used to create three rooms for each cluster. A total of 75 virtual rooms was represented in this study. All the virtual rooms were similar in size ( $W \times L \times H$ :

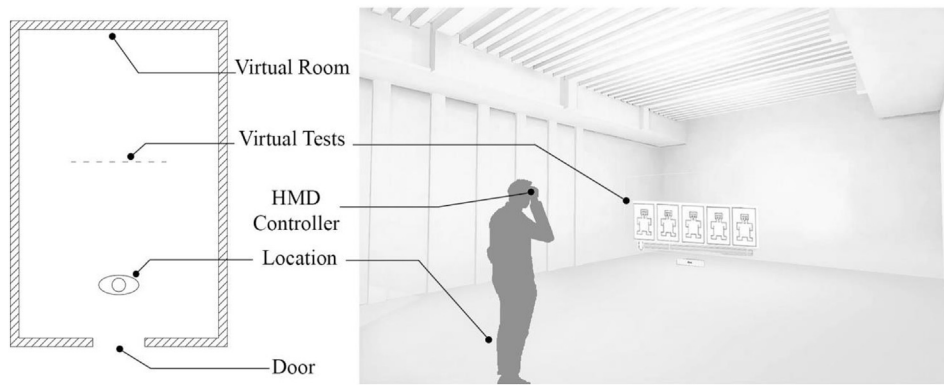
5.0 m  $\times$  7.5 m  $\times$  3.0 m), color (white), and lighting, with differences in their form features. White was chosen to make the rooms look like typical, common spaces. A similar paper-based study on forms likewise used white to show the samples (Madani Nejad, 2007). Neutral colors, such as white or gray, are generally used in environmental psychology to remove color effects in experiments. The Unity game engine software (Unity Technologies, San Francisco, CA) was utilized to create the virtual environment of the study.

The participants were asked to rate each room with respect to PAD by using a virtual self-assessment manikin (SAM; Bradley and Lang, 1994) test, which was validated for Persian speakers (Nabizadeh Chianeh et al., 2012). For convenience, a Persian translation of each scale endpoint word was displayed on the image according to the Mehrabian and Russell (1974) semantic differentials. The addition of verbal descriptions of emotional scales could easily help the participants rate the SAM, as shown in a similar study that used German words with the SAM test (Wilms and Oberfeld, 2017). Furthermore, the Persian-translated version of the NEO-FFI was used to measure the personality traits of the participants. The NEO-FFI was translated into different languages, and the validity and reliability of the Persian version was demonstrated in previous studies (Anisi et al., 2011; Farnam et al., 2008; Garousi et al., 2001). The test consisted of 60 items (12 items per trait), and each item was rated on a scale of 1–5.

### 2.3. Procedure

The experiment contained a training session and an experimental session. The participants wore the HMD (Gear VR) gear and chose the VR training session from the menu after answering the personality test and reading the instructions on answering the tests and using the controllers. The training session contained five sample rooms with the same procedure as that of the main experiment. A "The End" sign and a "Menu" button appeared at the end of the training session. Selecting the menu button caused the virtual menu page to appear, which allowed the participants to choose the experimental session. Those who were not ready for the test could choose the training session again.

The experiment started with a sample cubic room that was displayed for 5 s once the participant decided to proceed to the experimental session. This was the basic room that provided a neutral stimulus for a defined time period to transition between test rooms. The rooms were shown to the participants for 10 s after each baseline room in between. The participants could not walk through the virtual rooms but were free to look around. The experiment was conducted in a standing position, but a chair was available at all times for sitting and resting for those who became tired of standing. The participants stood in front of the entrance door, with a full view of the room (Fig. 1). The virtual SAM test was displayed after each room was presented, and the participants were given enough time to answer the tests. Each emotional PAD scale was shown separately with a nine-point Likert scale (1–9). The participants could adjust their preferred rating by using a slider under each image. The participants moved on to the



**Fig. 1** Sample virtual room. The participants performed the task in a standing position; they could not change their location but could easily rotate to look around the room. **Right:** 3D view of the room showing the SAM test (virtual test) with the slider and the “OK” button under it and the participant’s location. The participants used the HMD (Gear VR) controller located on the device. **Left:** Plan view drawing of the virtual room showing the location of the entrance door, the participant, and the virtual tests. The virtual room was created by [Banaei et al. \(2017\)](#).

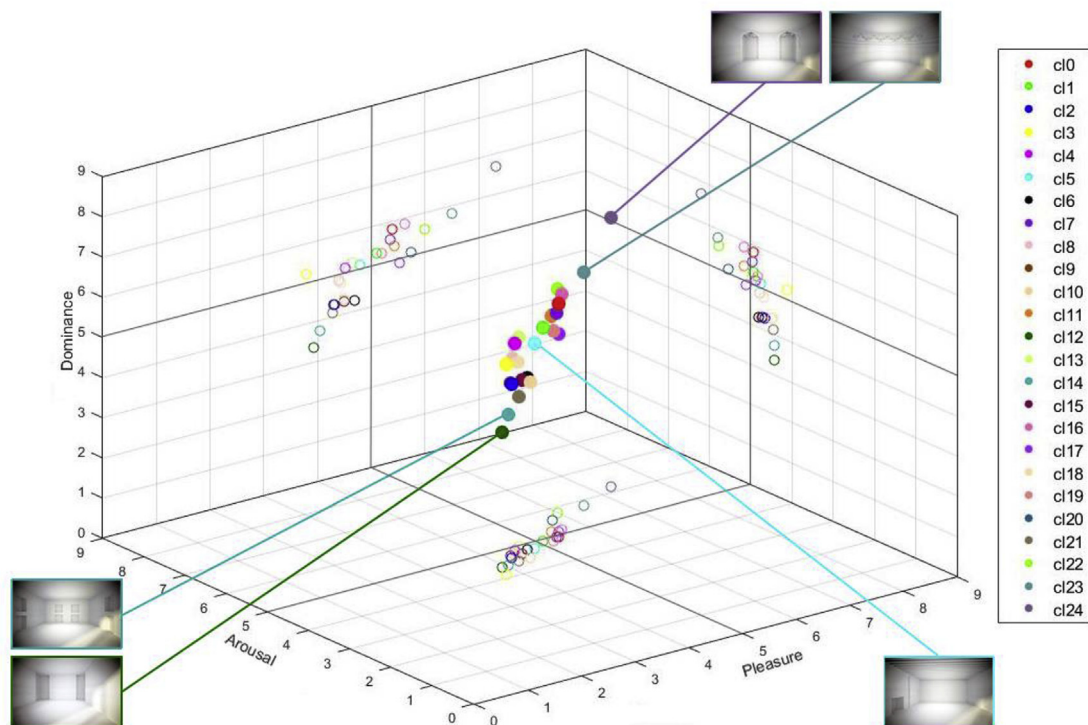
next step after each rating by pressing the “OK” button under the slider.

The experiment contained three randomized blocks of 25 trials each. The participants were free to ask for a break whenever they felt tired. A “The End” sign appeared at the end of the experiment. The participants answered questions regarding their VR experience, health conditions, and the shape of their own living room after the experiment. On average, the experiment lasted approximately 45 min for the VR presentation. No participant reported any motion sickness, and the main health issue was eye fatigue from wearing the HMD gear. VR immersion was measured with a

five-point Likert scale (1–5). The participants reported more than the average VR immersion, with a mean of 2.61 ( $\sigma = 0.78$ ).

### 3. Results

Predictive Analytics SoftWare (PASW) Statistics 18 (SPSS Inc. Released 2009; PASW Statistics for Windows, Version 18.0; Chicago; SPSS Inc.) was used for statistical analysis. The average rate of each cluster in the PAD scale was calculated ([Fig. 2](#)). The clusters were obtained from the study by



**Fig. 2** Mean rating of the PAD scale of each formal cluster. The scale of 1–9 represents the rates from low to high. The rooms were created on the basis of the study by [Banaei et al. \(2017\)](#).

Banaei et al. (2017). Cluster numbers 23 and 24 demonstrated the highest PAD rates, and cluster numbers 12 and 14 obtained the lowest rates. The form analysis indicated that the highest descriptive feature of cluster number 24 was sharp-edged features, which were located on the top and center, with less than a half scale compared with those of the room and neutral object elongation with a complex Z-axis angle and toward the room's X- and Y-axis angles (51.04%). Cluster number 12 mostly consisted of sharp-edged features, with a central location in full scale compared with those of the room and vertical object elongation. The features of this cluster had a straight Z-axis angle and toward the room's X- and Y-axis angles (58.33%). Cluster number 5 was located in the middle of the chart and mostly contained linear solid features located on the ceiling in full scale compared with the room and vertical object elongation with a zero Z-axis angle and toward the X- and Y-axis angles (46.55%).

Three mixed-measure ANOVAs with a 3 (rooms representing a cluster)  $\times$  25 (formal clusters) design were calculated for each of the dependent variables (i.e., PAD). The personality traits were the between-subject factors. To accomplish this, the personality scores for each of the five dimensions, namely, neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness, were divided into two groups of high and low by using a median split. The descriptive statistics for each personality trait is listed in Table 1. The corrected values of Greenhouse–Geisser were used for the results with violations of sphericity.

The results showed the significant main effect of the formal clusters on the pleasure ( $F_{(5.989, 89.840)} = 11.984$ ,  $p < 0.00001$ ,  $\eta^2 = 0.444$ ), arousal ( $F_{(5.210, 78.144)} = 4.182$ ,  $p = 0.002$ ,  $\eta^2 = 0.218$ ), and dominance ( $F_{(6.731, 100.958)} = 11.448$ ,  $p < 0.00001$ ,  $\eta^2 = 0.433$ ) scores. No significant impacts were observed in the rooms (all  $ps \geq 0.491$ ). A significant interaction effect of formal clusters  $\times$  extraversion  $\times$  agreeableness ( $F_{(5.210, 78.144)} = 2.790$ ,  $p = 0.021$ ,  $\eta^2 = 0.157$ ) was demonstrated in the arousal scores. Significant interaction effects of rooms representing a cluster  $\times$  formal clusters  $\times$  neuroticism  $\times$  agreeableness ( $F_{(9.713, 145.692)} = 2.313$ ,  $p = 0.016$ ,  $\eta^2 = 0.134$ ) and rooms representing a cluster  $\times$  formal clusters  $\times$  openness to experience  $\times$  agreeableness ( $F_{(9.713, 145.692)} = 2.138$ ,  $p = 0.026$ ,  $\eta^2 = 0.125$ ) also existed in the pleasure scores.

### 3.1. Regression analysis

Multiple regression analysis was used to investigate whether emotions were predictable in the forms and

personality traits. The test was conducted on two different levels of forms. One was conducted on formal clusters that evaluated the combination of forms in rooms, and the other test was performed on form features and evaluated the different features.

#### 3.1.1. Formal clusters, emotion, and personality

Multiple regression analysis and the backward elimination method were computed between the average rates of PAD scores for each formal cluster as dependent variables and the personality trait scores as independent variables. The tests were run to predict the PAD changes from personality traits in each room.

Only the form features that revealed significant correlations with PAD were added to the model. In addition, only the personality traits with significant interaction effects in the ANOVA were added to the model. Different regression models were used for each personality trait for the pleasure and arousal emotional scale (dominance was not significant in this study). The results were reported for the cases with normal distribution, for the Durbin–Watson statistics, and for the significant ANOVA test.

Three traits, namely, neuroticism, agreeableness, and openness to experience, were entered into the regression model for each cluster in the pleasure scale. The regression model for clusters 0, 3, 8, 15, and 23 was significant. Extraversion and agreeableness were entered into the model for the arousal scale, and cluster number 24 exhibited a significant result. The results of the significant regression models for the clusters and regression coefficients for significant personality predictors are presented in Table 2. The main descriptive features of clusters 0, 3, 8, 15, 23, and 24 are likewise displayed in Table 2.

Given that no significant interaction effects existed between personality traits and the dominance scale, the emotional factor was not added to any regression model.

#### 3.1.2. Form features, emotion, and personality

Multiple regressions were utilized to predict emotion from form features by considering personality traits. Form features with significant correlations with PAD were added to the model. In addition, personality traits with significant interaction effects in the ANOVA test were added to the model. The median number for all the personality traits was used in this step, and each personality trait was divided into high and low groups. Different regression models were applied for each personality trait for the pleasure and arousal scales (dominance was not significant in this part). Backward elimination was used as an enter method for multiple regression. The results were reported for the cases with normal distribution, for the

**Table 1** Descriptive statistics for personality traits; each personality trait was evaluated by using 12 items rated from 1 to 5.

Personality Traits	N	Minimum	Maximum	Mean	Std. Deviation	Median
Neuroticism	39	20.00	44.00	31.31	5.05	31.00
Extraversion	39	23.00	54.00	41.87	6.36	42.00
Openness to experience	39	31.00	53.00	42.15	5.22	43.00
Agreeableness	39	30.00	54.00	42.64	5.03	43.00
Conscientiousness	39	30.00	57.00	47.08	5.86	47.00

**Table 2** Regression model results with sample and main descriptive form feature of clusters 0, 3, 8, 15, 23, and 24. The regression model steps,  $F$ ,  $p$  value, and  $R^2$  are reported for significant models. The significant personality predictor is shown for pleasure and arousal scores, and the standardized regression coefficient ( $\beta$ ), standard error ( $SE$ ), and  $p$  values are reported. The characters of descriptive form features are type, geometry, angle, scale, and location (Banaei et al., 2017) for the main descriptive feature and are reported for each cluster. The table is adapted from the study by Banaei et al. (2017). (\* shows no significant result)

Cluster	Main descriptive feature										Model		Significant personality predictor	
	Type	Geometry	Scale		Location		Angle		Amount (%)	Model steps	$F$ , $p$ , $R^2$	Pleasure ( $\beta$ , $SE$ , $p$ )	Arousal ( $\beta$ , $SE$ , $p$ )	
			Object/Object	Object/Context	Corner/Central	Wall/Ceiling/Floor	X- and Y-axes	Z-axis						
#0	Linear solid	Linear	Neutral	Sc < 1/2	Central	Ceiling	Toward the X- and Y-axes	Slope	75.60	3	$F_{(1,37)} = 4.952$ , $p = 0.032$ , $R^2 = 0.118$	Agreeableness ( $\beta = 0.344$ , $SE = 0.056$ , $p = 0.032$ )	*	
#3	Linear solid	Linear	Vertical	Sc = full	Central	Wall	Toward the X- and Y-axes	Straight	81.40	3	$F_{(1,37)} = 5.820$ , $p = 0.021$ , $R^2 = 0.136$	Agreeableness ( $\beta = 0.369$ , $SE = 0.041$ , $p = 0.021$ )	*	
#8	Linear solid	Linear	Vertical	Sc < 1/2	Central	Wall	Toward the X- and Y-axes	Straight	70.70	3	$F_{(1,37)} = 4.223$ , $p = 0.047$ , $R^2 = 0.102$	Agreeableness ( $\beta = 0.320$ , $SE = 0.048$ , $p = 0.047$ )	*	
#15	Sharp edge	Linear	Vertical	Sc < 1/2	Central	Central	Toward the X- and Y-axes	Zero	38.80	3	$F_{(1,37)} = 4.581$ , $p = 0.039$ , $R^2 = 0.110$	Openness to experience ( $\beta = -0.332$ , $SE = 0.042$ , $p = 0.039$ )	*	
#23	Sharp edge	Curvature	Neutral	Sc < 1/2	Central	Top	Away from the X- and Y-axes	Zero	23.30	3	$F_{(1,37)} = 4.179$ , $p = 0.048$ , $R^2 = 0.101$	Neuroticism ( $\beta = -0.319$ , $SE = 0.039$ , $p = 0.048$ )	*	
#24	Sharp edge	Curvature	Neutral	Sc < 1/2	Central	Top	Toward the X- and Y-axes	Complex	28.60	2	$F_{(1,37)} = 4.160$ , $p = 0.049$ , $R^2 = 0.101$	*	Agreeableness ( $\beta = -0.318$ , $SE = 0.063$ , $p = 0.049$ )	

Durbin–Watson statistics, and for the significant ANOVA test.

**3.1.2.1. Pleasure.** Variables such as angles toward the X- and Y-axes; straight Z-axis; sum of sloped, curved, and combination Z-axis; ceiling location; neutral scale; vertical scale; and sum of linear and curvature geometries, were entered into the regression model to predict pleasure. Personality traits such as neuroticism, openness to experience, and agreeableness, exhibiting significant interaction effects in the ANOVA test were utilized in the multiple regressions. Each regression model was run in the number of steps with significant ANOVA results (all  $ps < 0.001$ , Table 3). The regression model results and predictive variables are listed in Table 3. The findings indicated that the predictive variables had a significant correlation with the dependent variables (all  $ps < 0.023$ ).

**3.1.2.2. Arousal.** Variables such as the angles toward X- and Y-axes; straight Z-axis angle; sum of sloped, curved, and combination Z-axis angle; neutral object/object scale; vertical object/object scale; less than half of an object/context scale; and the sum of linear and curvature geometries, were added to the regression model to predict arousal in different personality traits. Two personality traits, namely, agreeableness and extraversion, with a significant interaction effect, were used in the regression model. Each regression model was run in different steps with the significant ANOVA results (all  $ps < 0.001$ ). All the results are reported in Table 3, and the predictive variables demonstrated a significant correlation with the dependent variables (all  $ps < 0.040$ ).

## 4. Discussion

This study evaluated architectural interior forms to achieve a precise and complete emotional analysis of forms that can be used in architectural designs. The study was based on the formal clustering of architectural interior forms (Banaei et al., 2017) to conduct a comprehensive architectural form analysis. It considered gaps in the related literature, namely, unrealistic form combinations, 2D and 3D stimuli issues, and personality traits, and aimed to fill such gaps. The results showed which form had the most emotional effects on certain personality traits. The results were reported in two levels of form analysis, namely, clusters and form features. The analysis of formal clusters presented the effects of the combination of forms, while the investigation of different formal features indicated the emotional effect of specific 3D form features.

The analysis of personality traits as a predictor variable for pleasure in different clusters showed that agreeableness had a positive impact on increased pleasure for clusters with the most descriptive features, such as a full-scale vertical linear solid placed on a wall, a half-scale sloped linear solid on the ceiling, and a half-scale vertical linear solid placed on a wall. By contrast, openness to experience had a negative effect on pleasure for clusters that mostly contained linear sharp edges. Neuroticism decreased the pleasure in clusters that mostly contained curvature sharp

edges, while arousal decreased in clusters that mostly contained sharp curved edges with complex Z-axis angles.

The investigation of each emotional state from a form feature perspective demonstrated that curvature geometries had the most positive pleasure effect in participants with low openness to experience. Linear geometries had the most negative impact on pleasure in participants with low neuroticism. Regarding arousal, curvature geometries had the most positive arousal effect in participants with high agreeableness, and straight angles toward the Z-axis had the most negative effect on arousal in participants with low agreeableness. Previous studies have likewise shown these effects of curvature and rectilinear forms (Bertamini et al., 2016; Dazkir and Read, 2011; Madani Nejad, 2007; Poffenberger and Barrows, 1924; Silvia and Barona, 2009). However, the novel achievement of this study was in the very detailed relation between different forms and personality traits.

Costa and McCrae (1992) described the characteristics of each NEO personality trait. Neuroticism represented the individual tendency to experience psychological distress (Costa and McCrae, 1992). The present study showed that participants experienced pleasure in seeing forms with curved, sloped, or combination angles toward the Z-axis angle by increasing the level of neuroticism. Participants with a low level of neuroticism felt pleasure toward forms located on the ceiling. Participants with high and low levels of neuroticism showed less pleasure toward linear geometries. In summary, the results revealed that linear geometries significantly decreased pleasure in participants with high levels of neuroticism.

Agreeableness is a dimension of interpersonal behavior (Costa and McCrae, 1992). Agreeableness is likewise related to pleasant, arousal, and submissive characteristics (Mehrabian, 1996). In the present study, pleasure increased in participants with high agreeableness toward curvature geometries and curved, sloped, and combination Z-axis. Arousal increased with the same personality traits toward curvature geometries and less than a half object to context scale. However, participants with low agreeableness demonstrated increasing pleasure toward forms located on the ceiling and decreasing pleasure toward forms with linear geometries. The arousal level for this type of personality trait increased toward curvature, sloped, and combination Z-axis and decreased toward straight Z-axis angles.

The pleasure level in participants with high openness to experience increased toward ceiling locations and decreased toward linear geometries. By contrast, the pleasure levels in participants with low openness to experience increased toward curvature geometries and curved, sloped, and combination angles toward the Z-axis. A significant relation exists between openness to experience and 2D curvature forms rather than with linear polygons (Cotter et al., 2017). Openness to experience is related to aesthetics, art, and creativity (Costa and McCrae, 1992; Oleynick et al., 2017). Moreover, artists have additional emotional reactions toward art features compared with ordinary people (Silvia, 2013). This phenomenon can decrease pleasure toward linear geometries in people with high openness to experience. Given that the complexity of artwork is absent in interior forms, curvature interior forms

**Table 3 Regression model results.** Model steps, variance,  $F$ ,  $p$  value,  $R^2$ , standardized regression coefficient ( $\beta$ ), and standard error ( $SE$ ) are reported for different personality traits. Personality traits are divided into high and low groups, namely, high neuroticism (HN), low neuroticism (LN), high agreeableness (HA), low agreeableness (LA), high openness to experiences (HO), low openness to experiences (LO), high extraversion (HE), and low extraversion (LE). (\* shows no significant result)

			Pleasure						Arousal				
			HN	LN	HA	LA	HO	LO	HE	LE	HA	LA	
Model	Model steps		6	6	7	7	7	7	5	7	7	6	
	Variance (%)		75	81	82	79	79	79	85	66	74	79	
	$F$		$F_{(2,22)}$ = 34.054	$F_{(2,22)}$ = 46.969	$F_{(2,22)}$ = 52.175	$F_{(2,22)}$ = 41.664	$F_{(2,22)}$ = 43.322	$F_{(2,22)}$ = 42.106	$F_{(4,20)}$ = 28.859	$F_{(2,22)}$ = 21.630	$F_{(2,22)}$ = 32.816	$F_{(3,21)}$ = 26.281	
	$p$		<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
	$R^2$		0.756	0.810	0.826	0.791	0.798	0.793	0.852	0.663	0.749	0.790	
Predictable variables	Angle	Z-axis (sum of curved, sloped & combination)	$\beta$	0.395	*	0.389	*	*	0.315	0.631	*	*	0.639
			$SE$	0.302	*	0.280	*	*	0.282	0.270	*	*	0.356
			$p$	0.003	*	0.001	*	*	0.008	0.0002	*	*	0.001
		Toward X- and Y-axes	$\beta$	*	*	*	*	*	*	-0.880	*	*	*
			$SE$	*	*	*	*	*	*	0.300	*	*	*
			$p$	*	*	*	*	*	*	<0.0001	*	*	*
		Z-axis (straight)	$\beta$	*	*	*	*	*	*	*	-0.323	*	0.914-
			$SE$	*	*	*	*	*	*	*	0.198	*	0.396
			$p$	*	*	*	*	*	*	*	0.022	*	0.0003
		Location	Ceiling	$\beta$	*	0.356	*	0.398	0.416	*	*	*	*
			$SE$	*	0.274	*	0.269	0.277	*	*	*	*	*
			$p$	*	0.001	*	0.001	0.0003	*	*	*	*	*
		Scale	(Object/context) <1/2	$\beta$	*	*	*	*	*	*	*	0.290	*
			$SE$	*	*	*	*	*	*	*	*	0.119	*
			$p$	*	*	*	*	*	*	*	*	0.017	*
		Geometry	Rectangular (sum of 1D, 2D & 3D)	$\beta$	-0.624	0.755-	*	-0.715	0.707-	*	*	*	*
				$SE$	0.299	0.331	*	0.325	0.334	*	*	*	*
				$p$	0.00002	<0.0001	*	<0.0001	<0.0001	*	*	*	*
	Curvature (sum of 1D, 2D & 3D)		$\beta$	*	*	0.665	*	*	0.704	*	0.652	0.730	*
		$SE$	*	*	0.784	*	*	0.790	*	0.599	0.463	*	
		$p$	*	*	<0.0001	*	*	<0.0001	*	0.00005	<0.0001	*	



did not show any significant pleasant effect in artistic participants or those with high openness to experience but exhibited increased pleasure in those with low openness to experience. Increased pleasure toward forms located on the ceiling in participants with high openness to experience demonstrated the importance of this location in design. Furthermore, the change in ceiling height has a significant effect on the aesthetic evaluation of a room (Vartanian et al., 2015).

Extraversion is a character that includes a broad group of traits, including sociability, activity, and the tendency to experience positive emotions (Costa and McCrae, 1992). Arousal level increased in participants with high extraversion toward curved, sloped, and combination Z-axis but decreased in forms with angles toward the X- and Y-axes. However, participants with low extraversion exhibited an increased arousal level toward curvature geometries and a decreased arousal level toward Z-axis straight angles. Participants with high and low extraversion levels showed decreased arousal levels toward straight Z-axis angles.

Investigating the highest and the lowest regression coefficients eventually showed that a straight Z-axis angle demonstrated the most negative effect on arousal levels in participants with low agreeableness scores. Moreover, the sum of curvature geometries exhibited the most positive effects on arousal level in participants with high agreeableness.

## 5. Conclusion

This study investigated the effects of different interior architectural forms on emotional states by considering personality traits. This work also filled four main gaps found in previous studies by using comprehensive interior form clustering, analyzing forms in real combinations, allowing participants to explore 3D forms in VR, and considering different personality traits in design. The results illustrated the relationship among different forms, emotional states, and personality traits. Additionally, this study further examined the means of researching 3D-built environments in VR. The participants used VR to perceive space actively, and this study innovatively explored environmental psychology in interior architecture.

The current study had certain limitations in investigating the effects of interior forms on the emotional state of inhabitants. To control the number of variables in the experiment, other factors, such as color, material, and furniture, which could also be important in designing interior spaces, were not considered in this study. The number of form features for the regression model was too high despite limiting the interior variables to only 3D forms, thereby making the process complicated. Thus, we recommend similar investigations on other design factors in future studies.

## Conflict of interest

All authors declare no conflict of interest.

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