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# Advanced Methods and New Materials for Cultural Heritage Preservation

*Edited by Daniela Turcanu-Carutiu and Rodica-Mariana Ion*

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# Preface

This book highlights the efforts of researchers in the field of cultural heritage, including studies of advanced methods and new materials for preserving works of art and cultural heritage monuments.

The integration of science with art in the complex process of analysis, the knowledge and understanding that are necessary to save and protect works of art, and the preservation and restoration of cultural heritage, in general, is provoked by a need of those currently living to leave for the next generation an inheritance of art and culture that is as intact as possible.

The book is organized into three parts: Art Criticism, Intelligent Image, and Advanced Methods for Investigation, each distinct from one another but all with a common goal.

The book begins with a preliminary study of the role of environmental characteristics, including geological, hydrogeological, and geotechnical features, in rehabilitating historical and cultural heritage monuments. It discusses advanced methods, innovative solutions based on nanostructured consolidants, new materials for preservation, and polymer enclosures for protection, all with real chances for practical application.

Chapter 1 demonstrates how art criticism plays a crucial role in art rehabilitation and preservation. Guided tours on art-related topics improve one's artistic taste through visual contact with authentic art pieces.

Chapter 2 describes how optical information can be used to study archaeological objects in order to determine more precisely and noninvasively the characteristics of the shape and color of artifacts. Image-processing tools are used to reveal chromatic features and apparent geometric details. We address the issue of intelligent combining of digital image analysis functions to recognize and estimate possible color and shape evolutions. The purpose of this research is to develop a tool based on passive investigation techniques of artifacts to help experts make the best decisions in the process of authenticating, preserving, and restoring objects.

Chapter 3 addresses the issues that interfere with artistic criticism, biological, physico-chemical analyses, and intelligent mathematical modeling systems, such as Markerless Augmented Reality and 3D reconstruction. It describes advanced technical devices for identifying and stopping the degradation and deterioration of many of the world's most culturally and historically valuable artworks.

Chapter 4 describes the processes of degradation that affect cultural heritage sites, revealing interactions between the chemical characteristics of substrates, the underlying substrate penetration, and the microbiota systems. This chapter presents comparative studies of the conventional techniques generally applied to biodeterioration, such as microbiological cultures, light microscopy, and modern microscopy applications, including epifluorescence, scanning electron microscopy (SEM), and transmission electron microscopy (TEM).

I hope that this book proves to be a useful contribution to the field of cultural heritage.

I would like to give special thanks to all authors that contributed to this book: Tatiana Portnova, Silviu Ionita, Hoshang Kolivand, Abdennour El Rhalibi, Sarmad Abdulazeez, Pisit Praiwattana, Verginica Schroder, Adina Honcea, and Rodica-Mariana Ion.

**Daniela Turcanu-Carutiu**
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Section 1

# Introduction

Chapter 1

# Introductory Chapter: Environmental Characteristics of a Dobrudja Famous Archeological Monument

*Daniela Turcanu-Carutiu and Rodica-Mariana Ion*

## 1. Introduction

Assembly, dated IX–XI centuries is located in a hill of chalk cliff into a Roman career style, with churches, galleries branched vaults, housing the tombs [1]. Facings are inscribed with symbolic designs and different scenes and a large number of inscriptions. Some of these are palaeoslavonic and Cyrillic and some are written in Glagolitic or in Greek, but mostly in an enigmatic writing that could not be decoded so far [2, 3] (**Figure 1**).

### 1.1 Monument characteristics

After the discovery, in 1957, the assembly elements were partially crushed and the rocks have been repositioned in a structure of reinforced concrete and cement mortar. A protective building of concrete has been built for more than half of the site; the rest remained under provisional protection of wood and tar paper. These constructions have not assured proper microclimate, especially in the facing incised [4].

The monument is in an extremely critical situation, taking into account the sensitivity of the chalk rock; it was accelerated and damaged after the assembly discovery. For this reason, it is imperative exceptional measure for protection.

Since 1960, construction of a permanent building protection was expected to protect the whole site in front of adverse weather conditions, variations in temperature and humidity and other factors that could compromise the monument.

Cave monuments are conducted on an area of 2684 sqm. They are protected by a permanent building, on an area of 924 sqm. This construction is made of reinforced concrete with a roof inclined at 30°, applied to the building built between 1971 and 1974. The remaining 1760 square meters were covered with a temporary protection structure made of wood and reed, covered with tar paper. This construction was supposed to protect the monuments of rain, snow, wind and also of changes in temperature and humidity.

Currently, the wooden structure of the building was repaired under provisional protection, and cardboard asphalt was replaced with polycarbonate enclosures in summer 2006 (**Figure 2**).

The church monuments carved in the Chalk Mountain was strengthened in broken or degraded areas by frost infiltration in reinforced and enamel-coated concrete. Cracks that have been injected with cement and sand mortar have a dark gray appearance on the chalk surface, like a splash.



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**Figure 1.**
*The interior of the churches and crosses, figures incised in the chalk wall.*

**Figure 2.**
*Provisional protection structure.*

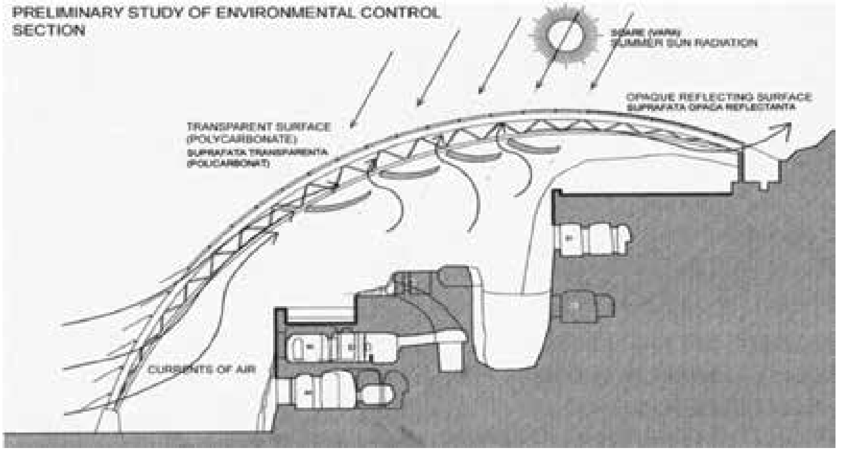


**Figure 3.**
*The scheme of the polycarbonate enclosure.*

The original protection plan, of the 1960s, of the monument building was carried out along of the chalk mountain, covering all caves, divided into seven sections corresponding to the monument's interest areas, respectively to the caves. Unfortunately, this project was interrupted, from a bad administrative conjunction. Since 1989, the project was revived to achieve (**Figure 3**). In 1994, they started provisional construction works for rehabilitation, with a progress noted especially in steep 2009. Currently, culvert was repaired to prevent rainwater from drain the entire downstream side directly inside the monument site. The roof still shows degraded areas. Since 2010, the monument is only in the scientific researches of specialists and prestigious experts for finding an interdisciplinary rehabilitation solution.

## 2. Experimental part

The investigations proposed are:

1. evaluation of the characteristics of rock samples by laboratory analysis;

2. determination of compressive strength of fresh and altered rocks;

3. mineralogical analyses for monitoring the extent of alteration area inside and surrounding of area of interest; and

4. determination of freeze-thaw durability.

### 2.1 Geophysical measurements

By geo-radar measurements type, a picture of the structure of the subsoil, especially when settling land, has been obtained.

The electrometric method "electric survey vertical" (EVS) and a gravimetric method have been used. The following measurements have been done: the presence of the fluid in saturated or unsaturated rocks, porosity and permeability of rocks, freeze-thaw durability, chemical content of fluids in rocks from the basement, resistivity changes due to different chemical and physical conditions.

Also, the chalk massive structure, changes in the structure and uniformity, the presence of voids, or areas of vulnerability may offer important information.

Geophysical work program should have the following objectives: geophysical detail to the foundation of the old and new buildings; geophysical detail of the state geological massif chalk in the archeological monuments; geophysical characterization of chalk massif state; geophysical permanent control of water accumulation condition in career; geophysical investigation to establish the area hydrogeological conditions; and investigations of the geophysical and hydrogeological conditions in the warehouse waste.

A total of approximately 150 EVS locations with investigating depths from 30 to 150 m, made with different equidistance, were performed according to the degree of detachment determined by the frost-freeze procedure for chalk pattern for 20 series, which were analyzed by repetitions: dry at 105°C to a uniform mass (M 1) for an hour, submerged 15 min in distilled water, removed from the water, cleaned with a damp canvas, dried up 3 h at 20°C and measured (M 2). After that the samples have been introduced into the freezer for 2 h at −18°C, taken off and immersed in water, thawed, and after that chalk samples are weighted (M 3), [5–7].

Deteriorated chalk measurement was estimated with the formula: % μg = (M 2 – M 3/M 1) × 100, where μg is the freeze factor [8, 9].

The examination of thin petrographic sections, is carried out with a microscope like Leitz polarizer, which is very useful to characterize properties of structure, minerals, cement composition, and the digenetic characteristics of the sample, and then explored with a polarized microscope.

*2.1.1 From hydrogeological point of view*

The proposed investigations refer the groundwater conditions' hydro-geological site near the monument, water accumulation in career and possible leakage of leachate to landfill career. For all these, it has been achieved six boreholes to depths of 15–20m, located outside the site with research role (**Figure 4**). Except these, the chemical analysis of pre-elevated water from drilling and the analysis of physical properties of the materials present in drilling have been achieved.

The obtained results are as follows: porosity—0.5–13.5%; and degree of saturation—ratio between natural humidity (Wn) and the humidity of the same rock but saturated with water (Wsat). In our case, this parameter has the value of 0.3–0.994; density: 2.55 kgf/dm$^3$; apparent density: 1.9–2.8 kg/dm$^3$; and strength = 30 kg/cm$^2$ (**Table 1**).

## 2.2 Petrographical and mineralogical analysis

From the compositional point of view, the piece of chalk is a limestone, which is characterized as a biological clay, containing a multitude of limestone sediments, porous with small granularity and extremely fragile. The chalk sample has an organogenic chemical composition consisting of calcium vaterite and mineral clay, with a chemical formation comprising iron oxides and sediments. The wall is composed of calcium carbonate in a proportion of 90% and silicon dioxide [10]. In some places, there are traces of shells and shells of mollusks and ostracods, foraminifera, radiolar and diatomee, sponges of spongiers and radiolars, as well as crushed animal bones. Analysis of petrographic microscopy confirms that vaterite is generally unstable, except that it becomes stable below 10°C when the framboid is present inside the organic structure in the presence of $CO_2$ [11]. These framboid is in fact a conglomerate of smaller, especially spherical elements, having a dimension size varying between 36 and 150 nm [12, 13] (**Table 2**).

**Figure 4.**
*The photo of naos.*

| Sensor location | Relative humidity | | | Temperature | | |
|---|---|---|---|---|---|---|
| | Minimum (%) | Medium (%) | Maximum (%) | Minimum (%) | Medium (%) | Maximum (%) |
| 1/inside | 49.9 | 68.5 | 75.8 | −1.0 | 6.5 | 17.4 |
| 2/inside | 65.7 | 77.4 | 95.9 | −1.5 | 6.8 | 18.2 |
| 3/inside | 63.7 | 83.2 | 90.9 | 0 | 4.8 | 11.7 |
| 4/inside | 55.4 | 77.4 | 96.2 | −2.2 | 6.8 | 17.7 |
| 5/inside | — | — | — | — | — | — |
| 6/inside | 67.3 | 84.6 | 100 | −1.2 | 6.0 | 15.8 |
| 7/inside | 63.5 | 82.2 | 97.9 | −2.4 | 6.9 | 19.1 |
| 8/inside | — | — | — | — | — | — |
| 9/inside | 55.4 | 76.5 | 87.9 | −0.6 | 6,5 | 13.9 |

**Table 1.**
*The humidity and temperatures variations for Basarabi church (naos).*

### *2.2.1 Freeze-thaw durability*

When water penetrates through the cracks or breaks of stones or through capillary spaces, it will freeze in winter and the stone will be under great pressure that will cause tearing or splitting, especially if the rock is weak. Chalk stone is considered to be very affected by frost, because it has many empty spaces in its structure, allowing the water to penetrate deep, being a rock with a granular structure with a weak, no frost resistance at all. In combination with these factors, the presence of salt in water, given the generally damp marine environment of the site, easily leads to the disintegration of the rocks [14, 15] by lowering the frost, generating longer periods of thawing, which lead to the creation for longer periods of moisture absorption. This test method has no absolute value but is a variable that provides an indication of frost and thaw resistance, so it does not serve as the only basis for determining the durability of rocks [16, 17]. After the completion of 20 cyclic frozen-thawed series, the weight loss of the samples was determined as shown in **Table 3**.

| Elements | Internal (ppm) | External (ppm) |
|---|---|---|
| Aluminum | 554 | 196 |
| Strontium | 317 | 496 |
| Calcium | 94,700 | 96,700 |
| Barium | 1.00 | 16.00 |
| Manganese | 169 | 217 |
| Iron | 379 | 116 |
| Magnesium | 132 | 1304 |
| Sodium | 837 | 1746 |
| Zinc | 2.5 | 82 |
| Copper | 0.3 | 3,5 |
| Potassium | 529 | 127 |

**Table 2.**
*The elements' focus inside and outside the church (minor elements).*

| Identification of samples | Initial weight (g) | Final weight (g) | Weight loss |
|---|---|---|---|
| Chalk | 54 | 47 | 7 |

**Table 3.**
*Results of mass loss by cooling and thawing.*

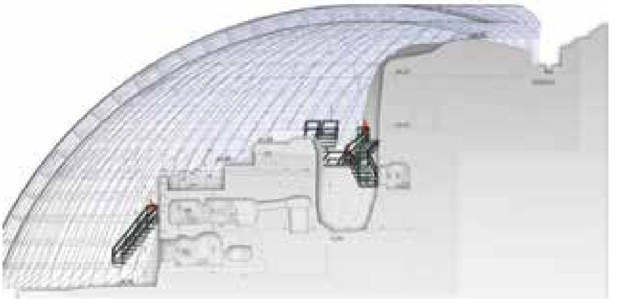

**Figure 5.**
*The section through the Chalk Mountain.*

The viable solution remains with the polycarbonate enclosures, with adequate respiration air flux (**Figure 5**).

## 3. Conclusion

One may conclude that our preliminary study of environmental characteristics and control, geological, hydrogeological and geotechnical is very important for research to rehabilitation of Basarabi Chalk Churches by innovative solutions based on nanostructured consolidants for preserving and polymer enclosure for protection with real chances for practical application.

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## Conflict of interest

None of the authors have any competing interests in the manuscript.

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Section 2

# Art Criticism

Chapter 2

# Excursions and Cultural Heritage in the Contemporary World (Practice and Methodology of Art Criticism Analysis)

*Tatiana Vasil'evna Portnova*


## Abstract

Modern society is characterized by the desire for information saturation. The range of cultural and historical material from which art history excursions are drawn is truly boundless. Meanwhile, if we compare the number of excursions with all their well-thought-out structure, excursions of an art criticism will undoubtedly turn out to be a clear minority. In the fields of the excursion scenario, there are sometimes question marks left by the tourists. Art objects have their own criteria, specifics and features. To understand them and to comprehend them at the scientific and theoretical level is an actual task for art critics and critics themselves. This chapter highlights the problems of modern excursion work as a form of communication, which is a special system, the important elements of which are the author's text, closely associated with the art criticism and the display of works of art in museums and in open spaces.


**Keywords:** guide, art object, visual material, art criticism analysis, methods of updating information, museum collections, storage units, demonstration method, complex display, diachronic and synchronous approaches

## 1. Introduction

The modern world is dealing with all kinds of information, and its art objects can be no longer presented through a purely empirical, descriptive and documentary approach. This representation hinders observations and often makes them subjective. Thus, today's guides aim to display visual materials from a creative and well-targeted viewpoint. Art criticism plays a crucial role in fulfilling this objective. Guided tours on art-related topics improve one's artistic taste through a visual contact with authentic art pieces. They teach the history of culture and society and enrich the knowledge of our reality and its reflection in art, i.e. these forms of aesthetic education are among the most popular and effective. Each piece of art (whether it is a painting, architectural object, drawing, sculpture, handicraft object, etc.) is a kind of magnet that attracts the viewer's attention and forms their aesthetic beliefs. Having completely opposite perspectives, they intertwine and define the functional orientation of art pieces, their ability to reveal themselves in works of art and be explained by these works and the analysis of their fulfilment of particular tasks. Artists usually have them in mind in order to realize their creative ideas. They are driven by a desire to convey something important to their viewers. If one wants to understand the social direction of some art piece, they should enter through this work the viewer's mind and reveal methods of visual perception contained in this work.

## 2. Features of an art-related excursion

From the theoretical and practical viewpoint, there are several types of excursions based on the following classification: art criticism, theatre, literature and music. However, art-related tours are the most popular, widespread and highly demanded. It is an excursion when the audience examines paintings and sculptures in art museums and galleries, as well as architectural, walking and coach tours with a large amount of demonstrated art objects. We should note that architectural monuments are closely connected with their place of origin and historical chronicles of any given territory (country, town or locality).

City sites often comprise architectural objects of various eras, styles and functions. Almost every tour guide has to dwell upon certain issues of architecture and urban development. Handicraft-related tours also demonstrate a wide range of artistic objects. This group of excursions includes open-air ethnographic museum tours that are currently gaining more popularity and acknowledgment. These guided tours reflecting problems of social development are captured in folk art and the handicraft evolution of different nations in the past.

The architectural handicraft heritage comprises objects of architecture, sculptures, frescoes, mosaic and stained glass windows, paintings, stucco, woodwork, lattice, fences, balconies and other pieces of art.

We cannot but mention that objects relating to the art heritage are more attractive and accessible to tourists (people with different backgrounds) in comparison with other forms of art since visual information is easier to perceive. It is better to take into contact with some piece of art, see it with your own eyes and learn facts about it rather than receive this data from books, articles and other literary sources. Besides, an experienced tour guide with vast scientific experience can provide valuable and generalized information that has been gathered from many different sources and synthetized. Each form of art can influence listeners and viewers in the direct ideological or artistic manner. The degree of this impact depends on the tourist's background knowledge, educational level, artistic taste, age and other factors that should be considered in the conducting of tours.

Art-related excursions can be of the following types: sightseeing, monographic (dedicated to creative works of one or more artists), thematic, organized by genre or some other principle.

## 3. The role of an art museum in the structure of an art-related excursion

The analysis of the corresponding artworks is the most significant element of these tours. Thus, it comes as no surprise that the profession of a guide is somewhat similar to that of an art critic due to quite understandable and close ties. Guides find art criticism very helpful because any art tour is based on a comprehensive review of paintings, drawings, sculptures and architectural monuments. This review should be conducted on a high level of art criticism so that each tourist properly understands the message of the chosen work and its value in the modern culture, as well as means and methods used by the author to convey the above-mentioned theme.

While conducting an excursion, a guide should decide what approach to use, i.e. themed, genre-specific, stylistic or forming. As a result, the review deals with different exhibits, with one piece of art involved in several themed tours. The artistic value of a museum's collection or exhibition is the main criterion for selection. Collections of large museums around the globe (including the Hermitage Museum, the Vatican, the British Museum of Art, the Louvre in Paris, New York's Metropolitan Museum of Art, etc.) have a similar nature and quantity of storage units. However, each museum preserves its unique features despite the changes occurring over the centuries and even decades. It is due to not only the funds renewal but also different interpretations of the same exhibits held in a particular museum. Thus, the main difference between the modern Hermitage and the pre-revolutionary Hermitage is the kind of feeling it creates. Today, its exposition halls are filled with the spirit of history. They present the development of cultures and art forms around the world in their specific historical context and through the clash of various art movements. If painting, sculptures, handicrafts and drawings are displayed in a comprehensive way, it becomes possible to study different artistic phenomena of the chosen period in their interconnections. Special attention is paid to the identification of national artistic features expressed in any given country's exhibition. For example, the Vatican museums have been enriching their vast collection of paintings and sculptures with outstanding exhibits for over 500 years. Starting as the city-state and residence of popes in the late fourteenth century, Vatican in Rome has been enjoying the reputation of the treasury holding the best art pieces of the Italian Renaissance. Its vast exhibition of ancient arts (the Ancient Greece and Rome) gives a chance to learn more about sources which formed and developed collections of the Italian art, works of the Renaissance masters (Michelangelo, Leonardo da Vinci, Raphael) and creative personalities of other artists belonging to different epochs. The Vatican museums are major research and educational centres that take into account the scientific work conducted by their employees on the study of collections, organization of exhibitions and lecture conducting.

Founded in 1753, the British Museum (holding about 13 million pieces from around the world, including world-famous masterpieces) is well known for a huge collection of paintings of European artists.

The Metropolitan Museum of Art was opened in a single building in New York. Since 1877, it has stored about 3 million exhibits divided into 19 themed sections.

Sotnikova wrote in her book, "...knowledge accumulated in the museum undergoes moral reflection, beginning to be rethought in the value categories, working on human identity. In this sense, a museum is a temple for a person, and museum communication serves as an off-temple mass" ([1], p. 112).

While demonstrating paintings, sculptures and drawings held in a large museum collection, a guide often has a limited time. On the one hand, a professional usually tries generalizing figurative images and bringing them to a common definition. On the other hand, a guide should somehow deconstruct one-dimensional and homogeneous concepts and reveal their essence through an art review. A special emphasis is laid upon the art context in which a classical piece of art is presented. The system of figurative images necessary for the presentation should also be considered. The search for artistic means to enrich the style and genre is closely connected with the search for imagery that intensifies impressions and impacts. Besides, the art review should cover the best pieces of art and acknowledged masterpieces that are the crown jewel of a museum exposition ([2], p. 512). The Vatican collection cannot be imagined without major images of the *Sistine Chapel* by Michelangelo and Raphael's *Stanze* and marble sculptures by Phidias and Praxiteles praising the human strength and beauty. The Uffizi Gallery cannot exist without Botticelli's "Three Graces", and the Louvre is imaginable without the mysterious smile of the *Mona Lisa*. If a guide does not take into account these factors, tourists can get different impressions from a tour, not those they were expecting. The analysis of an artwork must meet the highest scientific requirements. However, each piece of art should address the tourist's feelings and cause an emotional reaction. According to Fedorov, "By educating the mind, the museum educates the feelings as well, but only the ones of a noble and sacred nature" ([3], p. 391). The depth and authenticity of the reality represented by a painting is a deconstructible, detailed and infinitely diverse continuum. The artistic plane is more abstract than a three-dimensional sculpture and seems to be more coherent. It is a formal model comprising artistic elements associated with the viewer reaching the integrity of their depth. If one takes a look at some painting with certain emotions and lets it stimulate the viewer's attention to the depicted events, they can be perceived as a slice of a real life in its natural course. This feeling is born not only from the authenticity of graphic textures of any given artwork but also from its peculiar composition, the balance of light and colour and the general style of the chosen period. A guide should comment on these components of the artistic image during an excursion.

Sometimes, it is necessary to focus on some aspects of the biography of artists, especially the most renowned ones. For instance, Leonardo da Vinci and Raphael are not just historical figures associated with the time they were living in but also vivid images that continue to live in their artworks. Interested tourists can see all the intricacies of the human soul depicted by these great masters. It is the exact moment when they get familiar with the artist's personality.

The classic art review usually comprises diachronic and synchronous approaches to artworks exhibited in chronological order in museums and art galleries. Thus, Sotnikov describes one of the museum communication schemes and defines it as follows: "the visitor/the history and culture of certain time periods". "Museum exhibits serve as a link that allows for a diachronic (between the cultures of different time periods) and synchronous (between the cultures of regions, ethnic, religious groups, etc.) dialogue of cultures" [4]. This diachronic dialogue corresponds to the position and role of the chosen artworks in the historical art context. The synchronous dialogue analyses pieces of art in their relation as if they are contemporaries. They are regarded as contemporaries since they exist in one chronological period. Various art cultures relate to one another also as old and new ones in conformity with their historical genesis. They are like social and national artistic forces existing at the same time, whose interactions and contacts occur in the same field and are often characterized by a clash of different trends and styles. Since any exposition is not a frozen set of exhibits, it is characterized by "the variable composition", i.e. new exhibits are added and the existing ones are replaced or updated. Therefore, the theme of a guided tour should be clearly defined depending on the location of each museum exhibition that provides the audience with an opportunity to demonstrate specific results of the exhibition display at the excursion end ([5], p. 20).

## 4. Open-air objects in the structure of an art-related excursion

The analysis of three-dimensional pieces of art (including monumental and decorative sculptures, architectural constructions, ensembles and complexes, palaces and mansions, estates and houses, administrative and public buildings) is characterized by its own specific features. They are usually large objects reflecting major historical events. They do not illustrate certain data and scenes but rather conditions and highlights of the nation's memory. These figurative images become symbols and remind of the imagery of medieval icons where images of saints are elevated by graphical and compositional means. Initially, they much more intensely perceive the space in its sculptural or architectural transformation, which creates a fictional world open to reality. The idea of development plays the key role in tours devoted to sculptural complexes and architectural ensembles of Russia. The open, proud and happy feeling of love for one's homeland experienced by sightseers has something primal in its core.

Throughout a walking tour, all the movement thought out and organized by a guide gains exciting randomness of real life where feelings are more important than the mind. Each guide should consider the route around exhibits with fixed vantage points providing a particularly strong impression according to the artist's idea. The perception of exhibits depends on the viewer's open or closed perspective, the distance from which a building or sculpture is observed, i.e. a certain change of near and distant planes is also of great importance. As a rule, a city tour comprises a comprehensive presentation of its individual elements, including squares, streets, ensembles, historical buildings and neighbourhoods. While getting familiar with the urban planning, terrain features, city zoning and landmarks, tourists pay much attention to the integration of the latter into the modern city structure as city-forming factors ([6], p. 247).

Sightseeing tours around ancient cities and cities-reserves usually call for a multi-faceted and complex art review. While demonstrating the synthesis of architectural and plastic arts typical of these cities, guides highlight the leading role of architecture that organizes the space and defines the location and scale of paintings, sculptures and decorative art elements. Special attention is paid to the review of UNESCO World Heritage sites. The art review of three-dimensional objects must include data on archaeology, compositional means and techniques (proportion, scale, contrast and nuance, rhythm, colour, texture, etc.) and the composition nature (front, deep, spatial, etc.).

One more aspect of the art review is the interpretation of presentation and description of landmarks seen through the window of a tour bus and perceived in dynamics. In this regard, it is necessary to consider the speed a tour bus is moving with that leads to a quick change of scenes and objects (e.g. on a city square) requiring compressed information. In case of distant objects, a guide can provide more detailed information although the speed is much higher (on highways) ([7], p. 8). The view available from windows of a bus gets a special meaning. It lets tourists experience the unbreakable integrity of architectural landmarks within the urban environment (for instance, the Hermitage building with the great city). They prove that the Hermitage is the central architectural ensemble associated with significant pages of the Russian history. The scenery outside the bus windows is not just a neutral background as it has its own meaning (e.g. landscape principle in the Russian Orthodox architecture). Both a walking tour presenting three-dimensional objects and calling for a round trip and a sightseeing bus tour dealing with changing consecutive images different from one another eventually form a coherent whole. The dynamics and cinematography of frames-images are the rules that turn sculpture and architecture (static art forms) into "dynamic" ones. The expressive means comprise the physical notions of space and time. To thoroughly comprehend and understand an architectural construction, one needs to walk it around since the composition is based on the perception from many viewpoints within a certain time (a special type of composition can stop the time, i.e. the viewpoint of some building or ensemble remains the same). However, the physical time is inseparable from its artistic manifestation in comparison with the actual time of observation. Evening and night tours using artificial lighting (lanterns, lamps and luminescence) create a special mood.

The impressive look of an object may depend on circumstances. Light distribution and glare tones can completely change the effect of streets, buildings and ensembles. To conduct these tours, guides should think over routes in the context of impressive lighting and play of light and shadow, glares and reflections that create a rather impressionistic mood enriched by other acoustic and olfactory sensations more poignant at night-time. Light patterns of architecture and sculpture fulfil many functions. On the one hand, it ensures the chosen object functions in the visual and expressive context. On the other hand, illumination enhances the impression of authenticity and reality of the perceived object.

Light also plays an iconic role. Using unusual lighting and its expressive functions, guides can express their attitude towards the presented object and reveal the symbolic nature of the most crucial monuments, events, human figures and associated figurative images. Besides, the light atmosphere typical of some city and resembling a theatrical scene is completely visible through large windows of a modern tour bus and often becomes a real highlight of night city tours.

Finally, there is one more significant aspect of thinking over the objects seen and perceived throughout a guided tour, i.e. the ability to concentrate on the matters related to the interaction among artworks, the audience (guided tourists) and a conductor (guide), as well as their direct communication and feedback. An art-related excursion is always the result and the portrait of a guide, and it often addresses some burning issues. Today, these peculiarities are particularly evident since the type of modern guided tours is also changing. Guided tours become not only a form of data presentation but also a place of communication or a theatrical performance where paintings, sculptures, architectural monuments and handicrafts "play" and a guide-interpreter or guide-reviewer acts as a director.

Modern guided tours try going beyond the usual organizational work and the synoptic presentation of trite information. They use various options for structuring the material, analyse numerous objects belonging to the cultural heritage and realize humanistic ideas.

One of these ideas implies humanistic growth throughout a guided tour which is the participant's worldview and is manifested in the process of understanding the world around him ([8], p. 126). Each museum communicates the ideas received by the artist of any given painting or other artworks through their beliefs, personal experience and social background. The environment influences most experiences. According to the innovative understanding of environmental structures, they comprise not only environmental conditions of habitat areas but rather functional aspects of the chosen environment.

The understanding of the environment in the course of a guided tour can be expressed through the description of social and economic conditions which accompanied the creation and presentation of the chosen artwork. To focus the tourist's attention on the environmental object, one should highlight how the object blends with adjacent environmental objects and how its creation and functioning can be useful to overcome functioning errors of the existing cultural and everyday objects. We can conclude that the past of objects in their harmonious development is the key to ensuring the future of a sustainable human lifespan. It is necessary to adopt the basic idea that the object cannot be perceived without its environment. Since a guided tour involves personal influence (e.g. discourse), it would create an inextricable link between the object and habitat in the human mind.

The constant conduct of such activities will create a sustainable development discourse for the formation of an eco-oriented personal paradigm. The art review can stress out the fact that the observation of integrated places in nature reserves and cities separately from the environment cannot focus on the presentation of viewed elements, but their true nature can be truly revealed with the help of the comprehensive presentation approach (synergetic paradigm). In fact, it allows building new tourist routes, offering alternative programmes and increasing the attractiveness of fixed-route tours, as well as their economic viability and the overall profit that will provide opportunities for further development of the analysed area.

The excursion study of art in its development made attempts to elaborate expressive capacities which, to some extent, are analogical and used in the historical excursion programmes. However, live practice of the contemporary art is constantly delivering new unconventional genres and techniques in creation of artistic images, newly synthesizing and interpreting the traits of already established fine and expressive forms habitual for a viewer.

## 5. Principles of scientificity in art-related excursions

The talk about works of pictorial art, sculpture and architecture is often theoretically limited by their narrative side, which decreases the professional content-related analysis. The excursion deprived of informational origin is just a sightseeing, the effective influence of which on the excursionists' minds will be minimal. There is a growing contradiction between the need of the guide to acquire a new content, to give it a new form, and the ability of the excursionists to understand it. The imperfection of the culture of aesthetic perception and incomprehension of specifics of new directions in art lead to the loss of criteria to all the fine artworks regardless of their kind, genre and style, while the uniform standard measures are applied to them.

It defines the main goal of the present paper, which is concluded in understanding of the core of problems, which the modern excursion practice faces. The tasks consist in revelation of possible methods of actualization of scientific information in art excursions; they are considered at all the preparatory stages of the excursion from the definition of the excursion theme to its implementation. Perhaps, the term "scientific information" is not proper by itself if it relates to the works of art. It denotes the acquaintance and study of the objects applied to the actual documentary material. "The advantages of a museum excursion over the other educational forms are concluded in the fact that the objects of perception are the originals, and their range is very wide – from natural monument to piece of art. They have a great cognitive capacity being the reflection of the processes of development of nature and civilization, certain epoch, the destiny of author or the whole folk" [4], Stoljarov noted. Thus, the analytical and exploratory functions of the excursion activities grow. Excursion practice shows that even a small amount of information becomes richer due to the scientific character of the narrative, which organizes the listeners' attention and helps to make its generalizations and conclusions as well as to estimate the artistic objects in-depth. The scientific worldview is in fact the view of the world where the world is interpreted in a certain way. Tight connection exists between the contemporary art and the science, and surprisingly it is exactly the art innovators among which we most often reveal the correspondence of their art tendencies to the scientific commitments of the modernity. Today, we need such form of scientific knowledge transfer which may make the scientific truth available, explicable and clear without deforming it. And here the guides may come to help, who acquire a special power of imagination and are able to include the scientific model and the scientific notion into the range of the imaginative associations and into the symbolical fabric of an art object.

We got used, speaking about the scientific principles in the study of art, to the special terminology, the reference apparatus, new discoveries and researches in the sphere of the content of museum and private collections, activities on revelation of artistic values in the regions of different countries and on nationalization of large private collections and creation of the museum funds, expositional and restoration works, deep scientific analysis of the masters' creative work, cataloguing the pieces of art, etc. forming the infinity of interlocks, the aggregate picture of art studies which denotes the direction of its development to the growing interpenetration of the science and art [9].

In the excursion work, the cognitive theory may be considered not only from the perspective of acquisition by the excursionists of the pieces of art included into the excursion but also from the perspective of the cognitive forms themselves, used by the guide regardless of the conception content of the pieces of art; such consideration suggests a certain procedure between the categories as a certain standard. The cognitive ability of the listeners depends on the professionalism and the narrative skills of the guide. First, imaginative impression from excursion is formed at a certain level of information. Its deficiency does not give the entire image of the object, while the overload may destroy the image. Combination of scientific and imaginative origins is important here not only because every piece of art comes laden with a "solid sense" but also due to the fact that "solid artistic work" should have a certain extent of "lightness" in order to maximally influence the audience. Romanov, speaking about the mission of the guide at demonstration and narrative of the artistic objects, noted that he or she should "introduce the viewers into the aesthetical experience and provide them with the in-depth analysis of the famous piece of art" [10]. It seems that the audience success is the indicator of accuracy of this combination, organically connected with the personality of the guide. The motions of the guide's thought include unexpected associations, bold comparisons and the skill of understanding the inner contradictions peculiar to the information material about the objects. Besides, the motion of thought is the ability to get a view of the dynamics of the programme material in historical perspective and in time. The amazing combination of seemingly incompatible traits contains not less aesthetic advantages than any piece of art, sculpture or architecture. Then, the contact between the guide and the excursionists is based on the feeling of their community where moral and spiritual affinity is expressed.

## 6. Methods of actualization of the scientific material in preparing for and implementing art-related excursions

The methods of actualization of the scientific material may begin with the preparation of the excursion. It is known that general excursion methods consist of two parts—the methods of excursion preparation and the methods of its conduction.

The preparation to excursion may also be considered in two directions: development of new theme for the excursion and preparation of the guide for a new theme. The preparation of excursion is implemented gradually by the stages. It begins from the choice of the theme and the aim of the excursion. Correct statement of the aims and tasks is very important, because everything which will be shown and said in the course of the excursion is subordinated to them. So, in the chosen theme "Mansions of Moscow", architecturally diverse buildings of the Art Nouveau period are one of the integral peculiarities of the historic development of the old Moscow. Having formulated the aims and tasks, the guide should be very well aware that the principle of the material selection and its conceptual organization are a challenge. Then, there is the selection of the object for the excursion. They are selected according to their cognitive value, significance and location. The preferable focus only on the popularity of the piece of art may make the excursion material lighter and more entertaining. The number of the selected objects is also a significant criterion (if it is small, the excursion will be deficient, while if it is too big, then it will turn into amateurism). Any excursion programme should not be a static set of showpieces and objects; it should be characterized by variability of the composition, i.e. addition, removal and renewal of the suggested materials. Any group of excursions has its own classification of the objects. So, in the sightseeing excursions, it is accepted to distinguish the architectural monuments and ensembles, modern buildings, etc. In the excursions of the gardens, parks and country estates, the viewers will see pavilions, statues, grottos and pieces of water. The museum excursion will be devoted to the acquaintance and analysis of the pieces of art.

After the selection of the excursion objects, they are attentively studied, which include live inspection and the literature searches. The work on selection and study of the excursion object is completed by the composition of the excursion route, which can be built on the chronological, thematic or complex principle. After development of the route, the guide goes the round of it, elaborating the route, location of the objects, their accessibility and the parking points and developing the main and additional (reserve) showing points. In the process of the going the round, the timing (of the route) from one object to another is considered for precise calculation of the excursion time. Only after the route is completed, the work on the composition of the excursion text begins. "Excursion text includes introduction and conclusion, consists of the characteristics of the objects and certain material connected with this object, conclusions and generalizations, and logical transfers to the next sub-themes. The control text contains all the precise quotations, facts, numbers, examples and moreover the obligatory references. Individual text of the guide is built in accordance with the methodical development and exactly reflects the real structure of the excursion with the consideration of the time factor. It has the introduction, body and conclusion" [11], as noted by Sichinaeva in the "Excursion Work" publication.

Finally, the preparation of a thematic excursion is completed with the composition of a guidance paper with the excursion route, the places of interest, stops, duration, procedure of the demonstration and the narrative. The excursion text and the guidance paper can be peer reviewed. There is a direct analogy with the methods of scientific work. However, the above said is just the initial stage of the scientific formation of the principles, which are not composed as a finished system which might serve as the indicator of scientificity in general. The methods of preparation to the new excursion themes or the reconstruction of the old by themselves (which is quite natural if to mind the thoroughness, with which the excursion is being prepared) are not scientific discovery or research.

The approach to the material and the interpretation of it is another significant problem which should be primarily solved by the author of the forthcoming excursion. The method for actualization of the scientific information suggests first of all total correspondence of the excursion content to the categories of originality. Scientific knowledge is characterized by the objective truthfulness; it is based on the theoretically or experimentally proven facts and information. Scientific knowledge is also characterized by generality when chaotic and, from the first sight, accidental facts and phenomena hide general and significant regularities of objective world. Notably, the practice of the world art provides us with numerous examples of rapprochement of science and art, which last for centuries. They have numerous guises. Today, they are perceived by far not at the forgotten semantic background. From the mighty force of the abstraction of the Ancient Egyptian pyramids, elaborated structure of the Greek temple's "golden section", beautiful proportions of the "Doryphoros" by sculptor Polykleitos, perfect shapes of the dome of Pantheon, to the rise of the engineering thought in the structure of the Gothic cathedral, Renaissance acquisition of anatomy and linear perspective, optical techniques in the Western Europe painting in the seventeenth century and to the rational substantiation of functionalism in the architecture by Le Corbusier—these are the stages of scientific and creative achievements.

The requirement of the scientificity principle covers not only the content of the material. It should be strictly observed also in the process of its narrative: scientific interpretation of the excursion facts, phenomena and concepts is an integral part of every excursion, not to describe but to explore the pieces of architecture, painting and sculpture on the basis of a certain artistic and historical or contemporary material. The conceptual and artistic potential of the guide's narrative will be sharply reduced if the audience perceives it only at the level of the plot of a book, not comprehending the content of the second, third and fourth layers. However, in the archive of the excursion study, there is a series of the qualities peculiar only to it.

The first and the most simple is visual expression which is not equal to demonstrativeness; it may rise to some complete vision unavailable without natural overlook. The visual basis of any excursion is the excursion objects, serving mostly the centre of the guide's narrative. The excursion objects are the monuments of architecture and sculpture, memorial sites, natural sites, expositions of museums, art galleries and exhibitions. Memorial sites can be squares, streets and whole cities. The visible image of the demonstrated objects and phenomena is transferred through fine and graphical arts, which have an opportunity to imprint the reality in an especially spectacular and convincing manner.

The acutest problem for the guides is the achievement of audial and visual image. In the conducted excursions, visual images often illustrate the guide's text. The result is the illustrating lectures. However, on the way of eliminating this disadvantage, we more often face another extreme—isolation of the text from the narrative. The text does not only comment but even does not supplement the seen. It just indirectly relates to the images passing over the listener's eyes. Here, it is important to achieve the principle of connection of visual and observed with the information and audible origins.

Scientific excursion is not only logics but also the source of complicated emotions. In the conscience of a scientist and any other person having rather a high level of emotional culture, scientific concepts and philosophical truths are coloured with emotions which are hard to describe. Often, not only the information contained in the scientific or philosophical truth but also the feelings that we experience in connection with this information allow us to appreciate the thoughts and to comprehend their depth and significance. That is why a miraculous ability of creative transformation is important, which provides the author-guide with the opportunity not only to "depict" and describe the object but also to think in it figuratively. The engine of the sensuous process can drive the viewer-excursionist to his or her own discovery of the fundamental philosophical concepts.

Another quality of scientific excursion is spiritual community. Any excursion unites audience and provokes the necessity of communication and discussion of the heard and seen. Preparation of a new excursion now requires complex and systematic approach to studying the audience and conduction of certain sociological researches. The deeper the material is comprehended, the acuter the necessity in its discussion is. The guide applying in his or her analysis to the history recalls the past, where not only the historical fact is interesting by itself but also its correlation with the present, which allows achieving more level of generalization.

The pieces of art are perceived not just as a date with the past but as the dialogue with the present and future, whether they are connected with acquisition of new structures and technologies in architecture, new painting methods or sculptural forms. It seems that such scheme has nothing in common with the number of traditionally built pale narratives penetrating in the bulk of the usual excursions. The scientific way of thinking is generally characterized by a unique ability of mediating time with a great degree of credibility, because the science usually outruns the reality be several years. And if our excursion practice is attentive to the spiritual illumination of the scientific world, then it may manage to foresee the intellectual and moral appearance of the future humanity before the other spheres of activities. Penetration into the scientific and creative thought of architectural and other artistic masterpieces may play an important role in it.

The category of wholeness in the structure of excursion is a not-less-important fact and by its nature is close to the reflection and cognition of the world in its completeness. Even if the excursion has a narrow focus on a certain theme, it nevertheless cannot do without touching the issues of interrelation of an artwork and a human, the memorial of art and nature. The guide telling about and showing the memorials of art should illuminate the listeners by the touch with philosophical continuity of the world and the feeling of its penetration in all things existent. Then, the excursionists will transfer into the thinkers themselves; into the discoverers, who become aware of their involvement into the dynamical unity of the world; and into the organics of nature and the stream of the history. Excursions can help in establishing the modern way of thinking which is concluded in the ability to simultaneously see and consider the spiritual, psychological, moral, ecological and economic aspects.

At last, heuristicity is the quality peculiar to the best scientifically built solid excursions. They tune to creative perception of the scientific information concluded in them, develop imagination and suggest not only the ready conclusions but also the questions, stimulating the audience's own search.

It is not simple to organize a good excursion. It requires a perfect skill of the art study speaking, wide associative way of thinking and smart and skilful combination of sober mind with bright emotionality, i.e. requires high professionalism. It is obvious that the "Conclusions of the excursionists are based on not only the seen, but also on the heard" [12]. In-depth analysis of the demonstrated object concept and art core will manifold increase the scientific level of excursion. According to B. Emel'janov, "Professionalism of the guide is a special kind of art, which is built on the active interpretation and smart combination of show and narrative, participation in the perception process of interaction of such components as the guide, the excursionists, and the excursion objects …" [13]. The skill to add his or her own role by the guide to the harmonic correspondence with the system of the emerging unity is also necessary. The guide is at the same time both the actor and the director of his or her own play and role—he should be equally the analysing and reporting organizer of the entire concept and the programme as a whole.

## 7. Conclusion

So, the correct solution of the problems connected with the methods for actualization of scientific information in the art excursions has not only a great cognitive but also great methodological value. It is like a focus where such key issues and categories for excursion and art study gather as objective and subjective, emotional and intellectual and reality and imagination.

Thus, the methods for actualization of scientific material in the structure of excursion and art study programme, their key components and the mechanisms of interaction with aesthetic, social and cultural and ideological context are the necessary conditions not only for studying the history of cultural monuments and artworks but also for solution of practical tasks of efficient application of it in the excursion process as a whole. Integration of science and art is provoked by the persistent live necessity of creating the united and entire scientific picture of the world, correspondent to the modern level of the accumulated knowledge.

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## Section 3

# Intelligent Image

Chapter 3

# Intelligent Image Processing and Optical Means for Archeological Artifacts Examination

*Silviu Ioniță and Daniela Țurcanu-Caruțiu*

## Abstract

This chapter describes how optical information and advanced image processing can be used to study archeological objects and artworks in order to determine more precisely and noninvasively the characteristics of the shape and color of artifacts. The purpose of this research is to develop a passive experimental technique for artifact investigation to help human experts make the best decisions in the process of authenticating and preserving-restoring objects. The method used is digital capture of object images followed by processing them with specialized software tools to analyze the chromatic characteristics and apparent geometric details. The proposed methodology consists of intelligently combining digital image analysis functions to build a set of chromatic-structural features useful for recognizing possible differences and estimating color and shape evolution. The investigation of the artifacts through digital image processing is a noninvasive and precise complementary method of analysis that can reduce the costs, and it must be extensively integrated into decision support systems for experts and curators in the field of artistic heritage preservation.

**Keywords:** digital image analysis, artifact authentication, conservation-restauration

## 1. Introduction

Conservation, restoration, and authentication of artifacts are activities performed by human experts using a multidisciplinary set of knowledge and corroborating information obtained through advanced investigation techniques. In general, human experts rely on their own skills of recognizing the composition of works of art using complex cognitive processes of interpretation of forms, colors, and textures in correlation with information about the technique of realization of the work being analyzed. Artifacts are important and valuable in their appearance, but this is affected by the passing of time, environmental physical parameters, as well as other natural or man-made causes. In current activities of authentication, conservation, and restoration, human experts are increasingly being helped by technical methods involving invasive and noninvasive analyses.

Optical information provides essential data about the appearance of objects and plays a major role in classifying them. The apparent representation of objects is perceived by the visual system through shape and color features. The shape of an object is determined by the spatial relationship between the points defining its visible surface, while the color of each point is determined by the punctual interaction of the object with the optical radiation in the external environment. Between these two basic features of objects, there is a univocal relationship, meaning that the shape of objects can influence the perceived color, but not vice versa. The shape and color of objects can be assessed generally by geometric measurements or photometric techniques. Experimental methods are most effective in obtaining data to the extent that they do not affect the artifact. Optical scanning is a passive experimental technique, considered noninvasive, excepting the particular situations where artifacts may deteriorate due to exposure to light.

Based on the optical methods, quantitative and qualitative analyses can be made on the shape and chromaticity of artifacts of any kind such as distinct archeological pieces, stamps, paintings, and other forms of decorative art like mosaics, engravings, embroideries, and artistic upholstery. Image analysis models include special mathematical functions for calculating conventional measures to characterize shapes and parameters for color evaluation. Digital image processing is widely used in everyday life with many applications in the industry, health, transport, telecommunications, social security, and military. This chapter discusses the applicative features of digital image processing in the field of artistic and historical heritage protection by proposing complementary image-based analysis techniques for a better investigation of artifacts. The concepts discussed are supported by some applicative examples. The scientific purpose of this methodology is to obtain a relevant structural-chromatic set of features for an artifact at a certain time.

## 2. Fundamentals

### 2.1 The basics of colorimetry

Color is a perception of the surrounding world through our eyes. It is the most important graphic attribute of the images. Color is a notion that is defined from several perspectives as follows [1]:

i. *Physically*: the color represents electromagnetic radiation in the optical (visible) spectrum between 375 and 760 nm, which are normally selective stimuli for retinal cones. The color of an object is given by the radiation components of the visible spectrum that are reflected by the surface of the object (the other components being absorbed).

ii. *From a psychophysical point of view*: color is a characteristic of light that allows two fields of the same shape, size, and structure to be distinguished in the visible spectrum.

iii. *From the psychosensory point of view*: regardless of the stimulus used, any light sensation is characterized by certain properties or chromatic factors: illuminance or brightness, chromaticity or hue, and saturation or purity.

Objects that make up an image can be achromatic (no color, i.e., invisible) or chromatic (colored). For example, the white light is achromatic, and white, black, and gray are neutral colors also considered achromatic. The chromatic colors are those that reflect the nonselective sunlight or artificial light, that is, it reflects equally all the lengths of electromagnetic waves visible to the human eye. In this category are the white, black, and all the hues between them (shades of gray).

These last mentioned colors are distinguished by one characteristic feature: brightness (illuminance).

*2.1.1 Color properties*

Color properties are defined in relation to human visual perceptual capacity and sensory psychic mechanisms. As components of light, colors have three basic features as follows.

a. *Brightness or luminance*—represents the degree of intensity or amount of radiation energy reflected by a particular color. From the physical point of view, this property is determined by the amplitude of the light wave. Thus, bright colors reflect more light than dark ones. The brightest color is white, and the least bright is black. Generally, the colors at the edge of the visual spectrum (blue, purple) have a lower brightness than those at the center (yellow). A chromatic color is even brighter the farther away from the black.

b. *Chromatic tonality* is the attribute that refers to the qualitative perceptual scale of a color. Physically, it is given by the predominant wavelength of the light that stimulates the visual analyzer. Thus, chromatic tone refers to the colors red, yellow, green, and blue, leading to their particular attributes like bluish-green, bluish-greenish, white-yellowish, etc., also called chromatic tones or hues. From a physiological point of view, the human normal eye discriminates between 2 and 5 nm of the wavelength of light radiation, thus being able to perceive numerous chromatic tones or color hues [2]. A classic experimental study reported since 1923 by Laurens and Hamilton quoted in [3] reveals a nonlinear distribution of wavelength discrimination between 0.25 nm and 7 nm across the visible spectrum range. According to [2], for instance, on the wavelength range of 760 nm (dark red) and 390 nm (violet), between 130 and 200 chromatic tones can be normally distinguished. These colors form color families arranged around the components of the chromatic spectrum, as follows: red has 57 distinct hues, orange 12, yellow 24, green 12, blue 29, and violet 16. In total, they make up to 150 perceptible shades; this number being also referenced by [4].

c. *Saturation* is the purity or degree of blending of a color with white (total blending wavelengths in the visible spectrum), which gives the color to be more concentrated or pale (saturated). The color saturation is evaluated on a conventional scale of the distances at which a particular chromatic color is given relative to that achromatic white. From a physical point of view, saturation of colors depends on the uniformity of wavelengths perceived concurrently. A theoretically pure color is one determined by a single wavelength, the more we perceive more wavelengths while the color feeling is pale, less pure. If we perceive all the wavelengths concurrently, then we see the white. Due to the saturation property, the colors are classified as "strong" or "poor," "heavy" or "light," "bright" or "dead," and "colorful" or "sad." The saturation level affects the perceived chromatic hue. It is appreciated that by combining different degrees of saturation and roughly 200 chromatic tones, around 1700 chromatic hues can be obtained [2]. Based on physiological evidence and experimental psychology, the capabilities of the human visual analyzer to perceive the colors were estimated by different authors between 100,000 and 10 million distinctive colors [4]. These data tell us how performant should be a digital optical equipment to manipulate hues like humanlike.

### *2.1.2 Primary systems for color representation*

Traditional color classification refers to how to obtain them. As is well known, colors are divided into the following categories:

- *Basic colors* (also called primary or fundamental colors) are those that by mixing them can be obtained all the other colors. These are red, yellow, and blue (RYB). The chromatic pattern to represent images on electronic systems is red, green, and blue (RGB).

- *Composite colors* are those that result from the mixture of base colors two by two. There are composed colors of degree I, colors composed of grade II (which results from the mixture of those of first degree, two by two), and so on.

- *Complementary colors* are those that mixed in appropriate proportions (which are found in the spectrum) give a neutral color (white or gray).

The above description, although conventional, is applicable to the artistic combination of colors, a technique well-known by painters for a long time. In practice, the emergence and development of photographic techniques and subsequently electronic means for processing and displaying images, the color manipulation process required the emergence of specific patterns for representing, capturing and transmitting image information. As chromatic perception is an expression of the reflection phenomenon of light, which is dependent on ambient illumination and the contribution of additional light sources, color representation patterns are found as formal color calculation tools.

The International Commission of Illumination (CIE), a body established in 1913, which through its division for Vision and Color coordinates the development of standards in modern colorimetry, by the recommendation of 1931 defined the so-called standard colorimetric observer proposing two systems primary equivalent color representation [5]. In principle, these are three-stimuli color spaces based on the Maxwell's trichromatic theory [6] in accordance with spectral sensitivities of the human eye.

The *first conventional system* proposed by CIE for color representation is RGB (Red Green Blue) in which color components are wavelength functions as follows: $R(\lambda)$ for $\lambda = 700$ nm, $G(\lambda)$ for $\lambda = 546.1$ nm, respectively, $B(\lambda)$ for $\lambda = 435.8$ nm. The representation of the RGB color space with its combinations is shown in **Figure 1**.

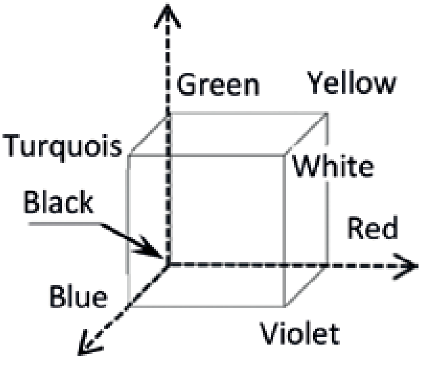


**Figure 1.**
*Conventional representation of the primary RGB space and its chromatic derivatives.*

The *second system* defined by CIE is XYZ whose functions are linear transformations of RGB system components expressed in a matrix form as follows [7]:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.490 & 0.310 & 0.020 \\ 0.177 & 0.813 & 0.011 \\ 0 & 0.010 & 0.990 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \tag{1}$$

*Derivative representation systems* have emerged as a result of the diversification of the technical means of capturing and processing images that required the use of other rules for representing basic components. Thus, color television systems were imposed by NTSC and PAL standards by transforming the primary RGB space into three specific terms: luminance and two chrominance components. For example, for the PAL standard matrix transformation is as follows [7]:

$$\begin{pmatrix} Y \\ U \\ V \end{pmatrix} = \begin{pmatrix} 0.300 & 0.590 & 0.110 \\ -0.148 & -0.291 & 0.483 \\ 0.526 & -0.518 & 0.096 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \tag{2}$$

Another derivative color space was developed by Kodak under the name of PhotoYCC and consists in transforming the RGB reference space into the Luminance—Chroma—Chroma (YCC) components in three steps: a gamma correction, a linear transformation described in matrix, and a binary quantization on 8 bit. This system is used to store images on PhotoCDs.

*Perceptual representation systems* attempt to describe how human observers feel and express colors. Starting from empirical analyzes, it has been observed that people notice very well the properties of colors: brightness, hue and saturation. Perceptual representation systems attempt to approximate, through mathematical formulas, the psycho-physical effect of the three chromatic properties. Basic perceptual system HSV (Hue Saturation Luminance), also known in different versions as HVC (Hue, Value, Chroma), HSI (Hue, Saturation, Intensity) or HSL (Hue Saturation Luminance) is a more complex nonlinear transformation concretized by a rotation of the RGB chromatic space followed by a cylindrical or spherical coordinate transformation. There are several formulas for evaluating the three components of the HSV system proposed by different authors [8]. The generic representation of the HSV perceptual color space in cylindrical coordinates is shown in **Figure 2**. Conventionally, the numerical range for HSV components is the range [0, 1]. The hexagon has sides equal to 1 and is located at elevation V = 1. The conventional position of the white component is at the center of the hexagon, where

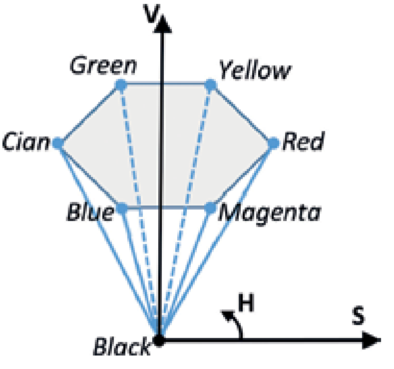


**Figure 2.**
*HSV color space in cylindrical coordinates.*

it is intersected by the Value axis. Thus, the white is not characterized by hue (it is “immune” to the variable H!); it has obvious saturation S = 0, and the value is maximum V = 1. The pure colors have the saturation equal to 1. The hue H is an angular coordinate on 360° and is conventionally represented on the [0, 1] range, so that, each color of the hexagon peaks is at a distance of 1/6 on the definition interval: Red → 0, Yellow → 0.1666, Green → 0.3333, etc.

Alongside the CIE, the International Color Consortium (ICC) is a focus group that promotes new concepts and provides technical notes in the field of color standards and their representation with various techniques and electronic means [9].

## 2.2 About forms and their classification

### *2.2.1 Shape and geometry indicators*

Shape is the outer appearance of an object that does not take into account its size. The shape of objects is perceived by their edges or contours. In a geometric sense, the shape of objects is described by properties that allow a classification of objects according to their appearance. Depending on their form and geometry, objects in nature can fit into a variety of hierarchically organized classes. The hierarchy of shapes is generated by the type of primitive graphics that describe the outline of objects, and their properties: their number and relative position, similarity or congruence so that by customizations or generalizations, very complex forms can be characterized. **Table 1** presents taxonomy of forms that can be used to characterize artifacts.

### *2.2.2 Measures of shape properties*

Shape analysis is based on the detection and labeling of distinct regions on the artifact image. Based on these regions, the objects presented in that image evaluating certain properties commonly called shape measurements are estimated. Software utilities for image analysis provide a broad set of measures that can be used to characterize distinct objects once they have been detected in an image. For example, MATLAB programming environment contains powerful toolboxes for video analysis and image processing. Some of the measures used by MATLAB [10] are summarized in **Table 2**.

### *2.2.3 Shape recognition*

Shape recognition is a decision process that is accomplished by a simple direct comparison action of a sample object with the reference object or by a more complex process of classifying template sets and subsequent reporting of unknown objects to these class sets. In the current work of examining artifacts, it is mostly to acknowledge direct comparison with the original. Here are the typical situations of authentication and restoration-reconditioning of artifacts in which knowledge of exact information about the original is essential.

When looking at artifacts with an unknown author is the question of framing the artwork at a certain time or in an artistic current, then recognition based on classification becomes important.

Comparison techniques include two methods of testing the match between the current object and the original: global matching and mathematical matching (based on significant properties). Global matching is applied based on artifact

| Graphic primitive (base element) | Class | Subclass defined by the number of elements | Subclass defined by relative position of some elements (angles, for instance) | Subclass defined by the similarity of the elements (ref. to sides) |
|---|---|---|---|---|
| Line | Polygons (closed chain) | Triangle | Right triangle | Isosceles |
| | | | | Any |
| | | | Equilateral | Equilateral |
| | | | Any | — |
| | | Quadrilateral | Parallelogram | Square |
| | | | | Rectangle |
| | | | | Diamond |
| | | | Trapeze | Isosceles |
| | | | Right trapeze | — |
| | | Pentagon | Convex | Regular/irregular |
| | | | Nonconvex | Regular/irregular |
| | | Hexa/...octo/... decagon... | Convex | Regular/irregular |
| | | | Nonconvex | Regular/irregular |
| | Open chain | Connected segments | Opened ladders | Regular ladder |
| | | | | Irregular ladder |
| | | | Zigzag shape | Regular |
| | | | | Irregular |
| | | Single segment | Horizontal/vertical/inclined | — |
| Curve | Closed curve | Circle/disc | | |
| | | Circular crown | | |
| | | Ellipse | | |
| | | Ovoid | | |
| | | Cardioids | | |
| | Open curve | Circle arc | | |
| | | Ellipse arc | | |
| | | Parabolic arc | | |
| | | Hyperbolic arc | | |
| | | Spiral | | |
| | | Evolvent | | |
| | | Cubic | | |
| | | Sinusoid | | |
| | | Cycloid | | |
| Combined | Circle sector | | Semi-disc | |
| | Circular crown sector | | Semi-crown | |
| | Ellipse sector | | | |

**Table 1.**
*Taxonomic hierarchy of 2D forms.*

images by checking the superimposition of the composite in detail. Matching details involves image processing and extraction of properties that give the artifact uniqueness—called *minutiae*. The calculation of minutiae provides the measures

| Property | Unit | Measure definition |
|---|---|---|
| "Area" | Pixel | Scalar representing the actual number of pixels in the region |
| "Centroid" | Pixel | Vector that specifies the center of mass of the region. The first element is the horizontal coordinate (or x-coordinate) of the center of mass, and the second element is the vertical coordinate (or y-coordinate) |
| "Eccentricity" | — | Scalar that specifies the eccentricity of the ellipse that has the same second moments as the region. The eccentricity is the ratio of the distance between the foci of the ellipse and its major axis length. The value is between 0 and 1 (0 and 1 are degenerate cases; an ellipse whose eccentricity is 0 is actually a circle, while an ellipse whose eccentricity is 1 is a line segment) |
| "Orientation" | Degrees | Scalar representing the angle (in ranging from −90 to 90 degrees) between the x-axis and the major axis of the ellipse that has the same second moments as the region |
| "Perimeter" | Pixel | Scalar measuring the distance around the boundary of the region. It computes the perimeter by calculating the distance between each adjoining pair of pixels around the border of the region |
| "BoundingBox" | — | The smallest rectangle containing the region |
| "Extent" | — | Scalar that specifies the ratio of pixels in the region to pixels in the total bounding box. Computed as the area divided by the area of the bounding box |
| "ConvexHull" | Pixel | Matrix that specifies the smallest convex polygon that can contain the region. Each row of the matrix contains the x- and y-coordinates of one vertex of the polygon |
| "EquivDiameter" | Pixel | Scalar that specifies the diameter of a circle with the same area as the region. Computed as sqrt(4*Area/pi) |
| "MajorAxisLength" | Pixel | Scalar specifying the length of the major axis of the ellipse that has the same normalized second central moments as the region |
| "MinorAxisLength" | Pixel | Scalar: the length of the minor axis of the ellipse that has the same normalized second central moments as the region |

**Table 2.**
*Measure definitions of shape properties.*

of the shape, and these must be known as a priority for the original. Usually, the comparison of artifacts is only at the level of minutiae with the establishment of decision strategies for validating or invalidating the match. The method for the minutiae-based recognition is devoted to biometric technologies, fingerprint recognition, face recognition, scar and tattoo recognition, etc., and is rigorously standardized [11].

Currently, the issue of automatic shape recognition has evolved in the field of artificial intelligence under the generic "machine learning" domain from statistical models toward the "deep learning" paradigm, proving spectacular performance especially in video analytics technology. These models are based on convolutional artificial neural networks that require massive pattern learning [12]. Their performance depends on the increased number of training patterns, while the uniqueness is the characteristic of the artifacts. An automatic pattern recognition system could be trained very easily to recognize a particular artwork of Monet among those of Cézanne, Renoir, or Degas, but he will not be able to learn to distinguish Monet de Monet or Monet from a fake Monet. Definitely, this remains the attribute of the human expert, assisted, of course, by advanced information processing tools.

## 3. Methods

### 3.1 Color software analysis

Automatic image processing tools are based on the interpretation of the pixel value that is designated by the primitive pixel graphics. The value of a pixel refers to its chromaticity and is measured by the so-called color index. An important problem is that the color index is a conventional measure that depends on the type of digital image: color, grayscale, or black-and-white. In general, real object images can be captured as color images in the RGB system and then converted to other image types by conversion or indexing. By indexing, color images require a lower amount of data due to the fact that the three RGB values are aggregated in one, but this involves numerical approximations. Thus, image indexing is done with the loss of original information about the value of the color components. Typically, grayscale and black-and-white conversions are used for image analysis, resulting in so-called binary images. These types of images can also be indexed, considering a gray-level reference threshold. For black-and-white images, there are two default indexing values: 0 and 1. Virtually, all digital image analysis methods apply to preliminary indexed images for which these methods have a degree of relativity and a conventional character. The morphological analysis of the objects, respectively, the forms and the composition of the shapes in a picture is also made on the basis of color, being affected by the weaknesses of this method. Investigating artifacts, however, requires a higher level of precision and the use of analytical tools to provide discriminators in accordance with human visual perceptiveness. We therefore show interest in an intelligent combination of using color-based digital image analysis techniques using both the RGB primary space and the HVS perceptual system.

### 3.2 Structural analysis

The issue of decomposing an image into component objects based on regions (the so-called region-based segmentation) is not trivial because of the ambiguity and relativity of the criteria. The principle of region detection is based on the application of a connectivity criterion for pixels of the indexed or binary image of the studied artifact. However, the method is dependent on the result of the decision about the pixel value, that is, the intensity (level) of gray at the point considered. Therefore, the result of the analysis depends on the enlightenment of the artifact. Some issues specific to the two methods are presented in **Table 3**. Thus, the standard methodology for analyzing forms that make up the artifact's image includes choosing the illumination pattern, setting thresholds for the pixel value selection range, and applying the connectivity criterion based on an adjacent rule of pixels having values in the same range.

| Description | Method | |
|---|---|---|
| | **Color analysis** | **Structural analysis** |
| Principle | Independent | Based on chromatic differences to detect edges |
| Computing effort | Evaluation of the conventional pixel value | Uses more complex algorithms based on filtering spatial light distribution |
| Precision | Accurate numerical evaluations in color space | The result is generally affected by uncertainty |

**Table 3.**
*Comparative aspects of the methods used.*

## 4. Artifacts study by intelligent image processing

### 4.1 Case study 1: tablet from Tartaria

Discovered in 1961 on an archeological site in the town of Tărtăria in Alba County, Romania, the objects known as the tablets from Tărtăria represent three ceramic pieces (made of loam).

The pieces, which were dated around 5300 BC by German researcher Harald Haarmann [13] have similar symbols to the Vinča culture, being the subject of numerous and controversial polemics among archeologists everywhere, since (in some opinion) the tablet is the oldest form of writing in the world. One of the tablets, the one of discoidal form, comprises four groups of signs, separated by lines. It is considered the closest to a true script with ancient symbols. Much of the signs contained in it are found in the letters contained in the Greek archaic inscriptions (but also in the Phoenician, Etruscan, Old Italian, Iberian writings). We have chosen for our study this engraved disc-shaped lenticular tablets with a diameter of 6 cm.

#### *4.1.1 Preliminary analysis of chromatic components*

It started from an RGB-captured image with the resolution 483 × 478 pixels under certain lighting conditions, available on the web [14]. The three-dimensional RGB data structure is accessible by reading the image with an application program and allowing it to be displayed as shown in **Figure 3**. Pixel values in terms of base chromatic components depend on lighting conditions so they include the effect of ambient light and any additional light sources. In this case, we are dealing with a three-dimensional object over which ambient light and especially additional sources produce significant effects on the image obtained. Therefore, we note first that color information is relative and uncertain as long as the exact pattern of illumination is unknown. Secondly, we notice effects on the perception of the real shape of the object and some shape details under the influence of the particular illumination pattern. Thus, uneven illumination, partial shading, glare as the effect of local dispersion on irregular surfaces, and the effect of roughness and texture add uncertainty to the perception of the object's appearance on the basis of optical means.

Under these conditions, the image analysis can be applied with the following features:

i. Under controlled and uniform lighting conditions on stands specific to photometric measurements.

ii. Using multiple images taken from different perspectives on the object.

iii. Performing analysis on image portions with particular adjustment/selection of parameters for the investigated area.

A first quantitative analysis of the color composition in the image can be done with the instrument called the image *histogram* applied to the RGB base components. This is the distribution of the values of all the pixels in the image on each color component. For the studied artifact, the histogram of its image on the three components is shown in **Figure 4**.

It can be easily observed by evaluating dimensional graphs that red is the component with the highest weight, and blue with the smallest. This translates into the brightness (intensity) of the image in planes R, G, and B, as can be seen in **Figure 5**.

*DOI: http://dx.doi.org/10.5772/intechopen.80615*

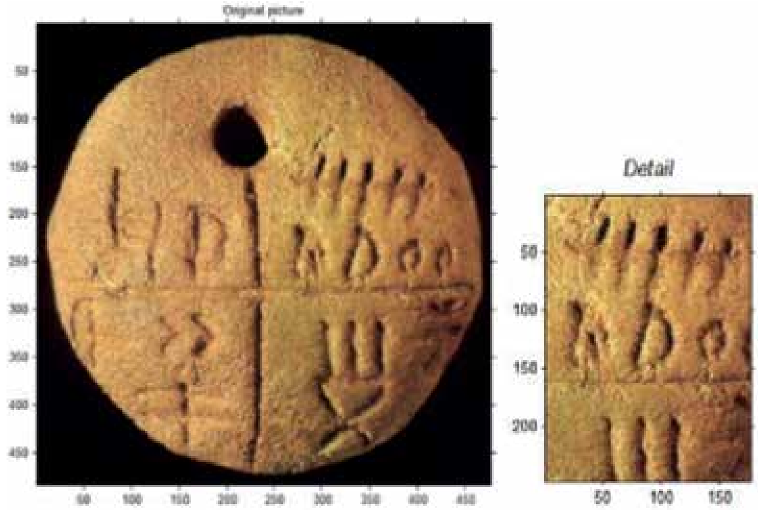


**Figure 3.**
*First tablet from Tartaria. Picture (483 × 478 pixels).*

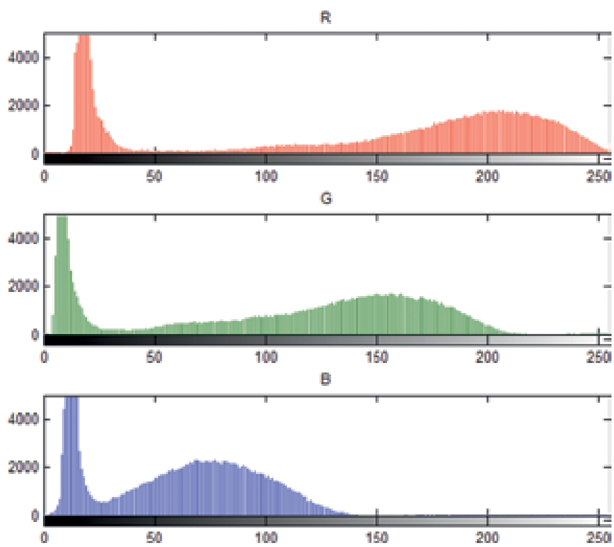


**Figure 4.**
*Histogram of the image on the base components.*


**Figure 5.**
*Images separated on RGB base components.*

Other qualitative information provided by histograms refer to their shape that tells us that the image does not contain pure green and blue components (value 255 is not reached), and their maximum concentrations are grouped at low (below 50), so with relatively low brightness.

Also, the red component is predominantly in relation to the other two at high brightness values (over 200), which confirms the chromatic aspect to the "hot" components of the object in **Figure 3**. It is obvious that in this statistic the pixels in the dark background, which do not belong to the object, also mattered. These can be largely eliminated through a level threshold filter and by matching the object within a suitable round frame. The histogram can be taken into consideration as an element in the formation of the structural-chromatic pattern of the artifact.

The second image analysis is done in the perceptual color space, which reveals the three essential characteristics specific to human visual analyzer: hue or color tones, color saturation or purity, and their brightness or illuminance. To begin with, convert the primary color image into the perceptual color space, for example, in the HSV system. The result of these transformations is shown in **Figure 6** by representing each of the hue, saturation, and value components in the corresponding images. The analysis is useful both qualitatively and quantitatively at the equivalent numerical data calculated by transforming RGB → HSV and interpreted in the coordinate system of **Figure 2**. To begin with, the image is poor in hues, supported by the uniformity of the numerical data of the hue parameter, which are massively grouped in the vicinity of the S-axis, so around the red component. Secondly, there is a saturation of gray-level typical components, the average calculated for the whole image being 0.5826 and a standard deviation of 0.014, which confirms insignificant information provided by saturation. Finally, the value illuminance component provides perceptually the most complete information, comparable to the red image plan (mean 0.5310 and standard deviation 0.0795).

We continue to focus the analysis on a distinct portion virtually cropped from the original image of the artifact, shown in **Figure 3**. The selected portion shows significant details of the artifact and is more uniform in lighting and chromaticity. The histograms in **Figure 7a** show a better concentration of RGB components around the maxima and the disappearance of the low luminance components compared to the histograms of the whole image of the artifact. The hue information H is insignificant, and in this case, the numerical values are very small (mean 0.0891) and the extremely small standard deviation (0.0208). Saturation is slightly higher than the whole image with an average of 0.6311, but the standard deviation is only 0.0103; thus, there is enough information uncertainty, which can also be seen from the S-plane image of **Figure 7b**. Finally, the perceptual luminance component with a higher average than the previous one of 0.6912 and the standard deviation 0.0415 provides the correct information, similar to the chromatic components red and green.

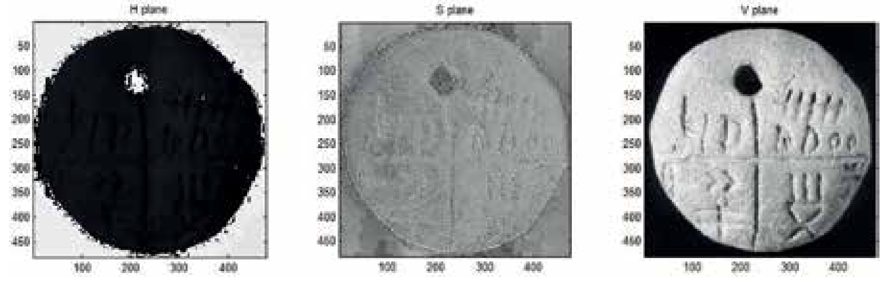


**Figure 6.**
*Image components in the hue-saturation-value perceptual system.*

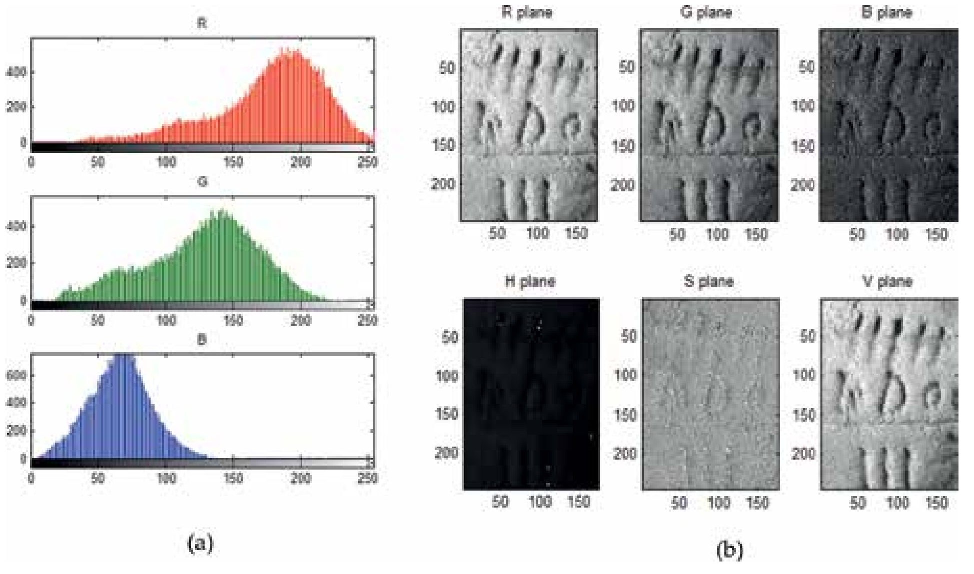


**Figure 7.**
*Color analysis of a detail.*

### *4.1.2 Shape analysis*

For three-dimensional artifacts, estimating forms is a complex problem characterized in most cases by uncertainty. The uncertainty comes mainly from two sources: (i) data accuracy, which in the case of images is affected by nonhomogeneous illumination, respectively and (ii) the lack of specific processing models and algorithms. In practice of authentication and especially restoration preservation, the physical presence of objects is indispensable. However, in the stage of elaboration of the structural-chromatic pattern of artifacts, the extraction of some form characteristics and their quantification may be reliable provided that image acquisition is made in optimal and reproducible conditions.

In the following we will show how to evaluate some shape property measurements for already studied tablet from Tărtăria.

The method involves three steps, which are described as follows:

a. Preliminary processing in the color space by following the next steps:

- The original image is converted to grayscale.
- The image obtained is filtered, for example, by applying, for instance, mediation filter of order 2.
- The new image converts to binary (black-and-white image) based on a threshold of intensity.

b. An algorithm is used to identify pixel regions that enjoy the same property by following the following steps:

- Check the connectivity of the pixels with the neighbors in variant "4-connect" or "8-connect."
- Label the linked regions as the list of component objects of the image.

c. Calculate the different properties of the component objects in the image:

- Additional filters for object selection apply, for example, regions detected on artifact that have a larger area than a required threshold.

- A list of shape property measurements is made.

Thus, for our artifact, after the application of steps (a) and (b), a number of 107 component objects resulted in the binary image of **Figure 8**. These objects were detected as image regions above the conversion intensity threshold, and so all the pixels belonging to them were changed to 1 (white). Therefore, the image is analyzed for brighter areas. In step (c), it was decided to select the objects by filtering according to the Area_object > 200 criterion, and so only five regions corresponding to objects highlighted and numbered in the order of their extraction by the algorithm were retained. These objects are marked in **Figure 8** by their centers of weight designated (see red points) and labels. The list of calculated properties of the five components considered is presented in **Table 4**.

For the analysis of the engraved symbols on the artifact, the darker areas will be those of interest. Therefore, it is necessary to perform a reversal of the binary image by the complementary operation so that the regions of interest (the darker depth) pass into 1 (white) and can be evaluated as in the previous situation. **Figure 9** shows the result of complementing the initial image and marking the detected forms with the position of the calculated center of weight. In the middle image, all regions detected are marked (with blue dot), most of which belongs to light scattering small areas. In the picture on the right, the number of interest regions was dramatically reduced by applying the area filter (Area_object > 200). Most of the parasitic areas were removed, and the remaining ones belong to the symbols of interest and were marked in the red points. It is true that based on the image available for processing, not all of the symbols have been detected. It can easily be noticed that due to uneven illumination, the shaded area on the lower-left side of the image requires separate treatment.

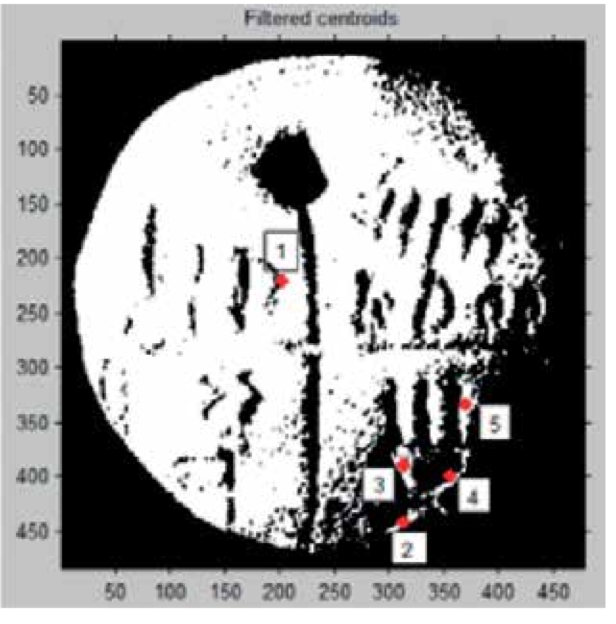


**Figure 8.**
*Image of the position of selected objects.*

| Region no. | Area | Perimeter | Orientation | Eccentricity | Center of weight | |
|---|---|---|---|---|---|---|
| | | | | | Xc | Yc |
| 1 | 111,222 | 4065.5 | 57.88 | 0.5486 | 201.64 | 220.55 |
| 2 | 222 | 100.6 | 36.87 | 0.9665 | 312.93 | 441.57 |
| 3 | 427 | 115.6 | −74.43 | 0.9270 | 313.74 | 390.27 |
| 4 | 313 | 187.2 | 55.68 | 0.9769 | 356.02 | 400.18 |
| 5 | 611 | 206.4 | 85.96 | 0.9641 | 370.17 | 332.94 |

**Table 4.**
*Numerical shape properties.*

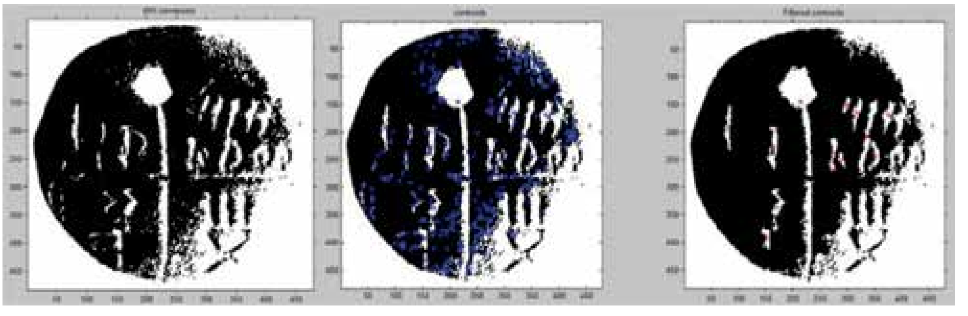

**Figure 9.**
*Detecting the engraved forms on the complementary image.*

Data obtained through shape analysis complements the information on the structure of the artifact. They can serve as a basis for comparison in the process of authenticating artifacts or evaluating their alteration (degradation) over time. The usefulness of these data depends on the uniformity of image acquisition conditions, the most sensitive factor being illumination.

### 4.2 Case study 2: C. Monet's paint "Water Lilies and Japanese Bridge"

Famous painted works of art are most commonly reproduced for commercial purposes. Combating illicit activities with paintings implies the development of the most effective methods for examining them for the purposes of authenticating them and detecting counterfeits. The restoration in terms of rehabilitation of the paintings, in the sense of intervention on the painting itself, does not apply to the easel works than in some exceptional cases in accordance with national legislation and the European convention for cultural heritage protection. Reconditioning and even reproduction (restoration) are fully practiced in the case of monumental paintings, most often in the case of frescoes. In both categories of problems, knowing the original is essential for obtaining the necessary reference data in the authentication process or reproduction for restoration purposes. To exemplify the proposed methods, we chose from the easel painting category the Claude Monet's work from 1897 to 1899 entitled "Water Lilies and Japanese Bridge." The original painting is oil on canvas with the dimensions of 89.7 × 90.5 cm and is exhibited at the Princeton University Art Museum at the Department of Modern and Contemporary Art. To apply the method, we chose the original jpeg file with the 1031 × 1001 pixel resolution shown in **Figure 10** [15]. The preliminary analysis reveals from the chromatic histograms (see **Figure 11**) that the predominant luminosity is green, but as a


**Figure 10.**
*Original painting of "Water Lilies and Japanese Bridge" (C. Monet) and detail.*

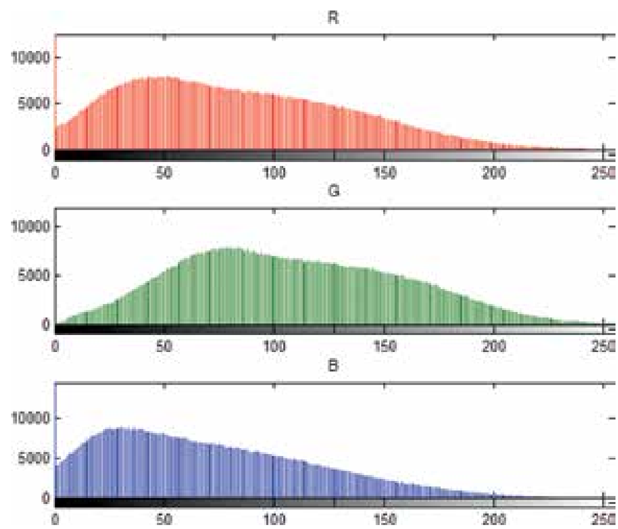


**Figure 11.**
*RGB histograms.*

whole, the three components have luminosity below half the conventional scale 0–255. Histograms show that its peak values are reached for the minimum brightness at which more than 10,000 pixels contribute with at least one of the red or blue components equal to 0, corresponding to the dark portions of the painting.

The information given by the analysis of the image planes R, G, and B shown in **Figure 12a** reveals a relatively balanced brightness of the three base components. Going forward with the analysis in the perceptual color space, we find the existence of good visual information in the hue plane, which is supported by the numerical distribution of the hue index on the whole field 0–1, with the greatest weight between 0.1 and 0.7 covering virtually all the chromatic derivatives. This is a confirmation for impressionist painting and C. Monet's particular style of creating iconic tones. In this painting, the artist used mostly green tones and tones to yellow but also tones between turquoise and blue. This results from the construction of the hue histogram shown in **Figure 13a**.

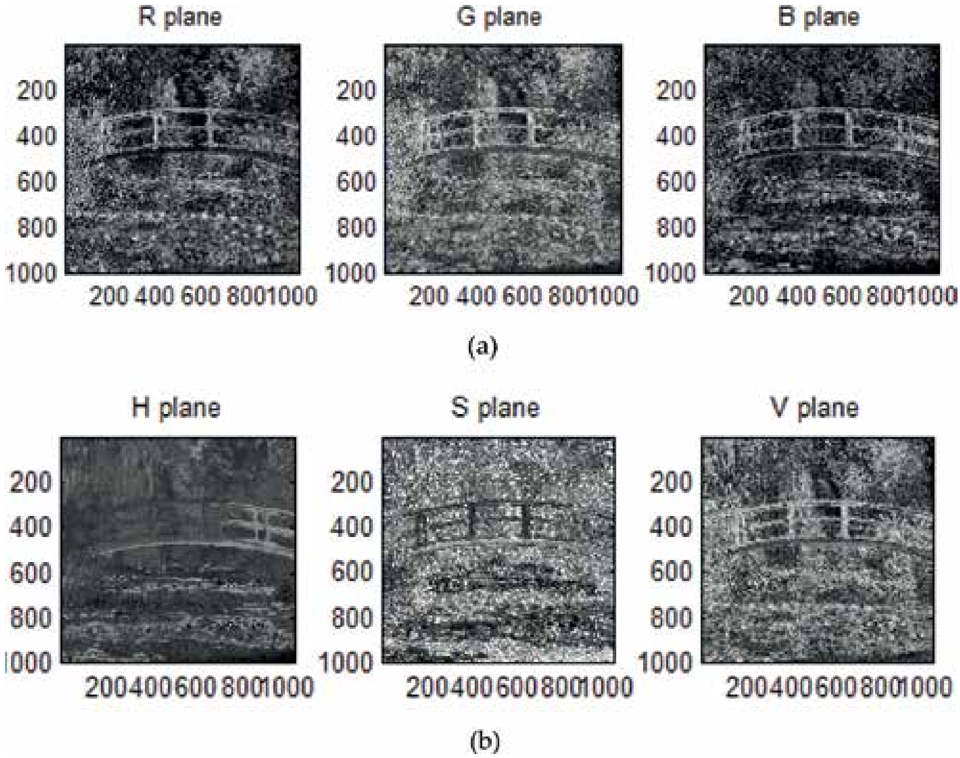


**Figure 12.**
*"Water Lilies and Japanese Bridge" in (a) RGB color system and (b) HSV perceptual color system.*

The saturation analysis shows an average of 0.49 and a regular distribution of saturation index at the level of the whole image, close to the Gaussian form, as can be seen in **Figure 13b**. Two particularities in the histogram of saturation are worth highlighting. The first refers to a significantly larger number of pixels (exactly 11,151) that define saturation peak very close to the median level of 0.5 (peak 1), which corresponds to the mixed half-half white colors. The second feature refers to a peak equal to 1 (peak 2), which corresponds to pure colors. From the saturation matrix evaluation, a number of 56,569 pixels corresponding to pure colors resulted. It can be said that Monet used in addition to the multitude of specific nuances and pure colors and mixtures of them with white half-half preparations. With respect to the whole picture, it is estimated that the proportion of the use of the mentioned colors is 1 and 5.48%, respectively, and the remaining 93.52% are blends made by the artist. Analysis of the perceptual value parameter reveals a global overall brightness at the level of the whole array. The value index distribution shown in the histogram of **Figure 13c** reveals an acceptable uniformity with a maximum around 0.3 with a similar shape of the green component distribution. There was no pure black in the image and barely pure white—1333 pixels (about 0.3% of the total)—detected. It can be assumed that the artist avoided the use of these chromatic components in this work, or if he has used them to some extent, they have altered in time.

### *4.2.1 Analyze an image detail*

The selected detail is a cropped image portion with a square frame from the pixel 700,760 to 900,960 as shown in **Figure 10**. We summarize the analysis of the histograms obtained in the HSV perceptual color system, as they are represented and annotated in **Figure 14**. Regarding the hues, we can see the following:

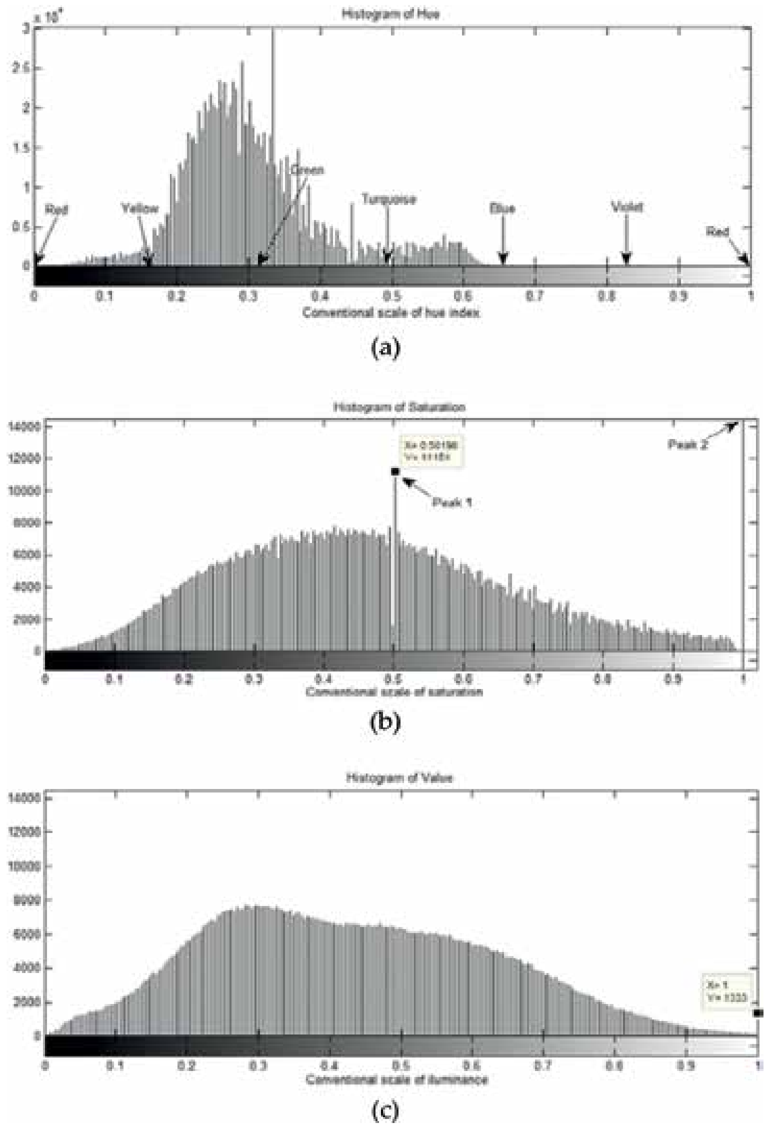


**Figure 13.**
*Histograms of perceptual components HSV.*

- They are massively distributed in the yellow-green and turquoise-blue portion of the color space.
- The distribution is uneven, showing numerous spiky peaks.
- The distribution on the analyzed detail retains the aspect and proportion with the distribution for the whole image.

The findings lead to the following conclusions:

- Confirm the observer/human expert's visual perception of the range of predominant hues.
- Irregularly distributed peaks highlight the specific touches by which the artist applied the respective hues.

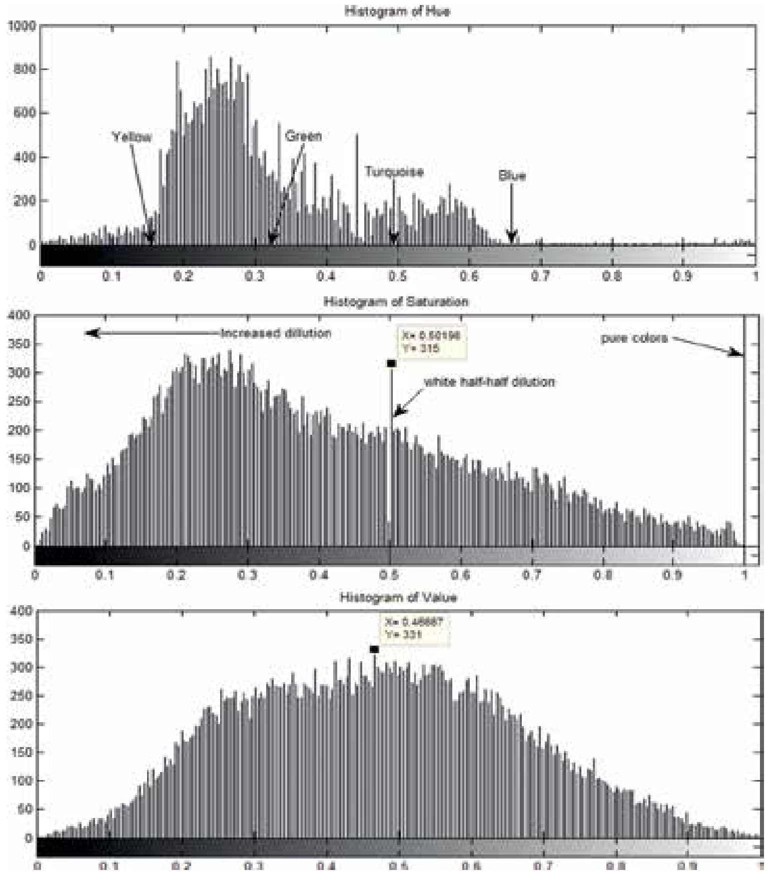


**Figure 14.**
*Histograms of detail in HSV space.*

- The weight of the hues is relatively uniform throughout the composition, which is in line with the representative impressionist note of this painting.

Saturation analysis at the level of detail reveals the following two interesting aspects:

- The weight of the saturation indices is shifted in the range of 0.15–0.40 from the whole image 0.25–0.60, the average of the values decreasing accordingly to 0.4254 from 0.4913.

- Histogram of detail reveals the same two distinct components present in the full image.

The conclusions lead to the following assumptions:

- The artist used in this area the painting colors with a slightly larger white dilution. The representation of the water lilies has certainly imposed this.

- The artist used both pure and half-diluted colors as well as the entire composition. These two components present in both histograms of saturation can be a way of recognizing the work.

The histogram of illumination reveals the following:

- A slight increase in the average value from 0.4327 to 0.4718. The maximum value is at the illumination value of 0.4666, while for the entire image, it is about 0.3000. Therefore, the detail area has brightness above the average of the whole picture.
- The distribution is more uniform and with a high degree of symmetry around the mean, approximating to a large extent the Gaussian curve.

*4.2.2 Structural analysis of the detail*

The detail area of painting, as shown in **Figure 10**, was selected in order to exemplify a local specific structural analysis. Detailed structural analysis of detail can provide essential information for evaluators and restorers. The chosen detail in this case is relevant because it contains a variety of colors and irregular shapes in relation to the whole image. Determining a structural pattern for the studied picture detail is done by analyzing the forms by passing the methodological steps enunciated in the first case study. By applying the image processing tools and the evaluation of the forms, the elements necessary for calculating the shape indicators are successively obtained.

**Figure 15** shows successively the result of image conversion in black-and-white, extracting regions with a filter for the area of detected regions and determining the center of gravity of the objects thus filtered (see red dot markings on the right). It is noted that the algorithm used light information to convert the image to black-and-white using an index value (intensity) threshold. The middle image in **Figure 15** shows the conversion result with the threshold automatically calculated by the algorithm based on average light. The white parts of the image correspond to pixels whose intensity exceeded the required threshold, so a considerable number of regions were detected.

At this stage, we could decide either to raise the intensity threshold to reduce the number of regions by keeping the brightest or to apply an extra filter to one of the shape measures, for example, the area. Applying the second option to Area_object > 200 has led to considerable reduction of regions and retaining more significant shapes, which are actually the largest and brightest pixel regions connected (see **Figure 15**, right-side picture).

Nondestructive methods of this type are effective in internationally recognized restoration and conservation analysis. We have chosen to apply them to art and archeology components that are part of the cultural heritage of Romania, are in a degree of advanced deterioration, and are threatened with extinction and for which any other method would not be efficient, in the field of fingerprint, authentication. For a more complete overview on the discussed methods, we extended the analysis with other two examples including metopes from Roman metopes to Tropaeum

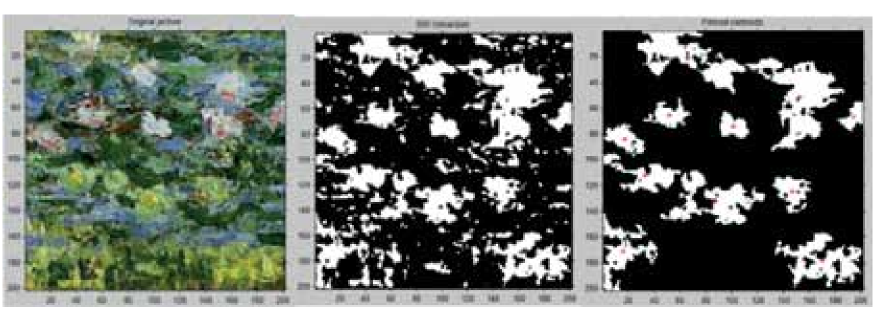

**Figure 15.**
*Successive steps in region detection.*

Traiani Monuments, Adamclisi, Dobrudja, and frescoes from Loggia Mathia to Corvin Castle, Hunedoara, Transylvania.

### 4.3 The analysis of Roman metopes to Tropaeum Traiani Monuments

A number of three metopes were compared based on the high-definition photos taken at the original artifacts. The chosen metopes are unpainted stone bas-reliefs as shown in **Figure 16**.

*Chromatic analysis* shows a well-balanced distribution of the RGB components for all three artifacts, which is in line with the nature of the base material—stone (most likely granite). The slight differences are done by the influence of dark areas in the pictures and the frame around the actual artifacts that are most present at Metopes 1 and 2. The RGB pattern of Metop 3 is the closest to the middle of the range, that is, gray. Perceptual color space reveals the nonspecific hue (H) distributions: singular (isolated) tones can be seen on the whole spectrum, but the remarkable concentration is still in the range of “warm” colors. The saturation (S) is definitely low: there are no pure colors in any cases. The luminance (V) is good in all three cases making them visible and comprehensible to the human observer. The discussed results are based on the histograms depicted in **Figure 17**.

*Shape analysis* aims to detect the significant regions of the artifacts in order to record them as a structural pattern. The basic steps for image processing described in Section 4 are followed. To obtain a better detection of the main contours of these bas-reliefs, we use the complements of the black-and-white images displaying darker and shaded areas in white. In **Figures 18**–**20**, the results of image processing for all three metopes are represented. In this analysis, we used classic color-based segmentation and a useful tool to label the detected regions with colors. The colors are conventionally allocated to the regions of connected pixels having the same level of darkness. In this way, the visual analysis of the shape itself can be made easier, and the details of the shape can be identified more accurately than with the original images. Finally, the properties of regions are numerically evaluated, and the image can be filtered according to certain criteria related on some properties obtaining an image with significant shapes. The structural pattern of the metop includes numerical measures of those significant shapes, for instance, centers of weight and relative distances between them.

### 4.4 The analysis of Loggia Mathia to Corvin Castle, Hunedoara

Loggia Mathia includes few murals currently damaged. The primary interest is to perform the image analysis at this point in order to obtain the current status of

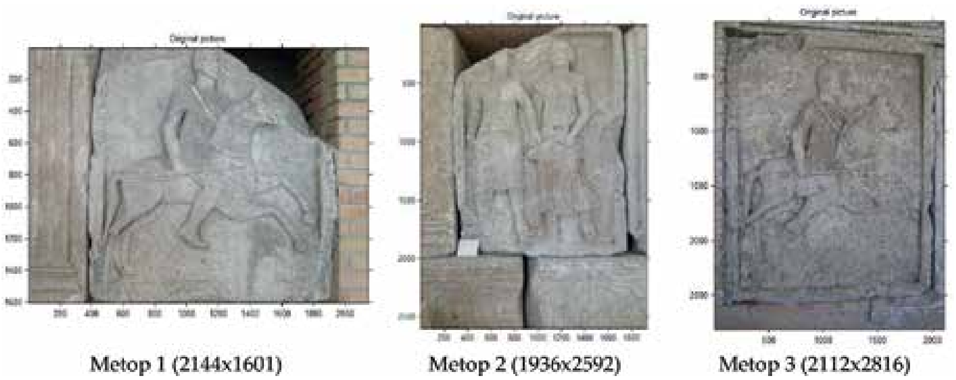


**Figure 16.**
*Three metopes from Tropaeum Traiani Monuments.*

the artifact. Then, the data will be used to perform comparative analysis with older images with significantly better quality. The most relevant analysis in this case is chromatics. The original image and the color-labeled regions are presented in **Figure 21**.

The chromatic analysis presented in **Figure 22** reveals the predominance of the red component in RGB spaces of the warm hues in perceptual space. No pure color was detected in the current fresco, but the histogram of the saturation shows a relatively high level of color blending with white. This is explained by the fact that painting is degraded by fading. The luminance of the image has the same distribution as R component which confirms the preponderant visual perception of this component. The color-labeled regions highlight the connected areas of pixels with same color in current images.

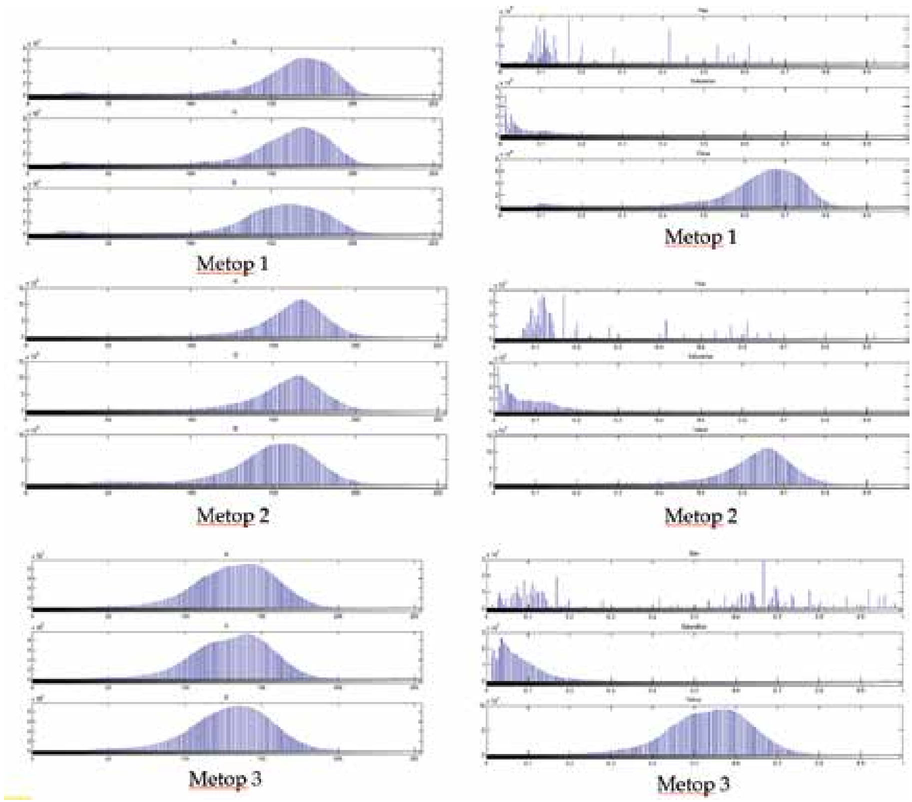


**Figure 17.**
*Chromatic components compared.*

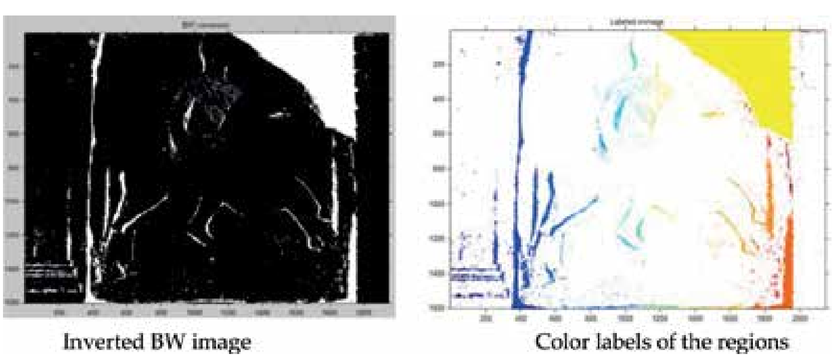


**Figure 18.**
*Metop 1: pattern detected.*

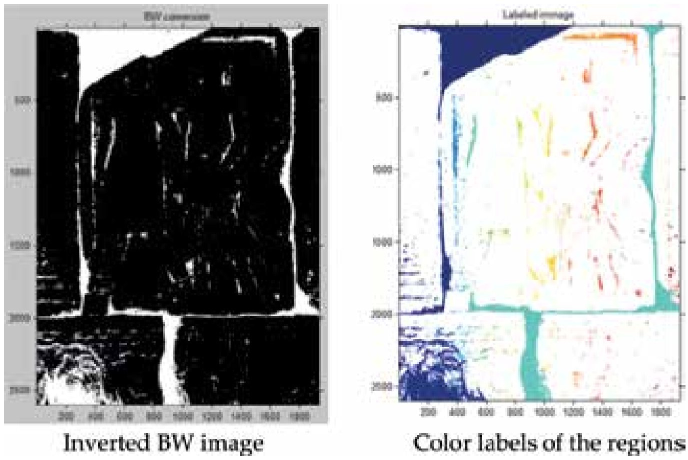


**Figure 19.**
*Metop 2: pattern detected.*

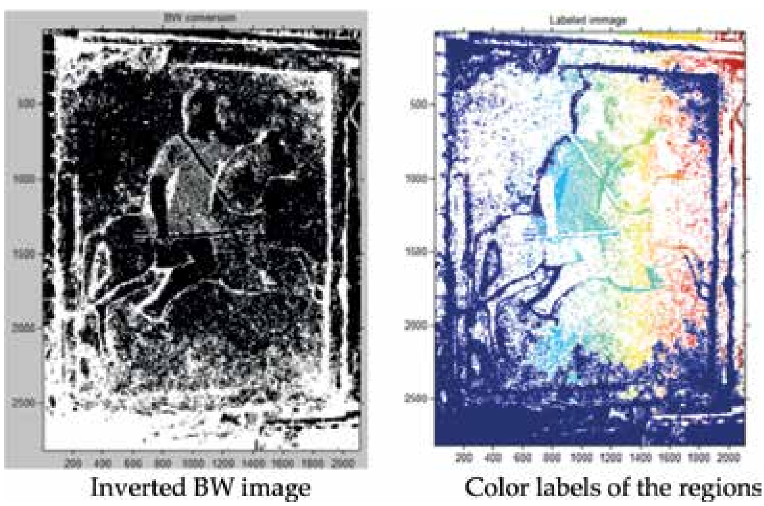


**Figure 20.**
*Metop 3: pattern detected.*

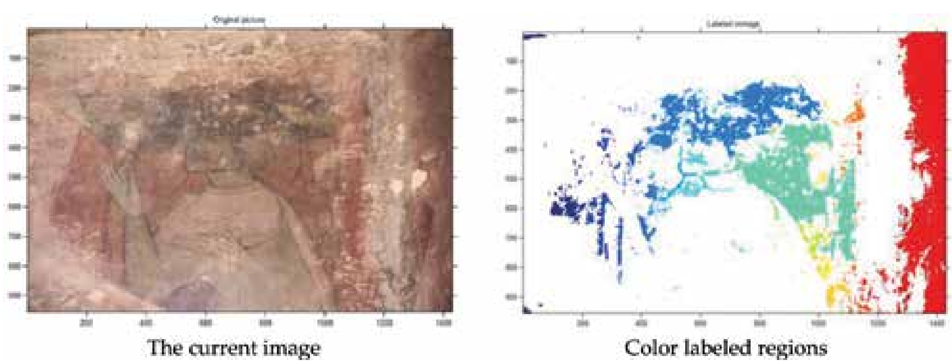


**Figure 21.**
*A fresco of Loggia Mathia.*

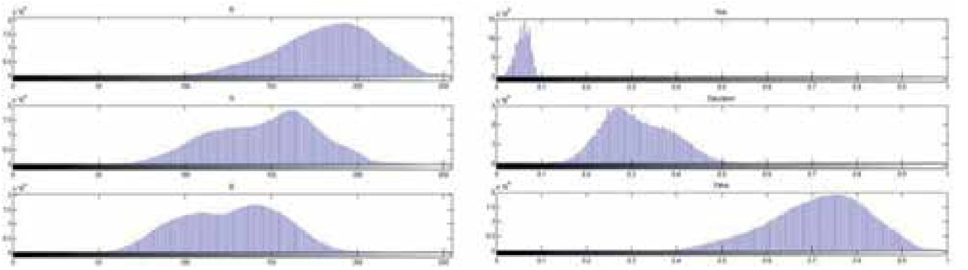

**Figure 22.**
*Histograms in RGB and HSV color spaces.*

## 5. Discussions

The methods discussed above and the examples presented show the applicative potential of image processing techniques in arts, archeology, identity, and cultural heritage conservation. The primary objective of artifact investigation is, in fact, to get the most complete picture of them. Whether it is intended to authenticate the artifact or restoration—preserving it, the structural and chromatic details of the piece are essential for making the decision. The two presented case studies and related examples deal with two categories of artifacts: archeological pieces as three-dimensional objects, respectively, and visual artworks on planar support. In the chosen examples, we have shown that the use of image processing models reveals interesting aspects and peculiarities regarding the chromatic composition and the structure of specific shapes and details. Moreover, formal image analysis tools provide numerical data (indicators) that can be integrated into information structures useful in the authentication, restoration, and conservation of artifacts.

The experiment in the first case study "Tablet from Tărtăria" is based on a picture taken from open sources about which we only know the resolution. The piece itself is a rough disc shape as a flatted calotte with a height (maximum thickness) of less than 1 cm. Its surface is etched with distinctive signs (ancient writing) and generally has local unevenness and rugoses specific to ceramic material. The perceived chromaticity is in the area of yellowish-reddish hues, which is also confirmed by the histogram. Evaluation of the chromatic composition across the image revealed an irregular color distribution (RGB), while detail analysis shows histograms with more concentrated and more regular distributions, close to the Gaussian form. The effect of uniform illumination at the moment of image capture is defining the quality of chromatic distribution.

For archeological artifacts, the chromatic pattern is generally due to alteration/modification of the piece over time. However, the acquisition of images and the evaluation of chromatic components at the time of discovery, at the time of exposure to the museum, and periodically at different time intervals are important for the artifact record. In this way, useful databases can be compiled for the assessment of counterfeiting and the study of changes over time, an important aspect of conservation-restoration work. Formal analysis is equally important for completing the artifact datasheet. The "Tablet from Tărtăria" examined presents essential details in the form of engraved signs. Due to the spatial shape of the piece, it is impossible to detect all the signs by processing a single frontal image. The main states are the deformed projection of inclined or curved surfaces and the effect of uneven illumination. Also, some peculiarities of archeological pieces such as stamps, engravings or bas-reliefs, and even embroidery require a differential analysis on the normal image and the complementary image. As was seen in the analysis of the shape of the engravings, it was necessary to use the complementary black-and-white image. Complex three-dimensional shapes marked by ornamental details characteristic of archeological artifacts generally impose certain limitations and special conditions when examining them based on images. However, shape analysis can provide trusted data for the artifact records if it is extracted from detailed images taken from the right angles with an optimal lighting scenario. All these conditions must be reproducible on stands with calibrated equipment for optical and photometric determinations.

In the case of flat surface artifacts such as canvas paintings, wall murals, floor mosaics or flat walls, upholstery, or other plain graphic artworks, image processing is very effective. The method is cost-effective, provides a lot of information, is not invasive or destructive to the artifact examined, and therefore is recommended to do it before any other method of analysis.

Image analysis on Claude Monet's "Water Lilies and Japanese Bridge" highlights the relevance of the method for painting works. The chromatic analysis has more relevant details that contribute to the uniqueness of the work and possible to identify the Monet style. The overall appreciation is that the image is balanced in terms of color composition. This is distinguished by the intelligible visual aspect of the component images in both the basic color system and the perceptual system as compared to the original image (see **Figures 10** and **12a–c**).

Compared to the analysis of "Tablet from Tartaria," we find a significant difference in the perceptual space regarding the hue and saturation components. While the archeological artifacts of ceramics have a specific natural color, undifferentiated in the nuances, and saturation planes, Monet's painting contains a shade treasure and reveals an elaborate technique of using colors mixed with white. Histograms in the perceptual color space provide identification data relevant to the "Water Lilies and Japanese Bridge" work, and in the case of the analyzed image detail, the general chromatic characteristics are preserved and in particular highlight the specificity of the execution of some elements by applying clues, for example.

The analysis of the shapes exemplified in the detail in "Water Lilies and Japanese Bridge" reveals the ability of the method to locate distinct regions in the image on a multi-criteria basis. The criterion used by us is "enlightenment and area" that selects all regions in the analyzed image that are brighter than a given threshold and larger than a prescribed value. Practically, any combination of criteria can be formed including chromatic parameters and/or shape properties (see **Table 2**).

The results from *Roman metopes to Tropaeum Traiani Monuments* show data specific to the stone artifacts in color space analyzed. Possible chromatic particularities may be caused by maneuvering or restoring cleaning itself. The shape analysis uses binary image and the color-labeled image in order to obtain information on topology of the artifact. The structural pattern of a metop includes geometrical information that helps restorers to reproduce faithfully.

The fresco from *Loggia Mathia to Corvin Castle, Hunedoara*, is a challenge for restoration. Because the painting is erased, i.e., blurry, the original chromaticity has been severely damaged, and at the same time, some elements of composition have been totally or partially lost. The color-based labeling helps to estimate the original shapes that were painted with the same color. Finally, the restorers have to use the comparative study to choose the colors and to restore the original composition as possible.

The extracted forms can be distinguished by their numerical measures (position, area, orientation, etc.) for the whole painting or its areas. Thus, the structural-chromatic pattern of artifacts in the category of graphical representations on planar support can be constituted by image and shape analysis. Image capture is also important for these artifacts, and great attention has to be paid to lighting. In the case of flat surface objects, there are no theoretical reasons for shading, but reflective and light scattering effects that compromise any image analysis may occur. Consequently, images must be captured at a resolution of at least 1,000,000 pixels in natural light conditions or near natural light sources, in the absence of concentrated and directional sources that cause reflections and diffuses on the surface of the artifact.

## 6. Final remarks

Examination of artifacts by optical means and image processing is an elegant and efficient solution. The usability of methods consists in the relevance and the large amount of data obtained by digital image processing. Other benefits such as relatively low costs, avoidance of artifact degradation, the possibility of post-data processing, easy repetition of investigations, productivity of analyses, automatic data processing, obtaining results in a timely manner, and the establishment of data archives relating to works of art and cultural heritage in general.

The prospects for developing these methods are two-way. The first one concerns the development of performance algorithms for image analysis and software applications for their implementation. The second direction is to plan some activities to create archive images of original artifacts and eventually known counterfeits.

The major conclusion is that investigating artifacts through digital image processing is a complementary method of analysis that must be applied with priority before any other invasive rule analysis. Although in some situations, image-based methods cannot substitute for more complex physicochemical analyses that are usually done with material sampling, image processing technology must be extensively integrated into decision support systems for experts and curators in the field of artistic heritage preservation.

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Chapter 4

# Cultural Heritage in Marker-Less Augmented Reality: A Survey

*Hoshang Kolivand, Abdennour El Rhalibi, Mostafa Tajdini, Sarmad Abdulazeez and Pisit Praiwattana*


## Abstract

Augmented reality (AR) is considered as one of the most significant technologies in the field of computer graphics and is utilised in many applications. In this chapter, we have presented a brief comprehensive survey of cultural heritage using augmented reality systems. This survey describes the main objectives and characteristics of marker-less augmented reality systems through presenting up-to-date research results in this area. We describe the marker-less technologies in the area of AR, indoor marker-less AR, outdoor marker-less AR, real-time solutions to the tracking problem, real-time registration, cultural heritage in AR, 3D remonstration techniques, as well as presenting the problems in each research.


**Keywords:** virtual heritage, culture heritage, augmented reality, marker-less AR, AR heritage

## 1. Introduction

Augmented reality is a technology in which user's view of a real scene is augmented with extra virtual information. Augmented reality (AR) registration of virtual objects is required having an accurate tracking or camera pose estimation, but tracking is one of the key technical challenges of AR system [1]. AR has many conceivable applications in a wide range of fields such as education, construction, public health, manufacturing and entertainment. With the increased computational speed and advancement of particular computer technology, augmented reality applications become possible in multidisciplinary fields, for example, education, simulation, entertainment, medical and games. Researches related to augmented reality (AR) and virtual reality (VR) have shown significant growth with the development of interactive computer technology and sophisticated 3D modelling packages [2]. Virtual heritage is considered one of the important fields in the computer-based interactive technologies in virtual reality [3]. It created visual representation of monument, artefacts, building and culture to present openly to global audiences. However, virtual heritage becomes as a platform for promoting the education process, motivating and understanding particular events and historical elements for the use of students and researchers. Augmented reality techniques can be classified into two main categories: vision-based AR and location-based AR [4, 5]. Location-based AR uses the capability of a specific device to determine its position in the world, for example, GPS and then the retrieval relevant information to that location. Then, this information is superimposed into the output of their device's camera to permit a more natural data presentation compared only using the map alone. Vision-based AR particularly depends on processing the data that is extracted from the images or video frames that have been taken by the device. This kind of AR includes a number of techniques that lend significantly from computer vision to the range, where research progress in AR relies on the progress of the latter [6]. Lately, augmented reality technology has become an accepted technology among scientific community and even public, which is used for merging of real and virtual objects, and mixed it into the real-world environment. However, this technology is used in virtual heritage to improve the visitor experience of a cultural heritage site, as well as, the possibility to present the ancient-ruined building without any damage. In this chapter, we have presented a survey of marker-less AR. This survey is based on the state-of-the-art related to marker-less AR such as indoor marker-less AR, outdoor marker-less AR, real-time solutions to the tracking problem, real-time registration and cultural heritage in AR. Section 3 introduces the marker-based AR and Section 4 is allocated to marker-less AR, while Section 5 presents the researches related to cultural heritage in augmented reality.

Section 6 reveals the issues with virtual heritage in augmented reality and Section 7 presents 3D reconstruction techniques for cultural heritage. Section 8 is all about location in AR. The work is concluded by section 9 which is the conclusion.

## 2. Augmented reality

Augmented reality is considered as one of the modern technologies that blends virtual objects into the real world. Augmented reality (AR) can be simply defined as a live and integrate direct or indirect view of a physical, real-world environment. It is real-time data that elements are augmented by computer-generated virtual content, for example, sound, video, graphics, or GPS data [7, 8]. Augmented reality is considered as an area in which 3D virtual objects are completely integrated into a 3D real environment in real time. An AR environment supplements the real-world with virtual objects, which are generated by using computer that appear to coexist in the same space as the real world [9]. In another words, augmented reality can be defined as the interactivity of humans with virtual objects that is located in the real environment in order to help the user in executing a task in a physical setting. AR is one of the significant forms of mixed reality (MR), in which real and virtual objects are mixed and showed in a single display in the same time and location as shown in **Figure 1**. Augmented reality seems like fiction because it creates interactive interfaces that specify the delusion that physical and virtual worlds are connected together and that users can physically cross from one to the other [10].

AR does not replace reality, as the virtual reality (VR); it complements real environment with digital information, virtual and computer-generated graphics

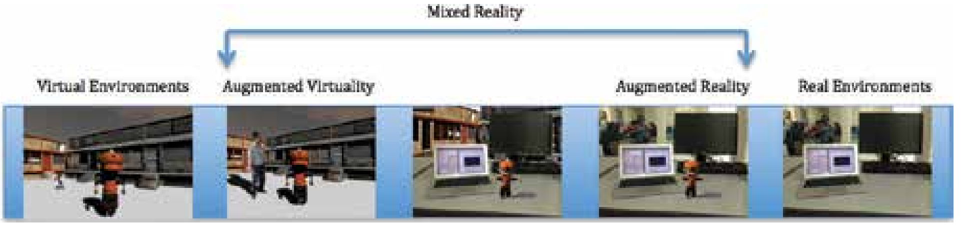


**Figure 1.**
*Reality-virtuality continuums [23].*

**Figure 2.**
*A real environment view is augmented with digital information.*

**Figure 3.**
*A user navigating in a virtual environment of VR.*

and/or virtual objects as shown in **Figure 2**. However, users navigate in VR by using a computer simulated or imaginary environment called a virtual environment, preventing the real environment. In this environment, all users' senses are controlled using a computer and immersed in a simulated environment [11] as shown in **Figure 3**.

## 3. Marker-based augmented reality

Marker-based AR uses markers (A two-dimensional pre-defined screen) that are placed in the scene and within the field of vision of the camera in order to help guide the camera pose estimation process [8]. The markers are frequently indicating to as fiducial markers because their position and orientation relative to the scenery are steady. The markers are always planar makers and commonly have powerful feature, for example, long edges, as well as, corners among black and white regions. In this technique, AR puts a powerful emphasis on the design of the marker. One of the most common kinds of marker design is square because the feature of square will allow for accurate localisation of the markers by using its four corner points [12]. Marker-based AR uses computer vision techniques in order to calculate the position and orientation of the camera relative to the marker. The virtual 3D objects can be overlaid accurately on the markers as shown in **Figure 4**. It has a primary operational principle: capture the video input from the camera, add 3D graphics to the scene and show the augmented frames as a video stream [13].

**Figure 4.**
*Marker-based AR [14].*

## 4. Marker-less-based augmented reality

Marker-less AR is completely different from marker-based AR because it does not depend on the artificial markers in order to reveal outstanding features in the scene. Marker-less AR systems work to integrate virtual objects into a 3D real environment in real-time, promote user's perception of and interaction with the real world [15]. Marker-less AR works by revealing features that are easily available from the natural objects in the scene, as well as, try to create a model or map from the scenery in order to represent the world as it is displayed by the camera.

### 4.1 Camera pose estimation

There are two main methods to camera pose estimation techniques called relative orientation and planar homography. Relative orientation is an approach that used to calculate the position and orientation of a camera relative to another from correspondences between five or more ray pairs. A ray pair can be defined as the vectors that arise from a fixed and visible point in the scenery to the camera centre positions [16]. Use the aspect of AR process that recruit computer vision algorithms, called feature detection and tracking, and then suggest a method to improve the subsequent process to output a best camera pose estimate [16]. A localised feature descriptor is used for the matching of salient feature points belonging to the present camera frame with those extracted from the reference frames. Camera pose can be estimated relative to it, however, the calculated 3D pose parameters can be used in order to render virtual objects into the real world [17]. Frikha et al. are proposed real-time monocular piece wise planar SLAM method using the planar scene assumption. Planar structures have used for mapping process in order to allow rendering virtual objects in a meaningful way, as well as improving the camera pose resolution in addition to the quality of 3-D reconstruction of the environment by adding restrictions on 3-D points, and settings in the optimisation process [18]. An energy function based on epipolar geometry has been developed in order to estimate intrinsic camera parameters during camera zooming [19]. Intrinsic camera parameters at each zoom value are calibrated, in order to obtain an accurate camera parameter estimation. The intrinsic camera parameters changes depending on the zoom value that are modelled [19].

### 4.2 Outdoor marker-less-based augmented reality

Augmented reality is the real-time incorporation of the virtual and physical worlds into a new environment, where digital information is registered with real-world elements in a coherent method. One of the big challenges when working in outdoor AR is the registration of the virtual elements in the real-world environment, where it is not realistic to prepare every building with visual markers. This issue is certainly much more accurate when dealing with outdoor augmented reality. Most augmented reality applications are taking the benefit of backpack systems with head-worn displays [20] or handheld devices [21] in order to compose real-worlds' views with digital information. Sophisticated hardware contains tracking devices, for example, GPS and gyroscope, which can be used to determine the position in the physical world.

Bateau Ivre [22] project have presented on the Seine River in order to make a considerable audience conscious of the possible developments of augmented reality through an artistic installation in an outdoor environment. The installation can be seen from a ship by a huge number of audience without specified equipment, through night-time video-projection on the River banks. The augmentation of the physical world is implemented using real-time image processing for live special effects, for example, contouring, particles and non-realistic rendering. The technical objective of the project was to immerge the audience into a non-realistic view of the River banks that would be different from traditional tours that highlight the main features of Paris' classical architecture. The implemented software is used in standard algorithms for particular effects to a live video stream and then re-projected these effects on the captured scenes to merge the real world with its modified image [23].

However, Sato et al. [5] have developed a novel marker-less AR system that uses local feature-based image registration and structure from motion (SfM) technology. The proposed system has some advantages, such as it supports free movement, less limitations, less efforts, as well as lower cost for outdoor AR applications. For the verification of the developed system, it has been applied to a renovation design project. One of the main advantages of the system is that it does not require particular equipment, for example, sensors for geometric registration between augmentations and the real world because the system uses sensor-based registration. Furthermore, the system does not need artificial markers, which reduce user's flexibility [5]. The accuracy of system's registration and tracking for this research is not enough for AR.

A development of a 3D map oriented handheld AR system has been presented by Chen et al. [24]. The system achieves geometric consistency by using a 3D map in order to obtain position data instead of using GPS, which provides low position information accuracy, especially in urban areas. In addition, the system features a gyroscope sensor to obtain posture data, as well as a video camera that used to capture live video of the present surroundings. All these components are installed in a smartphone and can be used to assess urban landscape. The authors have used the evaluation of registration accuracy in order to simulate an urban landscape from a short- to a long-range scale. The proposed AR system allows users to simulate a landscape from multiple viewpoints in addition to long-distance simultaneously, as well as walking around the viewpoint fields using just a smartphone [24]. The proposed system has the optical integrity and occlusion problem of the 3D-AR system when simulating urban landscape.

In addition, Chen et al. [25] presented tracking natural features in an agricultural scene. The main objective of the system is to perform marker-less AR techniques in order to assist in the visualisation of robotic helicopter-related tasks. By creating a virtual marker under a known initial configuration of the robotic helicopter, camera and the ground plane, the system is able to continuously track the camera pose using the natural features of the image sequence to execute augmentation of virtual objects. A simulation using a mock-up model of an agriculture farm have developed to evaluate the performance of the marker-less AR system. The experiment results showed that there are a number of improvements, which need to be taken in consideration before distributing the system in actual flight. The intermittent movement of the virtual marker vertices must be reduced in order to obtain better camera pose estimation. A feature recovery algorithm is one of the most important techniques for scaling the marker-less AR system to operate outdoors on the robotic helicopter [25]. This technique is trembling in the virtual marker vertices. Therefore, camera pose estimation accuracy is low.

## 5. Cultural heritage in augmented reality

Virtual heritage in AR can be defined as an interactive computer-based technology, which can be used to achieve visual reconstruction, assist scholars and educators of traditional entities, for example, buildings, artefacts and culture [26]. This technology is used to maintain delicate historical buildings from natural disasters and sabotage [27]. In order to create a virtual heritage, there are seven main design principles, which must be taken into account such as high geometric accuracy, high level of automation capture for all details, low cost, photorealism, flexibility, portability and model size efficiency [28]. Cultural heritage layers are proposed to visualise historic media such as drawings, paintings and photographs of buildings and historic scenes seamlessly superimposed on real environment through video see through using X3D [29]. The registration of the virtual objects in the video images is done by using a robust 6DOF tracking framework depending on two technologies that work simultaneously: randomised trees are used for initialization step and a frame-to-frame tracking phase based on KLT. This technique achieved simple, cheap and sustainable development augmented reality applications in the area of the cultural heritage depending on industry standards [30]. The main idea of this research is to use current historic media from archives and superimpose them seamlessly on reality at the suitable place. These local layers are context sensitively telling the location's history and give the impression of a virtual time trip. The results of the application showed in the area of cultural heritage, where the system runs on an Ultra Mobile PC (Sony Vaio UX) with 15 frames/sec. Only the reality filters and the 2D overlays can be selected by the application developer or online by the user [29]. This application is very simple and presented just 2D overlays, as well as the detection of the filter is done manually. Augmented reality for historical tourism using mobile devices has been proposed by Bres et al. [30]. The core of the proposed system is related to a marker-less outdoor augmented reality solution. This technique is based on scale invariant feature transform (SIFT) features for localisation and integration of 3D models into video. These features are used to project a digital model of the building facades of the square in order to get 3D coordinates for each feature point. The algorithms executed are responsible to calculate the camera pose for frame of a video from 3D-2D point correspondences among features that extracted from the current video frame and points in the reference dataset. The algorithms were successfully evaluated on video films of city squares. Despite they do not yet work in real-time, they are able to correct pose estimation and projection of artificial data into the scene. The algorithms automatically recover any loss of track. The research showed that the possibility of SIFT features are purely used for image-based marker-less outdoor augmented reality applications [30]. This research presented a simple mobile application that used to augment a small 3D image. HeladivaAR [31] proposed to reconstruct the historical and cultural heritage of Sri Lanka. HeladivaAR is a mobile phone application that used to show a reconstructed 3D model of these ancient ruins as they were in their initial state. In addition to use of AR technology, the application has used the mobile phone camera to determine and track the remaining ruins of the historical place and reconstructs the 3D model on it and then displays on the application interface. This application used different aspects to reconstruct the cultural heritage building such as image processing, 3D modelling, tracker identification using Android platform, historical books and reconstruct ruined sites. By using of AR, the real scene is enhanced by interactive multimedia information in order to increase the experience of the user, who can recover this information by a user-easy interface through their mobile phone. In education field, virtual heritage becomes a platform of learning, motivating and understanding of particular events and historical elements for students and researchers. This research provides a better understanding of Sri Lankan cultural heritage and allows users to gain interactive knowledge on archaeological facts of ancient kingdoms [31]. However, this research has several limitations. The first one is the application can apply only to android-based augmented reality devices; it cannot apply for the ISO-based operating system devices. The second limitation is the quality of the application that is based on the mobile device because it is not a desktop application. The last limitation is the application developed for Android 3.0 or above. The versions below may encounter rendering problems when running.

Indrawan developed marker-less augmented reality utilising gyroscope in order to demonstrate the position of Dewata Nawa Sanga [32]. This application is designed to learn, understand and recognise the properties of Dewata Nao Sanga by using a gyroscope. The sensor works to achieve the object of the deities in the coordinates to be identified, as well as, it is worked to provide information about Dewata Nawa Sanga along alongside and informative 3D animation. This research evaluates the usefulness, functionality of the application, in addition to the impact of the AR Dewata Nawa Sanga application that can motivate its users. The result of usability and satisfaction questionnaire value showed that the percentage average is 84.8%. It illustrates that the application is very useful for the participants to have knowledge about Dewata Nawa Sanga as well as very satisfied to use [32].

Kolivand and El Rhalibi presented a new technique to augment a realistic virtual building in real environments to be observed live through an AR camera [23]. There are some outdoor components when augmented a realistic building, for example, the sun position, shadows, sky illumination and virtual traditional animated characters. It is augmented in real environments at the place of real historical buildings, or desirable locations, at different times of the day and different days of the year [2]. The authors have presented some new ideas in the case of virtual heritage. First of all is modelling the 3D model of Portuguese Malacca. A structured real-time system is provided to trace the sun position, by using Julian dating, and Perez sky model is used for modelling sky colour, have presented in order to create outdoor illumination. A semi-soft shadow algorithm has been implemented to support the realism of outdoor augmented reality systems. A simple camera setup system has used to present Marker-less AR. The final system can be installed on head mounted display (HMD) or in the proposed device called ReVitAge to show the realistic reconstructed virtual heritage buildings, taking into account the main components of outdoor illumination [23].

## 6. Issues with virtual heritage in augmented reality issues

There are four main issues related to the virtual heritage in augmented reality. These issues are registration, reconstruction orientation, tracking and location.

### 6.1 Registration

Registration is one of the most significant issues in virtual heritage AR systems and currently subtracts some restrictions to different AR applications. Registration indicates the accurate compatibility of augmented objects with real environments [23]. Any AR system without an accurate registration leads to unsuccessful mixed environments because of the results of the defect wrong. The registration process is the overlay of virtual objects onto a real scene by using information that have extracted from the scene. Especially, this information is the feature points that extracted from the real scene using some tracking techniques. There are two categories of registration techniques, sensor-based and computer vision-based techniques. In sensor-based technique, there is a need to calibrate the external sensors, but the available sensors equipment's are either huge or expensive, or lack satisfactory levels of accuracy. Computer vision-based methods techniques work to avert calibration of external sensors, as well as offer the possibility for accurate tracking without huge and costly equipment. It can be categorised as two main types depending on camera calibration requirements [33]. The first kind does not require any calibration of camera parameters in advance, which includes the use of a known 3D calibration object. However, the second type is assuming that the intrinsic camera parameters are pre-calibrated. This is a common assumption in most of the existing AR systems.

There are several researches that work to develop the registration of the virtual elements in the real-world environments. These researches will be explained in the following section.

Gao et al. [6] introduced a new technique to improve the stabilisation and the accuracy of marker-less registration in AR. Based on three-dimensional map information generated by visual simultaneous localisation-SLAM. The proposed technique allows tracking and registration of virtual objects in order to ensure a stable in addition of real-time performance of marker-less AR applications. The stability of the system can be performed by integrating the Hough voting algorithm with the repeated Closest Points (ICP) technique. The proposed technique is faster than the standard methods. In addition, it is able to achieve more accurate registration results when compared with the previous techniques. The experimental results showed that the proposed technique can efficiently repress the virtual object jittering, as well as a higher tracking accuracy with good performance [6]. This technique can identify only one object for each recognition. Kanade-Lucas-Tomasi (KLT) natural feature tracker and the reconstruction technology is presented by Pang et al. [33]. KLT tracker technique is used to track the identical feature points in two control images. The authors presented three key stages in the proposed technique. The first stage is the affine reconstruction. In this stage, two control images from the video sequence are chosen and the KLT tracker is used for the extraction of the natural feature points. After that, the Affine Coordinate System (ACS) is defined by using these natural feature points. The user is responsible to select four planar points for setting the Euclidean WCS in two control images, respectively, and then the affine coordinates of the specific points are reconstructed by using the affine reconstruction method. While, the second stage is re-projection. Compute the corresponding affine re-projection matrix in the live video frame by using the natural feature points that have been tracked by the KLT technique. The image projections of the selected points are predestined in the live video sequence by using the affine re-projection matrix. However, the third stage is the camera extrinsic parameters such as camera pose, which are predestined in terms of the four selected points achieved in the second stage. Eventually, the virtual objects can be rendered on the real scene by using the graphics pipeline techniques such as OpenGL. The experiment results showed some improvement compared to the previous work [33]. The main limitation of this research is that the user has to manually determine the four points in the initialization stage, as well as, the authors do not consider tracking the feature points.

### 6.2 Reconstruction

Reconstruction is one of the basic processes in the AR. It refers to the construction of virtual objects in a similar way to replicate the original building [23]. Many cultural heritage applications require to reconstruct of real-world objects and scenes. Reconstruction process becomes increasingly common to use for modelling purpose of cultural heritage. This is fundamentally because of rapid development in laser-scanning techniques, 3D modelling, image-based modelling techniques, the power of the computer and virtual reality. The default objects appear on an appropriate model that covers the details of accurate enough is essential [23]. Objects must be exactly identical to the original ones which visitors can see clearly at the background of live videos. In addition, interest in objects' shadows is an essential part of the reconstruction process. Real-time shadows are created in relation to the sun position in a specified location, date and time. Eventually, the influence of the sky lighting on the virtual building during the daytime is the last part of creating the realistic virtual heritage in AR systems. Most virtual reconstruction techniques are based mainly on 3D scanning techniques, in order to get the objects faithfully [34]. **Figure 5** shows the reconstruction of the building and place it in the real environment.

### 6.3 Tracking

Tracking is a substantial subject in a real-time augmented reality context. The key requirements for tracking are the high level of accuracy and low level of latency at a sensible cost. Objects' tracking in the scene is defined as the amount of the pose between the camera and the objects. Virtual objects can be displayed into the scene using the pose. A local moving edges tracker have been used to provide real-time tracking of points normal to the object contours [27].

A new method for conception of vision-based augmented reality systems is presented by considering either 3D model-based tracking techniques or 3D model-free tracking approaches [1]. The method depends on decreasing the cost function expressed in the image and this decreasing is achieved via a visual serving control law. The main feature of a model-based method is that the information about the scene allows improvement of robustness and system' performance by the ability for predicting hidden movement of the object and acts in order to reduce the effects of outlier data introduced in the tracking process [35]. It is occasionally necessary to achieve the pose computation with minimal constraining information on the viewed scene because 3D information is not readily available in certain circumstances. The algorithm has been tested on different image sequences and for diverse applications, which illustrate a real usability of this approach [1]. This research has

**Figure 5.**
*Realistic reconstruction of cultural heritage.*

several limitations. The first limitation is the system that relies on a course manual initialization on the very first image. The second limitation is the system that does not take spatiotemporal aspect of the tracking process in depth consideration. Robustness can also be treated from one time-step to another. A novel marker-less camera tracking system and user interaction methodology for augmented reality (AR) on unprepared table-top environments is presented by Lee et al. [36]. A real-time system architecture is presented to merge two kinds of feature tracking. Marker-less tracking method is initialised by a simple hand gesture using the Handy AR system that used to estimate a camera pose from a user's outstretched hand. Detecting distinctive image features of the scene and tracking frame-to-frame by computing optical flow. The proposed system used distinctive image features for recognising the scene and to correct for accumulated tracking errors. For achieving real-time performance, multiple operations are processed in a synchronised multithreaded method: capturing a video frame, tracking features using optical flow, detecting distinctive invariant features and rendering an output frame. The speed and accuracy of hybrid feature tracking system have been evaluate and demonstrate a proof-of-concept application to enable AR in unprepared table-top environments, by using bare hands for interaction [36]. One of the significant limitation of this research is the system applied on 2D scene.

Novel interactive techniques for outdoor augmentation have presented to use a mobile device [37]. The system can be executed and perform real time on simple mini PC equipment. Feature tracking have been used for estimating camera motion when user turns the mobile device and examines the augmented scene. The authors have considered two scenarios. The first scenario is constantly applicable with any 3D model for ad hoc use without prior information or calibration process. The second scenario uses GPS for realising the viewing location and Google Earth KML files for locating the augmented object and its placement. This method, 3D object placed on Google Earth can be viewed on site without any addition data transformation steps. The systems have been tested with potential end users. The authors believe that the system is useful in diverse current real-life applications [35].

A model-based hybrid tracking system is proposed for outdoor AR applied for urban environments that allows accurate, real-time overlays for a handheld device [38]. The system merges different well-known techniques in order to provide a powerful experience that surpasses each of the individual components alone: an edge-based tracker that used for accurate localisation, gyroscope measurements to cope with fast motions, gravity measurements and magnetic field to avert drift and a rear store of reference frames with online frame chosen used to re-initialise automatically after dynamic occlusions or failures. A novel edge-based tracker distributes with the traditional edge model, and uses instead of a coarse, but textured, 3D model. This technique has several features [39]. The first feature is automatically disposing from scale-based detail, appearance-based edge signatures can be used to improve conformity and the models required are more usually available. The second feature is the system's accuracy and robustness is pretending with comparisons to map-based ground truth data. The tracking system have the possibility to apply to other types of display such as head mounted displays using video see-through overlays, while optical see-through displays would demand further calibration of the HMD's virtual camera with take in account of the video camera [38]. This system has the resulting asymmetry in the information display capabilities of the two environments (virtual and real-time environments). An integral natural feature-based tracking system is proposed to support the creation of AR applications that concentrated on the automotive sector [40]. An AR application was construct on top of the system to refer to the location of 3D coordinates in a specific environment. It can be applied to many various applications in cars, for example, a maintenance assistant, an intelligent manual and many more. The system is evaluated during the Volkswagen/ISMAR Tracking Challenge 2014, which designed to test state-of-the-art tracking technique based on requirements encountered in automotive industrial settings. Evaluation results illustrate that the system allowed users to correctly determine tasks points that involved tracking a revolving vehicle, tracking data on an integral vehicle and tracking with high accuracy. The evaluation of the system is allowed to understand the applicability boundaries of texture-based technique in the texture less automotive environment, a problem not addressed considerably in the literature [40]. This research has several limitations. The first limitation is low frame rate when the number of 3D key-points in the model is large. The second limitation is error accumulation when the entire vehicle is reconstructed in a single take. The third limitation is lack of temporal continuity, which may result for shivering; sensibility to extreme illumination conditions. The fourth limitation is accidental failures when cope with scenes that have minimum of texture information.

## 7. 3D reconstruction techniques for cultural heritage

AR technologies have become increasingly popular. These techniques are not just practical for developers of AR system, but also to the scientific community. The standard approach to create a 3D model is to build it from scratch using tools such as the unity 3D programme, which provides building blocks in the form of primitive 3D shapes. Many new technologies aim to increase the level of automation and realism by beginning with the real images of the object or converting it to direct digitisation using a laser scanner [28].

### 7.1 Image-based modelling

This technology includes vastly available devices, so the same system can handle a wide range of objects and scenes. These systems have the ability to create a realistic model, and those rely on photogrammetry have high geometric accuracy. This technique is usually used for geometric surfaces of architecture objects or for modelling precise terrain. It uses a mathematical model to capture 3D object information from 2D image dimensions or obtain 3D data using methods such as shading, texture, theory, contour and 2D edge gradient [41]. Deriving 3D measurements from images naturally requires that interest points be appearance in the image. Often, this is not potential, either because the area is hidden or covered behind an object or surface or because there is no mark, edge or visible feature to extract [28]. The main goal of image-based reconstruction is the ability to represent arbitrary geometry. For modelling complete geometric structures, it is usually necessary to remove the labour-intensive task through this approach [41]. The mechanism can also deal with the real-world effects that images take, but difficult to reproduce with the customary graphics techniques.

### 7.2 Range-based modelling

3D geometry information for an object can be captured directly by this technique [28]. The 3D measurement of images requires that interest points or edges be visible in the image, which is not constantly possible. Illumination or ambient light problems can impact the extraction process of such points and edges. Active sensors, for example, laser scanners have the ability to avert these restrictions by creating features on the surface using controlled light projection [41]. Many range sensors are produced organised points, in the form of an array or range image, appropriate for automatic modelling. However, texture information or colour can be attached from the scanner using colour channel or from separate digital camera [42, 43]. High-resolution colour textures that obtained from separate digital camera help to create of realistic 3D models. Generally, a single range image is insufficient to cover any object or structure [42]. The amount of necessary images rely on the shape of the object, the amount of self-locking and obstacles and the size of the object compared to the sensor range [41]. In order to wrap each aspect of the object, it is mostly required to perform multiple scans from various locations, which is commensurate to the size and shape of the object and occlusions. The alignment and groups of the various scans can affect the final accuracy of the 3D model, where each scanner has different range of resolution [28]. In addition, this technique can provide accurate and complete details with a high degree of automation for small and medium size objects, which reach the human size [42]. There are two major kinds of range sensors: triangular based and based on the principle of flight time [41]. Triangulation-based sensors are working dependent on project light in a known direction from a known position, as well as measure the direction of the returning light through its detected position. The measurement of accuracy depends on the triangle base relative to its height. Sensors based on the principle of flight time measured the delay between emitting and detecting reflected light on the surface, thus, accuracy does not quickly deteriorate as the range increases [44]. Time-of-flight sensors have the possibility to provide measurements in the kilometre range.

### 7.3 Image-based rendering

Image-based rendering used images as modelling and rendering primitives [28]. Image-based rendering uses images directly for creating new views for rendering without explicit geometrical representation. This technique is a significant mechanism for generating of virtual view, where certain objects and under particular camera motions and scene conditions. From the image input, this technique creates a new view of the 3D environment [41]. This technique has the feature of creating realistic virtual environments at speeds independent of scene complexity [42]. Image-based rendering depends on accurately knowing the camera positions to use automatic stereo matching, where the absence of geometry data, requires a major number of carefully spaced images to succeed [42]. Most of image-based rendering correspond to hybrids image-geometry, using means of the equal amount of geometry ranging from per-pixel depth to hundreds of polygons [45].

## 8. Augmented reality location

Each of indoor and outdoor sites offered many of similar challenges that must be processed to successfully implement AR systems, such as content acquisition [11], content storage and categorisation [46], tracking and calibration [47], marker placement, usability [48] and ergonomic issues [49]. Hence, there are various issues that must be taken into account in order to overcome by special internal or external sites.

### 8.1 Augmented reality for indoor heritage sites

AR's previous applications for indoor cultural heritage sites have frequently taken the form of "virtual museums". The visitors use AR technology to display objects that may not be accessible to them. This is because the great value or fragility of such objects, or the lack of space inside the museum or the physical object is existing in another museum [36]. One of the main issues that affect the design of AR systems for indoor sites are those of marker placement if using marker-based tracking, as well as ensuring the optimal use of the systems for all age groups and levels of computer literacy. In addition, it is substantial to make sure that hardware used is strong enough in order to support AR applications, and it is structurally robust if being lent to the public.

### 8.2 Augmented reality for outdoor heritage sites

It can be said that the development of AR systems for outdoor applications is more difficult than indoor applications. Realistic historical buildings in outdoor rendering AR systems require advanced effects such as shadows, lighting and the ability to detect the impact of sky dome illumination on virtual in addition to the real objects [23]. The environment and resources, such as lighting conditions and electrical energy, cannot be as tightly controlled, as well as hardware cannot normally be left outdoors. The use of mobile computer systems in outdoor AR generates several problems such as it is uncomfortable and heavy to wear, and it is very expensive if it is a wearable system combined with an HMD [11] Outdoor AR is a technology of executing augmented reality using outdoor GPS, compass, gyroscope sensor based on augmented reality technology. Unlike to indoor AR, outdoor AR is not subject to spatial restrictions. Indoor AR used a marker to ensure suitable synthesis of virtual object because it happens in relative narrow space, while outdoor AR used location information; it does not use any marker like in indoor system because it happens in relatively wide area [50]. Often the lack of ideal conditions means that marker-based tracking systems cannot be used, leading to rely on other techniques, for example, GPS and inertial sensors, which can be inexact.

One of the key problems that faced to design AR systems for outdoor sites are effectively tracking without using of markers in an environment that may be devoid of features in order to use for tracking. In addition, ensuring that any device used is weather-resistant and vandal-resistant. Furthermore, all the hard-wires that are used must be powerful enough to support AR applications, as with indoor sites. **Figure 6** shows the AR for outdoor cultural heritage **Table 1** shows a comparison between investigated works in AR systems, concentrated on outdoor, indoor, reconstruction and realism.

**Figure 6.**
*Augmented reality for outdoor heritage.*

| Researcher | Area | Indoor | Outdoor | 3-D reconstruction | Realistic VR |
|---|---|---|---|---|---|
| Sudirman and El-Rhalibi [16] | Camera pose estimation | X | | | |
| Yuan [17] | 3D camera pose | X | | X | |
| Frikha et al. [18] | Camera pose estimation | X | | X | X |
| HoK llerer et al. [20] | mobile augmented reality system | X | X | X | |
| Newman et al. [21] | AR wide-area sentient | X | | | |
| Jacquemin et al. [22] | Mobile AR | | X | | X |
| Fukuda et al. [24] | AR registration | | X | X | X |
| Chen et al. [25] | AR tracking | X | | | X |
| Lee and Höllerer [36] | AR tracking | X | | X | X |
| Honkamaa et al. [37] | AR tracking | | X | X | X |
| Reitmayr and Drummond [38] | AR tracking | | X | X | X |
| Lima et al. [40] | AR tracking | X | | X | X |
| Pang et al. [33] | AR registration | X | | X | |
| Hanisch et al. [26] | VR reconstruction | | | X | |
| Andrés et al. [27] | VR generation | | X | X | X |
| El-Hakim and Beraldin [28] | VR reconstruction | | X | X | X |
| Zoellner et al. [29] | Cultural heritage layers | | X | X | X |
| Bres and Tellez [30] | Mobile applications in culture heritage | | X | | X |
| Galmangoda et al. [31] | VR reconstruction | | X | X | X |
| Purnami and Putri [32] | VR reconstruction | X | | X | |
| Kolivand and El Rhalibi [23] | Realistic virtual heritage | | X | X | X |

**Table 1.**
*A full comparison of different techniques for marker-less augmented reality.*

## 9. Conclusion

This chapter has presented the survey of marker-less augmented reality system. In this chapter, we have discussed different techniques related to the augmented reality. An overview on each of them was introduced, identifying the major features and highlighting the main characteristic of each technique. In addition, we have explained in detail the main issues with virtual heritage in augmented reality. We have introduced the key techniques for 3D reconstruction that used in cultural heritage. We have focussed on the main issues of augmented reality for cultural heritage such as indoor marker-less AR, outdoor marker-less AR, real-time solutions to the tracking problem, real-time registration and cultural heritage in AR. We have presented the research related to these areas and highlighted the main problem of each research.

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Section 4

# Advanced Methods for Investigation

Chapter 5

# Microscopical Methods for the In Situ Investigation of Biodegradation on Cultural Heritage

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## Abstract

The processes of cultural heritage sites' degradation reveal interactions between the chemical characteristics of the substrates, the underlying substrate penetration, and the microbiota systems. Microorganisms penetrate the stone, causing extensive disaggregation of the materials. This chapter reveals comparative studies between the usual research approaches applied in biodegradation studies, especially optical microscopy, epifluorescence, and electron microscopy (SEM). These in situ microscopy techniques propose some complex analyses for the evaluation of the relationship between the microorganism's cells and the stone surfaces (adherence, interactions), and also for the evaluation of the level of health or balance of the niche complex, from mesoscale to microscale. The stages of the exact monitorization and evaluation of lithotypes and deterioration phenomena are periodical sampling and monument mapping. The aim of this chapter is to identify microscopical methods used in biodegradation studies, especially the facilities provided by these methods. Our in situ analysis (light microscopy, epifluorescence, and scanning electron microscopy) performed for the first time on the painted Matia-Fresco Loggia (Corvin Castle, Romania) highlighted several aspects, such as mixtures of mineral elements with different chromatic appearance and porosity, shredding degradation, depigmented areas, cracked portions, and highly biota activity (bacterial and fungal) on painted surface.

**Keywords:** microscopy, epifluorescence, biodeterioration, microbiota, stone surfaces, Matia-Fresco Loggia, Corvin Castle

## 1. Introduction

Most cultural monuments are subject to a degrading phenomenon induced by a number of abiotic and biotic factors: pollution, temperature, and humidity variations; periodic conservation interventions; touristic actions; and the colonization with biota. The microclimate defines the level of colonization, the type of contamination, the complexity of community, and its specific composition [1]. As a result, the degradation process is one that must be understood from an ecological perspective by considering the abiotic and biotic components and, respectively, their interactions. Studies on the complexity of biotic systems that interfere with the degradation of components of works of art and/or historical monuments represent an important part of the monitoring of processes that can lead to irreversible phenomena.

Knowledge of colonization, bioreceptivity, microbial diversity, and interactions between microorganisms are ways to "diagnose" historical monuments. By understanding the biofilm-induced phenomena from the ecological point of view (abiotic factors, biotic diversity, and biotic-abiotic interactions), the difference could be made between biodegradation and biological colonization without or with a protective effect, and this would allow for a closer approach to the way in which restoration or biocide intervention occurs on the surfaces of artworks or heritage buildings.

The biofilm is present in all types of environments (being ubiquitous), and is one of the most interesting biological systems with a very long history, dated over 2.5 billion years [2]. By definition, it consists in "microbial communities on interfaces" [3]. The interactions between abiotic factors and biotic elements induce changes at both structural and compositional level [4–8].

Cultural and historical monuments (buildings and archeological sites) or some artworks (pictures, tailored, or wooden objects) made from different materials (paper, textiles, glass, and wood) can constitute the habitat for micro- and macroorganisms. The species that have been identified on these materials range from microscopical bacterial cells to higher plants and animals [4]. In a study concerned with the biodegradation and restoration of monuments, it is important to know how microorganisms colonize surfaces.

Also, it is necessary to determine the risk induced by abiotic and biotic factors, and the indication of the biofilm-induced hazard is required as well. The existence of variable interactions or similar effects induced by different causes which act in synergy could yield remarkable findings. Some microorganisms (lichens and bacteria) may have protective effects on historical monuments [9]. For example, lichenic coating reduces the presence of water inside the rock, thus protecting the rock material from physical decay and disintegration [10] and such microorganisms could be positively used for the cleaning of salt crusts otherwise difficult to remove by traditional restoration methods [11].

## 2. The biofilm and biodegradation (BD)

Biofilm can be considered among the most complex living biological systems. Studies have highlighted numerous interactions and intrinsic mechanisms that reveal this complexity, and which manifest themselves spatially and temporally, resulting in the formation and maintenance of the biofilm.

The mechanisms involved in the complex biofilm formation process are cell-cell interaction [12], the development of mechanical forces and the correlation with the type of substrate, cellular metabolism (growth and energy efficiency) through material exchanges, and the horizontal gene shifts in the biofilm [8].

Microorganisms within the biofilm structure are characterized by the existence of certain surface active compounds (SAC) participating in the interaction interface [3]. These may include extracellular polymeric substances (EPS) of bacterial origin, multimeric cellular appendages, flagella, fimbriae, and pili which act as cell to surface adhesins, cell to cell adhesins [13], proteins of the amyloids and lectin type (Lec A and Lec B), Psi-binding proteins, the *Pseudomonas aeruginosa* model, enzymes, polysaccharides, hydrophobins, biosurfactants (*Bacillus subtilis* model)

[14], microbial surface-active compounds (SACs) such as amphiphilic polymers, and polyphilic polymers [3].

Another component of the matrix is the DNA. Extracellular DNA as a matrix component in biofilm is apparently involved in intercellular links (cell to cell interconnecting compound in many different biofilms) as well as in the horizontal transfer of genes [13, 15].

A single species can produce several different types of matrix components of the biofilm [13]. This ability to produce different matrices helps colonize various niches through different biofilm development pathways. Understanding the mechanisms through which infections occur and the comprehension of structures has been made possible by the development of microscopy analysis techniques [16–18].

Knowing the biological components in the biofilm structure and environmental exchanges finds multiple applications in fields such as building industry [19, 20], biofouling [21, 22], medicine [23], and biodegradation of buildings and/or works of art [5, 24–29].

Between the most interesting mechanisms of colonization are those that affect the hard substrate with different degrees of porosity (stone and building materials) [8, 19, 30, 31]. The studies on these communities and the interactions between micro- and macroorganisms are various [6, 7, 22, 30, 32–34] and they have allowed the identification of amazing diversity according to taxonomic, physiological, and ecological criteria. The microorganisms which are adapted to the strong surfaces of cultural monuments have ecological niches of the endolithic type and are classified as chasmendolithic (fissures and cracks), cryptoendolithic (internal porosities), and euendolithic (forms actively penetrated through the rock) [16].

The way of action on the surfaces and the ecological links between bacteria, algae, lichens, and fungi explains the biodegradation of monuments and works of art. The structure of the communities and the phenomena associated with alteration by biological activity vary and depend on the nature of the material (stone, wood, paper, textiles, metal, leather, glass, and painted surfaces) on which associations of microorganisms are formed. The organisms involved are bacteria (including actinomycetes and cyanobacteria), fungi, archaea, algae, and lichens [35].

The microorganisms that can be investigated can be divided according to metabolism into chemolithoautotrophic and photolithoautotrophic (algae and cyanobacteria). Chemolithoautotrophic bacteria are a specialized group included in the sulfur and nitrogen cycle. This group includes sulfur-oxidizing bacteria (*Thiobacillus* sp.), oxidation-reducing bacteria of nitrogen compounds, especially ammonia substrates (*Nitrosomonas* sp.), and nitric acid (*Nitrobacter* sp.) [32, 36]. Some bacteria from this group can grow mixotrophically, which denotes the assimilation of organic nutrients for the anabolic formation of cell substance (chemolithomixotroph). Chemoorganotrophic (bacteria and fungi) base their metabolism on organic substrate oxidation and are even capable of gaining energy through the oxidation of metal cations such as $Fe^{2+}$ or $Mn^{2+}$ [32]. Chemoorganotrophic bacteria are specialized, having the ability of inducing the appearance of an acidic medium and with causing mineral dissolution on the surface of the stone.

The organisms with photoautotrophic specialization extend to external stone whenever there are favorable conditions of humidity, heat, and light. These organisms are attached to the surface of the structures, with a very large adaptation in this respect, with visible effects both on their color and with morphological changes.

Lichen species have major implications for the pedogenic activity present on lithic substrate. Through their metabolism, they release organic acids with chelating properties containing complex mineral cations. Epi- and endolithic lichens that can be isolated from stones in archeological sites may include *Xanthoria, Caloplaca, Verrucaria, Aspicilia, Lecanora*, and *Protoblastenia* [4].

Fungal species that can be identified include *Cladosporium, Trichoderma, Phoma*, *Penicillium*, and *Fusarium*. Fungi induce the reduction and oxidation of mineral cations with specific activity. The function of fungi in the biodegradation of monuments has for a long time been ignored or undervalued, as they have been considered secondary colonizers compared to other microorganisms (chemolithotroph bacteria, cyanobacteria, and algae) or lichens [37].

All microorganisms which form communities with implications in the degradation of surfaces must be analyzed under special laboratory conditions for identification. A frequently assayed technique is microbiological culture. The use of new, modern automated and more selective culture media to identify new bacterial strains could help to identify in situ diversity [38].

Instrumental techniques which can be applied for the in situ detection of bacterial activity on rock samples collected from monuments or archeological sites include fluorescent antibody technique (FAT), enzymatic methods for hydrocarbon analysis (DHA) [39], alone or together with the determination of the protein content in the filtered solutions of the stone powder samples [40], colorimetric tests [41], bioluminescence tests that quantify ATP content or coupled with differential flow calorimeter determinations, and differential flux calorimeter (DFC) [41].

## 3. Microscopy techniques for highlighting the in situ BD phenomenon

The degradation process can be studied both by common methods (microscopy and culture of bacterial strains) and by modern techniques (in situ microscopy, molecular analysis, and in situ fluorescence induction).

The microscopic study of surfaces and the highlighting of deposits created over time allow a better understanding and correlation of degradation mechanisms. The most common method for the observation and evaluation of microorganisms on surfaces is light microscopy.

### 3.1 Light microscopy

This type of microscopy is the most used means in studying the damage caused by biological factors through in situ detection. Using the results of this evaluation, microorganisms can be identified on inorganic components in situ, that is, when the biological components are not separated from the lithic material [16].

The microscopy methods used over time have allowed for more and more remarkable observations, including important details. Thus, classical microscopy, light microscopy, and stereomicroscopy have underpinned the identification of microorganisms and the substrate-microbiota interaction [1, 7, 42]. The advantage with these methods is that the magnitude of the presence of the microbiota and the identification of the taxa can be established.

Large colonies of lichens and the presence of pigment forms such as cyanobacteria and green algae can be identified on surfaces by stereomicroscopy and optical microscopy. In determining these species, the advantage is given by the fact that the biological material does not require preparation and coloring for identification, photographing, and evaluating the images being a simple and sufficient method for the classification of taxa.

As a technique, analysis by direct image evaluation is preferred compared to other quantitative techniques. Such an assessment and the argumentation of the obtained imagistic analyses are made by comparing the cyanobacteria-induced biofilm on the stone surfaces with chlorophyll measurements (chlorophyll a measurement) [33]. Excepting direct observation, highlighting specific stains can be done through methods such as Gram staining and periodic acid Schiff (PAS), which identify details of the interaction between bacteria/fungi and the substrate. PAS colors fungal hyphae in red through the interaction of the dye with polysaccharides or other cell constituents (glycoproteins and glycolipids).

### 3.2 Fluorescence microscopy

Lately, new types of fluorescence microscopes that have been developed use sophisticated image capture and processing methods to identify as many fine details of fluorochromes-emitting and fluorescent-emitting cellular components. The most recent super-resolution fluorescence microscopes can push the limit resolution down even further to about 20 nanometers (nm) [43]. This technique has a superior sensitivity as compared to other microscopy analyses. For example, over 100–1000 times more dye being required in bright-field systems to yield the same visual qualities as those of fluorochromes [44].

The direct epifluorescence filter technique (DEFT) is successfully used in determining bacterial activity in various fields such as environment, nutrition [45], safe sterilization [46], as well as in clinical practice [47]. Many of the methods of analysis for the identification of biological activity by epifluorescence use the marking of structural components (cell walls and nucleic acids), by which the characteristics of microorganisms can be defined.

Fluorescence is recommended in evaluating the cell viability of certain microorganisms [44, 48], or for the study of microorganisms on plant surfaces and is ideal for studies of the general distribution of populations of bacteria and yeasts on natural surfaces of all kinds [49]. Some common methods used to identify cellular changes of the type of those present in apoptosis include several procedures of morphological structures' staining such as EB/AO (ethidium bromide and acridine orange), DAPI, Hoechst, annexin V, caspase-3/7 activity, and ssDNA staining [48, 50], SYTOX Green, SYBR green, and PicoGreen staining [32].

Methods of fluorochrome labeling are based on loss of membrane integrity and marking of intracellular structures (DNA, enzymatic systems, and structural proteins). The advantage of these techniques is given by the possibility of establishing the viability of the studied microorganisms [51–53]. The study of viability was also used in the assessment of bioactivity on some historical monuments. Highlighting and assessing the level of biological activity on the surfaces of different monuments or works of art is superior with the fluorescence microscopy technique, which can be used in situ as well.

Of particular relevance is the use of the fluorochromes acridine orange (AO) and DAPI (4; 6-diamidino-2-phenylindole) for details [50]. These fluorochromes can be used directly with epi-illumination, which represents an advantage for in situ analyses. Acridine orange is a fluorochrome that binds to the nucleic acids of bacteria and stains them orange. Also, some details related to structure and nuclear activity are highlighted using DAPI.

### 3.3 Electron microscopy

Electron microscopy studies include two most commonly used yet different techniques: scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The first, SEM, helps evaluate surfaces, while TEM evaluates subcellular components by highlighting details. Although the biological material is processed in order to be visualized, the benefits in both cases become evident owing to the fact that they allow for very large spatial resolutions. Modern methods have allowed the establishment of a system that performs in situ analyses, scanning electron microscopy with backscattered electron (SEM-BSE). This technique allows the assessment of the viability of the bacterial biofilm, or of the lichens, on the analyzed surfaces. The advantage is that several square centimeters are analyzed in situ, at a very high resolution, which is comparable to that of the TEM analysis system [16].

The modern methods for the identification and localization of microbes indicate that it is useful to make investigations through correlative light microscopy (LM) and electron microscopy (EM) techniques [54]. This modern approach helps identify both morphological and ecological details by visualizing microorganisms in their environment. Images obtained by optical microscopy techniques and fluorescence microscopy can be combined with images of subcellular structures obtained by electronic microscopy [55] to generate a database and obtain complex results that may reveal certain superior interpretations.

## 4. Particularities and advantages of modern methods for in situ BD assessment

Researchers use a technique or another according to the specific advantages of each method (**Table 1**), which can be related to faster identification time, better accuracy of details, avoidance of artifacts, small amount of sample being needed for analysis, etc. For instance, optical microscopy, although classical, offers the advantage of in situ observations that quickly establish interactions between organisms and lithic surfaces [16]. In situ techniques are therefore useful, more so because they only require small amounts of material [56].

These observations of details help in establishing more accurate ecological niches for the different microorganisms present in biofilm. The technique of strain selection in culture cannot shed any light on this relationship and cannot show with certainty that the selected species is the one that induced biodegradation.

Modern techniques using electron microscopy bring methodological advantages through the possibility of obtaining microstructure details (**Table 1**). In addition to images with very good resolution (less than a few nanometers), modeling can also be done via 3-D representation [57] of the studied samples.

The identification of bacterial species through modern molecular biology techniques has allowed the accumulation of a wide range of information, but with many unknown variables as regards the implications of this information in understanding the ecology of species on the surfaces of monuments. Quantified molecular differences also raise a number of practical problems (selective DNA extraction, selective PCR amplification, and the lack of a DNA amplification technique in the mixture) [58]. Genetic studies allow the identification of species by developing methods of labeling target proteins. In addition to the identification and classification of microorganisms, marking techniques bring data associated with the particularities of the expression and functioning of the target proteins, aspects related to the specificity of cell adaptation under particular environmental conditions.

These target proteins as well as nonprotein-labeled components (nucleic acids, lipids, and glycans) greatly contribute to obtaining data that increase the applicability of the correlative image method. However, molecular biology methods reveal the diversity of biological communities and can contribute to finding monument rehabilitation solutions based on the knowledge of these details of molecular flexibility (**Table 1**).

Lately, studies treating cultural monument degradation have been improved by successfully applying the laser-induced fluorescence technique, known as light

| Technique | The advantages of application | The type of investigations and complexity level |
|---|---|---|
| Light microscopy | • Quick observations and establish organisms with lithic surface interactions;<br>• Mark end evaluations of the microbiota communities;<br>• Important details for identifications of the taxa;<br>• Small amounts of material and sample;<br>• Fast evaluations of bioreceptivity;<br>• Limited artifacts | Laboratory analyses;<br>In situ investigations;<br>Direct analyses and samples without difficulty in preparations (stain methods) |
| Fluorescence microscopy | • High resolutions;<br>• Sensitivity;<br>• The highlight of the cellular components (cell walls, nucleic acids, and proteins);<br>• The changes of microbiota cell viability and predictions of biodegradation;<br>• Allow only observation of the specific structures which have been labeled for fluorescence | Laboratory analyses;<br>In situ investigations;<br>Preliminary sample preparations with medium difficulty (stain methods) |
| Electron microscopy (SEM and TEM) | • Very high resolutions;<br>• Spatial variability;<br>• Subcellular component evaluations;<br>• Complex details for correlation and interpretations of data | Laboratory analyses;<br>In situ investigations;<br>Preliminary sample preparations with medium and high difficulty |
| Molecular biology | • High diversity of biological communities identified;<br>• Molecular flexibility used for rehabilitation strategy;<br>• Biota-surface interactions | Laboratory analyses;<br>Preliminary sample preparations with high difficulty |

**Table 1.**
*The advantages of the microscopical and molecular techniques used for the evaluation of biodegradation and level of their complexity.*

detection and ranging (LIDAR). This technique was originally developed and applied for the study of vegetation and the marine environment and has recently been extended to the field of cultural monuments' preservation [59].

## 5. Case study research: in situ analyses at the painted Matia-Fresco Loggia, Corvin Castle, Romania

The diagnosis of the degradation stage of different materials such as natural stone, crushed stone, sands and gravels, clay, inorganic binders (lime, dolomite, natural cements, hydraulic lime, and gypsum), mortars, and artistic components (painted surfaces, Matia-Fresco Loggia, stone) from the Corvin Castle (**Figure 1**) have been examined by using advanced investigative techniques according to the recommendations on restoration and preservation operations.

Modern high-fidelity portable and laboratory equipment has been used for analyses: scanning electron microscopy (SEM-EDS), optical microscopy (OM),

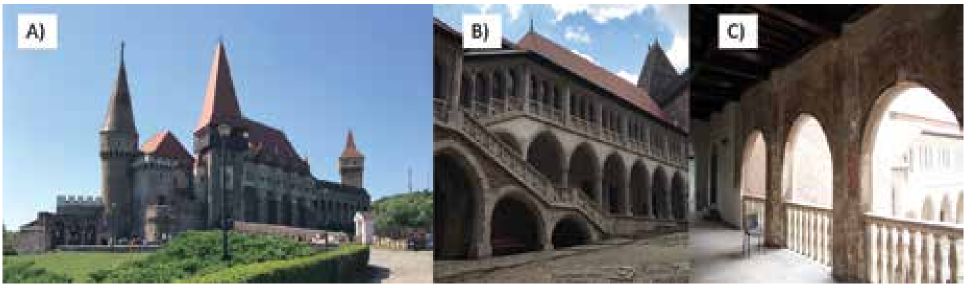


**Figure 1.**
*The locations of sampling points. (A) Corvin Castle—general view; (B) Matia Loggia—outside view; and (C) Matia-Fresco-Loggia—inside, two pillars view.*

X-ray diffraction (XRD), Fourier transformed infrared (FT-IR), and Raman spectroscopy as well as polychromic analysis (by chromatic parameters).

Besides the use of all of these, the monitoring and characterization of weathering/decay features and of environmental weathering effects are essential for this monument's preservation [60].

Based on XRD and WDXRF analyses, the Corvin Castle was constructed from dolomite-limestone blocks from local natural resources, crenelated in the upper part. XRD mostly indicates the presence of dolomite, calcite, and quartz, with small amounts of illite, muscovite, paragonite, montmorillonite, wonesite, feldspars, chlorite, and some clayey raw material: whitmoreite, kornelite, micas, and other heavy minerals.

Also, iron silicide is present in most of the samples, as recognized by the used analytical techniques. Incompatibilities between traditional materials and the new ones (wood-mortars and mortars-cements) observed after restorations over time are essential. It is important to focus on their effects on the walls and painted surfaces as well. For the whole area, the pH value is around 5.3.

Besides all of these investigations, it is important to ascertain the humidity migration and circulation inside of the Matia Loggia. The local measurements revealed higher humidity values at the external position (higher air circulation) of the loggia and lower humidity values at the internal positions (**Figure 2a**).

The deterioration of stone usually takes place at higher relative humidity, above 65%, and for external walls, it is more accentuated for porous building materials where it is caused by the excessive moisture content [61]. Changes in temperature induce a thermal gradient (**Figure 2b**) between the surface layer and the inner layer of materials which may result in the degradation of the mechanical properties of the material and can lead to the formation of fine cracks.

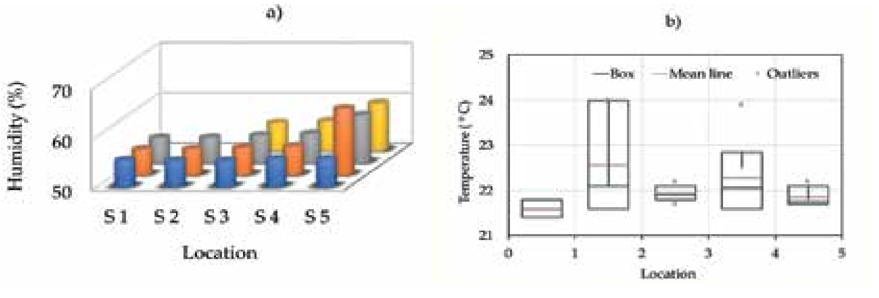


**Figure 2.**
*(a) The changes of the humidity and (b) the variations of temperature with the location: S1—the innermost; S5—the most outward.*

Studies on the degradation of fresco areas have been done at macro- and microscopic level. The in situ analysis (22 samples), performed for the first time in the fresco area, highlighted several aspects that concur with the phenomenon of degradation: the existence of materials with high porosity which favor moisture maintenance and increase the potential for biodegradation in the case of restored areas (**Figure 3a**), the presence of extensive deterioration over the entire painted surface, including depigmented areas (**Figure 3b** and **i**) and cracked portions (**Figure 3c** and **d**) and the existence of biogenic pigments green, reddish brown (**Figure 3f** and **g**) or black (**Figure 3h** and **j**).

The harvesting of biological samples on the surfaces indicating a visible degradation phenomenon was done by means of a sterile needle, by the removal from fresco areas of a few millimeters. The harvesting of the samples was done in sterile plastic containers (**Figure 3**). After scraping, the samples were processed and studied in the laboratory.

Microscopic preparations were analyzed by several microscopy techniques (stereomicroscopy, optical microscopy, epifluorescence, and SEM microscopy), both to highlight structural details and to evaluate the biological activity present on surfaces. To identify the morphological details of the microorganisms, methylene blue dyes and fluorochrome acridine orange (AO) were used, while for epifluorescence, the excitation filter of 488 nm and the emission filter of 515 nm were utilized. Small sample fragments were introduced into approximately 5 μL of distilled water and buffer solution (pH 6.8), and the cell suspensions were placed on slides and analyzed with the optical and epifluorescence microscopes.

To exemplify the way that the types of observations were correlated, the details of in situ microscopic analyses are presented for three types of samples collected at different soil levels and distinct degradation characteristics, considered as models of analysis.

Sample 1 was collected at a height of about 1 m to the soil, from painted portions with visible degradation elements (**Figure 4**) on the respective surfaces. Macroscopic and microscopic observations have identified porosity and high brittleness of materials. Dark brown biogenic pigmented areas and depigmented portions that are easy to detach are highlighted (**Figure 4a**). At the morphological level, there are different structural components with (**Figure 4b** and **c**) uneven

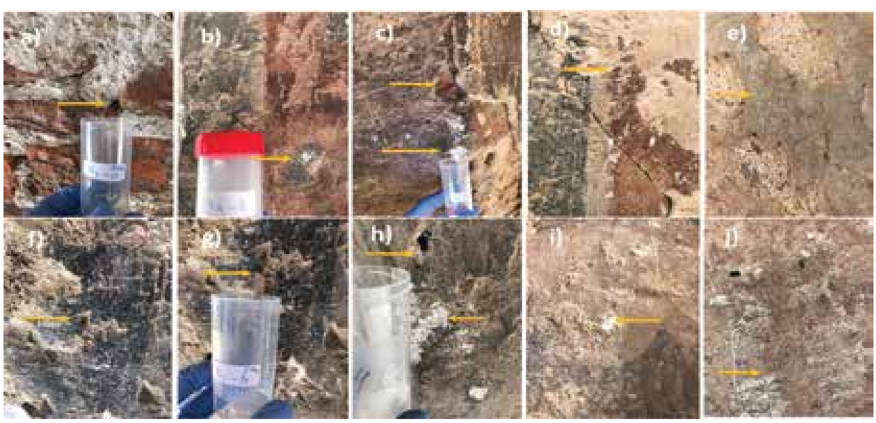


**Figure 3.**
*Sampling and indicating areas of high degradation of the material (yellow arrows): (a) the materials with high porosity in restored areas, (b) depigmented areas, (c) cracked portions, (d) deterioration areas with fissures and cracks, (e) green pigment portions, (f, g) biogenic reddish-brown pigment, (h) black pigment, (i) deterioration with depigmented areas, and (j) black pigment and extensive deteriorations areas.*

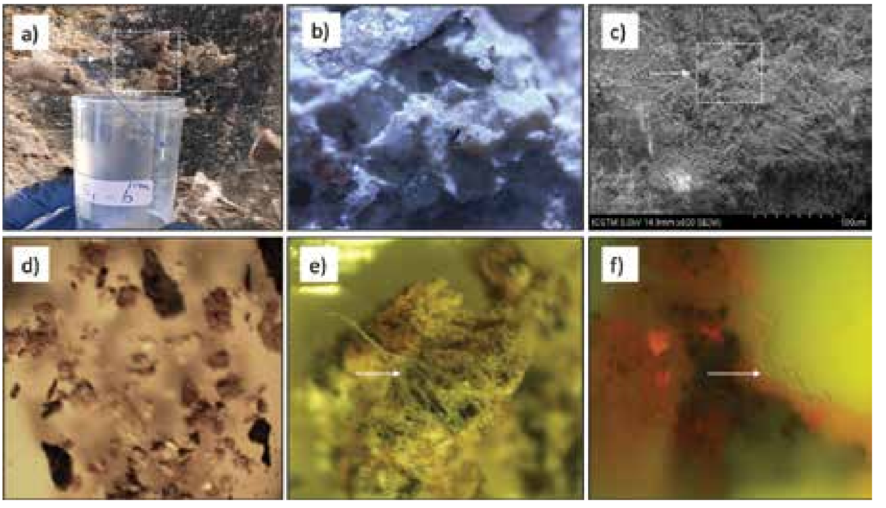

**Figure 4.**
*Evaluation from macroscopic to microscopic level of the degraded surface; (a) direct visual evaluation, surface details light microscopy 400×, (c) electron microscopy (SEM) 7000×, (d) stereomicroscopy 40×, light microscopy 400×, and (f) epifluorescence microscopy 400×.*

surfaces (**Figure 4b**), and at the micromorphological level, there is an obvious uniformity of the surface.

At this level, porosity is very fine, with ordered microspheres suggesting biogenic origin. In the sample analyzed with the optical microscope, during the first minutes after harvesting, very intense bacterial activity was revealed. The very large number and mobility of bacteria is evidence of the intense colonization of these microgalleries of the substrate. Extemporaneous samples also surprised fungal filaments (**Figure 4e**) adhering to the substrate and the stratification of the biofilm (**Figure 4f**), aspect suggesting the existence of anoxic conditions at the microhabitat level.

Sample 2 was collected at 1.50 cm to the soil, from an area with fine cracks (**Figure 5**), where superficial layers are easily detached.

Direct observation (**Figure 5a**) of the area of sample collection indicates that the zone was intensely degraded, with excavations likely induced by the shredding of the material and a mosaic appearance as a result of depigmentation. Microscopic analysis reveals fine granulation and mixtures of mineral elements with different chromatic appearances and porosities (**Figure 5b** and **d**). Shredding degradation is also visible in SEM analysis (**Figure 5c**). The study of wet microscopic preparations indicates fungal agglomerations (**Figure 5e**) and bacterial activity evidenced by intense mobility. Several bacterial morphotypes and clusters of the type of hulls found in clusters of irregular or filamentous forms were visible (**Figure 5f**).

Sample 3 was collected at 1.70 cm from the ground, painted with obvious bumps and dents, with a modified chromatic look (**Figure 6a**), possibly paint overlays overlapping previous restoration attempts. Microscopically, we found components that are different in shape and color (**Figure 6b**) arranged in layers with variable porosity and chromatic sequence (**Figure 6d**). From a biological point of view, the surfaces are intensely colonized (**Figure 6e** and **f**) of very large density micrococcus forms.

The analysis with specialized microscopy with epifluorescence highlighted the activity of the biota within the analyzed system. Live bacteria with an emission in

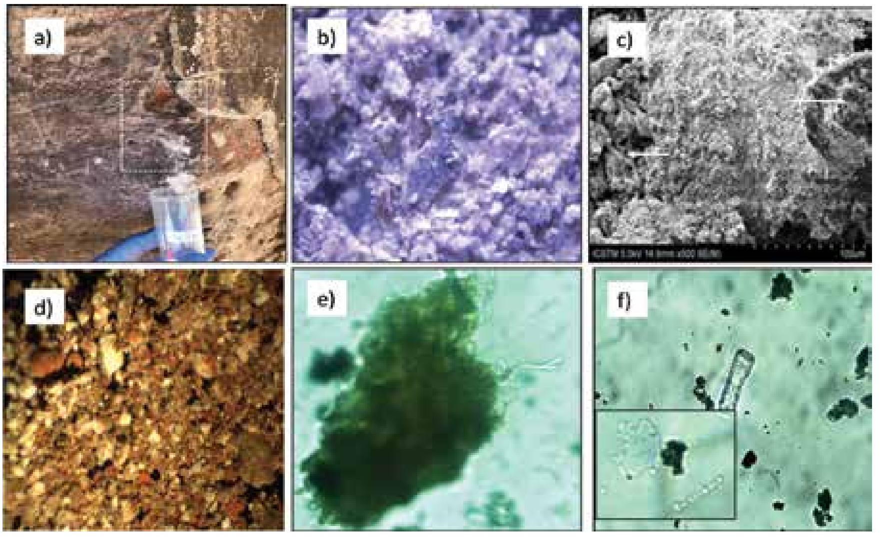


**Figure 5.**
*Evaluation from macroscopic to microscopic level of the degraded surface; (a) direct visual evaluation, (b) light microscope 400×, (c) electron microscopy (SEM) 7000×, (d) stereomicroscopy 40×, (e) light microscopy 400×, and (f) light microscopy 1000×.*

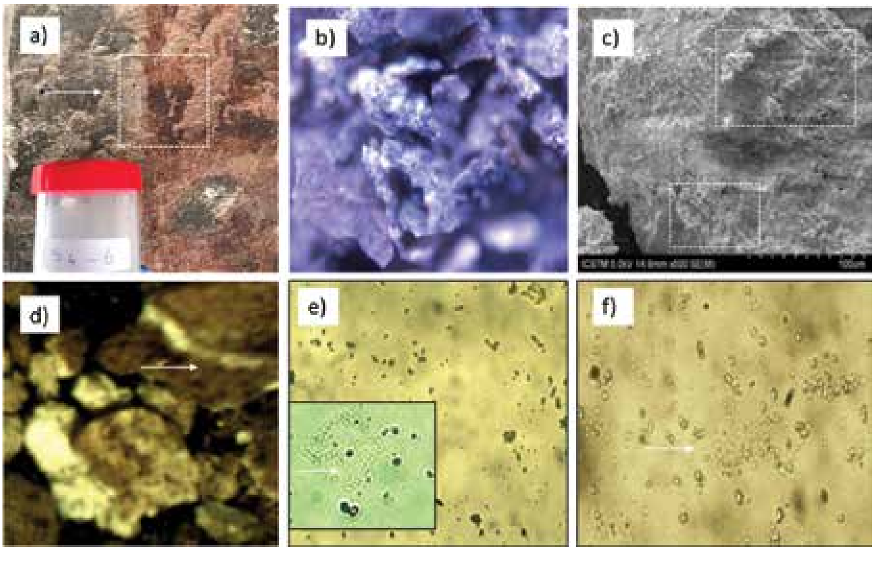


**Figure 6.**
*Evaluation from macroscopic to microscopic level of the degraded surface; (a) direct visual evaluation, (b) optical microscopy 400×, (c) electron microscopy (SEM) 7000×, (d) stereomicroscopy 40×, (e) optical microscopy 1000×, and (f) optical microscopy 1000×.*

orange shades have been noted in the presence of fluorochrome AO in an acid pH (**Figure 7a**). On inorganic surfaces, live components such as free-flowing filaments (**Figure 7c**) or filaments attached to the substrate (**Figure 7b, d** and **e**) were identified by this technique.

Metabolic activity is also noted through acidification phenomena marked by red emission on the carrier particles, probably caused by the death of some components of the microbial complex (**Figure 7b**).

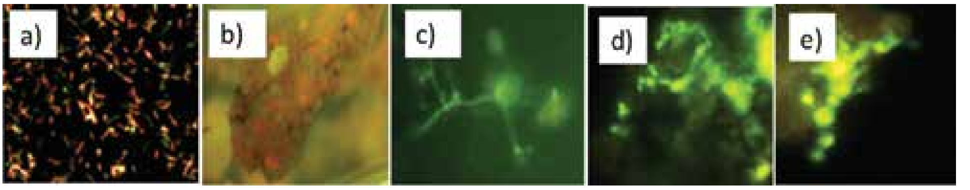


**Figure 7.**
*In situ observations using the epifluorescence microscopy technique and AO stain: (a) bacteria in suspension sample, (b) biofilm at substrate, and (c–e) fungal hyphae, (magnification 400×).*

## 6. Conclusions

The methods and techniques for assessing biofilm characteristic to historical monuments are difficult to standardize because of differences that may interfere (local climate, natural or artificial microclimate, microflora diversity composition, microbial pigment appearance, and the presence of rare or unknown species) and change the results between samples.

Among the easiest to apply and less expensive methods, but with a high degree of relevance, are the microscopy techniques. From the classic optical to the specialized microscope with fluorescence microscopy, to the most advanced microscopy (SEM or SEM-BSE, TEM), all of these have increased the degree of enlargement and the identification of structural details, respectively.

The discovery of morphological types and interactions between microorganisms (symbiosis, attachment, and complexity of matrix synthesis) was a feature of superior electron microscopy analysis systems and contributed to increasing the level of understanding of the ecology of microbiota systems.

On the analyzed Fresco area, Matia Loggia as a case study, in situ techniques applied for biodegradation assessment reveal an intense biological activity on the analyzed lithic systems. Following microscopic analyses, the extemporaneous samples highlighted the colonization of the analyzed surfaces with bacterial and fungal hyphae.

The intense bacterial activity was noted in all the samples taken from the points located at a distance of 1 m from the base of the walls by the in situ technique. The presence of fungus has been noted in interference areas between different types of substrates.

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## Conflict of interest

None of the authors have any competing interests in the manuscript.

## Contributions

Verginica Schröder, Daniela Carutiu Turcanu, Adina Honcea, and Rodica-Mariana Ion equally designed and performed the research. All authors reviewed the manuscript.

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The integration of science with art is a complex process of analysis and the knowledge and understanding of the need to save and protect works of art as well as preserve and restore cultural heritage. This is generally provoked by the living necessity, profoundly human, to leave our inheritance to new generations, as intact as is possible, the testimonies of the past.The issues approached interfere with artistic criticism, for example, biological and physico-chemical analyses, and intelligent mathematical modeling systems such as Marker-less Augmented Reality, 3D Reconstruction, intelligent combinations of digital image analysis functions to recognize and estimate the possible evolution of color and shape to help experts make the best decisions about authenticating and preserving-restoring art objects.Advanced technical devices such as digital databases and other tools and materials can allow for the eradication of offenses such as false art and falsification.

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