Preserving Sculptural Heritage in the Era of Digital Transformation: Methods and Challenges of 3D Art Assessment

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Abstract: Sustainable digital cultural heritage is now an essential aspect of our lives. The rapid development of 3D technology in the historic preservation industry provides the means of documenting, recovering, and presenting cultural heritage items. However, the digital transformation of 3D sculpture heritage is often led by technology without effective evaluation indicators as a guide. This study compares effective assessment methods for digital forms with traditional art. Our approach uses semantic differential scales and machine learning regression models to assess the importance of fifteen artistic attributes. The semantic differential scale is improved based on 15 artistic attributes and proves to be effective in evaluating the value of digital artwork. This research finds that digital artwork is significantly more popular among young people compared with elderly people, especially for attributes like colour variation, saturation, and texture. The research also finds that complexity and social attributes are more important in predicting the value of the digital 3D model. Digital transformation is a viable method for preserving the artistic value of sculpture and improving cultural sustainability.

Keywords: digital transformation; artistic attributes; digital heritage; art evaluation; sustainable

1. Introduction

The digital transformation of cultural sculptures is very important to protect and spread our extensive and varied human civilisation [1,2]. Although compared to other art forms, the sculpture is capable of enduring the effects of time, the sculpture still suffers from deterioration and damage. The cultural historic preservation industry requires effective methods to preserve sculpture art with the support of digital technologies. Against this backdrop of sustainable transformation and interdisciplinary integration, many organisations are experimenting with new technologies to protect artworks [3–5]. Malik et al. (2021) summarised the significance of 3D reproduction for restoration, conservation, participation, education, art history, and the authentic experience in their latest review [6]. Through the process of digital transformation, these valuable sculptures, artefacts, and monuments are protected from potential physical decay, loss, or damage caused by natural erosion, conflicts, or neglect [7–9] (Figure 1). In addition, digital transformation surpassed geographical limitations and gave individuals from diverse locations the opportunity to participate in and explore cultural heritage [10].

Although 3D digital art has become deeply embedded in our lives, especially as a digital transformation aimed at sustainability, it is still a relatively new concept with no clear evaluation standards, even as an art evaluation [12]. As a result, scholars have utilised both objective and subjective methodologies in order to evaluate digital transformation artwork. Academic research has predominantly examined objective aspects of form perception, such as the golden ratio and the Fibonacci sequence, comparing them to people’s subjective preferences using classical and statistical learning methods [13–15]. To the best of our understanding, however, none of these investigations satisfactorily evaluated the full picture of digital transformation, including those that employed statistical learning methods as objective metrics [16]. Conversely, scholars specialising in the visual arts and psychology employ linear statistical techniques to evaluate the degree of artistic ingenuity, relying predominantly on subjective assessments [17,18]. Following the pioneering work of Daniel Berlyne, these assessments became important [19–21]. Berlyne, a pivotal figure in art research, investigates the relationship of artistic properties primarily through preference judgments. For example, the University of Vienna enlisted the help of 78 psychology students to assess works of art [22]. Such evaluations have been used in art viewing studies, where participants complete drawings and provide ratings or standardised tests [23]. Although these methods appear to be accurate, art experts’ and non-experts’ assessments of the same work of art occasionally diverge substantially [24–26]. This interactive use of terminology to express opinions and provide justifications through attributes is a consequence of social–cultural and educational influences on the interaction with aesthetic products [27].

Despite this, prior research has not yet examined the manner in which individuals distinguish creative art by means of particular attributes. The majority of research studies employ a statistical model that operates under the assumption of a linear relationship between the dependent and independent variables. This implies that alterations in the scores of artistic attributes will have a direct impact on the evaluation of creativity, exhibiting a constant effect [28,29]. Conversely, it is possible that human behaviour does not adhere to such linear patterns, and oversimplifications of this nature could lead to impractical theories and questionable scientific deductions [22,30,31]. As a good thing, recent research conducted by Blanca T. M. Spee’s group has unveiled the possibility of non-linear relationships between unidentified attributes that impact the evaluation and perception of creative
works [10]. The samples utilised in this study, however, remain restricted to 2D works and exclude 3D digital art. In response to these concerns, we formulated the subsequent research inquiry:

1. How does one evaluate a work of digital art, mainly 3D sculpture, from a sustainable perspective?
2. What distinguishing characteristics do digital artworks (digital sculptures) have compared to traditional artworks (such as traditional sculptures)?
3. Which artistic qualities are subjectively perceived to contribute to the digital transformation of cultural heritage?

To address the gap, this research aims to modify the digital art evaluation scales to measure the attributes of the digital copy and analyse the authenticity. This research adds additional art attributes to the digital art evaluation in order to suit the needs of cultural heritage preservation. Since heritage value is a subjective issue, this research also compares the statistics between different age and gender groups to investigate the difference in digital copy acceptance. Then, this research uses random forest regression to identify the attribute with high-value prediction performance.

The contribution of this research is (a) the expanded scope of conventional statistical designs employed in digital art research. We facilitate further investigation into the intricate cognitive processes exhibited by digital three-dimensional artworks, with a particular focus on digital sculptures. (b) With an in-depth understanding of the age and gender group differences and the attribute performance difference in value prediction, future research could design a targeted digital transformation process and simplify the evaluation methods, thereby further expanding its practicality and relevance.

The structure of this study is as follows: Section 2 reviews the application and challenges of digital transformation in cultural heritage; Section 3 describes the procedure for conducting the questionnaire, design of Stimuli, and analysis methods; Section 4 presents the analysis results and initial findings; and Section 5 discusses attribute difference in different groups and value prediction and concludes this paper.

2. Literature Review

2.1. Digital Transformation as a Method to Promote Sustainability

The sustainable management of the sculpture could involve multiple technologies and strategies. The aims of sustainable management are to prevent the sculpture and the artwork from external damage and reduce the environmental impact [32]. The common technologies are environmental control, selection of sustainable material, and digitisation of the art.

Environmental control mainly aims to control the temperature, humidity, and light of the storage environment [33]. The constant temperature and humidity system is used to maintain suitable storage conditions. The variation of the temperature and the humidity of the environment is maintained in an acceptable range. By reducing the variation of temperature and humidity, material deterioration could be significantly reduced, reducing the large-scale repair and extending the life expectancy of the artwork [34]. Light management is another important aspect of environmental control. By controlling the duration and degree of exposure to light, especially ultraviolet light, the fading and degradation of materials could be significantly reduced, as well as the chemical changes of the surface material.

The selection of sustainable materials is also an important aspect of sustainable management. On the one hand, the creation of art could use recycled material or material with minimal environmental impact [35]. On the other hand, for the existing artwork, non-toxic or low-toxic cleaners and preservatives could be selected for the scheduled maintenance, which reduces the impact on the environment and personal health [36].

The digitalisation of artwork and sculpture is an emerging trend of sustainable management [37,38]. A sculpture can be scanned and reconstructed into a 3D model to record most of the details, including the physical shape, colour, and texture of the material [39]. Sansoni et al. [40] suggest that current sensors could have the accuracy to capture detailed
information about the sculptures’ physical shapes. Bruno et al. [41] use a high-definition camera to accurately capture and map the colour and texture of cylindrical decorated objects to the constructed 3D model. Using digital records and documents for the artwork could reduce the interaction between humans and the outside environment to a minimal level, thus reducing the deterioration of the art [42]. Researchers build information systems or platforms to store and present the 3D model to provide easy access instead of working with real artefacts [43]. A historical digital twin system has also been developed to help replace the traditional workflow with heavy human interaction to examine the artefacts [44]. After creating the digital copy of the artwork, the digital copy could be presented to the public with AR and VR technologies, with the experience of it being the original object [38]. A survey study has shown that museums can effectively use AR and VR to exhibit artefacts, which could enhance visitor experiences and satisfaction [45]. VR and AR also have the potential to reconstruct the tangible cultural heritages, which could present the perfect status of the damaged artefact, thus enhancing museum display effects [46].

The digitisation of art has several advantages over other sustainable management methods. The first is reducing the physical contact of the original artwork, which is beneficial to fragile art and artwork that is not suitable for transportation [42]. Research shows that users with experience with VR and gaming could effectively gain in-depth knowledge about the artefact through virtual interactions, thus reducing the need for accessing the original objects [47,48]. The second benefit is that it provides wide access to the public with a limited physical location. This method significantly reduces the difficulty of the general public participating in the art industry, which makes many art business models sustainable [49]. Hammer et al. [50] demonstrated that advanced image technologies could provide remote access to the heritage in conflict zones and remote places. McCandlish and McPherson [51] show that digital methods can be used to map and share hidden cultural assets and engage local communities with storytelling. The other benefit is the cost management of maintaining the art. While the initial investment in digitising sculpture art could be significant, the long-term maintenance cost of art could be significantly reduced [52].

2.2. Challenges of Preserving Artwork through Digitisation

However, the digitisation of sculpture art also has many issues and challenges. The first issue of digitisation is the accurate presentation of the sculpture [53]. The social value of art often resides in the tradition and historical background, which cannot be digitally recorded and presented [54]. Jones [55] argues that the social value of the artwork and artefact is related to the historic environment of the communities. For example, the sculptures need to be associated with the exhibition environment, including religious sites and historical sites [56]. The digital presentation of art could lower the requirement for art appreciation; thus, art forms could be attractive to young people and encourage more young people to learn and inherit sculpture art [57]. However, whether young people can understand and accurately experience the charm of fine art is not clear. Research suggests that younger generations have different learning styles and ways of observing and appreciating artwork [47]. Manna and Palumbo [58] conducted a survey to show that the museums need targeted strategies to attract young people. Inadequate experience of the artwork may pose challenges for promoting cultural continuity.

The other limitation is the difference between the digital copy and the physical object. Although digitalisation proves to be beneficial with convenient access and long-term storage costs, the digital copy can hardly replace the physical artwork [59]. The appreciation of fine art may require the audience to observe the art from different angles, which is limited by the original design of the digital presentation system [60]. Therefore, additional research is required to study the effectiveness of the digital presentation system in terms of restoring the connotation of the artwork.

Lastly, the initial investment is an important limitation of art digitisation. The investment includes purchasing high-quality 3D scanning equipment and digital presenting equipment (such as VR and AR) [61]. Tisma et al. [62] suggest that the infrastructural
investment of heritage protection is significant and poses a challenge to secure adequate funding. Researchers have begun to develop low-cost digital technologies to reduce the cost and time to create the 3D model [46]. Apart from the hardware cost, the person using the equipment needs to have suitable professional knowledge and skills in digitisation [63]. A survey found that the necessary skills for operating the digital system are often obtained from collaborators, which makes heritage preservation complicated [42]. Alsadik [64] found non-professionals and students need assistance with cameras and laser scanners and develop a simplified procedure for building 3D models. Those requirements could pose challenges for small-scale art organisations and individual art creators.

2.3. Evaluation Method for 3D Artwork

The 3D art evaluation differs from traditional art evaluation in several aspects and faces many challenges when applied to cultural heritage protection. The first difference is the evaluation criteria and attributes. Traditional art evaluation often focuses on attributes like composition, colour theory, brushwork, and material quality [65]. For the 3D art evaluation, additional criteria are required, such as texture mapping, rendering quality, and polygon count [66]. The evaluation may also consider the historical and cultural background, which is quite subjective [67]. The second difference is the medium and tools. Traditional art is mostly based on direct observation and assessment of the artwork itself, whereas 3D art evaluation involves both physical and digital forms of art [68]. Research shows that museums could provide virtual presentations to make the evaluation more interactive so that the value of digital art could be better understood [69]. AR and VR technologies could provide immersive experiences that are unique to 3D artwork [70].

The evaluation of the digital art and model’s value is complex and non-linear. Many attributes of the artwork are interrelated and could impact each other with a non-sequential pattern. The complexity is also caused by the partially subjective judgement of the artistic quality, originality, market trends, and the reputation of the artist. The complexity of the artwork itself is not a linear relationship since some artists prefer to use simple and minimalist pieces to present elegance and conceptual ideas [71]. Colour variety and colour saturation have a similar effect as different styles have different ranges of colour variety and colour saturation, and the colour choice can not be simplified with numerical value [72,73].

Due to the non-linear nature of the art value prediction, non-linear regression models like random forests could have great potential in capturing the non-linear relationships and interactions among art attributes. Castiello and Tonini [74] used the random forest model to automatically process the artefacts from the Roman settlement sites and compare the artefacts from different heritage sites. Grilli and Remondino [75] have used the random forest models to classify the architectural features of cultural heritage. Complexity might increase value in some contexts, but minimalism can be equally prized. Random forest models can adeptly assess this non-linear relationship by constructing multiple decision trees that simulate various styles; therefore, the random forest model could provide a robust prediction framework for survey data analysis. Akçapınar et al. [76] have used random forest to conduct data mining of user behaviour data for score prediction. Dureh et al. [77] conducted a survey on youth and young adults and used both linear regression and random forest for analysis; the results suggest that random forest can be an effective alternative tool.

3. Materials and Methods

3.1. Participants and Screening Questionnaire

Sixty participants (31 female, mean age = 20.28, SD = 1.47, ages 18 to 23) were recruited from the Dalian Jiaotong University student population. Thirty students from the School of Arts were deemed artistically experienced, while thirty students from non-art faculties were deemed artistically naive. We also recruited 30 professional art practitioners (18 female, mean age = 35.3, SD = 6.47, ages 24 to 45), which included independent artists, art critics, and art school teachers. After providing informed consent forms, all participants were duly apprised of the objectives of this study. We created a survey questionnaire (see Table A1) to
screen for 60 students who are familiar with sculpture art. It primarily screened whether the participants had been exposed to physical/digital sculptures and whether they had a clear understanding of these concepts. The questionnaire is designed to collect basic background information, such as familiarity with digital art, frequency of accessing digital art, and understanding of digital art industry. We aimed to minimise the impact of non-experts’ preference judgments on test results [24]. Finally, 53 students and 30 professional artists were invited to participate in the final comparative test. The testing process is shown in Figure 2.

![Figure 2. Participant position diagram.](image)

### 3.2. Procedure

We chose a lab room with plenty of natural light to display the artwork. The physical sculpture was placed approximately 60 cm from the participant, while the screen was maintained at an approximate distance of 50 cm. The subjects were instructed in writing that they would be presented with a sequence of sculpture artworks and requested to assign Likert evaluations to each one based on a predetermined set of attributes. It is worth noting that our analysis in this paper focuses solely on assessing differences between physical sculptures and digital versions. The participants were granted an unlimited amount of time to finish the ratings, with the option to take pauses whenever needed. The works were displayed on a display stand, and the same digital works were displayed on a MacBook. Each physical sculpture measures approximately 50 cm × 50 cm × 80 cm. Each digital work has a maximum size of 500 pixels (1280 × 1024, 60 Hz resolution). Finally, we collected a total of 83 questionnaires, with 80 being valid. Three questionnaires were deemed invalid because the participants did not complete all the necessary information. The questionnaire data are organised with each row representing numeric score for each participant and stored as .csv file for R and SPSS.

### 3.3. Assessment of Art Attributes

In this study, we investigate whether the characteristics of an artwork change during its digital transformation. Based on this, a procedure is necessary to quantify this transformation. The assessment of modifications to the artwork would prove arduous in the absence of quantitative metrics. Therefore, experts have used various methods to assess artworks’ attributes, including objective and subjective techniques. The most classic example of art attribute assessment methods is ‘THE ASSESSMENT OF ART ATTRIBUTES,’ published in 2010 by the Vidik team from the University of Pennsylvania [78]. The Art Attribute Assessment (AAA) model was introduced in this study. We utilised slightly modified versions of the six formal–perceptual attributes (balance, colour saturation, colour temperature, depth, complexity, and brushstroke) and six conceptual–representational attributes (animacy, emotion, realism, objective accuracy, and symbolism) that comprise the AAA.

We made the following modifications to our study’s formal–perceptual art attributes [79,80]: 
- **reflective colour** with simple or complex ambient reflection colours as opposite poles; 
- **colour...
variety with few or many colours; we removed brushstroke as it primarily applies to painting arts; and we added texture as an evaluative attribute, better suited for assessing sculptural works. We kept the subjective artistic attributes consistent with earlier studies [28,81], but we removed aspects like realism and objective accuracy to avoid bias towards specific artistic styles.

Furthermore, to meet the needs of art collectors and investors, we have integrated value and social attributes into our evaluation system [82–84]. These characteristics reflect not only the aesthetic value of the artworks but also their social and spiritual value [85,86]. Incorporating these characteristics aims to investigate the changes in the value of artworks during their digital transformation. Table 1 summarises the descriptive characteristics of this study. Finally, we customised the evaluation scale to fit the Chinese context, making it more appropriate for using Chinese terminology.

Table 1. Art attribute selection for rater assessments.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Instructions</th>
<th>Compare the Various Attributes of Digital Sculptures with Physical Sculptures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Items</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Formal–Perceptual</td>
<td>a. Visual Harmony</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Attributes</td>
<td>b. Depth</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>c. Complexity</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>d. Colour Saturation</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>e. Colour Variety</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>f. Colour Temperature</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>g. Reflective Colour</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>h. Texture</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>i. Touch</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Content–Representational</td>
<td>j. Abstraction</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Attributes</td>
<td>k. Imaginativeness</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>l. Symbolism (ambiguity)</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>m. Emotion</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Value</td>
<td>n. Social</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>o. Value</td>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

3.4. System Design of the Stimuli

As shown in Figure 3, we have created a stable and expandable test environment (Metajojo) for digital art. The platform covers everything from 3D artwork creation to user interface presentation to back-end services and infrastructure. On this platform, artists and developers have uploaded their original 3D test files (restored with ZBrush and Blender). Three.js, a JavaScript library based on WebGL, is then used to create and display all digital sculptures in the browser. The front-end interactive interface allows participants (senior and youth groups) to interact with the digital artwork. We deployed components such as IAM policies and databases to improve system stability and ensure high availability for testing results.

Figure 3. Metajojo workflow diagram.
For probe stimuli, we used physical sculptures and their digital copies. Yang, a well-known sculpture artist, and his team digitised all nine sculptures. Designed for research purposes, the stimuli disrupt consistency in motif (genre categories) and stylistic attributes (style, historical period subcategories), thereby guaranteeing the production of high-quality images. Figure 4 illustrates the titles and artworks.

![Figure 4. Physical sculptures.](image)

### 3.5. Data Analysis Method

For descriptive statistics and variable correlation analysis, we utilised SPSS 24.0 [87]. The responses gathered from the participants via the Likert scale were subjected to SPSS analysis. People’s attitudes towards traditional and digital sculptures were analysed based on various attributes during the digital transformation. The data were visualised using Rawgraph 2.0, an online data visualisation platform, to evaluate the relationship between attributes and analyse the influence relationship between variables.

Then, this research conducts further analysis to identify the indicators that are effective in value prediction. This research conducts random forest regression 100 times and records the importance indicator (%incMSE) of each variable each time. For the regression, the value is considered as the dependent variable, and the other 14 variables are considered as the independent variable. The random forest regression is conducted using R 4.2.1 software with the “randomForest” function from the “randomForest” package. The function is set to generate 1000 decision trees and calculate the variable importance. For each iteration, the data are randomly split into training and test data sets with a ratio of 9:1, respectively. The RMSE and R squared are selected criteria of the regression quality. A box plot of variable importance is plotted with %incMSE indicator values from iteration, and each variable is ranked according to its median importance value.

This research also compares the prediction outcomes of random forest regression and linear regression with 10-fold cross-validation. The regression accuracy is compared 100 times. For each iteration, the data are randomly split into training and test data sets with
a ratio of 9:1, respectively. Then, both random forest and linear regression are performed on the same data sets. After the regression, both R squared and RMSE are calculated for each method and compared to assess the prediction accuracy.

4. Results
4.1. Descriptive Statistics

This study presents the findings of a descriptive statistical analysis of the data set (see Table A2) to reveal the data’s essential characteristics and distribution. Validity analysis, correlation analysis, a single-sample t-test, difference analysis, and frequency analysis are examples of analysis content. This questionnaire looks at dimensions. As the score increases, the quality of the digital sculpture attribute improves. The lower the score, the greater the preference for physical sculpture. Based on empirical investigations, a sample is deemed to adhere to a normal distribution when the absolute values of skewness and kurtosis are both below 3 [88]. The variable data’s skewness and kurtosis satisfy the necessary criteria and are suitable for subsequent analysis.

The heat map (left) depicts the average rating of the senior team (A) and youth team (B) in each evaluation dimension. The heat map (right) depicts men’s and women’s average ratings on each evaluation dimension.

Higher scores are shown in Figure 5 for colour variety, colour saturation, social, and texture, indicating that participants recognise these characteristics of digital sculptures. The lower colour temperature, symbolism, and reflective colour scores indicate that participants are more aware of these physical sculpture attributes. On most evaluation dimensions, there is little difference in scores between men and women, but there are some differences on some specific dimensions. Women, for example, may give higher ratings on specific perceptual or aesthetic dimensions (e.g., “color variety” or “emotion”). In contrast, men may give higher ratings on technical or structural dimensions (e.g., “complexity”). Digital sculptures received higher scores from the youth team (B), particularly in dimensions such as depth, complexity, emotion, and value. Furthermore, almost all groups scored low on touch, indicating that there is a significant difference in touch between digital sculptures and physical sculptures.

![Figure 5. Average ratings by team and gender.](image)

4.2. Validity Analysis

Validity pertains to the extent to which psychological and behavioural attributes can be precisely assessed through the utilisation of a scale or test instrument. In other words, it denotes the precision and dependability of the test outcomes. As the significance level of Bartlett’s sphericity test decreases to $p < 0.05$, the probability increases that the original variables have a meaningful relationship. The KMO value contrasts basic and partial correlation coefficients between items; it ranges from 0 to 1. A correlation between the data is indicated by the Bartlett sphericity test statistic with a significance level of 0.000 < 0.01 and a KMO value larger than 0.6. The results of the correlation analysis and descriptive statistics are displayed in Table 2.
Table 2. KMO and Bartlett’s test.

<table>
<thead>
<tr>
<th></th>
<th>Kaiser–Meyer–Olkin Measure of Sampling Adequacy</th>
<th>Bartlett’s Test of Sphericity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Approx. Chi-Square</td>
<td>df</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kaiser–Meyer–Olkin</td>
<td>0.623</td>
<td></td>
</tr>
<tr>
<td>Measure of Sampling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adequacy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bartlett’s Test of</td>
<td>228.212</td>
<td>105</td>
</tr>
<tr>
<td>Sphericity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For data collection, the questionnaires in this article rely on personal self-reports. Each questionnaire is completed by a solitary investigator, potentially resulting in common method bias [89]. Consequently, a homologous variance test was performed utilising Harman’s single-factor test method [90] to ascertain whether or not it had an impact on the research findings. The process involved extracting factors with eigenvalues greater than one. The data test results, as presented in Table 3, indicate that the first principal component accounts for 23.568% of the variation, which is below the threshold of 40%. Consequently, it is postulated that this article does not contain any substantial common-method bias.

Table 3. Total variance explained.

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial Eigenvalues</th>
<th>Extraction Sums of Squared Loadings</th>
<th>Rotation Sums of Squared Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total % of Variance</td>
<td>Cumulative %</td>
<td>Total % of Variance</td>
</tr>
<tr>
<td>2</td>
<td>1.884</td>
<td>12.558</td>
<td>36.126</td>
</tr>
<tr>
<td>3</td>
<td>1.535</td>
<td>10.235</td>
<td>46.361</td>
</tr>
<tr>
<td>4</td>
<td>1.263</td>
<td>8.417</td>
<td>54.779</td>
</tr>
<tr>
<td>5</td>
<td>1.145</td>
<td>7.634</td>
<td>62.413</td>
</tr>
<tr>
<td>6</td>
<td>0.972</td>
<td>6.479</td>
<td>68.892</td>
</tr>
<tr>
<td>7</td>
<td>0.879</td>
<td>5.862</td>
<td>74.754</td>
</tr>
<tr>
<td>8</td>
<td>0.737</td>
<td>4.915</td>
<td>79.669</td>
</tr>
<tr>
<td>9</td>
<td>0.695</td>
<td>4.633</td>
<td>84.302</td>
</tr>
<tr>
<td>10</td>
<td>0.601</td>
<td>4.009</td>
<td>88.311</td>
</tr>
<tr>
<td>11</td>
<td>0.551</td>
<td>3.675</td>
<td>91.986</td>
</tr>
<tr>
<td>12</td>
<td>0.452</td>
<td>3.012</td>
<td>94.999</td>
</tr>
<tr>
<td>13</td>
<td>0.341</td>
<td>2.274</td>
<td>97.272</td>
</tr>
<tr>
<td>14</td>
<td>0.227</td>
<td>1.513</td>
<td>98.786</td>
</tr>
<tr>
<td>15</td>
<td>0.182</td>
<td>1.214</td>
<td>100.000</td>
</tr>
</tbody>
</table>

Extraction method: principal component analysis.

In executing a one-sample T-test [91], the applicability is identified by the following: ① a disparity existed between the prescribed test value and the mean value of a solitary variable that is statistically significant, with the significance of the difference between the sample and aggregate mean examined twice; ② significance test of the difference between the sample and mean.

A one-sample T-test was performed (Table A2), and the test value was 3 (neutral), among which the significance of b. depth, c. complexity, d. colour saturation, e. colour variety, h. texture, k. imaginativeness, n. social and formal–perceptual attributes, content–representational attributes, and value attributes is less than 0.05, a significant difference exists between the aggregate mean and the test value of 3, and the mean is in excess of 3. Therefore, at the 95% confidence level, subjects prefer digital sculptures in the aspects above.

On the contrary, the significance of reflective colour and touch is less than 0.05, a notable disparity exists between the overall mean and the test value of 3, and the mean value is also below 3. These results suggest that the subjects fall within the 95% confidence interval with respect to the aforementioned aspects. They consist primarily of conventional sculptures.

Finally, the significance of visual harmony, colour temperature, abstraction, symbolism, emotion, and value is greater than 0.05, suggesting no significant difference between a test value of 3 and neutrality. The subjects had little to no preference for digital or corporeal sculptures in the aforementioned respects.
4.3. Correlation Analysis

The nature and degree of correlation between two or more variables are described and analysed through correlation analysis [92]. The correlation between formal–perceptual, content–representational, and value attributes is significant (see Table 4). Each variable’s correlation coefficient is greater than zero, indicating a significant correlation between the subjects’ preferences and attitudes.

**Table 4. Correlations.**

| Variable                          | Correlation Coefficient
<table>
<thead>
<tr>
<th></th>
<th></th>
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<td>Content–Representational Attributes</td>
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</tr>
<tr>
<td>0.634 **</td>
<td>0.267 *</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Figure 6 depicts a correlation matrix heat map that shows the correlation between evaluation dimensions (Pearson’s correlation coefficient) [93]. The correlation coefficient ranges from −1 to +1, where a value of +1 signifies an ideal positive correlation, −1 signifies an ideal negative correlation, and 0 signifies the absence of any discernible linear association. In this diagram, various colours are used to denote the intensity of the correlation; red indicates a positive correlation, while blue signifies a negative correlation.

**Figure 6. Correlation matrix heat map.**

Figure 6 shows a strong positive correlation (0.6) between complexity and imaginativeness, which may indicate that participants believe the sculpture’s complexity is related to the imagination it inspires. There is also a strong positive correlation (0.69) between social value and content–representational attributes. This indicates that participants believe the sculpture’s social value relates to their personal value assessment. In contrast, there is a strong negative correlation (−0.49) between depth and abstraction, which may indicate that the depth of the sculpture is inversely...
proportional to its abstraction in the eyes of the participants. Furthermore, touch has very low correlations with all other dimensions, possibly because touch is a distinct sensory experience compared to other visual aspects of sculpture artworks.

4.4. Variable Importance Analysis

Value judgment is considered the dependent variable in this analysis, while other attributes are treated as independent variables. Non-linear relationships between independent and dependent variables can be captured with the random forest regression method. The results of the variable importance from the iteration are plotted in Figure 7, and the median number is presented in Table 5. The variables with the higher %IncMSE are the more important variables for value prediction. From the plot, the variables with high importance are complexity and social; the moderately important variables are texture, depth, imaginativeness, and abstraction. The variable with little importance is the touch variable. The importance of complexity and social variables is significantly higher than that of the rest of the variables, which suggests that complexity and social variables are really useful in value prediction. The interquartile range (IQR) of those two variables is relatively small, indicating consistent importance across iterations. In conclusion, the value prediction could focus more on the variables of high and moderate importance and pay less attention to the last three variables.

![Box plot of the variable importance with %IncMSE of 14 variables.](image_url)
4.5. Regression Model Comparison

This research compares the regression performance with plots of R squared and RMSE from 100 iterations. The results of iterations are plotted, as shown in Figure 8. The results suggest that the random forest method performs better than the linear regression method. The R-squared value of the random forest regression is around 0.9 to 0.95; the RMSE is around 0.2 to 0.3, which indicates a very high level of explained variance by the model. The linear regression also performed well but was lower than the results of the random forest. The R-squared value of the linear regression is around 0.85 to 0.9; the RMSE is around 0.4 to 0.5. The comparison shows that the random forest regression model is more effective for predicting the art value, offering better performance and reliability over the linear regression model. The result is consistent with the assumption that the value of the artwork and the artefact have a non-linear relationship with their attributes.

![Figure 8](image_url)

Figure 8. (a) The R-squared plot of random forest and linear regression iteration. (b) The RMSE plot of random forest and linear regression iteration.

5. Discussion

We pay special attention to the needs and preferences of the younger generation when investigating the sustainability of artworks. Attracting young people is beneficial for transgenerational inheritance. Expanding the scale and the depth of the young people’s involvement could enable the knowledge, skills, and appreciation of the sculpture art to circulate among the public, which contributes to the sustainable management of the sculpture heritage. Therefore, in the following paragraphs, a comprehensive analysis of our findings from a variety of disciplinary perspectives, including philosophy, psychology, and the humanities, is provided. All these fields revolve around the central concept of the digital transformation of artworks. In this study, we used various methods to compare the differences in 15 artistic attributes between digital and physical sculptures. The research outcomes were inclined towards digital versus traditional statuary, given that the p-value
exceeded 0.05. We noticed the following trends when comparing average ratings across age groups (senior and youth):

a. **Visual harmony:** The senior group rated physical sculptures’ visual harmony slightly higher than the youth group, indicating a preference for the visual performance of traditional sculptures.

b. **Depth and complexity:** These two characteristics have long been studied in art history and are frequently regarded as drivers of beauty and preference [25,58].

c. **Colour saturation and variety:** The scores of the two groups are similar, and there is a general belief that digital sculpture performs better in these areas. These visual-related dimensions received high ratings, reflecting participants’ overall positive assessment of the colour performance of digital sculptures, emphasising the role of advanced digital technology in enhancing the expressive power of artistic works.

On the contrary, touch scores were lower in both groups, particularly the senior group, indicating that most participants thought physical sculptures performed better in terms of touch. The senior group gave higher ratings to physical sculpture abstraction, indicating that they have a more traditional and conservative aesthetic concept. Imagination is at the heart of innovative thinking in digital art [16,94]. According to our findings, digital artworks score higher on this dimension, implying that younger people consider digital artworks with imaginative, fantasy, or surreal content more creative.

This research also demonstrates that the digitisation of the sculpture is adequate in maintaining and presenting their cultural spirit. Although the digital copy cannot replace the original sculpture, our research suggests that the digitised sculpture could effectively present their emotion, complexity, and cultural value. Thus, this research proves that the digital transformation of the sculpture heritage could improve the sustainable management of the heritage. On these dimensions, the youth group scored significantly higher than the senior group, suggesting that they possess a greater capacity to comprehend the sentimental and value-driven manifestations of digital sculptures. An artwork’s emotional appeal is closely related to symbolism, abstraction, imagination [95], and the interaction of personal experiences and values [96]. Emotional associations may be one of the most critical factors in the digital transformation of artworks.

The result from variable importance analysis shows that complexity has the most significant predictive importance on art value among all attributes. The complex structure and sculpture details could present rich stories and symbolism and express diverse themes and emotions. The complex sculpture is also visually appealing and can attract the audience’s attention and appreciation. Moreover, complex sculpture also requires a higher skill level and more effort to complete, demonstrating sculpture value. The social attribute represents unique cultural symbolic significance, which shows the unique characteristics of a country, nation or culture. The sculptures associated with a specific historical event and person are often widely recognised and enjoyed by the public. The second group of important attributes are texture, depth, and imaginativeness. Depth attribute could enhance the three-dimensional effect of virtual sculptures, making sculptures more vivid and realistic, which is highly related to the sculpture’s value. For imaginativeness, artists can convey deep feelings and thoughts, causing the audience to have a strong emotional response when viewing the work.

Those attributes show the advantages of virtual sculpture over traditional sculpture. Virtual sculptures have the potential to present unlimited details in digital space and create complex spatial effects without being limited by physical materials and production tools. Audiences can immerse themselves in specific cultural heritage through virtual reality technology, enhancing their understanding of cultural backgrounds.

Digital transformation is generally a manifestation of integrating art and technology, not just a transformation of art forms. The rise in popularity of digital sculpture reflects the art world’s acceptance and use of new technologies, heralding a significant shift in artistic expression. This integration expands artistic expression and gives artists more creative space and forms of expression. Furthermore, the study’s findings reveal how art evolves in
a changing social environment and how audiences understand and evaluate their times through works of art.

6. Conclusions

The main conclusions that can be drawn from this quantitative research are as follows:

1. This study shows that our improved semantic differential scale based on 15 artistic attributes can effectively evaluate digital artworks. This approach opens up new research avenues for assessing the digital transformation of three-dimensional artworks, especially digital sculptures. Some new dimensions are provided for the digital sustainable restoration of sculptures;

2. Compared with traditional art forms, digital artworks are more popular among young people. Digital artwork is rated higher on attributes such as colour variation (e), colour saturation (d), and texture (h), indicating that it is more expressive. In terms of the sustainable dissemination of cultural heritage, the digital art form has a strong appeal to young people, which is related to its ability to promote the intergenerational inheritance of sculpture art. In addition, digital works reflect stronger social attributes and are more in line with contemporary trends;

3. The research results show that the virtual sculpture successfully demonstrated its artistic value, which demonstrates the potential of digital transformation in cultural heritage preservation. In the transformation, complexity, social, texture, depth, and imaginativeness attributes are significantly related to the value of digital artworks. The assessment of virtual sculpture could focus on those attributes to simplify the assessment process without loss of evaluation performance.

This research could be applied in the fast and simplified evaluation of virtual sculpture and cultural heritage. NFT (non-fungible token) value evaluation is one such potential application. The creation of NFT art based on cultural heritage is expanding fast. Therefore, a large quantity of NFT items takes considerable time and human effort to evaluate. A fast and simple value prediction method could help identify the high value of the virtual sculpture and select the valuable NFT that is connected to the cultural heritage.

Future work is needed to fully understand the implications of digital transformation. First, there is a need to more deeply explore the mechanism by which attributes influence the value of digital artworks. This involves quantitative analysis and experimental research into how precisely attributes shape the appeal and market value of digital artworks. Secondly, artwork evaluation tools need to be continuously improved. Utilising machine learning technology, we can extract and analyse key attributes from a large amount of digital artwork data to establish more accurate evaluation models. Further research should focus on comparing the performance of different machine learning algorithms to find the most suitable technical solutions for art evaluation; Finally, cross-cultural research is an interesting area for the sustainable future. The acceptance and evaluation standards of digital artworks may vary significantly across different cultural backgrounds. Through cross-cultural research, we can understand the preferences and cognitive differences of various cultures regarding colour, texture, and other artistic attributes, thereby formulating more inclusive and diverse evaluation standards. This will help in the global promotion and recognition of digital artworks.

Author Contributions: Y.L. and C.Y. wrote the main manuscript text; Y.L. designed the study; Y.L. and C.Y. supervised the study; Y.L. was the leader of the study; Y.L. and C.Y. analysed ratings; C.Y. and Y.L. conducted the experiment; C.Y. and Y.L. pre-processed the dataset; Y.L. and C.Y. prepared all figures and tables. All authors reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.
**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the privacy restrictions.

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**Appendix A. Questionnaire**

**Table A1.** Art experience questionnaire.

1. How often do you view physical sculptures?
   - Never
   - Occasionally
   - Monthly
   - Weekly
   - Daily

2. What do you value most in physical sculptures?
   - Shape
   - Value
   - Culture
   - Artist
   - Material

3. How do physical sculptures make you feel? (Rate 1–5, 5 being very positive)
   - 1
   - 2
   - 3
   - 4
   - 5

4. How important do you think physical sculptures are in the field of art? (Rate 1–5, 5 being extremely important)
   - 1
   - 2
   - 3
   - 4
   - 5

5. How often do you view digital sculptures?
   - Never
   - Occasionally
   - Monthly
   - Weekly
   - Daily

6. What do you value most in digital sculptures?
   - Technology
   - Creativity
   - Interactivity
   - Visual Effects
   - Artist

7. How do digital sculptures make you feel? (Rate 1–5, 5 being very positive)
   - 1
   - 2
   - 3
   - 4
   - 5

8. How important do you think digital sculptures are in the field of art? (Rate 1–5, 5 being extremely important)
   - 1
   - 2
   - 3
   - 4
   - 5

9. Which form of sculpture do you prefer?
   - Physical
   - Digital
   - Both

10. Which form do you think can better express the artist’s creativity?
    - Physical
    - Digital
    - Same

11. Which form is more likely to move you?
    - Physical
    - Digital
    - Same

12. In the future, which form of sculpture do you think will be more popular?
    - Physical
    - Digital
    - Same

13. In the average week how many hours do you spend making visual art? (Rate 1–5, 5 being very positive)
    - 1
    - 2
    - 3
    - 4
    - 5
Table A2. Descriptive statistics.

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