Determining the Importance of Factors in the Selection of Immersive Technology for Artworks Reproduction

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Abstract

This article explores the peculiarities of using immersive technologies in art. This sphere of human activity is not separated from all the changes that take place in the process of social informatization. As it is stated in the paper, the main information technologies that are commonly used by most art institutions and artists today are augmented reality and virtual reality, which offer a wide range of opportunities to implement their ideas. As for artworks presented in the form of paintings and exhibits, the use of augmented reality prevails here.

The process of selecting a certain technology for the implementation of augmented reality for artwork reproduction is quite complex and related to various factors that influence this process in a certain way. Thus, this study aims to identify and prioritize the most important factors in the expert opinion. For this, the Analytic Hierarchy Process is used. The application of this method has shown good results in solving various problems that cannot be described mathematically and numerically. The obtained data show that the most important factor influencing the selection of a certain augmented reality technology is its cross-platform software. Commerciality, external environment, and access to the Internet turn out to be not significant factors.

Keywords

Immersive technology, art, augmented reality, influencing factor, analytic hierarchy process, connection graph, hierarchical priority model

1. Introduction

In today's rapidly evolving world, we are transitioning from informatization to digitalization, marking a new phase in the development of modern information technologies. The swift progress of information, communication, and digital technologies has underscored the growing significance of immersive technologies. The key advantage of these technologies lies in the ability to fully immerse oneself in a constructed reality, offering additional opportunities to experience and analyze both the positive outcomes and potential adverse consequences of planned actions, as well as simulate the unfolding of future events. The incorporation of immersive technologies has become an essential component in enhancing our perception of the world around us.

In the realm of art, a noticeable trend in recent years is the active shift towards virtualization. One of the reasons was a certain curiosity, the idea of creating a new artistic transmitting platform and attracting more attention. Navigating such a large flow of information became difficult, so they began to create a structured platform for presenting art and cultural objects online. Museums and galleries have contributed to the development of the infrastructure of the online cultural market and brought

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some logic to the chaos created in the Internet with the advent of new technologies, quarantines, and various restrictions.

The main information technologies commonly used by most art institutions and artists today are Augmented Reality (AR) and Virtual Reality (VR), which offer a wide range of possibilities to implement their ideas.

When comparing various applications, it becomes evident that they share similar functionalities and offer a broad array of opportunities for utilizing augmented reality. They are user-friendly, but it's essential to take into account specific nuances in the process of creating objects, such as uploading files and videos in a particular format. Similarly, during the creation of the final project and the attachment of reading markers, external factors such as lighting, perspective, and reflective surfaces need to be taken into account, as the application's camera relies on these markers for accurate recognition. Augmented reality technology in the specialized training of technical specialists during joint training can be used to reproduce the equipment operation in real working conditions, simulate emergency situations, demonstrate structures and processes occurring in complex technical complexes.

A crucial prerequisite for adopting augmented reality technologies is the feasibility of implementation and access to the necessary technological resources. This encompasses the availability of appropriate equipment, established procedures, and compliance with the conditions and methods of their use. Such measures facilitate the visualization of augmented reality objects specific to their organization, enabling the seamless fusion of computer-generated elements with the physical environment.

Today there are 4 types of augmented reality:

- markerless AR is also known as positional AR. The technology uses a compass, GPS, gyroscope and accelerometer to transmit the user's location. This is a form of augmented reality based on notifications from the user's location. It is used for navigation, notifications, and local advertising;
- marker-based augmented reality uses images or objects as a basis for content reproduction. An example is a QR code scanned by a smartphone. The interaction between the device and the image tells AR technologies when and where to transmit the content. After scanning a special image in the museum, a person will receive, for example, a 3D model of the exposition;
- superimposition-based AR scans the source image for a specific location and replaces it with an augmented image. The key point of the technology is the object recognition. The IKEA app uses overlay-based augmented reality so that users can see how a certain item will look in the room. The technology is also used in the fashion industry, allowing customers to "try on" clothes or shoes without physical interaction;
- projection-based AR involves projecting light beams onto a physical surface, allowing people to see images in the moment. Such holograms are used at concerts and in movies.

Augmented reality has huge potential and many areas of application, therefore, in our opinion, it is relevant.

2. Related works

Immersive technologies, as mentioned above, have already been widely used in various fields of human activity, especially in the manufacturing industry [1]. In the paper [2], the authors describe and indicate that the manufacturing industry is currently experiencing the fourth industrial revolution using interesting technologies of human-machine interaction, increasing the flexibility of real-time knowledge exchange between different processes in the development of the product life cycle management in order to create high-quality and customized products and mass production in the shortest terms of entering the market. The authors emphasize that augmented reality can significantly facilitate knowledge transfer during crucial production stages, including assembly, repair, and maintenance. This paper provides a comprehensive overview of the current literature on the application of AR technology in product assembly and disassembly, focusing on the perspective of maintenance and repair. Each module's functionality in augmented reality is thoroughly examined, accompanied by pertinent illustrations to enhance the user experience on the control platform. The study also delves into potential areas for future research, such as enhancing lifelike virtual interfaces, developing worker behavior recognition, and enabling seamless collaboration and information sharing across various channels within industrial environments.

Another production industry in which immersive technologies began to be used is the architecture and construction industry. Thus, in the work [3], the authors state that information technologies used in architectural and construction design, namely 2D and 3D design, are still very ineffective and reduce the productivity of this industry. These studies have found that many of the critical problems that arise in the design sector are directly related to the inability of the personnel, designers, architects, and engineers to truly test the design before it is executed. In this context, good opportunities for visualization and interaction have attracted the attention of the immersive technology industry.

Immersive technologies are also widely used in the medical field, that is, in the educational process. In the study [4], the authors note that these technologies can help doctors and patients learn the work of the cardiovascular system, supplementing traditional teaching methods. Surgeons are successfully using VR to plan complex operations and AR to facilitate complex interventions with specific hardware and software [5]. One can also see their use in the process of patients' rehabilitation.

In recent years, a significant interest can be observed in the use of immersive technologies in art, which is evidenced by a number of publications and an increase in the holding of purely artistic events using these technologies.

One of the interesting, in our opinion, studies of the use of these information technologies is their use for the preservation of cultural heritage objects and the possibility of their demonstration to all interested parties. Thus, in the work [6], the authors state that cultural heritage materials, such as archaeological sites and artifacts, are an expression of the wealth of humanity in the past. Wars, natural disasters and other negative factors threaten their existence and preservation, due to which many techniques, and technologies are focused on their preservation, documentation, and dissemination. In [7], the information is presented that augmented reality (AR), mixed reality (MR), and virtual reality (VR) have the potential to improve the quality of perception and educational effect of these museums, stimulating users' senses in a more natural and vivid way. Certain hardware allows visitors to enhance the experience of cultural sites by digitizing information and integrating additional virtual cues about cultural artifacts, resulting in a more immersive experience that engages the visitor both physically and emotionally. It is also stated that the digitization of cultural monuments and museums plays a significant role in the promotion and dissemination of culture, and it is now becoming a necessity to meet new societal needs. Works [8] are devoted to the study of the Paleolithic era and the perception of art by people during this period. Thus, this work describes the use of immersive technologies to simulate certain natural conditions of this period for a clearer understanding of how people perceived art, including placement, lighting, sound, and tactility.

In other works [9, 10], the authors analyze and research the use of immersive technologies as a marketing tool in exhibition activities. It is noted that there are discussions about the managerial implications of using augmented reality. At the same time, the authors note that the use of dynamic visual prompts in augmented reality technologies helps visitors to ensure a high level of willingness to pay more, this effect, according to the authors' research, allows to increase the effect of virtual presence.

The authors in their works [10] state that nowadays, the traditional way of holding exhibitions may not always be possible and now this problem is particularly relevant. Human activity has moved more from the physical environment to the digital side. Therefore, nowadays, many museums that keep up with the times are forced to implement computer technologies to attract new visitors and increase interest, and to make the museums themselves more interactive and attractive to visitors. Another problem that museums face is that some objects of exposition can have extraordinary dimensions, be very small, and over time they can also be destroyed. The authors also raise the issue of using augmented reality in the field of calligraphy, but do not address this issue. Therefore, as the authors note, there is a hypothesis that the mobile application can be used as a platform for digital exhibitions of calligraphy. In this way, it is possible to increase public attention to virtual exhibitions and to this field in general.

At the same time, it is obvious that research data and publications on the use of immersive technologies are quite rare, so in our opinion, they need more study.

3. Methodology of using the Analytic Hierarchy Process

The Analytic Hierarchy Process is a systematic approach to decision-making that allows to formulate and evaluate complex problems, compare different alternatives, and determine their priority based on the importance of different criteria and sub-criteria. Proposed by the mathematician Thomas Saaty in the 1970s, the method has gained popularity due to its suitability for solving a variety of problems in management, economics, engineering, scientific research, and more [11].

The main steps for using the analytic hierarchy process:

1. Determination of a problem: The task for which a decision needs to be made is determined. It can be a selection between different alternatives, an assessment of the factors' influence, a strategy determination, etc.
2. A hierarchy construction: The problem is divided into smaller components: criteria, sub-criteria, and alternatives. This forms a hierarchical structure, with general categories at the top and more specific factors at lower levels.
3. Pairwise comparison: Experts compare factors at each level of the hierarchy based on their importance. They use a scale or numbers to express the relative importance of one factor over another.
4. Calculation of matrices of pairwise comparisons: Pairwise comparison matrices are created for each level of the hierarchy, in which each element of the matrix reflects the relative importance of one factor relative to another.
5. Calculation of factor weights: Using mathematical methods such as eigenvalues and vectors, the weights for the factors at each level of the hierarchy are calculated.
6. Synthesis of weights: The weights of the factors at each level are aggregated to calculate the overall importance of each alternative or criterion.
7. Calculation of final results: Total weights help to determine the most prioritized alternatives or criteria in the context of solving the given task.

The main tool that helps to do this is pairwise comparison matrices.

A pairwise comparison matrix shows the relative importance of one criterion or alternative compared to others. The relative importance is expressed in numerical rating that the expert assigns to each element relative to the others. The evaluation can be positive (if one element is more important than another) or negative (if less important). Usually, a scale is used for evaluation, which can be numerical or textual (for example, "very important", "more important", "equivalent", etc.) [12].

Let's consider the main steps of establishing the actual influences between criteria using the analytic hierarchy process:

1. Creating a pairwise comparison matrix: Experts assess how important one criterion is over another for achieving the set goal. This might include questions like "How often is criterion A more important than criterion B?"
2. Using an evaluation scale: Experts use a numerical or textual scale to express the relative importance of criteria. For example, a numerical scale could be from 1 to 9, where 1 means "not important at all" and 9 means "very important".
3. Determination of criteria weights: Based on the pairwise comparison matrix, mathematical methods such as eigenvalues and vectors are applied to calculate the criteria weights. These weights indicate the level of importance of each criterion in the context of problem-solving.
4. Synthesis of criteria weights: Criteria weights at different levels of the hierarchy are aggregated to obtain total weights. This helps to determine the overall importance of each alternative or criterion.

The process of creating a pairwise comparison matrix within the Analytic Hierarchy Process includes the following stages:

1. Definition of relationships between elements: When initiating work with each level, it is essential to establish which elements will be compared with one another. This step involves identifying the specific elements that will be subject to comparative analysis or evaluation.
2. Using a scale of pairwise comparisons: A scale of pairwise comparisons is used to compare the importance of elements. This scale usually has numerical or textual values that express how much

one element is more important than another. The crucial aspect is to assess and determine the degree of relative importance or preference for each element in comparison to others.

3. Pairwise Comparison: To compare each item with the other at the same level. This requires pairwise comparisons. For instance, if there are 5 criteria, a total of 10 pairwise comparisons would be necessary to evaluate the relative significance or priority of each criterion in the decision-making process.
4. Determining numerical scores: For each pair of items, assign a numerical score according to the pairwise comparison scale. These scores indicate the importance of one element over another. For example, possible scores: 1 (or "equal"), 3 (or "slightly more important"), 5 (or "much more important"), 7 (or "very important"), 9 (or "absolutely important").
5. Completing the matrix: Scores for each pair of elements are entered into the matrix. The matrix is square and symmetric, that is, the importance value of element A compared to element B will be the same as the importance value of element B compared to element A.
6. Generalization of scores: Each column of the pairwise comparison matrix is summed, and this sum indicates the overall importance of each item relative to the others.

Once this process is complete, mathematical techniques such as eigenvalues and vectors can be used to calculate the weights of the elements at this level of the hierarchy. Thus, the Analytic Hierarchy Process allows experts to reveal their preferences and relationships between the elements of the analyzed system [13, 14].

4. Research Results

4.1. Determination of influencing factors

As previously indicated, the Analytic Hierarchy Process enables the systematic organization and quantification of diverse elements within intricate and extensive issues. This, in turn, aids in facilitating improved decision-making through the utilization of expert evaluations and thorough analysis. The task of determining the influencing factors on the selection of augmented reality implementation technology for the reproduction of the artwork will be performed. Let the set of factors be the set $i=\{1, 2, 3 \ldots\}$. Let’s select a subset of the most significant factors from them [15].

The commercial factor refers to important aspects of a product, service, idea, or concept that affect its ability to gain popularity and generate the revenue. This factor evaluates how well the product or service meets the needs and desires of the target audience, as well as how competitive it is compared to other offers on the market. In general, it can be said that this factor is complex and includes many aspects that interact with each other. Evaluating this factor helps businesses or organizations make decisions about developing, marketing, and selling their products or services.

The next factor that, according to experts, affects the selection of the appropriate augmented reality technology is the type of markers that refer to objects or features and are used by the augmented reality system to recognize and interact with a real object. This ultimately allows to overlay computer-generated content on a real object that is perceived by users through various devices. This factor is considered quite essential in the existence of an augmented reality system, as it determines how the system identifies, tracks and interacts with real objects and users.

Among the highlighted important factors in the determination of augmented reality technology is the cross-platform factor of the application, that is, whether the application can work on different platforms and devices without significant changes in the code or development. Of course, this factor, in turn, depends on the approach to the development and the specific needs of the project, and in turn, a certain positioning of the augmented reality application on the market.

Another key factor identified by experts is hardware, encompassing several essential characteristics that facilitate the creation and interaction with virtual objects within the physical environment. This hardware component plays a critical role in enabling seamless and effective integration of virtual elements into the real world. Among its main characteristics, which are required for hardware are: the performance of the processor and graphics subsystem; tracking sensors; cameras; displays and other peripherals. These hardware characteristics collectively determine the quality of the AR experience for users. Accordingly, to achieve the optimal level of augmented reality, it is important to consider all aspects of the hardware.

An important factor in the selection of technology for the implementation of augmented reality is the influence of the external environment, and sometimes it is quite significant. The external environment can affect the optical conditions and perception of augmented objects. Another feature is the geospatial context. Some augmented reality applications use geospatial context, so external landscapes, buildings, and other objects can influence the reproduction of augmented objects. Rooms, walls, and furniture can also affect the interaction of users with objects of augmented reality. The social aspect also plays a significant role, some people may feel a certain discomfort if other people use immersive technologies in public places. Summarizing the characteristics of this factor, it can be noted that the external environment has a significant impact on the perception and use of augmented reality. It should also be stated that developers should be attentive to this factor, and users should understand that the quality of technology may depend on environmental conditions.

Another factor that experts identified as important is access to the Internet. Access to the Internet plays an important role in the work of augmented reality since this technology combines the real world with the virtual one using different devices. Downloading or updating content, interacting with other users, and data processing will in turn depend on the reliability and speed of the Internet. Thus, access to the Internet is an important factor that ensures the full and balanced functioning of augmented reality technology.

For clarity, let's assign each a number:

g_1 – commerciality *C*;
g_2 – cross-platform software *CS*;
g_3 – hardware *HW*;
g_4 – external environment *EE*;
g_5 – type of markers *TM*;
g_6 – access to the Internet *AI*.

4.2. Construction of a graph of connections between influencing factors

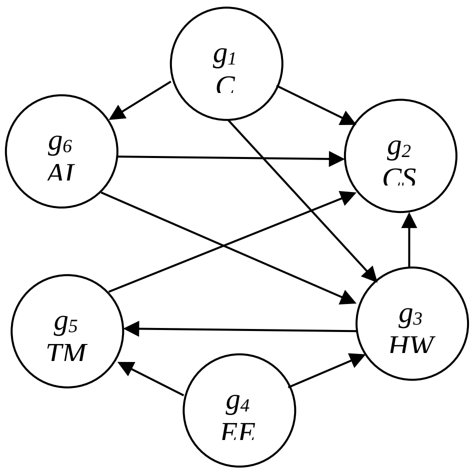

Figure 1: An example of a graph of connections between influencing factors on the selection of technology for the implementation of augmented reality for the artwork reproduction

4.3. Construction of a binary dependency matrix

Based on the above graph, a binary dependency matrix *B* is constructed for the set of vertices G_1 as follows (please, check

Table 1) [16]:

$$g_{ij} = \begin{cases} if\ the\ factor\ i\ does\ not\ depend\ on\ the\ factor\ j, \\ if\ the\ factor\ i\ depends\ on\ the\ factor\ j. \end{cases} \quad (1)$$

Table 1
Dependency matrix B

	C	CS	HW	EE	TM	AI
C	0	0	0	0	0	0
CS	1	0	1	0	1	1
HW	1	0	0	1	0	1
EE	0	0	0	0	0	0
TM	0	0	1	1	0	0
AI	1	0	0	0	0	0

4.4. Construction of the reachability matrix

Using the matrix dependency *B*, the reachability matrix is constructed.

$$(I+B)^{k-1} \leq (I+B)^{k} = (I+B)^{k+1}. \quad (2)$$

Its construction entails the creation of Table 2. Binary elements are determined according to the following rule [17]:

$$g_{ij} = \begin{cases} if\ one\ can\ get\ from\ the\ vertex\ i\ to\ j, \\ otherwise. \end{cases} \quad (3)$$

Table 2
Reachability matrix

	C	CS	HW	EE	TM	AI
C	1	1	1	0	0	1
CS	0	1	0	0	0	0
HW	0	1	1	0	1	0
EE	0	1	1	1	1	0
TM	0	1	0	0	1	0
AI	0	1	1	0	1	1

4.5. Determination of hierarchy levels

The vertex g_i is called reached from the vertex g_j if there is a path from g_j to g_i in the directed graph. The subset of reached vertices is denoted by R(g_i). The vertex g_j is called a predecessor of the vertex g_i if there is a reach of g_i from g_j. The subset of the predecessor vertices is denoted by $A(g_i)$. The intersection of subsets of reached vertices and predecessor vertices will be the subset $A(g_i)=R(g_i) \cap A(g_i)$. The set of vertices for which the specified unreachability condition is performed can be determined as a hierarchy level.

Table 3 is formed with the elements g_i, $R(g_i)$, $A(g_i)$, and $R(g_i) \cap A(g_i)$. For its formation, the numbers of the elements that have 1 are written out from the *i*-th row of the reachability matrix. To form the subset $A(g_i)$, the numbers of elements that have units are written out from the *i*-th column of the reachability matrix. The subset $R(g_i) \cap A(g_i)$ is formed as a logical intersection of the elements of the subsets $R(g_i)$ and $A(g_i)$ [18].

As it can be seen from Table 3, in the first iteration the equality $A(g_i)=R(g_i) \cap A(g_i)$ is performed for elements 1, 4, and 6. These numbers represent the factors of commerciality, external environment, and access to the Internet. The rows with numbers 1, 4 and 6 are excluded from Table 3, and in the second column the numbers 1, 4, and 6 are removed. Thus, the data for the second iteration is received. Similarly, the following iteration levels are determined (Table 4, Table 5).

Table 3
The first iteration level

gi	R(gi)	A(gi)	R(gi) ∩ A(gi)	
1	1, 2, 3, 5	1	1	←
2	2	1, 2, 3, 4, 5, 6	2	
3	2, 3, 5	1, 3, 4, 6	3	
4	2, 3, 4, 5	4	4	←
5	2, 5	1, 3, 4, 5, 6	5	
6	2, 3, 5, 6	6	6	←

As it can be seen from Table 3, in the first iteration the equality $A(g_i)=R(g_i) \cap A(g_i)$ is performed for elements 1, 4, and 6. These numbers represent the factors of commerciality, external environment, and access to the Internet. The rows with numbers 1, 4 and 6 are excluded from Table 3, and in the second column the numbers 1, 4, and 6 are removed. Thus, the data for the second iteration is received. Similarly, the following iteration levels are determined (Table 4, Table 5).

Table 4
The second iteration level

gi	R(gi)	A(gi)	R(gi) ∩ A(gi)	
2	2	2, 3, 5	2	
3	2, 3, 5	3	3	←
5	2, 5	3, 5	5	

As it can be seen from Table 4, in the first iteration the equality $A(g_i)=R(g_i) \cap A(g_i)$ is performed for element 3. This number represents the factor of hardware. The row with the number 3 is excluded from Table 4, and in the second column, the number 3 is removed.

Table 5
The third iteration level

gi	R(gi)	A(gi)	R(gi) ∩ A(gi)	
2	2	2, 5	2	
5	2, 5	5	5	←

As it can be seen from Table 5, in the first iteration the equality $A(gi)=R(gi) \cap A(gi)$ is performed for element 5. This number represents type of markers factor. The row with the number 5 is excluded from Table 5, and in the second column the number 5 is removed.

4.6. Construction of the hierarchical priority model of influences between factors

Based on the results of the previous calculations, we construct a hierarchical model for determining the priority of the influences between the factors of selection of augmented reality implementation technology for the artwork reproduction (Figure 2).

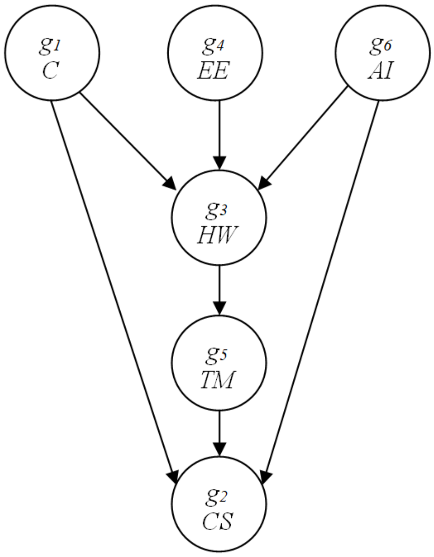

Figure 2: Hierarchical model for determining the priority of the influences between the factors of selection of augmented reality implementation technology for the artwork reproduction

5. Conclusions

As a result of solving the problem of determining the influencing factors affecting the choice of augmented reality implementation technology for the artwork reproduction, a well-structured hierarchical model has been developed (Figure 2). This model clearly demonstrates the prioritization of the factors under consideration. Notably, the crucial determinants in the selection process of augmented reality implementation technology include the type of markers and cross-platform software.

Evidently, the application of the Analytic Hierarchy Process yields favorable outcomes in addressing complex processes that are difficult to describe in the form of mathematical units. Consequently, employing this process facilitates a comprehensive evaluation and prioritization of the factors influencing the selection of augmented reality technology for artwork reproduction.

The research findings serve as a fundamental groundwork for subsequent studies, enabling the validation of the accuracy of the results obtained.

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