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Article

Energy-saving realization method of commercial space decoration and display design by combining with computer vision

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Abstract: How to achieve energy saving and energy conservation while being aesthetically pleasing and practical is a major challenge that is being faced by the trend of increasing enrichment of commercial space display design. Based on computer vision, this paper utilizes a fisheye camera to obtain a panoramic image of the indoor space environment. Cutting-edge computer image processing technology is chosen to digitize the commercial space elements after edge detection and contour extraction. Through digitizing the spatial images acquired by the fisheye camera, a commercial space environment design model based on computer vision is constructed. At the same time, it discusses the application and performance of form, color and material elements in commercial display space, and realizes energy-saving by complementary matching of elements. The model is used to design the interior decoration and class display of a shopping mall, and analyze the static measurement results, spatial relationship of the shopping mall, goodness-of-fit and regression test results of the design scheme. Among them, the RMSEA of the model design scheme = 0.03 (less than 0.08), and the indicators of GFI, IFI and CFI are all greater than 0.90, which is a good fit. It shows that the model is acceptable for energy-saving design on commercial space.

Keywords: commercial space; edge detection; computer vision; energy-saving design

1. Introduction

Commercial space, as a part of social public space, is a space carrier that reflects the effective dissemination of social civilization and value [1]. Commercial space should not only focus on economic benefits, but also ensure that the layout of the space content to meet the needs of the people's spiritual and cultural needs, so that the quality of the enhancement and guarantee, pay attention to the sustainable development of cultural connotation [2-3]. In this situation, the commercial space should also adhere to the public demand-centered design orientation, strengthen the value connotation of public space art innovation, and strive to create a commercial public space that meets people's spiritual and material needs and is close to the public [4-6].

For commercial space, its interior design is mostly based on commercial marketing as the main purpose, through some soft and hard decorative design to fully attract users and realize the economic benefits of goods [7-8]. Good commercial space interior design can help to improve people's shopping environment, mood, and then produce a certain sense of identity for the commercial space, strengthening the purchasing power [9-11]. In addition, interior design also helps to promote the diversion of commodity types, such as according to different commodity attributes, the space can be designed with different colors and decorations, to form the industrial chain of the local area of commercial space [12-14]. Commodity marketing as the focus of commercial space interior design, soft space design can also be able to categorize commodities, enhance user guidance, and promote the generation of consumption [15-16]. Current research data show that with the characteristics of the interior design, and can match the psychological condition of consumers, the customer's consumption

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behavior in commercial space will greatly increase [17-18]. Therefore, how to scientifically and reasonably carry out the interior design of commercial space has been the focus of attention of current enterprises.

This paper analyzes in detail the basic principle and process of the fisheye camera to obtain and analyze the visual information of the commercial space environment, and uses the computer image processing technology to detect the edges of the acquired commercial space elements, extract the contour, and digitize the conversion, thus building the commercial space environment design model. Then, the application and performance of form, color and material elements in commercial display space are theoretically elaborated, and the energy-saving design is completed through the collocation of elements with the technical support of the model. Finally, the feasibility of the model is tested by analyzing the static measurement results of the model design scheme and the spatial relationship of the shopping mall. The model performance is tested with the reliability test, fit and regression test of the scale.

2. Commercial space environment design model

2.1. Commercial space environment visual information acquisition

A fisheye camera is used to acquire a panoramic image of the commercial space environment and determine the connection between it and the 3D points, extract the color information as well as the light and shadow information of the commercial space layout, and map the information of the commercial space layout into the 3D space. The commercial space environment light and shadow effect is the visual effect of alternating light and dark on the surface of indoor objects or in the surrounding environment after they are reflected or refracted by reflective mirrors, and the link between the visual sensors and reflective mirrors can be described by the following equation, which is calculated as equation (1):

$$\delta p = \delta \begin{bmatrix} Y''T \\ E'' \end{bmatrix} = \delta \begin{bmatrix} j\left(\|h''\|\right) \\ d\left(\|h''\|\right) \end{bmatrix} = P \cdot M, \delta > 0 \tag{1}$$

Where: Y'' is used to describe the reflective mirror surface, and E'' denotes the plane where the fisheye camera vision sensor CMOS is located. In the commercial space environment, the location of an arbitrary object is denoted as p, the spacing between it and the reflective mirror surface is denoted as T, and the matching parameter is denoted as δ. The visual mapping of the distribution of the object in the commercial space environment can be denoted by $j(\cdot)$, and the reconstruction equation of the light and shadow transformation is denoted by $d(\cdot)$. In the visual imaging plane α, C is a random point on it, O is the center of the plane, the distance between them is denoted as h'', the coordinates of O points are denoted as P, and the photographic image matrix is denoted as M.

The commercial space layout plane is described by β, and the connection between α and β planes can be described by equation (2):

$$h'' = Qh' + t \tag{2}$$

where: t denotes the translation vector and Q is the transformation matrix.

Substituting Eq. (2) into Eq. (1) yields Eq. (3):

$$\delta p = \delta \begin{bmatrix} j\left(\|Qh' + t\|\right) \\ d\left(\|Qh' + t\|\right) \end{bmatrix} = P \cdot M, \delta > 0 \tag{3}$$

Since the optical system of the fisheye lens adopts a symmetric design, the mapping function between α and β planes is defined through the following equation, and the calculation formula is described as equation (4):

$$f\left(\|h''\|\right) = a_0 + a_1\|Qh' + t\| + a_2\|Qh' + t\|^2 + \cdots + a_n\|Qh' + t\|^n \tag{4}$$

Where: the incidence angle parameter is expressed through a_n.

The acquisition of commercial space environment image information, under the action of factors such as the optical characteristics of the camera lens, leads to the problem of aberration in the acquired image, therefore, it is necessary to utilize Equation (5) to correct its bias in order to obtain a visually effective visual image of the commercial space environment, and the calculation formula is described as Equation (5):

$$\delta p = \delta \begin{bmatrix} h'' \\ f\left(\|h''\|\right) \end{bmatrix} = \delta \begin{bmatrix} Qh' + t \\ f\left(\|Ah' + t\|\right) \end{bmatrix} = P \cdot M ,\delta > 0 \tag{5}$$

On the basis of completing the acquisition of the relevant parameters of the indoor environmental space, the relationship between the α -plane pixel points and the incident points is calculated using the following formula, which is given as equation (6):

$$\tan\theta = \frac{\delta p}{a_0 + a_1 \|Qh' + t\| + a_2 \|Qh' + t\|^2 + \cdots + a_n \|Qh' + t\|^n} \tag{6}$$

Where: θ is the angle between the line connecting the pixel point and the incident point respectively with the center point O .

Under the premise of completing the commercial space calibration, the visual mapping function is used to map the points in the commercial space environment into the three-dimensional space, to realize the determination of the three-dimensional coordinates of the points and to obtain the color information of the commercial space environment, and the computational formula is described as Eqs. (7)-(8):

$$\begin{cases} g_{j(z)} = j(z)/\cos\theta \\ \theta_{j(z)} = \arctan \dfrac{a_0 \|h''\|}{a_2 \left\| j(z)\varphi^2 \right\|} \end{cases} \tag{7}$$

$$\begin{cases} x = g\cos\theta \\ y = g\cos\varphi \\ z = g\sin\theta \end{cases} \tag{8}$$

Where: in three dimensions, the distance from any point to the center of the commercial space environment is denoted as g .

2.2. Edge Detection and Contour Extraction

Edge detection and contour extraction aim to transform commercial space elements from 2D images into solid element processes that can be applied to commercial space design. First of all, edge detection is the process of determining the boundaries and shape characteristics of objects in an image by localizing the places where the intensity of image pixels changes drastically. Sobel edge detection operator is used to process the texture pattern of commercial space elements such as horse head wall and brick carving, and the basic idea is to use a template to perform convolution operation on each pixel point in the image, and then determine whether the pixel point is located on the edge of an object according to the result of the operation.The Sobel operator consists of templates in two directions, horizontally and vertically. For each pixel point in the image, the convolution operation is performed on it with these two templates respectively to obtain the gradient values in the two directions, and then the edge intensity of the pixel point is calculated based on these two gradient values. Specifically, for a two-dimensional image K , the Sobel operator is computed as follows: first, a convolution operation is performed on the image K using the horizontal direction template S_x and the vertical direction template S_y to obtain two gradient images G_x and G_y , as in Eqs. (9)-(10):

$$G_x = I * S_x \tag{9}$$

$$G_y = I * S_y \tag{10}$$

where * denotes a convolution operation. Following this, the gradient images G_x and G_y are normalized to obtain the edge intensity image E as in equation (11):

$$E = sqrt\left(G_x{}^2 + G_y{}^2\right) \tag{11}$$

Where sqrt denotes the square root operation. Next, a threshold value T is set to determine whether each pixel point is an edge point, and if $E > T$, the pixel point is an edge point, otherwise it is a non-edge point.

Further, contour extraction is a connectivity domain analysis and refinement operation of the already detected edge portion to obtain the precise shape contour of the target object. Marching Squares algorithm is applied to realize this process. The algorithm generates polygonal contour lines by traversing and judging the threshold points according to the 2D raster data of the image; while the active contour model utilizes the principle of minimization of energy generalization, so that the initial contour curves gradually approximate the real contour under the action of internal and external forces. In practice, the discrete edge points are first transformed into continuous contour lines by Hough transform technology, and then the contour lines are smoothed by using Bezier curve in computer graphics, which is a kind of parametric curve determined by the control points, and the advantage is that it can be adjusted locally very easily, so as to get the smooth contour lines that meet the design requirements. The smoothing process is as follows:

(1) Given a set of control points $P_0, P_1, \cdots, P_a$, where a is the number of control points that correspond to key turning points on the contour line.

(2) Calculate the Bézier curve segment for each control point. For control point u, the Bézier curve segment calculation result $B_u(t)$ is shown in equation (12):

$$B_u(t) = (1-t)^u \times P_0 + t^u \times P_u \tag{12}$$

Where t is the Bézier curve parameter and u is the control point serial number.

(3) Connect all Bézier curve segments to obtain the Bézier representation of the whole contour line.

(4) Optimize the Bézier curve using Newton's method to eliminate local peaks and valleys in the curve and improve the smoothness of the contour line.

Finally, these accurately extracted contour data can be converted into a format that can be recognized by three-dimensional modeling software, and then integrated into the space design for constructing or decorating virtual or physical space, thus fully demonstrating the artistic charm and cultural connotation of commercial space elements and realizing the deep integration of tradition and modernity, art and technology. In general, with the technical support of computer image processing, edge detection and contour extraction not only reveal the rich visual form of commercial space elements, but also provide a strong data base and technical support for their innovative application in spatial design, which enables designers to maintain the traditional cultural heritage while flexibly using digital means to give commercial space elements a new vitality and form of expression.

3. Expression of Compositional Elements in Commercial Display Space

3.1. Morphology in space

As the basic element of flat modeling, point has the basic attributes of size, area, shape and location in visual expression. Using points in flat structure to view the physical elements in commercial space, abstracting the figurative objects, evolving them into points, and then conceptualizing and integrating them is a common technique in spatial design.

In commercial display space, furniture, space decorations, lighting, etc. can be regarded as “point” elements, and their expressions in space design also have certain functionality. When the physical objects in the space exist as point elements, the energy utilization efficiency can be improved by dealing with their position, gathering and dispersing and reorganizing relationships.

The expression of lines in commercial display space is rich and varied. Generally common solid lines such as furniture, doors and windows, columns and beams formed by the entity line. Dashed lines are the space lines in entities such as gaps and recessed parts.

Different shapes of the surface to bring consumers different psychological feelings, different forms of expression of the surface of the limited space characteristics are also different, the visual effect presented is also different.

3.2. Color in Space

Color is the most recognizable element in visual cognition and plays an important role in spatial expression. Color contrast and harmony in the space is an important means of creating attraction, the contrast and harmony of the two can be combined to maximize the purpose of spatial performance.

The characteristics and functions of commercial display space can be highlighted by contrast. Color contrast mainly includes the three elements of color and color contrast between warm and cold.

Commercial display space needs to use high purity colors to enhance the sense of spatial liveliness, but also with the gray system to create a calm color environment.

Harmonized colors should be selected for long-term use and not easy to produce visual fatigue of the color. Color harmony mainly includes the same color, the same brightness, purity and colorless system of the same harmony and brightness, purity, hue contrast between the harmony.

The spatial sense of color is the sense of volume, the use of color through the sense of temperature, distance, weight and other elements to shape the sense of space. In general, warm colors and high purity colors have a certain sense of forward, cold colors and low purity colors have a certain sense of backward.

3.3. Representation of materials in space

Material and texture can not only bring the visual feeling and tactile feeling, and can trigger the association of tactile so that people have different aesthetic feelings.

The materials used in commercial display space include wood, stone, metal, glass, ceramics, wallpaper fabrics, plastics and so on, each of which has different forms of expression and application areas with unique properties.

Timber is widely used in space, can be used for grass-roots and surface decoration, with warm and simple natural properties. Stone is mostly used in interface paving, with rich texture. Metal is rich in variety and has modern attributes. Glass material is light and clean, with light transmission properties, can create a rich sense of hierarchy. Ceramic material texture texture can be imitated other material production, add space artistic flavor.

Material through the texture of the decorative effect. Material processing technology and characteristics effectively enhance the feasibility of the design and creativity, to promote the space between art and technology more effective combination.

In conclusion, through the selection of different materials, with different forms and color design, on the basis of the commercial space environment design model proposed in the previous section, it can effectively carry out energy-saving design.

4. Application evaluation and validity test of the model

This paper selects a shopping mall research object, using commercial space environment design model for its space declared within the decorative and class Chen energy-saving program design, analyze the static measurement results in the design program and the mall space relationship, the application of the model assessment. Then we conducted a questionnaire survey on the consumers of the shopping mall. Analyze the fit of the model and regression results, to test the validity of the model.

4.1. Application assessment

4.1.1. Static measurement analysis

In the indoor coordinate system, the spatial positions of several groups of target points were measured using floor lines and tape measures, and compared with the system measurements are shown in Table 1, and the measurement errors were all within 15 mm.

Table 1. Compared static measurement result with true position

Actual coordinates of the target point /mm			**Measurement coordinate value /mm**			**Maximum error /mm**
X	***Y***	***Z***	***X***	***Y***	***Z***	
0	0	45	6.088	7.739	43.218	7.739
500	500	115	493.115	503.974	114.558	6.885
500	-1000	249	495.157	1013.877	244.126	13.877
500	-500	347	502.073	-511.474	349.008	11.474
-1000	1500	573	-1012.505	1511.218	569.747	12.505

4.1.2. Analysis of spatial relationships in shopping malls

The relationship analysis of indoor space is the division of indoor spatial relationship through the collection and integration of information when carrying out the basic spatial configuration. There are three kinds of indoor spatial relationships: dense, general and distant, which are indicated by the values of 0.3, 0.2 and 0.1 respectively.

Considering the basic functional area and owner's demand that the shopping mall has, combined with the utilization rate of each spatial function and the analysis of cross-flow lines, the analysis of spatial relationship on the first floor of the shopping mall is now considered to be shown in Fig. 1. There are a total of (F11) entry and exit area, (F12) service desk, (F13) security booth, (F14) staff workroom, (F15) restroom, (F16) atrium, and (F17) retail store on the first floor of the shopping mall, (F18) dining area, (F19) leisure area nine space design. As can be seen in Figure 1, the access area and recreation area have a dense relationship with the other spaces.

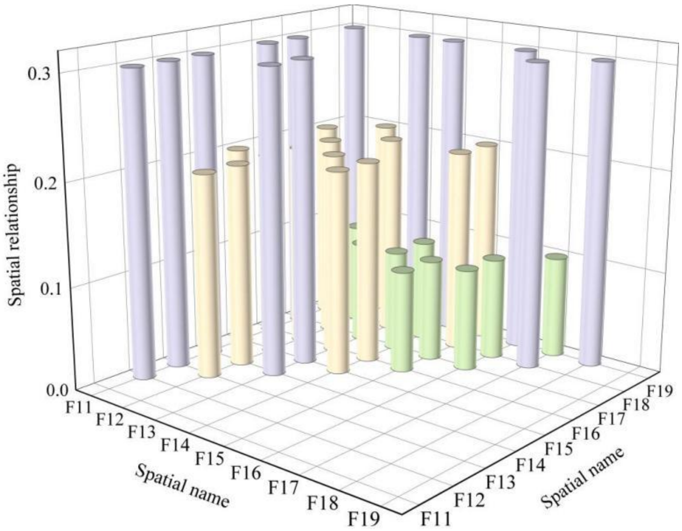

Figure 1. Analysis of spatial relationship on the first floor of shopping mall

The spatial relationship analysis of the second floor of the mall is shown in Fig. 2. There are seven spatial designs in the second floor of the mall, namely (F21) service desk, (F22) employee workroom, (F23) restroom, (F24) atrium, (F25) retail store, (F26) dining area, and (F27) leisure area. One of the service counter spaces is dense in relation to all other spaces.

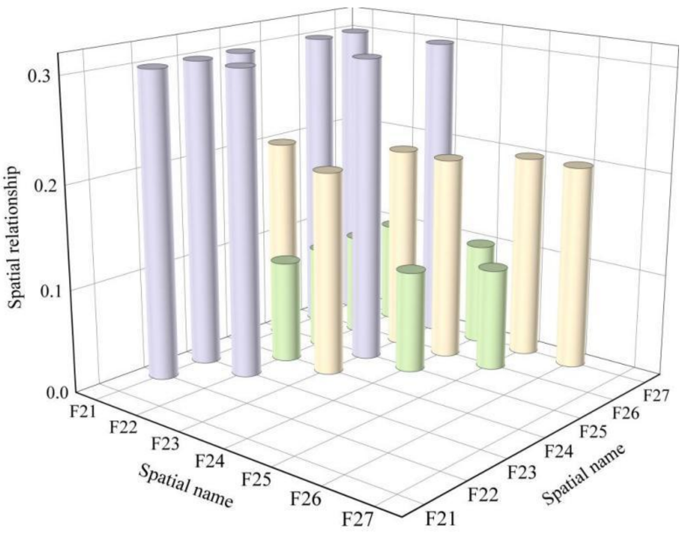

Figure 2. Analysis of spatial relationship on the second floor of shopping mall

The spatial relationship analysis of the negative floor of the mall is shown in Fig. 3. The negative floor of the mall has a total of (F31) atrium, (F32) restrooms, (F33) retail stores, (F34) food and beverage area, and (F35) leisure area. The relationship between the atrium and all other spaces in the negative floor is dense.

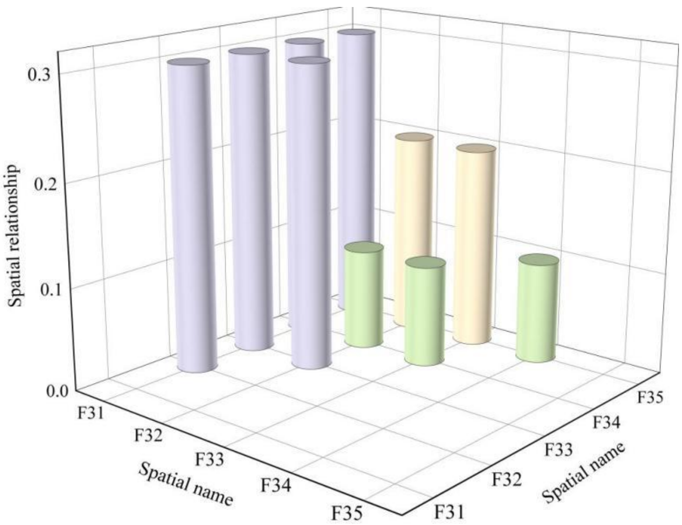

Figure 3. Analysis of spatial relationship of negative first floor of shopping mall

4.2. Validity tests

4.2.1. Sample and data collection

Based on theoretical combing, AHP hierarchical analysis and on-site research, the constructs were supplemented and screened. The applicability of the measurement topics was optimized with reference to the commercial space energy-saving scale. Considering that the survey subjects are ordinary consumers rather than professionals, the study adopts an easy-to-understand question and answer form, combines professional elements to set up questionnaire questions, and uses a 5-level Likert scale, which is divided into five quantitative levels from "strongly agree" to "strongly disagree", so as to facilitate consumers' scoring. The questionnaire consisted of quantitative questions on consumer demographic characteristics, as well as display space elements and energy-saving presentation. On the basis of pre-survey and questionnaire revision and finalization, the questionnaire was centrally distributed by snowballing between November 2023 and February 2024, and a total of 1,050 questionnaires were distributed, removing incomplete and contradictory samples, and 961 valid questionnaires were finally obtained, with an effective recovery rate of 91.52%. The study was mainly conducted with the help of questionnaire star, SPSS26.0 and other statistical tools to collect and analyze the data, and the results of the statistical characteristics of the interviewed consumers are shown in Table 2.

Table 2. Statistical characteristics of interviewed consumers

Project	Sample category	Frequency/person	Proportion (%)
Gender	Female	367	38.19
	Male	594	61.81
Age bracket	under 20 years old	223	23.2
	21 -40 years old	549	57.13
	41 -60 years old	181	18.83
	Over 60 years old	8	0.84
Occupational attribute	Student	201	20.92
	Teacher	41	4.27
	Public institution	80	8.32
	Enterprise personnel	289	30.07
	Individual business operators	327	34.03
	Else	23	2.39
Level of education	Junior high school and below	53	5.51
	High school or technical secondary school	76	7.91
	College or undergraduate	658	68.47
	Master degree or above	174	18.11

4.2.2. Reliability test of the scale

In this study, Cronbach's alpha reliability coefficient was used to determine the internal consistency of the scale data, and when the alpha coefficient is higher than 0.8, it indicates high reliability. When the coefficient is between 0.7 and 0.8, it indicates good reliability. When the coefficient is between 0.6 and 0.7, it indicates reasonable reliability. And when the coefficient is less than 0.6, it indicates poor reliability. Table 3 shows the Cronbach's alpha reliability coefficients for the scale data.

Table 3. Construct factor reliability statistic -Cronbach's α

Latent variable	Variable classification	Variable coding	Number of items/items	Cronbach's α
Physiological dimension immersion	Spatial construction	(a11) space interface (a12) comfort level (a13) function layout (a14) Infrastructure construction	4	0.788
	Sensory stimuli	(a21) visual (a22) auditory (a23) texture (a24) smell (a25) degustator	5	0.731
Maneuvering dimension immersion	interactive experience	(b11) virtual reality technology (b12) Art interactive installation (b13) service experience (b14) Social interaction	4	0.688
	Spatial guidance	(b21) Spatial guidance (b22) Moving line planning	2	0.624
Emotional dimension immersion	narrative space	(c11) Spatial plot (c12) Spatial theme (c13) Spatial narrative	3	0.758
	Degree of control	(c21) sense of immediacy (c22) Feeling of control	2	0.614
	Perceptual transformation	(c31) Time perception transformation (c32) Spatial perception transformation (c33) time consumption (c34) Reality perception	4	0.636
Overall reliability statistics			24	0.914

The results of this study showed that the alpha coefficients of the six latent variables were all above the reasonable value of 0.6, while the overall alpha coefficient value of the scale was 0.914, which was much larger than the critical value of 0.6, and had a high reliability indicating that the scale was set up reasonably and could be analyzed by factor analysis.

4.2.3. Goodness-of-fit and regression tests

The results of the model fit indices are shown in Table 4. From the previous section, the sample size is 961. in the table x^2 is the chi-square value, x^2/df is the chi-square degrees of freedom ratio, GFI is the goodness of fit index, AGFI is the adjusted goodness of fit index, RMSEA is the asymptotic root-mean-square error, NNFI is the non-conventional fit index, IFI is the growth fit index, and CFI is the comparative fit index.

Table 4. The fitting index value of the model

Fit index	Adaptation standard	Parameter of this model	Fit result
x^2	The smaller, the better	302.92	Good
x^2/df	<3.00	1.32	Good
GFI	>0.90	0.96	Good
AGFI	>0.80	0.92	Good
RMSEA	<0.08	0.03	Good
NNFI	>0.90	0.97	Good
IFI	>0.90	0.98	Good
CFI	>0.90	0.98	Good

Note:*P* is 0.000.The degree of freedom {df} is 237.

It can be known that the construct element model chi-square value x^2=302.92, *P*=0.000 (significant), degree of freedom (df)=237. Referring to the model fit evaluation system proposed by the scholars, the RMSEA of the model=0.03 (less than 0.08), and the indexes of GFI, IFI and CFI are all greater than 0.90, which indicates that the model fit is better, and the model can be accepted.

The constructing elements are form, color and material, and the corresponding paths are energy-saving perception and perceptual transformation. In the regression coefficient and test results of the model, the regression coefficient of provincial energization on perceptual transformation is 0.267 and shows a strong positive significance. The results of the regression coefficients of the constructing elements on the perception and perceptual shift of provincial energization are shown in Figure 4.

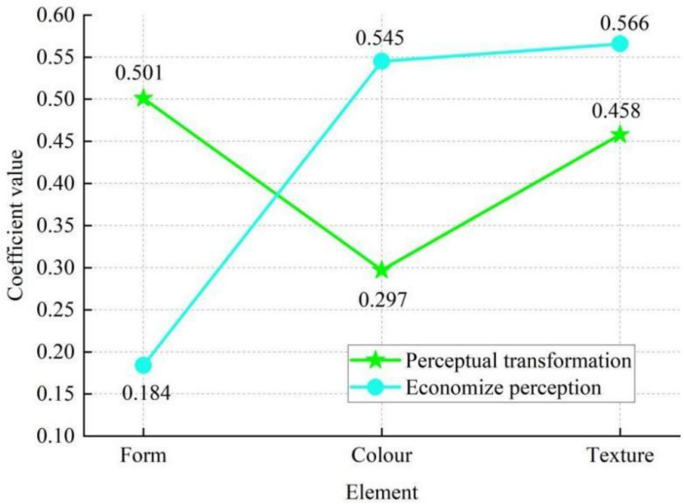

Figure 4. Model hypothesis verification and path coefficient results

As can be seen from Figure 4, morphology, color, and material all have a significant impact on the audience's perception of provincial energy during the experience. In terms of the size of the influence, material has the most significant influence, followed by color and finally form. For the audience's perceptual transformation, form has a positive and significant effect on it. Comparing the influence of each element, material (0.566) has the most significant influence role, followed by material. The standardized path (0.267) of the audience's energy-saving perception of perceptual shifts during the shopping process verifies that it has a positive and significant effect, verifying the effectiveness of the model design solution's energy-saving.

5. Conclusion

This paper proposes an energy-saving design method for the decoration and display of commercial space by combining fisheye camera and computer image processing technology. The commercial space environment design model, based on computer vision technology, can combine different forms, colors and materials with the theme of commercial display space, so as to effectively carry out the energy-saving design of commercial display space. In the practical application of the model, the energy-saving design scheme effectiveness test, the energy-saving perception of the shopping mall audience in the process of consumption on its perceptual transformation path is 0.267.

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