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# CONSERVATION SCIENCE IN CULTURAL HERITAGE

(formerly QUADERNI DI SCIENZA DELLA CONSERVAZIONE)





# CONSERVATION SCIENCE IN CULTURAL HERITAGE

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[formerly *Quaderni di Scienza della Conservazione*]

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On front cover

Large photograph:

Marcantonio Raimondi (1482-1534), Baccio Bandinelli (1493-1560) (attributed)  
*L'uomo e due trombe* / The man with two tubas (burin, Musei Civici di Pavia, Italy)

Small photographs from papers in this volume (clockwise from top left to right):

1. *The Wedding Feast at Cana, Paolo Veronese (Artificial intelligence and digital reproduction in art).*
2. *The left half of Christ in a painting by Marcello Venusti based on a drawing by Michelangelo and the face of the Shroud (Between Michelangelo and the Holy Shroud: artificial intelligence and its miracles).*
3. *White and luminosity inside the mosques, Ghardaïa on the left and Beni-Izguen on the right (The colors of Mزاب cities: heritage, culture and symbolism).*
4. *View of the entrance portico of Biskra city hall. On the right, the lion statues after shifting (Tracing "orientalism" through architecture and art during the French colonisation of Algeria).*
5. *Notre Dame de Paris: restoration process after the fire in 2019 (Notre-Dame Cathedral in cinematic interpretations).*
6. *Casa di Diana, present-day 360° panorama view (A tool to access unreachable sites inside the Archaeological Park of Ostia Antica in Rome).*

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## **Publication Ethics and Publication Malpractice**

The following statement is inspired by COPE (Committee on Publication Ethics – website: <http://publicationethics.org/>).

### **Duties for the Editor-in-Chief of the Journal**

The Editor-in-Chief of the Journal Conservation Science in Cultural Heritage is responsible for the selection and publication of the articles submitted to the Journal.

The Editor-in-Chief takes all reasonable steps to ensure the quality of the material published in Conservation Science in Cultural Heritage.

The Editor-in-Chief's decision to accept or reject a paper for publication in the Journal is based on subject relevance and originality and is guided by the review of suitably Qualified Reviewers.

The Editor-in-Chief will ensure that appropriately Qualified Reviewers are selected for submissions.

The Editor-in-Chief strives to ensure that peer review at the Journal is fair, unbiased and timely.

A description of the peer review process is published below and Scientific Editors are ready to justify any important deviation from the described process.

### **Organization of peer review**

The process of peer review must satisfy principles of autonomy, and therefore follow lines of democratic and unprejudiced evaluation in order to be objective.

In practical terms it is structured as follows:

First is the Editor-in-Chief, with his specific competences and direct obligations, followed by the Deputy-Editors; this, to balance any demands which might arise regarding possible conflict of interest relating to the Editor-in-Chief himself.

A list of Scientific Editors follows, made up of scholars of consolidated personal and scientific rigor, whose corresponding backgrounds, skills and experience must respond to the different scientific areas covered in aspects related to the Journal's objectives of interdisciplinarity and internationalization. It is precisely these pre-established aims and objectives, that have been achieved during the period from 2001 to date with the publication of the respective issues of the Journal, formerly "*Quaderni di Scienza della Conservazione*" and renamed "Conservation Science in Cultural Heritage" in 2007.

In this way, published papers answer to the specific characteristics of the Journal, described as "historical-technical" and refer to studies and research related to cultural and environmental heritage, covering fields within the various scientific worlds in respect of the holistic value of cultural heritage. The members of the Scientific Board come from wide-ranging scientific and humanistic backgrounds – technical-experimental, historical-humanistic, ministerial, professional, managerial and political – as evidenced by its composition.

The Editor-in-Chief evaluates manuscripts for their scientific content without regard to race, gender, sexual orientation, religious belief, ethnic origin, citizenship or political philosophy of the Authors.

The Editor-in-Chief's decision may be constrained by such legal requirements regarding libel, copyright infringement and plagiarism.

The Editor-in-Chief provides appropriate guidelines to Authors that encourage accuracy, completeness and clarity of research reporting, including technical editing, to correctly draw up their manuscript.

The Editor-in-Chief ensures that material submitted to the Journal remains confidential while under review. Confidentiality of individual information obtained in the course of research or professional interactions is guaranteed.

The Editor-in-Chief has a duty to act if he suspects misconduct or if an allegation of misconduct is brought to him. This duty extends to both published and unpublished papers.

The Editor-in-Chief manages his own conflicts of interest as well as those of the entire editorial structure and of the Authors.

The Editor-in-Chief ensures unbiased review for manuscripts submitted by components of the editorial structure.

### **Evaluation of submitted papers**

After a preliminary assessment based on the established objectives of the historical-technical Journal, "Conservation Science in Cultural Heritage", in the event of a positive evaluation, the Editor-in-Chief will send the paper to the Scientific Editor with expertise in the relevant field the paper covers. It is then sent to two Qualified Reviewers belonging to the same field of competence for "double blind peer review". They will proceed in their evaluation by making comments and suggestions, where necessary. The Author will subsequently revise the paper, which is then sent once more to the Qualified Reviewers. After final review, the corrected paper will be ready for publication.

The following diagram shows the players in the hierarchical pyramid:



The Editor-in-Chief, in drafting the Journal, will adopt innovative procedures relating to trends in peer review and publishing standards.

The Editor-in-Chief guarantees that errors, inaccurate or misleading statements are corrected promptly and with due prominence.

The Editor-in-Chief will publish corrections, clarifications, retractions and apologies when needed.

The Editor-in-Chief will respond promptly to complaints and will ensure there is a way for dissatisfied complainants to take complaints further. Complaints and appeals should be sent to the aforementioned Editor-in-Chief.

The Editor-in-Chief ensures that content is published on a timely basis.

The Editor-in-Chief takes all reasonable steps to guarantee that the published material is securely preserved, and all articles are published in open access, freely available to anyone. Permanent identifiers, such as Digital Object Identifiers (DOI), guarantee tracking and preservation of articles in the long term.

### **Duties for Authors**

Authors are responsible for the articles they submit: they must assure the originality of their works, being aware of the consequences of misconduct.

Authors should always acknowledge their sources and provide relevant citation details for all publications that have influenced their work.

Authors are asked to provide the original data regarding their paper for editorial review and should be prepared to retain such data for a reasonable time after publication in order to provide access to such data.

Authors are asked to follow the **Author Guidelines** published by the Journal, therefore ensuring accuracy, completeness and clarity of research reporting, including technical editing.

Authors are kindly requested to complete and sign the form: "Authorization for release and publication of individual contributions to collective works" which will be sent by the editorial staff only if the article is deemed fit for publication.

Archiving and free use of the post-print are permitted.

Self-archiving of the pre-print, peer review and any previous versions are not permitted.

Please note that papers should be submitted at the proper time, thereby allowing time to finalize editing and publication.

### **Duties for Qualified Reviewers**

Qualified Reviewers are provided guidance on everything that is expected of them including the need to handle submitted material in confidence.

Qualified Reviewers are required to disclose any potential competing interests before agreeing to review a submission.

Qualified Reviewers are requested to comment on the originality of submissions and to be alert to redundant publication and plagiarism. They will alert the Editor-in-Chief regarding intellectual property issues and plagiarism and work to handle potential breaches of intellectual property laws and conventions.

Qualified Reviewers should indicate relevant published work that has not been cited by the Authors.

Journal policies will be reviewed periodically, particularly with respect to new recommendations from COPE.

## Quality control

Conservation Science in Cultural Heritage is a historical-technical Journal, the Authors and discussed topics, therefore come from different scientific backgrounds and disciplines. One of the Journal's main objectives is to achieve an all-encompassing vision of interdisciplinarity and internationalization, essential elements in today's society and relevant cultural sectors. In this, the Journal responds to a natural demand for information and professional growth – as far as possible correct and complete – on issues related to the cultural heritage sector for which the specific literature is somewhat limited. Another equally important aim is to ensure a high standard in the scientific content of the Journal together with high resolution of text and images in both hard copy and open access versions.

The Journal is also accessible through the websites of the previously listed publishers, collaborators, academic libraries, ministries and institutions, highlighting the need for complete information in the scientific field, understood as a symbiosis of the social and human sciences and experimental sciences: the globalization of culture.

The journal is accessible online (at: <https://conservation-science.unibo.it/>) and has been included in numerous websites of interest to all those looking for information regarding the subject areas listed in the main topics of publication.

The Journal has also officially been included in international databases:

- DOAJ (Directory of Open Access Journals)
- ERIH PLUS (European Reference Index for the Humanities and Social Sciences)
- EBSCO (Elton Bryson Stephens Company) research database giving the Journal visibility and raising cultural heritage awareness

The Journal has been indexed and classified in:

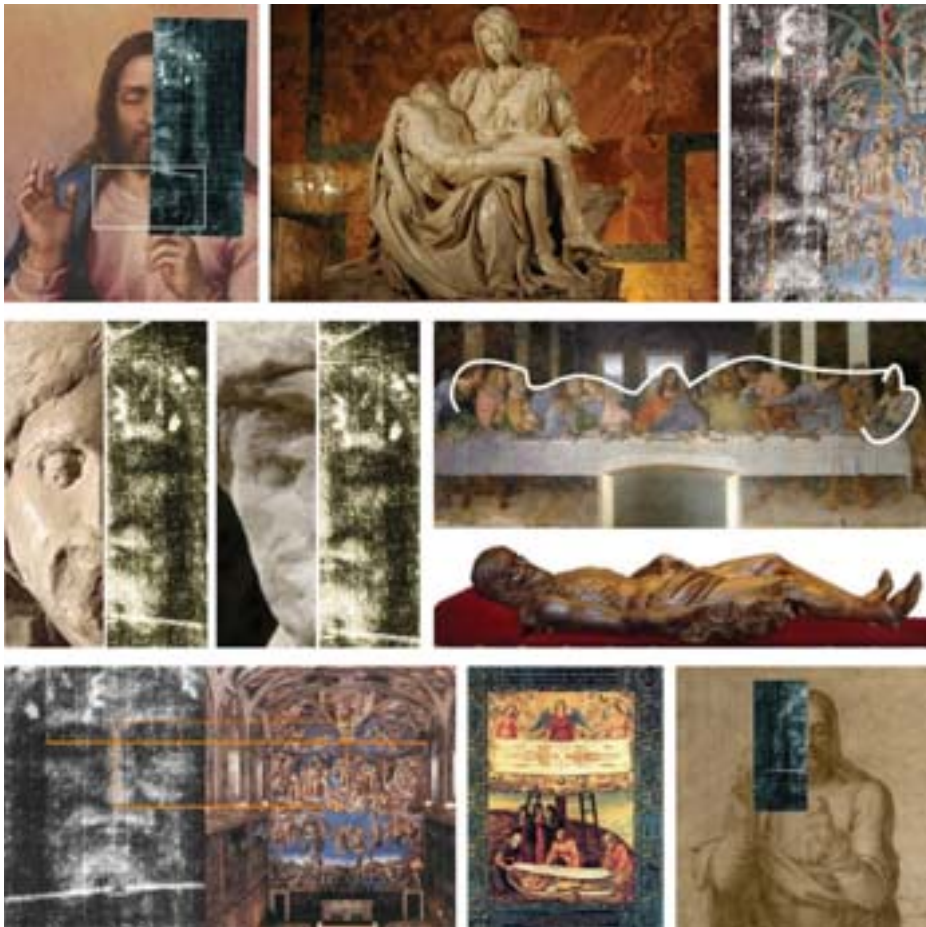
- ANVUR (Agenzia Nazionale di Valutazione del Sistema Universitario e della Ricerca) in Class A.
- SCOPUS – SCImago Journal and Country Rank (SJR), a bibliographic database containing abstracts and citations for academic journal articles produced by Elsevier.
- ESCI (Emerging Sources Citation Index – Journal List Web of Science) by Clarivate Analytics (formerly Thomson Reuters).

The Journal has a SPARC (Scholarly Publishing and Academic Resources Coalition) “seal” and CC license (Creative Commons): important certification for open access journals.

# MAIN TOPICS OF PUBLICATION

- Study of the system: artifact-environment-biota
- Historical-artistic knowledge of cultural heritage (ie. author, art movement, period of realization, techniques, society and cultural characteristics, socio-economic context, commissioning, financing, interested public)
- History, diagnosis, restoration, maintenance, conservation, valorization, prevention, protection, preservation
- Document research
- Book, codex and manuscript production in its historical context
- Appropriate methodologies and analytical techniques used for the characterization of historical artifacts and evaluation of the conservation state
- Environmental monitoring: assessment of atmospheric pollution and correlated degradation of monuments and historical-artistic sites
- Micro and macroclimatic monitoring in confined areas (ie. museums, libraries, archives, churches, galleries...)
- Art diagnostics and evaluation of the authentication of art works
- Art market and auction houses
- Experiences in cultural heritage conservation
- Evaluation of the suitability of products for restoration, conservation and maintenance of works of art
- Information science and cultural heritage: data processing and cataloguing methods
- Virtual re-elaboration and use of historical artifacts and environments
- Study, valorization and digitalization of archive and library heritage
- Environmental context and technical-conservative issues related to historic architecture
- Virtual or traditional conservation, cataloguing and processing of photographs
- Various other topics including education, training, safeguard, legislation, economics, social aspects, management, marketing, interdisciplinarity, internationalization, etc.





*From: BETWEEN MICHELANGELO AND THE HOLY SHROUD:  
ARTIFICIAL INTELLIGENCE AND ITS MIRACLES*

*by Átila Soares da Costa Filho*





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# **E**DITORIAL



## **SYNERGY, TECHNOLOGY AND IDENTITY IN ART, FACING THE CHALLENGE OF ARTIFICIAL INTELLIGENCE**

**Salvatore Lorusso**

Editor-in-Chief, Foreign Member of the Russian Academy of Natural Sciences, Russia

**Mauro Mantovani**

Prefect Vatican Library, Vatican City, Italy

### **1. Encounter and dialogue of the humanities and experimental sciences**

In addition to creating opportunities outside consolidated and sometimes restrictive stereotypes, exchanges between cultures can also create conditions to overcome that fragility which often relates to a poor interpretation of identity based on narrow-mindedness and rejection. Coexisting in an "ample space" is what has allowed civilizations to grow in value and may even be considered a condition for a cultural life. A limited cultural background is a barrier that can create gaps, generate misunderstandings and conflicts, and above all, prevent planning for the future using interpretative keys suited to understanding the complexity of living with science. Discussion opens people's minds to a solid culture, and allow prejudices and artificial notions that hinder knowledge to be removed: scientific progress has happened also, or even especially, thanks to cultural exchanges. Culture sustains us in our ability to imagine a new future, offering evaluation criteria that are now universal. The challenge is also characterized by knowing how to make the values of the "founding pacts" of today's institutions migrate to the computer architecture which designs and influences our institutions in a decisive way. The expression "complementing each other" in the field of research is extremely significant for the "unity of diversity", inspired by a vision that knows how to look forward, without flattering or stumbling on barriers that may have been created in this regard: acquiring real awareness may even prevail over currently convenient or functional narratives of contrasts or coexistential crises. Recalling an aphorism taken from the comedy written in Latin, "The Self-Tormentor" by the Roman playwright Terence, who lived in the second century B.C.: "Homo sum, humani nihil a me alienum puto" (I am human, and I consider nothing human is alien to me), he points out that the attitude towards culture produced by people and artists can only relate to openness, curiosity, knowledge, and comparison, even though genuinely critical. Progress is born from openness, not from prejudice or ignorance: the cultural context is the product of a transformation, sometimes dialectical or discontinuous. Culture, moreover, rejects any convenient categorization and aspires to offer itself as a means of comparison by merging and evolving with other cultures, but also shunning homologation and conformism; in other words, what we are unconsciously or culpably subjected to because of mental laziness or opportunism.

Thus, it is transdisciplinarity or crossdisciplinarity - the result of mutual enrichment and interaction, of knowledge and experience, and on which are based the theories and methodologies of the humanities and experimental sciences – that weaves the connective tissue that surrounds us. In this regard, transdisciplinarity or crossdisciplinarity is different from simple multidisciplinary or “weak” interdisciplinarity. In fact, multidisciplinary is a simple sum and juxtaposition of disciplines which usually remains anchored to individuality in content or meaning. On the other hand, “weak” interdisciplinarity only interacts with other disciplines in a mutual need for completion. It is at a later stage that transdisciplinarity and crossdisciplinarity aim to enrich knowledge and is the result of a methodology that implies a connection between theories and methods and, consequently, between scientific principles, the basis for the humanities and the experimental sciences: each discipline continues to exist in its own right but each one is enriched by interaction and dialogue.

This is the basis of study and research in the field of art which, in representing the spirit of the time and the autobiography of a people or of a country, is its cultural autobiography. Scientific truth is fundamental and is based on a communion of intents and synergy of skills, so that a result may be achieved that is reliable and shared.

## 2. The scientific revolution in art

In his book, "The Fourth Revolution", the Oxford University philosopher Luciano Floridi points out how the last three scientific revolutions have had a great impact on the way we think about ourselves, since they have changed our understanding of the external world, and as a result, the understanding of ourselves.

Following the Copernican revolution, heliocentric cosmology *removed* the earth from its central position, and consequently, humanity's position at the centre of the universe. The Darwinian revolution showed that living species had evolved from common ancestors through natural selection and so *removed* humanity from the purely biological world. The Industrial Revolution then *removed* humans from many production processes to increase automation. Nowadays, the digital revolution is also profoundly transforming every aspect of our lives, and is seen in education and entertainment, communication and commerce, love and hate, politics and conflict, culture and health. Many more can be added, all of them transformed by technology whose main function is to record, distribute and process information. Since the 1950s, the computer and digital technologies have started to change the concept of who we are. In fact, we have discovered that we are not isolated entities, but rather interconnected informational agents and engineering artefacts that share a global environment with other biological and artificial entities ultimately consisting of information. Floridi not surprisingly defines this common environment "infosphere" and names Alan Turing as the progenitor of the fourth revolution, the father of computer science. The fourth revolution thus offers an opportunity to rethink our intelligent behaviour that must now include artificial artefacts that adapt more and more effectively to the "infosphere". In this regard, it should be noted that digital technologies are not only tools limited to changing the way we interact with the world, as in the case of the wheel or the engine. Advances made in information technology give us the possibility to shape ("form" and "format") the infosphere, increasingly influencing the way we understand the world and how we relate to it, as well as the way we think about ourselves and interact with each other. In other words, they are "ontologizing" systems able to modify the intrinsic nature (ontology) of what they touch. It follows, therefore, that our behaviour must be confronted with the predictability and possible manipulability of our choices, as well as with the development of an artificial

autonomy. Having examined the specific peculiarities of these technologies that interact with reality, and examined and reviewed them in depth, there is no doubt that our behaviour is extremely important, and must be seen not only as an attitude, but also as vitally interacting with these technologies. In the face of these scenarios, a question arises: should there be a supine acceptance of everything at once, or a gradual and critical acceptance?

It is important to continue debating the topic that is already changing our lives and will probably change our future: Artificial Intelligence (AI). However, it is not easy to find a common definition of AI from among the numerous general or purely technical notions. Of course, the immensely exciting opportunities related to this technology are clear, as well as the existence of three different levels of risk to our individual and social life: limited, serious, and unacceptable. One example is the real-time biometric identification of people in public spaces, or their categorization according to sensitive characteristics, social scoring, and behavioural manipulation. For this reason, there is no shortage of catastrophists (doomers), who fear the unpredictable consequences of an uncontrolled and savage development of AI for humanity; they are contraposed to boomers, who, on the other hand, believe that thanks to AI, scientific progress can "explode" and will be able to solve the many present-day crises, starting from the environmental issue.

It is worth noting that the European Union has been working on an agreement to regulate the use of artificial intelligence (EU AI Act). Pope Francis, in his message "Artificial Intelligence and Peace" for the 57<sup>th</sup> World Day of Peace (January 1<sup>st</sup>, 2024), launched an appeal for the control of new digital technologies to become a shared asset, pinpointing the need for an internationally binding treaty to "regulate the development and use of artificial intelligence in its many forms". So, what can be done?

Time is important and is not synonymous with weakness. In fact, time is the ancillary condition to understand what was accepted and codified in the past, and in the event, discuss and demonstrate what is claimed here. We are not only referring to the subsequent revision and completion of the already existing regulation framework, but also to what today is being imposed by the digital revolution and social networks. Many factors come into play when a discussion starts: there is non-acceptance and the will to resist with one's theory without allowing oneself to be overpowered, even when one is faced with a system that is globally recognized as a decision-maker. The journey for each new idea and theory takes time, because we ourselves are part of that time. The topic is particularly interesting if we transfer what has been said to the specific case of art evaluation, made not only from a historical, artistic, aesthetic, and iconographic point of view, i.e. through subjective evaluation, but also through objective evaluation using new technologies. And it is the objective evaluation that gives a concrete meaning to transdisciplinarity and crossdisciplinarity which, by witnessing the meeting, listening, comparison and resolution of the specific issues, provides a scientific contribution deriving from the humanities, as well as from the digital, diagnostic, and experimental sciences. This is in reference to both the historical-humanistic, philological-philosophical-social disciplines and technical-economic-managerial, and legal-identity disciplines, which are all involved in the peculiarities that distinguish an artwork and its holistic value. The approach to uphold must be, not to accept what in the past - with a "reductionist perspective" - determined, and even today continues to determine, doubts and/or second thoughts. In the art market, the attribution and authentication of artwork is an emblematic case and has been the subject of many a heated debate by experts from various institutions, universities, and research centres. It has been argued for years that an artwork can be authenticated only by evaluating it subjectively, even if carried out by art historians with great experience and competence. It is, however, just as essential to

support and/or refute the latter with an objective evaluation made by technicians, thus arriving at a unique, but complete scientific truth, which includes a corresponding economic evaluation. In this case, art and science combine also with respect to the aforementioned transdisciplinary or crossdisciplinary approach, i.e. a common theory and methodology on whose principles the humanistic and experimental sciences are based, thus acquiring a unique value and definitive result. But it is also equally important to underline the fundamental contribution of the other previously mentioned disciplines for the characterization of artworks: the economic-managerial and legal-identity areas. Considering the importance of time as a necessary condition for understanding and accepting what one believes is right, it is worth noting how the advent of the digital revolution and social media has aggravated the situation, giving the impression that everything happens immediately, and that it must be immediately commented, reposted, and amplified. The past conditions our choices, actions and decisions, our acceptance of what we have already accepted. At the same time, the future pushes us to change, react, desire, and want new things. As for the digital revolution, it should be noted that most major historical events are much more nuanced and far too complex to describe in a simple post or tweet, in some cases, certain situations, positions, specious questions sound like "acts of violence". Ultimately, to better understand and listen well, we have to rethink the concept of "supine acceptance" in some cases and "everything at once" in others; not only is our autonomy at stake our very humanity is. Thus, philosophical thinking is fundamental as it helps to offer a deeper meaning to these considerations bringing with them pedagogical repercussions. Defending what you believe in, is not a sign of arrogance or bad faith if proven to be valid, nor is it a weakness or a "waste of time". To really understand things, it is important to measure time: one must not be dominated by pre-established decisions, theories, opinions or a series of instantaneously posted images, but be like the strings of a bow stretched between the past and future, knowing that the truth unfolds and is reached with the passing of time.

### 3. The case of reproduced artwork

The above subject matter takes us to deal with issues in the field of art, in which there is a clear albeit problematic distinction between an authentic work and a different - intended as reproduced - artwork. In fact, among the different terms that distinguish the origin of a work of art in the context of its attribution (authentic, original, replica, copy, attributed to, signed by, school of, follower, forgery), there is also the term "reproduced", which refers to art created through reconstruction and digital reproduction. A well-established example is the oil painting on canvas "The Wedding at Cana" by Paolo Veronese, produced in 2007, which represented something totally new at the time, but was followed by many other reproduced works in successive years. Thus, through computerization it is possible to obtain a work identical to the original one, in which shape, colours and, even, "materiality" are identical. Therefore, it is not easily distinguishable without both a subjective and objective evaluation, which must also take into account the cultural identity of the artwork and its economic value. A question follows: "Can ethics be applied to a reproduced work of art?"

The impressive development of information technology raises the question of whether we have any moral obligation toward those instruments that are so sophisticated they sometimes perform better than humans. In the case of art, it allows works to be reproduced that are identical to the original. It is not only a question of respecting the competence of the operator, or the scientific ability with which the instruments have been developed, but of respecting their ability to learn from mistakes and to find new



problems to solve - here, it is the duplication or reproduction of a specific artwork. This is true even if the very machines we have created seem to have a "life" of their own, despite the fact they have no self-awareness or feelings. In this regard, how can one not link the basic difference that exists between an "authentic" and a "reproduced" work of art, to the difference between a "discoverer" and an "inventor"?

One of the first Greek philosophers and the first cartographer in history, Anaximander, who lived between 610 and 546 BC defined "discovering" as seeing something that is there but that no one sees. The *identikit* of the modern inventor, as outlined by Maurizio Ferraris, philosopher and academic at the University of Turin, who the art critic Vincenzo Trione mentioned in an article which deals with several aspects and considerations related to the theme of the difference between "authentic/reproduced".

"Unlike the discoverer, the modern inventor is like a mechanic who has a spark of imagination: they recover already existing materials, study what they have, try to use their ability to bring out similarities between different phenomena, together with their talent for separating contiguous notions, ranging from the discovery of the new and inventory of the old". This is to highlight the fact that conceptually the author of an artwork is to be considered a "discoverer", while the person who reproduces it is an "inventor". The same happens for those who work with AI, and virtual and augmented reality applied to artistic and architectural fields. The consequence is that nowadays research centres, journals, and cultural institutions have started to address and discuss these issues, developing studies, reflections, and criticisms. It is not our intention to side with technophobes or techno-enthusiasts, adopting the attitudes of negationists or neopositivists. It is, however, important to consider that working with such technologies means establishing boundaries between traditional and new techniques, between what is natural and artificial, between analogue and digital, between morality and ethics, and between human and non-human. At the same time, by using computer technologies, the "operator-inventor" reveals and detects knowledge that comes from a world of observation that exists online and in the web.

#### 4. On the possibility of judging a reproduced work to be legitimate

However, it is not the wish of artists who use computer media and advanced technologies to lead us towards a futuristic place with respect to the present, they do not want to predict what will happen there, their aim is to highlight and disseminate the findings of what exists in the present: using technological instruments they can reveal hidden aspects by seeing and participating in events that are prohibitive for our "normal" condition. The setting of the reproduced images also helps in this process, as they are presented in a continuum of space and time and are open to concrete possibilities and interactions. This is even more evident and engaging for untitled artworks. In this regard, Vincenzo Trione pointed out that for centuries there have been works with "mimetic" titles that confirmed the subject they represented: an emblematic example is the painting *Primavera* by Sandro Botticelli. In the twentieth century, many artists used descriptive titles to help the public better understand the cryptic representations they painted: one example of this is Paul Klee's *Main Street and Secondary Streets*. Other artists chose to experiment with sophisticated connections between the motifs they depicted and the titles they chose, eliminating any immediate relationship between words and icons: Magritte's *Ceci n'est pas une pipe* is one such example, the title denying what is depicted in the picture. In the period that followed, many works were untitled, and it became a fashion, involving artists from different generations and backgrounds; they included portraits, landscapes, still life, installations, *happenings*, and

*performances*, but also films and novels. What is the meaning of such a decision?

Among the various hypotheses and/or motivations, it is worth mentioning one elaborated by the versatile writer, Umberto Eco who said that through their untitled works, artists invite viewers to free themselves from any superficial referentiality. By ignoring interpretations in accordance with the titles, and not abandoning oneself to a passive and contemplative attitude, one is emancipated, and thus engages in a deeper relationship with the artwork. This is how computer technologies and the reproduction of artworks, particularly untitled ones, can give rise to further applications and meanings, and so enhance the interaction between the reproduced image and the user. In conclusion, to answer the question about if, or why, a reproduced work of art should be controlled rather than prohibited, one might consider it legitimate if it is clearly indicated. Besides, if the same question is asked in the evaluation of a reproduced artwork comparing it with the original, it is essential to carry out a serious and scientifically accurate analysis, integrating the subjective with the objective evaluation. As previously underlined, this is possible only with the scientific collaboration of art historians and technicians, a collaborative process which, in a broad sense, results in dimensions and limits ranging from the real to the virtual. Virtuality and reality: two dimensions, two connected worlds that can explain things about each other and open themselves to multiple interpretations.

## 5. Conclusion

Tracing a path made of deep awareness, art is at the centre of a responsible transformation of society. To start a change, it is necessary to actively involve researchers, historical and technical operators, and users in real practices. We are forced to proceed each day along our life path, moving forward towards a goal. We must understand how to find again a balance, and this is what one wishes would happen in the processes that involve "*I + You = We*". The *we* that needs to be responsible for this mutual meeting and need so that history and technology can share a sustainable balance. Sustainability is made up of continuous regeneration. The question is: "Has the concept of beauty also changed?"

In truth, it has not changed: what is beautiful can be dangerously diabolical if there is no balance between emotion and reason. Balance is not fixed but dynamic, and the relationship has meaning in that it moves forward. You should never stop after having achieved something, but always have faith in the next step you are going to take. A breakthrough in research is something to believe in and gives impetus to the dynamics of thinking and acting. To effectively bring together historians and technicians, in the interest of present and future generations, it is essential to open a renewed chapter in the evaluation of artworks, whose aim is to remove obstacles that limit freedom, equality, the evaluator's development and participation, and to share common purposes, in order to resolve issues. Faced with proliferating algorithms and "cybernetic engines", for digital technologies to become freedom-friendly, they need to be used prudently and productively, which means it will be necessary to reinvest in... human intelligence! In fact, these technologies are interfering in an increasingly rooted way on the human faculty of thinking, individually and collectively. Hence, it is essential to act now to maintain the relationship between intellect and spirit, alive and plural. If this does not happen, the great opportunities offered by the digital revolution may even turn out to be harmful. For this reason, a clear and timely analysis of the risks and opportunities involved in the use of AI is becoming increasingly necessary. Today, not only is the face of communications, public administration, education, and consumption changing, interaction between people (including cultural orientation and choices) is changing too. What is needed is "sapiential discernment" that provides the necessary tools for the social and

ethical implications of AI, enlightened by the fundamental criterion on which scientific and technological progress is based, to the extent that – if and only if – it contributes to advancing human society, to increasing freedom and fraternity, and to a better human-kind and change in the world. We are therefore dealing with topical issues and decisive challenges concerning ethics, education, teaching methods, international law, etc., and for this reason, the exercise of critical thinking and the ability to discern about the use of data, is of vital importance. In this regard, Pope Francis, in his Message "Artificial Intelligence and Peace", expresses the hope that the "immense growth and spread of technology are accompanied by adequate training in how to behave responsibly in its development; this is because our current technocratic and efficiency-driven mentality leads us to overlook an aspect which is decisive in personal and social development: the "sense of limit". With our obsession of controlling everything, we are losing control of ourselves, and in our search for absolute freedom, we risk falling into the spiral of a technological dictatorship. Instead, it is necessary to ensure that progress in the development of forms of artificial intelligence ultimately serves the cause of human fraternity and peace. It is not the responsibility of a few, but of the whole of humankind. Peace is the fruit of relationships that recognize and welcome others in their inalienable dignity, and of cooperation and commitment in seeking the integral development of all individuals and peoples". It is important to note that the problem arising from AI and generative digital technologies is the ownership, processing, and destination of the enormous amount of data and information available. Without data, the capabilities of generative AI instantly disappear, while interesting results can be obtained only with huge-sized high-quality databases. The quality of generative AI output is also closely linked to the quality of the information available. The consequent problem of author copyright, in the long term, is therefore inevitable, and can lead to charges of systematic data theft. There are various ways to steal and take possession of other peoples' property. Among them, generative AI is simply the most technological and effective, with the possibility that some algorithms may result in false or non-existent information, damage to public image, false truths, and as such, thoughtless and/or appropriately hidden. In discussing this first aspect, relating to ownership of the information used by algorithms, others come into play, such as its treatment and end use: web pages for patents maintained with public funds, international results of important ongoing scientific research, and Wiki web pages that survive thanks to collective donations, all products of the human intellect used free of charge to support the lucrative activity of generative algorithms. A case in point is the large number of "bloggers" globally who take advantage of algorithms for their posts and so provide a significant economic return for the companies that have developed them. Until recently, laws regulated private property only in the case of physical and intellectual objects, since money represented the main medium for the exchange of these goods. The advent of the web and the diffusion of digital technologies has disrupted this scenario, spreading information about the intellectual products developed by the many who have worked hard to achieve these results with tenacity, commitment, creativity, and originality. We are still not fully aware of the value related to these results when they become digital - a vast resource of data which represents the foundations of the ongoing digital revolution and generative artificial intelligence. Ultimately, in today's digitalized world, problems related to ownership, such as how data and information are managed, need to be addressed, so that the benefits of this revolution reach the highest number of people without reducing global well-being or causing damage. Consequently, we have to resist the fascination of all things digital because if it has some form of intelligence, it is nothing more than the result of the intellectual property on which social relations/values/interaction are based and often not exploited to the full.



## EDITORIALE

# LA SINERGIA, LA TECNOLOGIA E L'IDENTITÀ IN ARTE, DI FRONTE ALLE SFIDE DELL'INTELLIGENZA ARTIFICIALE

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### 1. L'incontro e il dialogo delle scienze umanistiche e sperimentali

*L'incontro e il dialogo fra culture, oltre l'opportunità di conoscersi al di fuori di consolidati e a volte riduttivi stereotipi crea, nel confronto, le condizioni per superare la fragilità di un'interpretazione povera dell'identità basata sulla chiusura e sul rifiuto dell'altro. Il rispecchiarsi in uno "spazio largo" è ciò che ha consentito il crescere delle civiltà come un valore, anzi come condizione della stessa vita culturale. Un bagaglio di studi limitato è una barriera che, oltre a creare divari, genera incomprensioni e, dunque, conflittualità e, soprattutto, impedisce di progettare il futuro con chiavi interpretative adeguate a comprendere la complessità del nostro vivere con la scienza. Lo scambio apre le menti tanto più per una cultura solida e ammirata, consentendo di rimuovere pregiudizi e nozioni artefatte che ostacolano la conoscenza: il progresso scientifico è avvenuto anche, se non soprattutto, grazie agli scambi con le culture "altre". La cultura ci sorregge nella nostra capacità di immaginare fin d'ora il tempo nuovo, offrendoci criteri divenuti universali.*

*La sfida è caratterizzata anche dal saper far migrare e incarnare i valori dei patti fondativi delle Istituzioni contemporanee nelle architetture informatiche, che disegnano e influenzano in modo determinante le nostre Istituzioni. L'espressione "completarsi a vicenda" nell'ambito della ricerca rappresenta quanto di più significativo si possa immaginare per "l'unione delle diversità" ispirata da una visione che sappia guardare lontano, senza il rischio della lusinga, dell'inciampo in barriere create al riguardo: le acquisizioni di consapevolezza più autentiche abbiano la meglio anche su narrazioni correnti e a volte comode o funzionali di contrasti e di crisi di convivenza. Ricordando un aforisma del commediografo romano Terenzio, vissuto nel II secolo a.C., tratto dalla commedia latina "Il punitore di se stesso", "Homo sum, humani nihil a me alienum puto" (tutto ciò che è umano a me non è estraneo) si fa presente che l'atteggiamento di fronte alle culture prodotte dall'uomo e dai più diversi artisti, non può che essere l'apertura, la curiosità, la conoscenza, il confronto, sia pur anche autenticamente critico. Il progresso nasce da questo, non dal rifiuto aprioristico, non dalla cancellazione: il contesto culturale è il*

*prodotto di una continua trasformazione, spesso dialettica e con andamento non lineare. La cultura, d'altra parte, rifiuta le catalogazioni di comodo e aspira ad offrirsi come confronto fondendosi ed evolvendosi con le altre, ma anche rifuggendo l'omologazione, il conformismo ovvero ciò a cui sottostiamo inconsciamente o colpevolmente per pigrizia mentale o per opportunismo.*

*È, quindi, la transdisciplinarietà o crossdisciplinarietà, quale risultato di arricchimento reciproco e di interazione, di saperi ed esperienze, su cui si basano le teorie e le metodologie delle scienze umanistiche e sperimentali, a tessere il tessuto connettivo in cui ritrovarsi. Si è fatto cenno a proposito alla transdisciplinarietà o crossdisciplinarietà distinguendola dalla semplice multidisciplinarietà e interdisciplinarietà "debole", quale fase successiva alle precedenti con diversi contenuti e significati. Infatti, la multidisciplinarietà si ferma ad una mera sommatoria e giustapposizione di discipline che, come tale, rimane ancorata ad una individualità di contenuti e significati. D'altra parte, l'interdisciplinarietà "debole" interagisce soltanto con le altre discipline in un bisogno reciproco di completamento. La transdisciplinarietà e crossdisciplinarietà in un passaggio successivo si prefigge il reciproco arricchimento dei saperi come risultato di una metodologia che implica la connessione delle teorie e dei metodi e, quindi, dei principi scientifici, su cui si basano sia le scienze umanistiche che le scienze sperimentali: ogni disciplina non cessa di essere se stessa, ma viene arricchita nel suo essere se stessa attraverso l'interazione e il dialogo.*

*Quanto fatto presente è alla base dello studio e della ricerca nel campo dell'arte che, rappresentando lo spirito del tempo e l'autobiografia di un popolo, di un Paese, è la sua autobiografia culturale. In essa è da ritenere fondamentale la verità scientifica e, quindi, la comunanza di intenti, la sinergia di competenze per pervenire ad una risultanza affidabile e condivisa.*

## **2. La rivoluzione scientifica nell'arte**

*Il filosofo dell'Università di Oxford Luciano Floridi nel libro "La quarta rivoluzione" fa presente come le tre rivoluzioni scientifiche succedutesi nel corso dei secoli abbiano avuto un grande impatto sul modo in cui concepiamo noi stessi. Modificando la nostra comprensione del mondo esterno, esse hanno modificato anche la comprensione che abbiamo di noi stessi.*

*A seguito della rivoluzione copernicana, la cosmologia eliocentrica ha "rimosso" la terra e, quindi, l'umanità dal centro dell'Universo. La rivoluzione darwiniana ha mostrato che le specie viventi si sono evolute nel tempo da progenitori comuni attraverso la selezione naturale e ha perciò "rimosso" l'umanità dal solo regno biologico. La rivoluzione industriale ha poi "rimosso" l'uomo dai processi di produzione e di automazione. La rivoluzione digitale sta oggi anch'essa trasformando profondamente ogni aspetto della nostra vita. E questo riguarda: istruzione e intrattenimento, comunicazione e commercio, amore e odio, politica e conflitto, cultura e salute. Si possono aggiungere ben altri comparti, tutti trasformati dalle tecnologie che hanno come funzioni principali quelle di registrare, distribuire e processare informazioni.*

*A partire dagli anni '50, l'informatica e le tecnologie digitali hanno iniziato a mutare la concezione di chi siamo. Abbiamo infatti scoperto che non siamo entità isolate, ma piuttosto agenti informativi interconnessi, che condividono con altri agenti biologici e artefatti ingegneristici un ambiente globale costituito in ultima istanza da informazioni, che Floridi non a caso chiama "infosfera". Quale capostipite della quarta rivoluzione, egli nomina Alan Turing, il padre dell'informatica. La quarta rivoluzione offre pertanto l'opportunità storica di ripensare al nostro comportamento intelligente che deve confrontarsi con quello di artefatti ingegneristici che si adattano in modo sempre più efficace all'infosfera. A questo riguardo si fa presente che le tecnologie digitali non sono soltanto strumenti che si limitano a modificare il modo in cui interagiamo con il mondo, come la ruota o il motore. I progressi delle nuove tecnologie dell'informazione, specie nella sfera digitale, infatti, ci insegnano soprattutto dei sistemi che danno forma ("formano" e "formattano") e influenzano sempre di più il modo in cui comprendiamo il mondo e ci rapportiamo ad esso, così come il modo in cui concepiamo noi stessi e interagiamo tra noi. In altre parole, si tratta in un certo senso di sistemi "ontologizzanti", cioè che modificano la natura intrinseca (ontologia) di quello che toccano. Ne deriva, quindi, che il nostro comportamento deve confrontarsi con la prevedibilità e la possibile manipolabilità delle nostre scelte, nonché con lo sviluppo dell'autonomia artificiale. Ora, in relazione alle particolari e spiccate peculiarità di tali tecnologie interagenti con la realtà, presa in esame e, comunque, rivista e letta in maniera approfondita e ad un tempo fedele, è indubbio che risulta importante il nostro comportamento, inteso non solo come atteggiamento, ma anche come interazione vitale con le suddette tecnologie. Di fronte a questi scenari, ecco a tal riguardo il porsi della domanda: accettazione supina e tutto e subito, o accoglienza graduale e critica?*

*È importante tenere viva la conoscenza e la discussione su un tema che sta già cambiando le nostre vite e ancor più le cambierà in futuro, mentre nel contempo non è facile trovare, nel dibattito, una definizione comune e condivisa dell'Intelligenza Artificiale (AI), tra nozioni troppo generali e altre squisitamente tecnicistiche. Certo ne sono evidenti le grandi ed entusiasmanti opportunità, sotto gli occhi di tutti, così come anche, tuttavia, i diversi livelli – limitato, grave o inaccettabile - di rischio che ne possono derivare per la vita individuale e sociale, ad esempio l'identificazione biometrica delle persone in tempo reale negli spazi pubblici, o la loro categorizzazione in base a caratteristiche sensibili, il social scoring, la manipolazione comportamentale. Per questo non mancano da un lato i catastrofisti (doomers), che temono le conseguenze imprevedibili per la stessa umanità di uno sviluppo incontrollato e spregiudicato dell'AI, e dall'altro i boomers, i quali ritengono che grazie ad essa possano invece "esplodere" progressi scientifici capaci di aiutare a risolvere le tante crisi dei nostri giorni, a cominciare da quella ambientale.*

*È interessante, per esempio, che l'Unione Europea abbia elaborato un testo di accordo sul Regolamento per l'Intelligenza Artificiale sul quale dovranno pronunciarsi in via definitiva il Parlamento e il Consiglio d'Europa. Anche Papa Francesco, nel suo Messaggio per la LVII Giornata Mondiale per la Pace (1° gennaio 2024), dal titolo "Intelligenza artificiale e Pace", ha lanciato un forte appello perché il controllo delle nuove*

*tecnologie digitali diventi un patrimonio condiviso, con la necessità di un trattato internazionale vincolante che “regoli lo sviluppo e l’uso dell’intelligenza artificiale nelle sue molteplici forme”. Che fare, dunque?*

*Il tempo è importante e non è sinonimo di debolezza. Infatti, è proprio il tempo la condizione accessoria per comprendere quanto in precedenza è accettato e codificato ma anche, nel caso, proporre e dimostrare quanto si sostiene. Ci si riferisce a interventi successivi di revisione e completamento di quanto è già presente ma anche a quanto oggi si impone con la rivoluzione digitale e i social network. Entrano in gioco tanti fattori quando si è oggetto di discussione: la non accettazione, la volontà di resistere con la propria tesi non lasciandosi sopraffare, avendo di fronte, nel caso, un apparato riconosciuto unilateralmente valido e unico decisore.*

*Per ogni nuova idea e teoria occorre affrontare un percorso per il quale serve tempo, perché il tempo è anche la materia di cui siamo fatti. Se si trasferisce quanto detto al caso specifico dell’esame di un’opera d’arte oggetto di valutazione non solo dal punto di vista storico, artistico, estetico, iconografico ovvero con valutazione soggettiva, ma anche con valutazione oggettiva mediante l’impiego di tecnologie, il tema diventa particolarmente interessante.*

*Ed è la valutazione oggettiva che, testimoniando l’incontro, l’ascolto, il confronto e la risoluzione comune dello specifico problema inerente alla suddetta opera d’arte da parte degli esperti coinvolti, dà un concreto significato alla realizzazione della transdisciplinarietà o crossdisciplinarietà, fornendo un contributo scientifico derivante sia dalle scienze umanistiche sia dalle scienze sperimentali diagnostico-analitiche, informatiche e digitali. Ci si riferisce, in completezza, alle aree disciplinari storico-umanistiche e filologico-filosofico-sociali e alle aree tecnico-economico-gestionali e giuridico-identitarie, il cui coinvolgimento risponde alla peculiarità che contraddistingue l’opera d’arte e il suo valore olistico. Ecco, quindi, quanto si vuole sostenere non accettando ciò che in un passato remoto e tuttora corrente, in una prospettiva riduzionistica, ha determinato e determina ancora, in questo specifico settore, dubbi e/o ripensamenti. Il caso emblematico è rappresentato nel mercato dell’arte dalla attribuzione e autenticazione di un’opera d’arte, oggetto di accese diatribe da parte degli esperti appartenenti a Istituzioni, Università, Centri di ricerca. Ebbene, si è da anni sostenuto come sia possibile ricondurre l’autenticazione di un’opera d’arte alla sola valutazione soggettiva ancorché effettuata con esperienza e competenza dallo storico dell’arte.*

*È altrettanto fondamentale, però, confortare e/o confutare la precedente con la valutazione oggettiva da parte del tecnico, pervenendo in tal modo ad un’unica e completa verità scientifica e permettendo anche la corrispondente univoca valutazione economica. In questo caso l’arte e la scienza trovano la loro combinazione nel rispetto anche della sopradetta transdisciplinarietà o crossdisciplinarietà, ovvero di una comune teoria e metodologia sui cui principi si basano le scienze umanistiche e sperimentali acquisendo, di conseguenza, un valore e un risultato finale univoci. Ma è altrettanto importante, d’altra parte, sottolineare il fondamentale apporto delle altre aree disciplinari di indagine precedentemente nominate e caratterizzanti l’opera d’arte: ci si riferisce alle aree economico-gestionale e giuridico-identitaria.*



*Nel considerare poi l'importanza del tempo quale condizione necessaria per comprendere e accettare ciò che si sostiene sia opportuno e giusto, si fa presente come l'avvento della rivoluzione digitale e dei social networks abbia esasperato il presente, dando la convinzione che tutto accada subito e che debba essere immediatamente commentato, ripostato, amplificato. Noi siamo pieni di passato che condiziona le nostre scelte, le nostre azioni e decisioni, la nostra accettazione di quanto già accettato e, d'altra parte, siamo anche pieni di futuro che ci sprona a cambiare, a reagire, a desiderare e a volere il nuovo. E, in particolare, per quanto riguarda la rivoluzione digitale, è opportuno sottolineare che la maggior parte degli avvenimenti principali della nostra storia sono assai più sfumati e complessi da descrivere di quanto ci consentano un post o un tweet e, in alcuni casi, certe situazioni, posizioni, domande capziose che suonano come violenze ulteriori.*

*In definitiva, per fare spazio alla comprensione e all'ascolto, dovremmo ridimensionare "l'accettazione supina" in alcuni casi e "il tutto e subito" in altri: ne va non solo della nostra autonomia, ma anche della nostra stessa umanità. In questo senso l'apporto della riflessione filosofica risulta fondamentale perché offre spessore e profondità a tali considerazioni, con le rispettive ricadute pedagogiche.*

*Non è sinonimo di arroganza o malafede difendere ciò a cui si crede e che si dimostra valido o, al contrario, oggetto di debolezza "prendere tempo". Per comprendere davvero, per affermare davvero, misurare il tempo è importante: quindi non essere succubi a decisioni, teorie, opinioni prestabilite o ad una somma di istantanee da esibire in diretta, ma essere archi tesi fra passato e futuro sapendo che la verità si svolge e si raggiunge nella durata come tutto ciò che resta.*

### **3. Il caso di studio dell'opera d'arte riprodotta**

*E proprio in riferimento al giusto equilibrio che deve condurci ad affrontare le problematiche nel campo dell'arte, un distinguo netto ancorché problematico è quello fra l'autentico e il diverso, inteso come riprodotto, nel caso di un'opera d'arte. Infatti, fra i diversi termini che contraddistinguono l'origine di un'opera d'arte nell'ambito della sua attribuzione (autentico, originale, replica, copia, attribuito a, firma di, scuola di, seguace, falso), per quanto qui compete, vi è anche il "riprodotto" ovvero l'opera realizzata mediante la ricostruzione e la riproduzione digitale: ne è un esempio ben acclarato il dipinto ad olio su tela "Le nozze di Cana" di Paolo Veronese, realizzato nel 2007, che rappresenta decisamente qualcosa di totalmente "nuovo", ma che ha già avuto seguito con altre opere riprodotte nel corso degli anni.*

*Così, attraverso la computerizzazione è possibile ottenere un'opera identica a quella autentica, in cui forma, colori e, persino, "matericità" sono identici e, pertanto, non facilmente distinguibili se non con una valutazione sia soggettiva che oggettiva relativa alla identità culturale dell'opera d'arte e alla sua quotazione mercantile. Ne consegue la domanda: "C'è un'etica che possiamo applicare ad un'opera d'arte riprodotta?"*

*L'imponente sviluppo dei mezzi informatici pone la questione se*

*abbiamo qualche obbligo morale nei confronti di quelle strumentazioni così sofisticate che si rivelano di prestazioni talvolta migliori delle nostre, consentendo di realizzare opere riprodotte identiche alle autentiche.*

*Non si tratta soltanto di rispettare la competenza dell'operatore, nonché la capacità scientifica con cui sono state progettate e realizzate le strumentazioni impiegate all'uopo, ma di rispettare proprio la loro intelligenza intesa come abilità di apprendere dai propri errori e di scoprire nuovi problemi da risolvere: in questo caso, la duplicazione, appunto, ovvero la riproduzione di una specifica opera d'arte. E questo anche se quelle macchine, che abbiamo creato noi, ci paiono esse stesse "vive", benché non abbiano autocoscienza e sentimenti. E a tal proposito come non ricondurre, per un'opera d'arte, la fondamentale differenza fra "autentico" e "riprodotto" alla stessa differenza che vi è fra "scopritore" e "inventore"?*

*Sul significato relativo a "scoprire", si ritiene espressivo e indicativo quanto già evidenziava Anassimandro, uno dei primi filosofi greci e primo cartografo della storia, vissuto fra 610 a.C. e il 546 a.C. circa: "Scoprire significa vedere qualcosa che c'è ma nessuno vede". Per quanto riguarda l'identikit dell'inventore moderno delineato da Maurizio Ferraris, filosofo e accademico dell'Università di Torino, di cui fa cenno il critico d'arte Vincenzo Trione in un articolo che presenta aspetti e considerazioni condivise ancorché collegate con la presente tematica, fra "autentico-riprodotto".*

*A differenza dello scopritore, l'inventore moderno opera come un meccanico con un po' di fantasia: recupera materiali già esistenti, fa i conti con quello che c'è, mira a saldare capacità di far emergere somiglianze fra fenomeni diversi e talento nel separare nozioni contigue, oscillando fra scoperta del nuovo e inventario del vecchio". Questo, per evidenziare concettualmente, operativamente e significativamente che, l'autore di una opera d'arte è da considerarsi "scopritore", mentre chi la riproduce è, come tale, "inventore".*

*Accade altrettanto, com'è noto, con chi si misura con esperienze come l'intelligenza artificiale, la realtà virtuale, la realtà aumentata in campo artistico e architettonico, con la conseguenza che, da alcuni anni, Centri di ricerca, Riviste, Istituzioni culturali affrontano e discutono tali tematiche dedicando ad esse studi, riflessioni, critiche.*

*Non è nostro intento schierarci con tecnofobi o con tecnoentusiasti, assumendo atteggiamenti da negazionisti o neopositivisti. Si fa presente, tuttavia, che operare con tali tecnologie significa stabilire i confini fra tecniche tradizionali e queste ultime, fra naturale e artificiale, fra analogico e digitale, fra morale ed etica, fra umano e non umano. E ciò facendo presente che, mediante l'impiego delle tecnologie informatiche, questi operatori-inventori rivelano e rilevano aspetti e conoscenze provenienti da un mondo di osservazione qual è il mondo online e del web.*

#### **4. Sulle possibilità di giudicare lecita l'opera riprodotta**

*È altrettanto vero che gli artisti che ricorrono a mezzi informatici e tecnologie avanzate e sofisticate non vogliono condurci verso un altrove futuribile rispetto al presente, non vogliono predirne l'avvenire, ma evidenziare e diffondere le risultanze di ciò che esiste appunto al presente:*

con tali strumentazioni essi accrescono la possibilità di rivelare aspetti anche nascosti vedendo e partecipando ad eventi proibitivi per la nostra condizione "normale". A ciò contribuisce anche l'ambientazione delle immagini riprodotte che si presentano in continuità con il nostro spazio-tempo, aperte a possibilità e interazioni concrete. E ciò è ancor più evidente e coinvolgente per opere d'arte senza titolo. A tal riguardo, come fa presente Vincenzo Trione, per secoli vi sono state opere con titoli "mimetici" che confermavano i soggetti rappresentati: un esempio emblematico è rappresentato dal dipinto "La Primavera" di Sandro Botticelli. Nel Novecento molti artisti hanno impiegato titoli descrittivi per aiutare il pubblico a comprendere meglio le rappresentazioni spesso ermetiche da essi dipinte: ne è un esempio "Strada principale e strade secondarie" di Paul Klee. Altri artisti, invece, hanno scelto di sperimentare sofisticati collegamenti fra i motivi raffigurati e i titoli scelti, eliminando così ogni relazione immediata fra parola e icona: ne è un esempio "Ceci n'est pas une pipe" di Magritte, il cui commento diniega l'immagine. Il periodo successivo è costituito da opere senza titolo, diventato poi moda, coinvolgendo artisti di diverse generazioni ed esperienze. Si tratta di ritratti, paesaggi, nature morte, installazioni, happening, performance, ma anche film e romanzi. Qual è il motivo e il senso di tale decisione?

Fra le varie ipotesi e/o motivazioni, si fa riferimento, in particolare, a quanto elaborato da Umberto Eco. Il poliedrico scrittore fa presente che con l'opera senza titolo l'artista rivolge un invito allo spettatore affinché si affranchi da ogni referenzialità superficiale. Non attenendosi ad interpretazioni come da titolo e non abbandonandosi ad un atteggiamento passivo e contemplante, si emancipi dando luogo ad una relazione più profonda con l'opera d'arte. Ecco, quindi, come l'impiego delle tecnologie informatiche e della riproduzione delle opere d'arte, in particolare di quelle senza titolo, può ancor più dare adito ad applicazioni e significati ulteriori, promananti dall'opera d'arte riprodotta, esaltando le conseguenti possibilità di interazione fra l'immagine riprodotta e il fruitore. In definitiva, al quesito: "Perché e se l'opera d'arte riprodotta va controllata piuttosto che vietata", è possibile rispondere facendo presente che si potrebbe, nel caso, giudicare lecita la riproduzione computerizzata di un capolavoro purché sia indicato chiaramente di che si tratta. E, d'altra parte, se lo stesso quesito è posto allo scopo di valutare l'opera riprodotta rispetto alla autentica, risulta fondamentale effettuare un'analisi seria e scientificamente completa nell'ambito di una integrazione delle suddette valutazioni, soggettiva e oggettiva. Come si è sottolineato in precedenza, ciò è possibile con il contributo scientifico, in un bisogno reciproco, dello storico dell'arte e del tecnico. Dando luogo all'aspetto che ne deriva, ci si riferisce, in una visione più lata, a dimensioni e limiti fra reale e virtuale. Virtualità e realtà: due dimensioni, due mondi che possono spiegare tuttavia qualcosa l'una dell'altra e aprirsi a molteplici interpretazioni.

## 5. Conclusione

Tracciando un itinerario di profonda consapevolezza, l'arte è al centro di una trasformazione responsabile della società. Per attivare un cambiamento, è necessario coinvolgere attivamente i ricercatori, gli operatori

storici e tecnici ed anche i fruitori con delle pratiche reali. Siamo costretti a procedere ogni giorno lungo il nostro percorso di vita, andando avanti verso una meta. Dobbiamo capire come ritrovare un equilibrio ed è quanto ci si augura possa accadere nell'lo + Tu = Noi. Noi, che dobbiamo essere attori responsabili di tale incontro e di tale bisogno reciproco perché storia e tecnologia possano condividere un equilibrio sostenibile. La sostenibilità è fatta di rigenerazione continua e, di conseguenza, ci si pone la domanda: "È cambiato anche il concetto di bellezza?"

In verità esso è rimasto com'era: il bello può essere pericolosamente diabolico, se manca il bilanciamento tra emozione e ragione. L'equilibrio non è fisso, è dinamico, il rapporto trova il suo senso nell'andare avanti. Non ci si deve mai fermare dopo aver raggiunto qualcosa, avendo sempre avuto fiducia nel passo a venire. Il passo avanti nella ricerca è qualcosa in cui credere, mettendo in moto la dinamica del pensare e dell'agire. Per unire effettivamente storici e tecnici, evitando soltanto interventi saltuari in casi altrettanto casuali, nell'interesse delle presenti e future generazioni, è fondamentale aprire un capitolo rinnovato nella valutazione di un'opera d'arte, con il compito di rimuovere gli ostacoli che limitano libertà, uguaglianza, sviluppo del valutatore e partecipazione, in comunità di intenti, all'organizzazione e alla risoluzione del tema in questione. Per quanto riguarda, infine, le tecnologie digitali, per rendere tale ambiente amico della libertà, insieme con il loro impiego oculato e produttivo, è opportuno far presente che si ritiene necessario, proprio di fronte alla proliferazione degli algoritmi e dei "motori cibernetici", reinvestire sull'intelligenza ...umana! Poiché, infatti, tali tecnologie stanno interferendo in maniera sempre più radicata sulla facoltà umana di pensare, facoltà che è sia individuale che collettiva è fondamentale operare per mantenere viva e plurale la relazione fra intelletto e spirito. Se questo non avverrà con forza e tempestività, le grandi opportunità del digitale potranno anche rivelarsi dannose. Per questo è sempre più necessaria un'analisi chiara e puntuale dei rischi e delle opportunità offerte dall'AI, in un tempo in cui – come abbiamo già fatto notare - cambia il volto non solo delle comunicazioni, delle pubbliche amministrazioni, dell'istruzione e dei consumi, ma anche delle stesse interazioni tra le persone, compresi gli orientamenti culturali e i condizionamenti delle scelte delle persone. Serve un "discernimento sapienziale" che fornisca le indicazioni necessarie per le implicazioni sociali ed etiche dell'utilizzo dell'AI, illuminato dal criterio fondamentale secondo cui il progresso delle scienze e della tecnica, nella misura in cui – e dunque se e solo se - contribuisce all'autentica promozione della società umana, e ad accrescere la libertà e la fraternità, porta al vero miglioramento dell'uomo e alla trasformazione del mondo.

Stiamo dunque affrontando temi scottanti e sfide decisive che riguardano l'etica, l'educazione, i metodi di insegnamento, il diritto internazionale, ecc., e per questo sono sempre più necessari l'esercizio del pensiero critico e la capacità di discernimento nell'uso dei dati.

Ci sembra prezioso, a tale riguardo, quanto auspica Papa Francesco nel testo del Messaggio "Intelligenza artificiale e Pace", lì dove ricorda che l'immensa espansione della tecnologia deve essere accompagnata da un'adeguata formazione alla responsabilità per il suo sviluppo, proprio perché la nostra mentalità attuale, tecnocratica ed efficientista, poco

*riflette su un aspetto trascurato ma decisivo per lo sviluppo personale e sociale, il “senso del limite”. Con l’ossessione di voler controllare tutto si perde il controllo di sé stessi, e nella ricerca di una libertà assoluta si rischia di cadere nella spirale di una dittatura tecnologica. Bisogna invece “far sì che i progressi nello sviluppo di forme di intelligenza artificiale servano, in ultima analisi, la causa della fraternità umana e della pace. Non è responsabilità di pochi, ma dell’intera famiglia umana. La pace, infatti, è il frutto di relazioni che riconoscono e accolgono l’altro nella sua inalienabile dignità, e di cooperazione e impegno nella ricerca dello sviluppo integrale di tutte le persone e di tutti i popoli”. Ed è bene, a tal riguardo, far presente che il problema che nasce con l’AI, nel contesto delle tecnologie digitali generative, è riconducibile alla proprietà, al trattamento, alla destinazione dell’enorme quantità di dati e informazioni oggi disponibili in rete a vent’anni dalla nascita del World Wide Web. Senza dati, infatti, le capacità dell’AI generativa scompaiono istantaneamente, mentre si ottengono risultati interessanti con l’impiego di data base di enormi dimensioni e grande qualità. La qualità delle risposte dell’AI generativa è strettamente legata alla qualità delle informazioni disponibili ed è inevitabile il conseguente problema sui corrispondenti diritti d’autore sfociante, se protratto nel tempo, in accuse di sistematico furto di tali dati. Ci sono vari modi di sottrarre e far proprio quanto di altrui proprietà. Fra essi l’AI generativa è semplicemente quello fra i più tecnologici ed efficaci con la possibilità che alcuni algoritmi possano fornire informazioni false o non esistenti, danni di immagine o verità nascoste e, come tali, improvvide e/o opportunamente celate. Ecco, quindi, che ad un primo aspetto in discussione, relativo alla proprietà delle informazioni impiegate da algoritmi, ne subentrano altri, nel corso dell’impiego, quali il trattamento e la successiva destinazione tanto varia quanto problematica: pagine di brevetti mantenute con fondi pubblici, risultati da ricerche scientifiche in corso di svolgimento di particolare importanza a livello internazionale, pagine di Wikipedia che vive di donazioni collettive, tutti prodotti dell’intelletto umano utilizzati gratuitamente per sostenere la lucrativa attività degli algoritmi generativi. Il caso emblematico è rappresentato dai “bloggers”, i quali, ormai in gran numero sulla scena internazionale, forniscono un significativo contributo dando parvenza di intelligenza ad un algoritmo e producendo ritorni economici per le grandi imprese che lo hanno sviluppato. Fino a poco tempo fa disposizioni legislative regolamentavano la proprietà privata per gli oggetti fisici e la proprietà intellettuale per le creazioni del pensiero poiché il denaro rappresentava la necessaria mediazione regolatrice dello scambio di questi beni. L’avvento del web e della diffusione digitale ha sconvolto tale scenario dando adito a informazioni su quanto prodotto da tanti che con tenacia, impegno, creatività, originalità si sono impegnati e applicati per conseguire tali risultati. Non siamo ancora abbastanza coscienti del valore che promana dai risultati che si traducono poi in dati digitali, risorsa immensa di informazioni, che rappresentano le fondamenta della rivoluzione digitale in corso e della intelligenza artificiale generativa.*

*In definitiva, in un mondo digitalizzato è necessario affrontare il problema legato alla proprietà dei dati e delle informazioni e di come essi si gestiscono, per modo che non siano pochissimi i beneficiari ed una infinità gli altri che possano perdere una parte significativa del loro*

*benessere. Ne deriva, di conseguenza, la necessità di resistere al fascino del digitale perché, se ha qualche forma di intelligenza, questa non è altro che una risorsa quale valore insito, a volte non del tutto sfruttato, della proprietà dell'intelletto alla base delle relazioni sociali.*

# **C**ONTENTS





# ARTIFICIAL INTELLIGENCE AND DIGITAL REPRODUCTION IN ART

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## 1. Introduction

In recent years, AI (artificial intelligence), seen as a set of different technologies employed in the most diverse fields in emulating human intelligence, undoubtedly represents an extension of human capabilities, but nevertheless cannot substitute it [1]. Its application can be found not only in the management of civil and social life and economic and political organization [2-3], but also in art and culture [4].

Indeed, as far as AI is concerned, in an area considered unique to human nature, i.e. creativity, today AI is used in art, a situation which generates both enthusiasm and perplexity. It is now seen as stimulating creativity, after being considered as having no value in evaluating that faculty of which human beings are so proud, namely creativity, in particular, artistic creativity.

Hence the question: "Compared to digital ecosystems that integrate enabling technologies, such as the IoT (Internet of Things), big data, the metaverse and artificial intelligence, are personal initiative, pluralism and solidarity still decisive factors and, can they, nevertheless, contribute to determining a result and/or a choice in the final decision-making?". This is a challenge that involves very different levels: both cultural and scientific, as well as economic and political. The heart of the problem, then, is to prove that highly digitalized models are compatible and that they indeed, make an additional contribution to arriving at the truth. It is also true that such widespread intelligence can only grow in organizations (universities, companies, public administrations, schools, hospitals, the media) that do not limit their employees to being mere executors of protocols and procedures but, on the contrary, value the creativity, responsibility, and autonomy of judgement they express in their work.

## 2. The application of AI in art and culture

The fields of application of AI in art and culture can be found in the production of works of art and cultural events and the critical-aesthetic evaluation of artistic products.

In truth, when talking about artworks, whether they are produced using AI or

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executed by an artist, the fundamental problem that arises revolves around the concept of creativity [5] and brings us to the question posed in the introduction: the attribution and authentication of the work of art based on an assessment – a point that will be focused on later – which must not only be critical-aesthetic and therefore subjective, but also objective, i.e. evaluated through the use of diagnostic-analytical technologies.

Hence, the next question: "Within this subjective and objective assessment, where does the intervention of AI stand and how can it be considered valid and reliable, in its correctness and completeness?".

In this respect, one cannot fail to underline that with the advent of AI, another aspect arises concerning the authorial identity of the work of art and the heated debate it generates, which is not only of a historical-technical nature, but also legal.

Before dealing with this topic more in detail, and to provide a framework, albeit a limited one, some applications of AI are given.

- a. In the creative and cultural industries it is used, in particular, in scriptwriting, film presentation and in the interactive film industry, as well as in the extensive sector of video games.
- b. In music algorithms are used in the most diverse musical genres, from choral arrangements to real-time soundtracks. The involvement of digital companies, as well as major digital players, has resulted in the successful production and enjoyment of culture through the use of intelligent agents.
- c. In libraries and archives, with AI, the development of an open access system enables the digitization of documents with respect to the traditional criteria of cataloguing and usage, and systems are already in place that independently propose new reading paths for both book and art collections. Different projects have also been developed with the intention of breaking away from the extensive consultation of documents by allowing them, on the basis of pre-established models, not only to be read, but by providing links and connections to aid further examination of a chosen topic.
- d. In exhibitions and displays, a particularly developed field of applications of AI, the themes addressed in many important national and international museum venues aim to make it easier for the public to approach and be directly involved in the work of art itself. And this objective is not only directed towards accompanying, describing and/or simulating the works of art for the visitor during the museum tour, it also presents some particularly topical themes, such as the relationship between man and machine or between different cultures and/or identities, the impact of new technologies, and AI itself, on life. In addition, during their emotive and emotional involvement, digital devices are used to qualify and quantify the intensity of the spectators' sensations during the museum tour in their silent conversation with the work of art.
- e. With the impact of AI in art, the accumulation of digitalized cultural data has enabled the introduction of intelligent agent-guided learning and classification systems.

Some results are mentioned below.

One such example is a video installation in which AI manages the integrated spectacularizing of a stream of numerical, textual, visual and sound data that envelops the viewer in an immersive environment. Another methodology that has been developed is based on the fictional world of cinema. An example of this is *A woman with the technology* by Ziyang Wu which involves in the creative process the very life of the artist whose work is to be produced: in particular, her recorded everyday activities which become a video that an AI agent transforms into a product.

And more inherent to the art sector, with great media impact, was the auction sale at Christies in 2018 for \$432,500 of a painting produced by AI entitled *Portrait of Edmond Belamy* (Figure 1). Its aim was to connect the artwork to the tradition of great portraiture by imitating the painting of past centuries. To achieve this, specific algorithms were used for which more than 15,000 portraits from the Renaissance and modern periods were examined.



Figure 1. *Portrait of Edmond Belamy*

### 3. AI generated art and digitally reproduced art

With the emergence of AI as a means of producing works of art, it has become necessary to question how the canons, rules and the very idea of artistic beauty emanating from a work of art produced by a designer of generative AI algorithms compares with a work of art executed by a human.

It must therefore be asked:

- a. whether it is appropriate, in view of human creativity and, therefore, products made by artists, to give rise to a new creativity for which automation and, therefore, products made by AI are considered.
- b. whether the viewer, in contemplating the work of art produced by AI, and possibly

experiencing a non-positive influence or reducing the level of their enjoyment of that work of art, is inclined to approach it in the same way as a work of art produced by a human hand, thereby opening up to new perspectives of visual forms and the corresponding content.

This brings us to the concept mentioned above and will be discussed in more detail later, a concept related to the topic of art work attribution and valuation, that is, art executed by an artist, which has been the subject of heated debate for years. This topic in turn also raises, in the context of the different degrees of certainty in attribution, the problem of its digital reproduction, giving rise, as with an AI-generated work of art, to a legal debate on copyright.

#### 4. Attribution of a work of art

To start with, it should be said that the attribution of a work of art is a fairly complex operation, in which it is very easy to be misled. It is therefore essential that an in-depth study of the work in question is carefully carried out.

The difficulty arises from the fact that, from the term original to the term fake, in between there are a number of intermediate categories such as copies and replicas. Replicas, despite having been executed by the same hand, have small differences that are sometimes difficult to recognize. Such works must therefore be studied expertly and meticulously: a careful and experienced eye cannot miss the discriminating element of quality. Copies, on the other hand, are easier to detect for an expert eye. In the past, however, in several cases, original works and replicas have been considered copies: this often happened because of the poor state of conservation (repainting, dirt, yellowed paint) of these works, a factor which contributed to their incorrect identification.

Often, in order to distinguish a replica or a copy from the original, it is necessary to use diagnostic-analytical technologies, for example, to detect any *pentimenti*: in this regard, without generalizing, it can be stated that if a painting has no *pentimenti*, it generally means that it is not an original [6-7].

In the art market, the buying and selling of forgeries, fakes and counterfeits is widespread and the corresponding economic returns are significant: according to experts, a very large percentage of art works on the market are, in reality, fakes.

Moreover, in the past, forgery and restoration often amounted to the same thing: restoration work carried out by forgers was either aimed at completely replacing the original or altering the entire work to such an extent that it was no longer possible to distinguish the coeval from the non-coeval [8].

The increasing number of forgeries and the problem of attribution therefore represents a major problem in the art market. Indeed, many misattributions are made without the intent to deceive, and are very often made to the detriment of the buyer and/or seller. These are just a few aspects that further emphasize the importance of a certain degree of scientificity in the valuation of art market sales.

Fakes and forgeries abound in libraries, archives, museums and private collections. From ancient Greece to the present-day, the debate on forgeries constitutes a fascinating (and, in some cases, painful) chapter of our civilisation.

The clash between forgers and critics has paradoxically resulted in better knowledge of our literary, artistic, religious and political history.

A data-driven approach to support attribution processes certainly represents an opportunity for the industry. Below are the main areas in which algorithms, classifiable as AI-based technological species, could support experts, thereby reducing human error:

- Stylistic analysis: use of stylistic trait recognition algorithms, such as *convolutional neural networks* (CNN) trained on datasets of artworks, to recognize and analyze artistic styles. These are a type of artificial intelligence algorithm inspired by the functioning of the human brain. They are widely used to analyze images and recognize complex visual patterns. CNNs are able to automatically identify relevant features in images, enabling tasks such as facial recognition, object classification and autonomous driving.
- Signature recognition: use of Optical Character Recognition (OCR) algorithms applied to artists' signatures on works of art, using techniques such as segmentation and character classification.
- Brushstroke analysis: use of image processing algorithms to extract and analyze the characteristics of brushstrokes, such as direction, length and density, using techniques such as the Hough transform or texture analysis. These are algorithms used to detect geometric shapes, such as lines and circles, in images. It uses a mathematical representation to identify the parameters of the desired shapes. It is widely used in computer vision for detecting and extracting geometric features from complex images.
- Analysis of painting techniques: use of image processing algorithms to analyze specific techniques used by artists, such as shading or the use of colour, by identifying patterns or applying machine learning models.
- Texture analysis: use of image analysis algorithms to recognize and compare textures in artworks, using techniques such as Fourier transform or Haralick features (analysis of image textures to describe their complexity and structures) for feature extraction.
- Historical context analysis: use of textual analysis algorithms to extract information from historical documents, such as letters or records, and to identify links between a work of art and a specific artist or historical period.
- Searching for similar works: use of content-based image search algorithms to compare a work of art with a large database of works, using visual characteristics or machine learning algorithms to find stylistic or technical similarities.
- Iconographic source analysis: use of image recognition algorithms to identify and compare iconographic sources used by artists, using techniques such as deep learning (an artificial intelligence technique that uses deep neural networks to automatically learn complex representations and solve complex problems) for object identification or pattern recognition.
- Analysis of corrections or *pentimenti*: use of image segmentation algorithms to identify and analyze the corrections or *pentimenti* present in the artwork, using techniques such as contour analysis or processing of regions of interest.

## 5. Terminology and objective and subjective evaluation

Let us look at the terminology to distinguish different degrees of certainty in the attribution of a work of art [9]. Below are several employed in the specific field of authentication and attribution.

- Authentic: the work of art is entirely from the indicated era or is by a specific author;
- original: the work of art is by a particular artist whose stylistic characteristics are quite evident;

- Replica: a re-edition of an original prototype made by the artist himself;
- copy: reproduction of a work executed by a different artist;
- attributed to: this indicates that the work was executed at the time of the artist in question and that he is the most probable author;
- signature of: the purpose of this indication is to guarantee attribution to the named artist, although the authenticity of this signature must be verified;
- school of: the author of the work is an artist gravitating in the environment of the artist mentioned directly or is a pupil;
- follower: an artist who uses certain stylistic traits that can be traced to a particular master;
- fake: consists in the total replacement of an artefact for speculative purposes;
- Reproduced: this refers to a work that is identical to the original and produced by digitalization.

To this brief outline must be added the specifically adopted legal terms used in the field of forgery.

At this point, one must ask: "What is and how is the methodology<sup>1</sup> of assessing the authenticity of an artefact in the art market carried out? To answer this question a short description of what happens at a national and international level is given.

Fundamentally, the valuation carried out by auction house experts is a subjective evaluation, based on an analysis of the historical, stylistic, aesthetic, iconographic and, therefore, visual elements of the artefact of artistic interest, without the support of appropriate diagnostic techniques which, respecting the uniqueness and non-renewability of the asset, are non-destructive and non-invasive. The investigations carried out by the experts of the auction houses are summarized in a condition report, a written record containing qualitative and not quantitative information about the artefact. For this subjective assessment, the experience of the expert is, of course, a crucial element. An objective evaluation, with regard to the attribution of a work of art, its authenticity, and the assessment of its state of conservation, is instead based on the use of diagnostic methodologies, also with reference to new technologies. To be complete, the study of a work of art must be conducted with the synergic contribution of both the diagnostician-conservator and the art historian.

## 6. The reconstruction and digital reproduction of works of art

For some years now, digital mediation is being used in the reconstruction and reproduction of works of art. By combining the use of sophisticated equipment and advanced technologies with craftsmanship, it has won the trust of many international museums in conducting operations of great historical and artistic significance [10].

Interest in the philological aspect of artistic activities takes the shape of collaboration with sociologists, historians, anthropologists and semiologists.

In this regard, mention is made of the digital reproduction of the painting on canvas *The Wedding Feast at Cana* by Paolo Veronese (Figure 2), which was brought to France by Napoleon's commissioners in September 1797 and is now housed in the Louvre. The painting was 'scanned' in 2007 by the skillful technician Adam Lowe: it was decidedly something completely 'new'. Not just a copy and probably an excellent one, but a painting identical to the original, not only of the same size, texture, and material, even including the aura that Walter Benjamin says a reproduction usually loses. Thus, through digitalization, it is possible to obtain an artefact identical to the original, in which

form, colours and even the 'materiality' of the same are absolute. Since it is a pictorial work by a great master and, therefore, an unrepeatable *unicum*, no matter how successful its reproduction may be, let us say that its copying is nevertheless questionable.



Figure 2. *The Wedding Feast at Cana, Paolo Veronese*

It follows that, to the questions posed above and consequent to the production of works of art with AI, there follow, even in the case of digital reproduction, certain questions of a more ethical rather than aesthetic nature that are the prerogative of a work of art. In particular:

- where has the principle of *unicum* gone?
- where is its unrepeatability?
- where is its inevitably high market value?

The easiest way to answer these interrogatives is to rely on a serious and scientific analysis. The reproduction of a masterpiece could be considered legitimate, as long as it is clearly indicated. That said, hypothesizing specific areas in which AI technologies could be employed in processes to faithfully recreate art works, let us look at some that were proposed directly by an AI when asked the question. The resulting list was then refined by experts in the field by framing it in the literature [11-20]:

- High-resolution digitalization: use of upscaling algorithms, i.e. processes to increase the quality of an image based on artificial intelligence and thus increase the resolution of digitized images of works of art, preserving their details and improving visual fidelity.
- Three-dimensional reconstruction: using computer vision and image processing

algorithms to reconstruct three-dimensional models of works of art, allowing the work to be viewed from different angles and perspectives.

- Virtual restoration: application of artificial intelligence algorithms to digitally restore damaged or degraded works of art, reconstructing missing details or repairing defects such as scratches and stains.
- Accurate colour and lighting: using machine learning algorithms to accurately determine the colours of the authentic work and reproduce the correct lighting for faithful representation.
- Colour thickness analysis: using image analysis algorithms to determine the thickness of the different layers of colour in a work of art, enabling accurate reproduction of the painting techniques of the authentic work.
- Reproduction of texture and materials: using artificial intelligence-based texture generation algorithms to faithfully reproduce the different textures and materials present in a work of art, such as the texture of the brushstrokes or that of the surface.
- Animation and virtual reality: use of animation and virtual reality algorithms to create interactive experiences that allow people to explore and interact with the artwork in a realistic way, recreating the form and context of the authentic work.
- Simulation of the artistic style: use of artificial intelligence-based image generation algorithms to simulate the artistic style of a specific artist or historical period, enabling new works to be faithfully reproduced in a specific style.
- Haptic reproduction: using haptic feedback and 3D modelling technologies to create physical reproductions of works of art, allowing users to experience the tactile sensation and size of the work under examination.
- Digital archiving and preservation: using data compression and archiving algorithms to create high-resolution digital archives of artworks, ensuring long-term preservation and accessibility for future generations.

## 7. Concluding remarks

A work of art is characterized by a set of values (cultural, historical, aesthetic, artistic, spiritual, symbolic, social, technical, economic, financial, mercantile, authenticity, identity, interdisciplinarity, internationalization), which concern different areas of investigation: historical-humanistic, philological-philosophical-social, technical-economic-managerial, legal-identity. This holistic value should help to determine the specific price of the artefact and thus establish its economic-financial-mercantile-market value. It is nevertheless true to say that the price is what you pay, the value is what you get.

Many different factors, albeit linked to conditions and situations that may be considered uncertain and unpredictable, can contribute to determining the price of a work of art, based, moreover, on a subjective and objective assessment of its authenticity and its legal profile - a fundamental point to refer to, as already emphasized. It is at this point in the discussion on artificial intelligence and the digital reproduction of a work of art that we arrive at our main question:

"As regards the described potential relating to AI and the heated debate between historians and technicians on the topic of authenticating a work of art on the basis of a subjective and objective evaluation, does the accumulation of digitalized cultural data, the elaboration of an open access system, intelligent agents and generative algorithms, have the power to eliminate any kind of stereotype and prejudice, and so further contribute to finding a decisive solution to the heated and enduring debate on



authenticating a work of art, and finally confirming a single shared scientific truth?" This has been the focus of this paper. It can undoubtedly be said that the technologies listed in this work are enabling ones, i.e. those that provide the means to improve human performance and capabilities to achieve set goals. Those listed are just some of the areas where artificial intelligence could make a contribution in complex challenges, as in the case of art work attribution. It is important to emphasize that human interpretation and expertise remain essential to reach definitive conclusions.

Picking up on the above, in the technological environment that is being shaped by digital technologies, can we still seriously believe in freedom?

In this respect, it is necessary to demonstrate that even in the age of digitalization, freedom and creativity are still the trump cards for creating a social organization that is superior to a centralized and controlled model. This constitutes a challenge involving very different levels: cultural, but also political, economic and scientific. Fundamentally, it is a matter of nurturing and increasing human intelligence in its entirety, both individual and collective, qualifying the idea of freedom inherited from the 20th century, despite the fact that artificial intelligence and the digital world are already radically changing the way we know the world today and how we interact with it. From this, it is clear that our ability to correctly deploy and develop these technologies is particularly important, demonstrating that highly digitized models are compatible with human capabilities and complement them or indeed are even better. We can succeed with massive and deliberated investment in training. Education is therefore just as strategic as research and infrastructure: there is no future without quality education and lifelong learning. But that is not all. Widespread intelligence, as pointed out earlier, can only grow in organizations that value creativity, responsibility and autonomy of judgement. After the season of radical individualism, which is still widespread, we need an intelligent kind of freedom that can be cultivated and cared for and be responsibly employed in relations with others and the environment. Businesses, moreover, will have to adapt to change, by integrating new skills centered on innovation, digital technologies and artificial intelligence, framing data and offering the views of outstanding professionals at national and international level. This, then, is how experts from international scenarios become a permanent platform for analyzing cultural relations between geopolitical and geo-economic dynamics projected towards a more stable and less conflictual future with a structural impact on access and growth strategies in emerging and mature markets.

## Notes

<sup>1</sup> The term 'methodology' means the study of methods. The term 'method', on the other hand, refers to the set of actions required to perform a chemical analysis: sampling, sample preparation, measurement. The term 'technique' refers to an action requiring a specific instrumental means. The term 'technology' is a synonym for 'applied science' oriented towards practical, concrete objectives and is based on scientific foundations.

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### Biographical notes

**Salvatore Lorusso** was formerly a full Professor at the University of Bologna. He is a Foreign Member of the Russian Academy of Natural Sciences; Emeritus Professor of the Cultural Heritage Institute of Zhejiang University (China); formerly a Visiting Professor at the Academy of Social Science of Zhejiang University, China; Visiting Professor of the Faculty of Arts, Lomonosov Moscow State University, Russia; formerly vice-president and Councilor of the Società Italiana per il Progresso delle Scienze (SIPS, established in 1839). He is Direttore Generale of the Accademia della Cultura Enogastronomica. His biography appears in the 2016 Marquis Edition of Who's Who in the World. He is the author of over 415 publications in national and international journals and 25 volumes and monographs covering commodity science, cultural heritage and environmental issues. In 1997, he founded the Diagnostic Laboratory for Cultural Heritage at the Ravenna Campus of the University of Bologna and remained head of the Laboratory for eighteen years. In 2001 he founded the historical-technical Journal "Conservation Science in Cultural Heritage" of which he is Editor-in-Chief. His scientific work deals mainly with the study of the "system: artifact-environment-biota" and diagnostic, analytical, technical and economic evaluation within the context of the protection and valorization of cultural and environmental heritage.

**Lucio Colizzi** holds a Graduate degree in Computer Engineering. He has a Ph.D. in Computer Science and Mathematics and is a lecturer in Computer Science and Co-operative Systems at the Department of Computer Science at the University of Bari - "Aldo Moro," where he conducts his research activities. He has experience in designing and developing virtual reality applications in a private company. From 2001 to 2017, he served as the Director of the Department of Computer Engineering at CETMA (European Research Centre for Technology, Design, and Materials), where he oversaw several industrial research projects. He holds European patents in the field of mechatronics and has authored numerous scientific publications. His expertise spans ICT technologies in Industry 4.0, cultural heritage, smart agriculture, and healthcare.

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### Summary

The growing presence of artificial intelligence (AI) in the management of civil and social life as well as in economic and political organization has led to a debate on AI involved in various scientific, philosophical, legal and moral questions, including cultural ones. In this paper, after a brief presentation of the application of AI in art and culture, we focus on art production using AI and the digital reproduction of art which temporally precedes that of AI-generated art. The very idea of artistic beauty emanating from works

of art produced with AI is consequently questioned, giving rise to a new creativity that is to be added to the human creativity of an artist's products. Lastly, the possibility is raised that specific generative algorithms may contribute to the resolution of the topical debate on the issue of attribution and authentication of works of art.

# L 'INTELLIGENZA ARTIFICIALE E LA RIPRODUZIONE DIGITALE NELL'ARTE

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## 1. Premessa

*In questi ultimi anni l'intelligenza artificiale (AI secondo l'acronimo inglese), quale insieme di tecnologie differenti impiegate nei più diversi settori, rappresenta senza alcun dubbio, emulando l'intelligenza umana, una estensione delle capacità umane e non un sostituto [1].*

*A tal riguardo è possibile ricondurre le sue applicazioni non solo alla gestione della vita civile e sociale e alla organizzazione economica e politica [2-3], ma anche all'arte e alla cultura [4]. Infatti, per quanto qui compete, l'AI, in un ambito ritenuto unico della natura umana, ovvero la creatività, è ormai presente nell'arte generando ad un tempo entusiasmo ma anche perplessità. Essa è vista come stimolazione della creatività, dopo essere stata considerata ben lontana dalla possibilità di essere valutata nell'ambito di quella facoltà di cui l'essere umano è orgoglioso qual è la creatività e, in particolare, la creatività artistica. Di qui il porsi la domanda: "Rispetto agli ecosistemi digitali che integrano tecnologie abilitanti, come l'IoT (Internet of Things), i big data, il metaverso e la intelligenza artificiale, l'iniziativa personale, il pluralismo, la solidarietà risultano ancora decisivi e, comunque, possono contribuire a determinare una risultanza e/o una scelta nella ultima decisione da prendere?". Ecco una sfida che coinvolge piani molto diversi: culturale, scientifico ed anche economico e politico. Il cuore del problema, quindi, è dimostrare che i modelli altamente digitalizzati sono compatibili e, anzi, forniscono un contributo ulteriore per pervenire ad una situazione di verità. Ed è altrettanto vero che tale intelligenza diffusa può crescere solo in organizzazioni (Università, imprese, Amministrazioni pubbliche, scuole, ospedali, media) che non riconducono i propri collaboratori a meri esecutori di protocolli e procedure ma che, al contrario, valorizzano la creatività, la responsabilità, l'autonomia di giudizio che si esprimono nel lavoro dell'uomo.*

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## 2. Applicazioni dell'AI nell'arte e nella cultura

*Gli ambiti di applicazione dell'AI nell'arte e nella cultura sono riconducibili alla produzione di opere d'arte ed eventi culturali e alla valutazione critico-estetica dei prodotti artistici. In verità parlare di produzione di opere d'arte con l'impiego dell'AI o eseguite dall'artista pone, comunque, il problema fondamentale riconducibile alla creatività [5] e alla domanda posta nella premessa che rappresenta il tema fondamentale di discussione del presente lavoro: ovvero l'attribuzione e l'autenticazione dell'opera d'arte sulla base di una valutazione che – si sottolineerà in seguito – deve essere non solo critico-estetica e, quindi, soggettiva, ma anche oggettiva ovvero con l'impiego di tecnologie diagnostico-analitiche.*

*E di conseguenza la successiva domanda: “Nell'ambito di tale valutazione soggettiva e oggettiva l'intervento dell'AI come si pone e come può risultare valido e affidabile in correttezza e completezza?”.*

*A tal riguardo non si può non far presente, con l'avvento dell'AI, l'ulteriore aspetto che ne consegue relativo alla identità autoriale dell'opera d'arte e all'acceso dibattito non solo di carattere storico-tecnico, ma anche giuridico.*

*Ma prima di trattare tale argomento, allo scopo di fornire un quadro, ancorché contenuto, si fa cenno ad alcune applicazioni dell'AI.*

- a. *Nelle industrie creative e culturali, ci si riferisce in particolare alla scrittura di sceneggiature o alla presentazione di film o al comparto cinematografico interattivo, ma anche ad un settore espansivo come quello dei videogiochi.*
- b. *Nella musica, vengono impiegati algoritmi nei generi musicali più diversi, arrangiamenti corali e colonne sonore in tempo reale. Il coinvolgimento di aziende come di grandi attori del digitale ha dato luogo ad un grande successo di produzione e di fruizione della cultura con l'utilizzo di agenti intelligenti.*
- c. *Nelle biblioteche e negli archivi, con l'AI, l'elaborazione di un sistema di accesso aperto permette la digitalizzazione di documenti rispetto ai tradizionali criteri di catalogazione e fruizione, essendo inoltre già in atto sistemi che autonomamente propongono nuovi percorsi di lettura di opere non solo di collezione ma anche artistiche. Sono stati anche sviluppati progetti differenti con l'intento di distaccarsi dalla diffusa consultazione documentale permettendo, sulla base di modelli prestabiliti, non solo la lettura ma anche collegamenti e connessioni.*
- d. *Nelle mostre ed esposizioni, settore di applicazione dell'AI in particolare sviluppo, le tematiche affrontate in varie sedi museali importanti nazionali e internazionali si prefiggono l'obiettivo di realizzare un più facile accostamento e diretto coinvolgimento del pubblico all'opera d'arte. E tale obiettivo non è soltanto direzionato all'accompagnamento, descrizione e/o simulazione inerenti le opere durante i percorsi museali, ma è anche rivolto alla presentazione di alcune tematiche di particolare attualità quali: rapporto uomo-macchina, rapporti di culture e/o identità diverse, impatto delle nuove tecnologie e della stessa AI sulla vita. Vi è poi, in un coinvolgimento emotivo*

*ed emozionale, l'impiego di dispositivi digitali rivolti alla qualificazione e alla quantificazione della intensità emotiva dello spettatore durante il percorso museale nel suo colloquio silente con l'opera d'arte.*

- e. *Con l'impatto dell'AI nell'arte, l'accumulo di dati culturali digitalizzati ha permesso l'introduzione di sistemi di apprendimento e la classificazione guidati da agenti intelligenti.*

*A tal riguardo si fa cenno ad alcuni risultati.*

*Ci si riferisce ad una videoinstallazione in cui l'AI gestisce la spettacolarizzazione integrata di un flusso di dati numerici, testuali, visuali e sonori che avvolgono lo spettatore in un ambiente immersivo.*

*Un'altra metodologia messa a punto si rifà al mondo fittizio che richiama il cinema. Si tratta di "A woman with the technology" di Ziyang Wu, che coinvolge nel processo creativo la vita stessa dell'artista di cui si desidera produrre una opera: in particolare la sua attività di ogni giorno registrata che diventa un video che un agente AI trasforma in un prodotto. E più inerente al settore artistico, con un grande impatto mediatico, è avvenuta nel 2018 la vendita all'asta da Christies per 432.500 dollari di un dipinto prodotto dall'AI. Si tratta del dipinto "Portrait of Edmond Be-lamy" (Figura 1) con cui ci si prefiggeva di collegarsi alla tradizione della grande ritrattistica, imitando la pittura dei secoli passati.*

*Sono stati usati specifici algoritmi, ai quali sono stati forniti più di 15.000 ritratti di epoca rinascimentale e moderna.*

### **3. La produzione con l'intelligenza artificiale e la riproduzione digitale di un'opera d'arte**

*Con l'affermarsi dell'AI come mezzo di produzione di opere d'arte non si può non far presente come si ponga imperante la messa in discussione dei canoni, delle regole e della idea stessa di bellezza artistica promanante da un'opera d'arte, prodotta dal progettista degli algoritmi generativi nel confronto con un'opera d'arte eseguita dall'artista.*

*Ne conseguono le domande:*

- a. *se sia opportuno, nella considerazione della creatività umana e, quindi, dei prodotti eseguiti dall'artista, dare vita ad una nuova creatività per la quale si considerano l'automazione e, quindi, i prodotti ottenuti dall'AI.*
- b. *se lo spettatore, nel fruire l'opera d'arte prodotta dall'AI, pur subendo, nel caso, una influenza non positiva o di abbassamento del suo godimento tratto da tale opera d'arte, sia propenso ad accostarlo a quello dell'opera eseguita dall'artista, aprendosi in tal maniera a nuove prospettive di forme visive e corrispondenti contenuti.*

*Questo ci porta a quel concetto di cui si è fatto cenno in precedenza e che sarà più estesamente discusso, riconducibile al tema sulla attribuzione e valutazione di un'opera d'arte, in particolare eseguita dall'artista, che da anni è oggetto di acceso dibattito.*



Figura 1. Portrait of Edmond Belamy

*Questo tema pone, a sua volta, nell'ambito dei diversi gradi di certezza nell'attribuzione, anche il problema della sua riproduzione digitale dando luogo, come per un'opera d'arte generata dall'AI, ad un dibattito giuridico sul diritto d'autore.*

#### **4. L'attribuzione di un'opera d'arte**

*A tal riguardo inizialmente si ritiene opportuno far presente che l'attribuzione di un'opera d'arte è una operazione alquanto complessa ed è molto facile essere tratti in inganno: è, dunque, fondamentale uno studio approfondito dell'opera in questione.*

*La difficoltà deriva dal fatto che, tra l'opera originale e il falso, esistono un gran numero di categorie intermedie come le copie e le repliche. Le repliche, nonostante siano state eseguite dalla stessa mano, presentano piccole differenze, a volte difficili da riconoscere. Tali opere vanno pertanto studiate a lungo e con perizia: ad un occhio attento ed esperto non può sfuggire la discriminante della qualità.*

*Le copie, comunque, risultano meglio individuabili ad un occhio esperto. Ma, in diversi casi, opere originali e repliche sono state*



*considerate in passato copie: ciò è dipeso spesso dal cattivo stato di conservazione (ridipinture, sporco, vernici ingiallite) delle suddette opere, la qual cosa ha contribuito alla non corretta identificazione.*

*Spesso per distinguere una replica o una copia dall'originale, è necessario l'impiego di tecnologie diagnostico-analitiche dalle quali si evincono eventuali pentimenti: a tal riguardo, pur senza generalizzare, è possibile affermare che, se un dipinto non ha pentimenti, in linea di massima vuol dire che non è l'originale [6-7].*

*Il mercato dei falsi è diffuso e il corrispondente ritorno economico risulta rilevante: secondo gli esperti una grandissima percentuale delle opere presenti sul mercato sarebbe costituita da falsi.*

*Inoltre, in passato spesso è accaduto che falsificazione e restauro coincidessero: restauri eseguiti dai falsari sono stati interventi diretti o a sostituire completamente l'originale o ad alterare l'intera opera a tal punto da non poter più distinguere il coevo dal non coevo [8].*

*Il grande sviluppo dei falsi e il problema delle attribuzioni rappresentano, quindi, le grandi problematiche del mercato dell'arte, riconducibili non sempre a false attribuzioni eseguite con tale intento, ma anche alcune volte a proprio svantaggio. Questi sono soltanto alcuni esempi che sottolineano ulteriormente l'importanza di una certa scientificità nella valutazione dei beni oggetto di vendita.*

*Biblioteche e archivi, musei e collezioni private pullulano di falsi. Dall'antica Grecia ad oggi il dibattito sulle contraffazioni costituisce un affascinante (e, in taluni casi, doloroso) capitolo della nostra civiltà.*

*Lo scontro tra falsari e critici, infatti, ha paradossalmente prodotto una migliore conoscenza della nostra storia letteraria, artistica, religiosa e politica.*

*Un approccio datadriven a supporto dei processi di attribuzione rappresenta sicuramente una opportunità per il settore. Di seguito si riportano i principali ambiti in cui algoritmi classificabili come specie tecnologiche basate su AI potrebbero affiancare gli esperti, riducendo conseguentemente l'errore umano*

- *Analisi stilistica: Utilizzo di algoritmi di riconoscimento dei tratti stilistici, come reti neurali convoluzionali (CNN) addestrate su dataset di opere d'arte per riconoscere e analizzare gli stili artistici. Si tratta di un tipo di algoritmo di intelligenza artificiale ispirato al funzionamento del cervello umano. Sono ampiamente utilizzate per analizzare immagini e riconoscere modelli visivi complessi. Le CNN sono in grado di identificare automaticamente caratteristiche rilevanti nelle immagini, consentendo di svolgere compiti come riconoscimento facciale, classificazione di oggetti e guida autonoma.*
- *Riconoscimento delle firme: Algoritmi di riconoscimento ottico dei caratteri (OCR) applicati alle firme degli artisti su opere d'arte, utilizzando tecniche come la segmentazione e la classificazione dei caratteri.*
- *Analisi delle pennellate: Utilizzo di algoritmi di elaborazione delle immagini per estrarre e analizzare le caratteristiche delle pennellate, come la direzione, la lunghezza e la densità, utilizzando tecniche come la trasformata di Hough o l'analisi delle texture. Sono algoritmi*

utilizzati per rilevare forme geometriche, come linee e cerchi, in immagini. Utilizza una rappresentazione matematica per individuare i parametri delle forme desiderate. È ampiamente utilizzata in ambito di visione artificiale per il rilevamento e l'estrazione di caratteristiche geometriche da immagini complesse.

- *Analisi delle tecniche pittoriche:* Utilizzo di algoritmi di elaborazione delle immagini per analizzare le tecniche specifiche utilizzate dagli artisti, come la sfumatura o l'uso del colore, tramite l'identificazione di pattern o l'applicazione di modelli di apprendimento automatico.
- *Analisi delle trame:* Utilizzo di algoritmi di analisi delle immagini per riconoscere e confrontare le trame presenti nelle opere d'arte, utilizzando tecniche come le trasformate di Fourier o le feature di Haralick (analisi delle texture dell'immagine per descriverne la complessità e le strutture) per l'estrazione delle caratteristiche.
- *Analisi del contesto storico:* Utilizzo di algoritmi di analisi testuale per estrarre informazioni da documenti storici, come lettere o registri, e individuare collegamenti tra un'opera d'arte e un artista specifico o un periodo storico.
- *Ricerca di opere simili:* Utilizzo di algoritmi di ricerca delle immagini basati su contenuti per confrontare un'opera d'arte con un vasto database di opere, utilizzando caratteristiche visive o algoritmi di apprendimento automatico per trovare somiglianze stilistiche o tecniche.
- *Analisi delle fonti iconografiche:* Utilizzo di algoritmi di riconoscimento delle immagini per individuare e confrontare le fonti iconografiche utilizzate dagli artisti, utilizzando tecniche come deep learning (tecnica di intelligenza artificiale che utilizza reti neurali profonde per apprendere automaticamente rappresentazioni complesse e risolvere problemi complessi) per l'identificazione di oggetti o il riconoscimento di pattern.
- *Analisi delle correzioni e dei pentimenti:* Utilizzo di algoritmi di segmentazione delle immagini per identificare e analizzare le correzioni o i pentimenti presenti nell'opera d'arte, utilizzando tecniche come l'analisi dei contorni o l'elaborazione delle regioni di interesse.

## 5. Terminologia e valutazione oggettiva e soggettiva

Sembra opportuno prendere in esame la terminologia per distinguere i diversi gradi di certezza nell'attribuzione di un'opera d'arte [9]:

- *Autentico:* l'opera d'arte è interamente dell'epoca indicata o di un determinato autore;
- *Originale:* l'opera d'arte è realmente di un determinato artista del quale presenta tutte le caratteristiche stilistiche;
- *Replica:* riedizione di un prototipo originale eseguita dall'artista stesso;
- *Copia:* riproduzione dell'opera eseguita da un artista diverso;
- *Attribuito a:* tale indicazione evidenzia che l'opera è stata eseguita ai tempi dell'artista in questione e che lo stesso è l'autore più

- *probabile;*
- *Firma di: tale indicazione ha lo scopo di garantire l'attribuzione all'artista nominato, sebbene vi sia comunque da verificare l'autenticità di tale firma;*
- *Scuola di: l'autore dell'opera è un artista gravitante nell'ambiente dell'artista citato in maniera diretta o si tratta di un allievo;*
- *Seguace: artista che rivela alcuni tratti stilistici riconducibili ad un determinato maestro;*
- *Falso: consiste nella sostituzione totale di un manufatto a fini speculativi;*
- *Riprodotta: opera che risulta identica all'originale e realizzata mediante la digitalizzazione.*

A questo quadro vanno aggiunti i termini giuridici specificamente adottati in materia di falsificazioni.

La domanda che ci si pone a questo punto è: "Qual è e come si svolge la metodologia<sup>1</sup> di valutazione dell'autenticità di una opera nel mercato dell'arte?". Al riguardo, si illustra la situazione la quale coinvolge la realtà nazionale ed internazionale.

Fondamentalmente, la valutazione svolta dagli esperti delle case d'asta è una valutazione di carattere soggettivo, basata sull'analisi degli elementi storici, stilistici, estetici, iconografici e, quindi, di carattere visivo del manufatto di interesse artistico, non supportata da tecniche diagnostiche appropriate che, nel rispetto dell'unicità e non rinnovabilità del bene, sono non distruttive e non invasive. Le indagini svolte dagli esperti delle case d'asta sono riassunte dal "Condition Report", una scheda contenente informazioni di carattere qualitativo e non quantitativo. Per tale valutazione soggettiva risulta fondamentale, ovviamente, l'esperienza dello studioso. La valutazione oggettiva, relativamente all'attribuzione di un'opera d'arte, alla sua autenticità, alla valutazione del suo stato di conservazione, si basa invece sull'utilizzo delle metodologie diagnostiche, anche in riferimento alle nuove tecnologie. In completezza, lo studio di un'opera d'arte deve essere condotto con il contributo sinergico del diagnosta-conservatore e dello storico dell'arte.

## **6. La ricostruzione e la riproduzione digitale delle opere d'arte**

È nata già da alcuni anni la mediazione digitale nella ricostruzione e riproduzione di opere d'arte che, combinando l'utilizzo di apparecchiature sofisticate e tecnologie avanzate con la sapienza artigianale, ha conquistato la fiducia di molti musei internazionali conducendo operazioni di grande rilievo storico-artistico [10]. L'interesse nei confronti dell'aspetto filologico delle operazioni artistiche si concretizza nelle collaborazioni con sociologi, storici, antropologi e semiologi. A tal riguardo si fa cenno alla riproduzione digitale di "Le Nozze di Cana". Una versione del dipinto su tela "Le Nozze di Cana" di Paolo Veronese (Figura 2) – portata in Francia dai commissari di Napoleone nel settembre 1797 e conservata al Louvre - è stata "scannerizzata" nel 2007 dall'abile tecnico Adam Lowe: ciò costituiva decisamente qualcosa di totalmente "nuovo".



Figura 2. Le Nozze di Cana, Paolo Veronese

*Non una copia, magari eccellente, ma un dipinto identico all'originale, non solo della stessa misura, stesura, materia, ivi compresa quell'"aura" benjaminiana che appare integra. Così, attraverso la digitalizzazione, è possibile ottenere una realizzazione identica all'originale, nella quale forma, colori e, persino, "matericità" degli stessi sono assoluti. Trattandosi di un'opera pittorica di un grande maestro e, quindi, di un unicum irripetibile, per quanto riuscita possa essere la sua riproduzione, diciamo che la sua contraffazione è comunque discutibile. Ne deriva che, alle domande poste in precedenza e conseguenti alla produzione delle opere d'arte con AI, fanno seguito, anche nel caso della riproduzione digitale, alcuni quesiti di ordine più etico che estetico prerogativa di un'opera d'arte. In particolare:*

- *dove è finito il principio dell'unicum?*
- *dove la sua irripetibilità;*
- *dove la sua immancabile elevatissima quotazione mercantile.*

*Il modo più semplice per rispondere a queste obiezioni è proprio quello di affidarsi ad una analisi seria e scientifica. Si potrebbe giudicare lecita la riproduzione di un capolavoro come autorizzata purché sia indicato chiaramente di che si tratta. Detto ciò, potendo ipotizzare ambiti specifici di utilizzo delle tecnologie AI nei processi di riproduzione fedele, vediamo alcuni proposti direttamente da una AI quando le è stata posta direttamente la domanda. L'elenco è stato poi raffinato da esperti nel settore inquadrandolo in letteratura [11-20]:*

- *Digitalizzazione ad alta risoluzione: Utilizzo di algoritmi di upscaling, ovvero processi per aumentare la risoluzione o la qualità di un'immagine, basati sull'intelligenza artificiale per aumentare la risoluzione delle immagini digitalizzate delle opere d'arte, preservando i dettagli e migliorando la fedeltà visiva.*
- *Ricostruzione tridimensionale: Utilizzo di algoritmi di visione artificiale e di elaborazione delle immagini per ricostruire modelli tridimensionali di opere d'arte, consentendo di visualizzare l'opera da diverse angolazioni e prospettive;*
- *Restauro virtuale: Applicazione di algoritmi di intelligenza artificiale per ripristinare digitalmente opere d'arte danneggiate o degradate, ricostruendo i dettagli mancanti o riparando difetti come graffi e macchie.*
- *Colore e illuminazione accurate: Utilizzo di algoritmi di apprendimento automatico per determinare con precisione i colori dell'opera autentica e riprodurre l'illuminazione corretta per una rappresentazione fedele.*
- *Analisi dello spessore del colore: Utilizzo di algoritmi di analisi delle immagini per determinare lo spessore dei diversi strati di colore in un'opera d'arte, consentendo una riproduzione accurata delle tecniche pittoriche dell'opera autentica.*
- *Riproduzione di texture e materiali: Utilizzo di algoritmi di generazione di texture basati sull'intelligenza artificiale per riprodurre fedelmente le varie texture e materiali presenti in un'opera d'arte, come la consistenza delle pennellate o la trama di una superficie.*
- *Animazione e realtà virtuale: Utilizzo di algoritmi di animazione e realtà virtuale per creare esperienze interattive che permettano di esplorare e interagire con l'opera d'arte in modo realistico, ricreando la forma ed il contesto dell'opera autentica.*
- *Simulazione dello stile artistico: Utilizzo di algoritmi di generazione di immagini basati sull'intelligenza artificiale per simulare lo stile artistico di un determinato artista o periodo storico, consentendo di riprodurre nuove opere con fedeltà a uno stile specifico.*
- *Riproduzione tattile: Utilizzo di tecnologie di feedback tattile e di modellazione 3D per creare riproduzioni fisiche di opere d'arte, consentendo agli utenti di sperimentare la sensazione tattile e la dimensione dell'opera in esame.*
- *Archiviazione e conservazione digitali: Utilizzo di algoritmi di compressione e di archiviazione dati per creare archivi digitali di opere d'arte ad alta risoluzione, garantendo la conservazione a lungo termine e l'accessibilità alle generazioni future.*

## 7. Considerazioni conclusive

*Un'opera d'arte è caratterizzata da un insieme di valori (culturale, storico, estetico, artistico, spirituale, simbolico, sociale, tecnico, economico, finanziario, mercantile, mercatistico, di autenticità, di identità, di interdisciplinarietà, di internazionalizzazione), che riguardano diverse aree di*

indagine: area storico-umanistica, filologico-filosofico-sociale, tecnico-economico-gestionale, legale-identitaria.

Tale valore olistico dovrebbe concorrere a stabilire lo specifico prezzo e, quindi, il valore economico-finanziario-mercantile-mercaticistico. È pur vero che il prezzo è quello che si paga, il valore è quello che si ottiene.

Sono molteplici e vari i fattori, ancorché collegati a condizioni e situazioni non certo riscontrabili se non in un range di insicurezza e imprevedibilità, che possono contribuire alla determinazione del prezzo dell'opera d'arte, sulla base peraltro – da ritenere punto fondamentale a cui riferirsi, come già sottolineato – della valutazione soggettiva e oggettiva sulla sua autenticità e del suo profilo giuridico.

Sorge a questo punto della trattazione sulla intelligenza artificiale e sulla riproduzione digitale di un'opera d'arte, la domanda alla quale in definitiva si voleva tendere:

*“In relazione alle potenzialità descritte e relative alla AI e all'accesso dibattito fra storici e tecnici sul tema autenticazione di un'opera d'arte alla base della valutazione soggettiva e oggettiva, l'accumulo di dati culturali digitalizzati, l'elaborazione di un sistema di accesso aperto, gli agenti intelligenti e gli algoritmi generativi hanno il potere di eliminare stereotipi e pregiudizi di genere dando un ulteriore contributo per una decisiva soluzione all'accesso e perdurante dibattito sull'autenticazione di un'opera d'arte e confermando infine una unica e condivisa verità scientifica?”*

È questo il precipuo intento che ha costituito l'obiettivo del presente lavoro. Possiamo affermare che sicuramente quelle elencate in questo lavoro sono tecnologie abilitanti, ovvero che danno più abilità all'uomo di raggiungere i propri obiettivi. Quelli indicati sono solo alcuni degli ambiti in cui l'intelligenza artificiale potrebbe fornire un contributo nella sfida complessa ad es. dell'attribuzione delle opere d'arte. È importante sottolineare che l'interpretazione umana e l'expertise degli esperti rimangono essenziali per giungere a conclusioni definitive.

Riprendendo quanto riportato in precedenza, nell'ambiente tecnologico che va formandosi con la digitalizzazione, possiamo ancora seriamente credere nella libertà?

A tal riguardo è necessario dimostrare che anche nell'era della digitalizzazione la libertà unita alla creatività sono ancora le carte vincenti per creare un'organizzazione sociale superiore ad un modello centralizzato e controllato.

Ciò costituisce una sfida che coinvolge piani molto diversi: culturale, ma anche politico, economico, scientifico. Fondamentalmente si tratta di curare e far crescere l'intelligenza umana nella sua integralità, individuale e collettiva, qualificare l'idea di libertà ereditata dal XX sec., nonostante l'intelligenza artificiale e il mondo digitale stiano già radicalmente cambiando il modo in cui conosciamo il mondo e interveniamo su di esso.

Ne deriva quanto risulta particolarmente importante la nostra capacità di impiegare correttamente e sviluppare queste tecnologie, dimostrando che i modelli altamente digitalizzati sono compatibili e anzi funzionano meglio delle possibilità umane o le completano.

Possiamo pensare di farcela con un massiccio e deliberato investimento nella formazione. La formazione è, quindi, tanto strategica quanto la ricerca e le infrastrutture: non c'è futuro senza scuola di qualità e senza formazione permanente.

*Ma non si tratta solo di questo. L'intelligenza diffusa, come si è già fatto presente, può crescere solo in organizzazioni valorizzando la creatività, la responsabilità, l'autonomia di giudizio. Dopo la stagione dell'individualismo radicale, ancora diffusa, abbiamo bisogno di una libertà intelligente, curata e coltivata, capace di essere responsabilmente impiegata nella relazione con gli altri e con l'ambiente.*

*Inoltre i business si dovranno adattare al cambiamento, integrando nuove competenze imperniata su innovazione, tecnologie digitali e intelligenza artificiale, inquadrando i dati e offrendo il punto di vista di professionisti d'eccellenza a livello nazionale e internazionale.*

*In tal maniera gli esperti di scenari internazionali devono diventare una piattaforma permanente di analisi delle relazioni culturali tra dinamiche geopolitiche e geoeconomiche proiettate verso un futuro più stabile e meno conflittuale e con un impatto strutturale sulle strategie di accesso e crescita in mercati emergenti e maturi.*

### **Note**

<sup>1</sup> Con il termine “metodologia” si intende lo studio dei metodi. Per “metodo” si intende invece l'insieme delle azioni necessarie per l'effettuazione dell'analisi chimica: prelievo, preparazione del campione, misura. Il termine “tecnica” si riferisce ad un'azione richiedente un mezzo strumentale specifico. La “tecnologia”, sinonimo di “scienza applicata” orientata verso obiettivi pratici e concreti, si basa su fondamenti scientifici.

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## **Riassunto**

*La crescente presenza della intelligenza artificiale (AI) nella gestione della vita civile e sociale e nella organizzazione economica e politica ha determinato vari interrogativi scientifici, filosofici, giuridici, morali nel dibattito anche culturale. Nel presente lavoro, dopo una sintetica presentazione delle applicazioni dell'AI nell'arte e nella cultura, ci si sofferma sulla produzione con AI e sulla riproduzione digitale, temporalmente precedente, delle opere d'arte. Si evidenzia, di conseguenza, la messa in discussione dell'idea stessa di bellezza artistica promanante dalle opere d'arte prodotte con AI dando vita ad una nuova creatività insieme con la creatività umana dei prodotti eseguiti dall'artista.*

*In ultima analisi si fa presente la possibilità che specifici algoritmi generativi possano contribuire alla risoluzione della discussa e accesa diaatriba sulla problematica della attribuzione e autenticazione di un'opera d'arte.*



# A TOOL TO ACCESS UNREACHABLE SITES INSIDE THE ARCHAEOLOGICAL PARK OF OSTIA ANTICA IN ROME

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*Keywords:* virtual tours, photogrammetry, 3D model evaluation, cloud computing, 5G networks.

## 1. Introduction

With the computational revolution and the advent of information technology, the way cultural heritage can be communicated has been revolutionized. New technologies such as 3D vision, virtual and augmented reality, mobile applications, and new communication devices have brought new possibilities. In the most innovative museums and archaeological parks today, it is possible to carry out virtual tours using mobile or specific on-site digital applications. The inherent benefits of applications include not only the population, but also stakeholders, such as archaeologists, restorers, and cultural heritage professionals in general. Today, using computed tomography, computer vision, laser scanning and photogrammetry, it is easy to create three-dimensional (3D) models for production, sharing, and manipulation. Moreover, 3D data may be incorporated directly into the site or viewed remotely. Thanks to its low hardware and software requirements, photogrammetry has emerged from among other technologies to play an important role in cultural asset digital modelling. Moreover, photogrammetry requires very few tools to develop quality 3D models, therefore, it is a good candidate for surveying difficult sites when there is no electrical power available, as well as interior spaces where there is little room for manoeuvring or where it is impossible to use instrumentation other than cameras, lights and simple LIDAR (Light Detection and Ranging) systems. This paper discusses the development of an innovative tool for making virtual tours of unreachable sites using 5G technology, 3D photogrammetry models and information layers. Moreover, a case study is presented of the “Casa di Diana” (House of Diana) located inside the Archaeological Park of Ostia Antica in Rome. There are some important questions to consider when discussing photogrammetric reconstructions, as evidenced also in the work of Magnani [1]: “Does photogrammetry have greater interpretive potential than previously employed archaeological methods? Or is it best suited as a new medium for community outreach and visualization? In either case, does its practice address the needs of archaeologists and the communities we work with, or are we preoccupied with demonstrating the merits of the latest software and workflows?”. The following points answer these questions concerning the present

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study: photogrammetry has been used as a tool to improve the accessibility of unreachable sites, thus increasing their outreach potential; it was considered a simple and effective methodology to create a 3D model of an asset that can then be used for site conservation and preservation (developing a fundamental “zero layer” for restoration processes) and a widely accessible and interoperable model to inspect the site. Moreover, any 3D model can be integrated with informative layers (historical photos, texts, etc..) or other 3D elements from different methodologies (LIDAR, 3D reconstructive hypotheses, etc..). This integration process can increase the capacity to communicate specific aspects of the asset as well as increase the scientific and scenic value of the result. Therefore, the authors encourage the use of photogrammetry as a base tool to create a more complex and valuable outcome, useful not only for outreach purposes but also for scientific and archaeological studies that can exploit the benefits of digital 3D models. Other elements worth noting, for example, arise from Shott’s claim: “Certainly, the burgeoning literature on digital methods in archaeology has its share of ‘See what I did because I could do it’ contributions. There is nothing wrong with such papers when they serve as proof-of-concept, but they do not always contribute directly to the accumulation of archaeological knowledge” [2].

The same problem was also evidenced by Zubrow: “There is a tendency to use digital technological solutions simply because one has the available ‘toys’” [3]. The present work is not intended to increase the archaeological knowledge for a cultural asset but as a methodology to increase the outreach capability of an otherwise unreachable site, a proof-of-concept for sites normally closed to the public due to their intrinsic nature following the idea expressed by Grosman [4]: “We should target issues that cannot be resolved using traditional approaches and benefit from data that are accessible only by applying digital methodologies”.

The technology was developed in the VADUS project (ARTES 20 call), co-founded by ESA (European Space Agency) and the consortium led by NEXT Engineering Systems and with the participation of TIM, ENEA, the Archaeological Parks of the Colosseum and Ostia Antica, the Sapienza University of Rome with its research centre CIT-ERA and the DIAG department. The name VADUS (Virtual Access and Digitalization for Unreachable Sites) comes from the Latin name for “ford”, intended as a metaphorical passage to overcome the difficulties associated with physical access to unreachable archaeological assets.

## 2. Casa di Diana - Archaeological Park of Ostia Antica

The “*Casa di Diana*” (House of Diana) is located at “Regio I” the central area of the ancient city of Ostia, near the most important public and sacred buildings.

The demographic growth from the economic and commercial activities linked to the ports of Claudius and Trajan between the end of the first and the beginning of the third century, increasingly favoured the construction of large multi-storey buildings, the so-called *insulae* [5–7]. The *Casa di Diana* is one of the most important buildings in ancient Ostia (the harbour of Rome, Italy) and was used both for residential functions of the middle class and for commercial activities. Built in brickwork during the first half of the second century A.D., it has a quadrangular plan with an internal courtyard from which various access corridors to the apartments and common areas branch off. The *Casa di Diana* was unearthed in Ostia between 1915 and 1918 during the Paribeni-Calza excavations from which the first graphic reconstructions by Gismondi come from [8]. Since then, numerous other research and restoration campaigns have followed. The building takes its name from a terracotta tile depicting the goddess Diana, discovered on the

walls of the central courtyard. It is hypothesized that the *Casa di Diana* was originally a five-storey building (Figure 1).

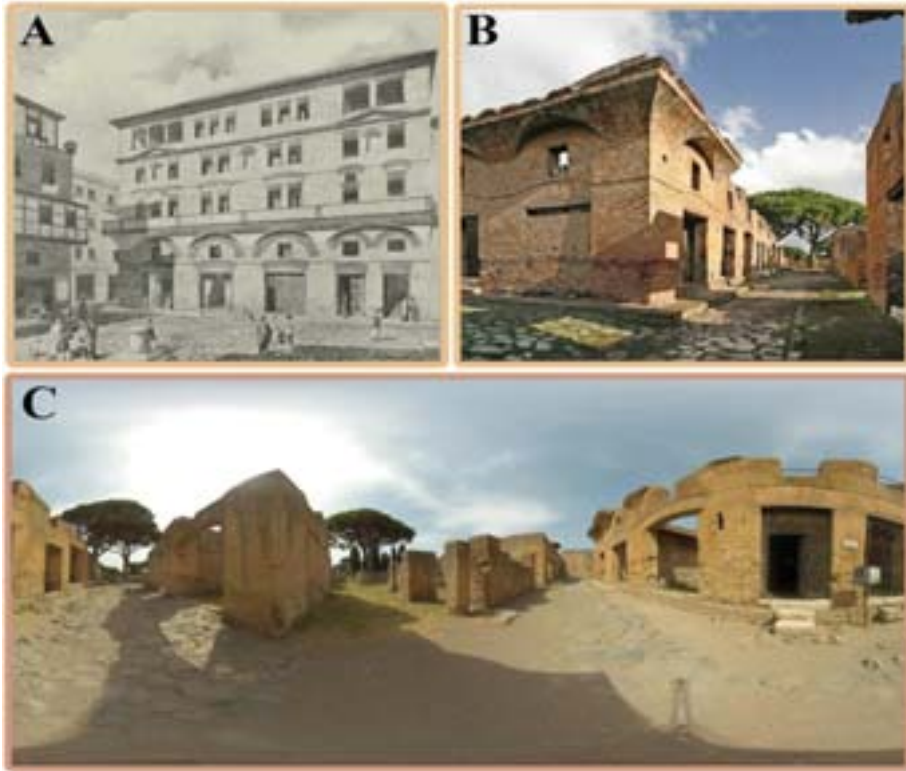


Figure 1. A: Gismondi's reconstruction of the *Casa di Diana* (Wikimedia Commons, CC BY-SA 3.0); B and C: *Casa di Diana*, present-day view (C is a 360° panorama).

On the ground floor, there were shops overlooking the street, while private apartments and common areas were placed on a mezzanine floor and accessed by internal staircases. The first floor had an external balcony overlooking the street of which part of the walls and the valuable pictorial decoration are still visible today. The upper floors, on the other hand, were intended as a residence for the poorer social classes. However, there are other functional interpretations for the *Casa di Diana*, as it was used both as a hotel and as a boarding school.

During the ages, a series of structural changes were performed as evidenced by the analysis of the walls, the decorations and the overlapping of different floor levels [9]. These transformations involved not only the distribution and organization of spaces and the renewal of decorative elements [10], but also changed the function of some rooms. In the second half of the second century, for example, a fountain decorated with a polychrome mosaic was built inside the porticoed courtyard (C) and was later replaced by a less elegant one in *opus latericium*.

Another significant example of architectural transformation was recorded during the third century B.C. when the floors were raised and fitted with new mosaics.

Among the most significant interventions of re-functionalization, however, was the construction of a *mithraeum* (F), in the innermost rooms, consisting of an *aedicula*, a marble altar (reused) and some *podia* in masonry. During a later phase, a stable was built inside the *tablinum* (E), the main representative rooms were decorated, and a fountain was placed in the centre of the building in front of the porticoed courtyard (C).

### 3. Visual storytelling

The *Casa di Diana* is a site that cannot be accessed, due to its fragility and conservation issues, therefore, it was selected, under guidance from the park officials, as a demonstrator site within the VADUS project. The site was digitally reconstructed using photogrammetry techniques, developing a 3D model for the most representative and best-preserved rooms in the building.

Only the rooms on the first floor were chosen for the virtual tour, which was modelled with information layers populated by references, reconstruction hypotheses and general information about the history of the building.

The environments selected were those which surround the porticoed courtyard (C) and are fundamental for a complete reading of the archaeological palimpsest. Moreover, a storyboard was realized consisting of 5 main historical-archaeological informative layers positioned in the 3D photogrammetric model near the entrance corridor (A), at the *Tablinum* (E), at the antechamber of the *Mithraeum* and in the *Mithraeum* itself (F), as well as a topographical frame outside the house along *Via di Diana* (the ancient street in front of the building, visible in Figure 2).

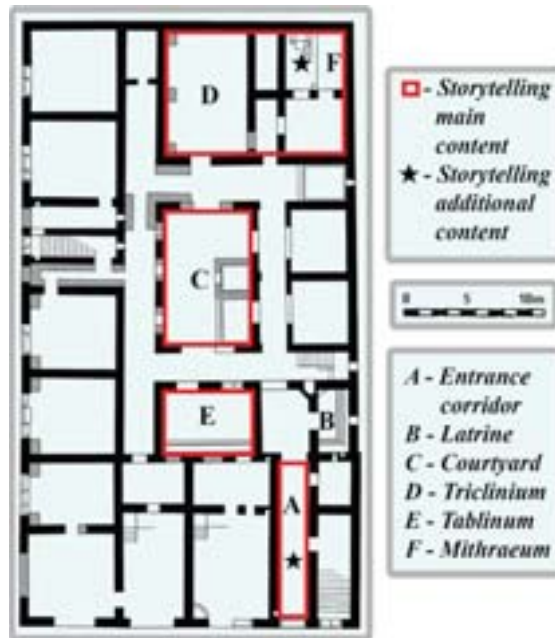


Figure 2. “Casa di Diana” plan on right, with indications of the environments involved in the storytelling.

Multiple data and details make up each of the five informative layers which, in turn, are made up of multiple elements based on available information, also visible to the user (inside the 3D model). For instance, one of the informative layers placed in the virtual tour is related to an inscription visible on a leaden fistula at the fountain in the porticoed courtyard (C). It is interactable by users and is positioned inside the entrance corridor (A). The inscription bears the name of *Marcus Cornelius Secundus* and that of a woman belonging to the *Sergii Pauli* family, who probably owned the house around the middle of the second century AD. The virtual tour also has high-level informative layers (not detailed as for the fistula), which were developed to show a more generic and large-scale historical framework for the site. An example is the *Mithraeum* (F) information layer, which describes Mithraic cults in Ostia and introduces the tourist to the ancient religions of Rome. Other layers aim at keeping and capturing the visitor's interest, as well as directing them toward other monuments and archaeological sites connected to the *Casa di Diana*. Furthermore, an attempt was made to describe some details of the site that are generally little known to non-experts. At a methodological level, the storytelling was developed with reliable and scientifically correct information after it was thoroughly researched; it involved: archives studies, interviews with archaeologists and on-site scientific measurements. Moreover, the storyboard was created following the requirements expressed by the authorities responsible for the management and conservation of the site, as well as with indications from the stakeholders. The choices made in developing and preparing the information layers allow for a "conscious" visit: that is, it can be enjoyed according to the cultural level and personal interests of the tourist, who has the possibility of accessing graphic, audio, video and textual information, including that deriving from diagnostic measurements (LIDAR and hyperspectral imaging). Therefore, different users can find different information, both from a general and a more specific/scientific perspective.

Furthermore, the different information layers, which provide the tourist with a clear picture and a connection to their surroundings and the available information, are all related to visible elements belonging to the site or another that is nearby and accessible. The content was organized within a narrative structure that could combine scientific needs with the interests of the visitors [11]. For this reason, an experimental campaign to test the visual storytelling capabilities of the tourists was made at the archaeological park of Ostia in the autumn of 2022. The aim was to understand if the narration was effective and interesting for visitors. The outcome was positive showing that the storytelling had been greatly appreciated, with visitors also making suggestions on how to improve the service.

Visual storytelling was developed as multilingual and all contents are scalable in terms of time duration and available information, based on users' choices. On a technical level, considering that the virtual tour runs on a smartphone APP, it was decided that video and images could be skipped or paused to best suit users' wishes and could easily be followed on small screens, such as tablets and smartphones. The photographic material used comes from the park of Ostia's historical archives, restoration archives and recent investigations.

For the storytelling, the following steps were followed:

1. Development of a storyboard for content definition.
2. Elaboration of storytelling based on the storyboard, where the narration is built on a maximum of 1000 words to avoid excessive length.
3. Definition of additional contents based on visitors' interests and little-known archaeological aspects.
4. Accurate selection and processing of illustrative material from the archives of

the *Ostia Antica* archaeological ark.

5. Development of animated visual storytelling.

#### 4. Photogrammetry campaign

As mentioned previously, the selected demonstration site was the “*Casa di Diana*” (see Figure 3) in ancient Ostia and the various data collected during the measurement campaign (planar and 360° views, planimetry, hypotheses about room destination and graphical façade reconstruction).

The archaeological park of *Ostia Antica* identified two rooms as primary and secondary reconstruction targets (Rooms E and F), whose location and visual appearance are reported in Figure 3.

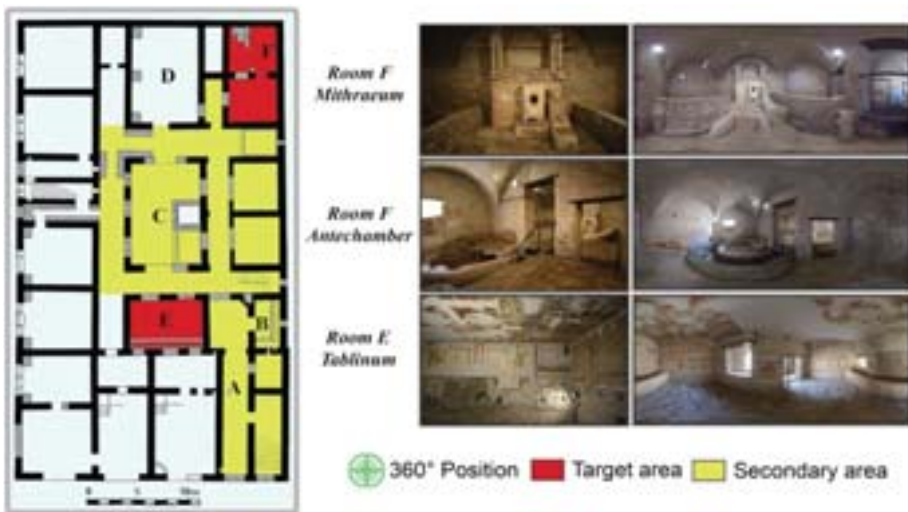


Figure 3. Target rooms and secondary areas for the reconstruction process (left), and views of the rooms in photos and 360° images (right).

The site was reconstructed using photogrammetry techniques at two different levels of details (LODs): the first level, used for the target rooms, has a higher reconstruction quality due to the higher number of images used in the photogrammetry software and is less decimated and simplified during the postprocess operations. High quality is mandatory where the rooms are of greater interest due to their importance in storytelling when compared to other locations on the site. In this case, a higher resolution was necessary to ensure the maximum quality for the frescoes, mosaics, and the *Mithraeum* altar in rooms E and F. The other rooms (A, B, C) were developed using lower quality, fewer images, and higher simplification during the postprocessing. This was done because the rooms had less important details and little available information. It must be underlined that the reconstruction is oriented at dissemination where it is more important to have an overall good performance for visualization of the models (due to the limited computing power of the rendering hardware) and to avoid any lag in loadings compared to having a too-high model quality for irrelevant details.



Moreover, the rooms/spaces A, B and C were captured to create a potentially continuous tour path for the virtual tourist. For unreachable sites, such as the “*Casa di Diana*”, which is normally closed to the public, there are some issues to be considered during a photogrammetry campaign.

First, the site required preliminary access authorizations, inspections and interlocutions with the site and risk managers to:

- Define a timetable and security plan.
- Organize logistics as a function of the environment (clean the environment, get keys, move experimental hardware to the location, switch on the electrical system if present, etc.).
- Identify specific critical issues to be addressed and fixed before the start of activities.
- Define in detail the surfaces and target spaces for the reconstruction campaign.

Defining space and surface targets also needs archaeologists and personnel specialized in conservation, maintenance and valorisation, which are the same professional figures that are not only involved in the process of identifying the demonstration sites but are the main protagonists, with the Italian Ministry of Culture (MIC) and cultural institutions, in acquiring information to develop the “informative layers” and 3D reconstructions that enrich immersive visits.

The list of activities carried out for the photogrammetry campaign are listed below.

1. Preliminary activities (i.e., camera calibration, lighting preparation, correct positioning of photogrammetry markers).
2. Acquisition of physical dimensions for rooms using an EDM (Electronic Distance Measurement) device and coded markers.
3. Populating the photographic database with high-quality shots.
4. Taking photos for documentation purposes by frame and 360° cameras.

Other photogrammetric activities are summarized in Table 1. Before the campaign, preliminary camera calibration was performed in the laboratory using a checkerboard to completely calibrate the photographic lens [12], including non-linear and barrel distortion coefficients.

*Table 1. Main computational photogrammetric steps*

COMPUTATIONAL STEPS	PROCEDURE
<i>ELABORATION OF PHOTOS</i>	After the first visual analyses to identify missing elements (i.e., hidden building elements, small or occluded details, etc.), the available photos were pre-processed to analyse their quality in terms of focus, colours and over/under exposed areas. The areas with over/under exposure (luminance in hue colour spaces) were masked and excluded in the photogrammetry process.
<i>CREATION OF A PHOTOGRAMMETRY ENVIRONMENT</i>	The photos were loaded into the software’s workspace creating a photogrammetry workspace and organized. The distance of the markers was then imported into the model to scale the photogrammetric environment.
<i>SPARSE AND DENSE POINT CLOUD GENERATION</i>	The photos were aligned by the software generating the sparse and dense clouds. Then, the point clouds were filtered based on the number of correspondences in the photogrammetry

	database (the number of photos where the point is visible); the points which were not correctly aligned were removed.
<i>CREATION OF 3D MODELS</i>	The 3D models as well as the textures were generated by meshing the point cloud and using mosaic projections.
<i>MODELLING POSTPROCESSING ACTIVITIES</i>	The 3D models were post-processed using Open-Source software (Blender, Meshlab) to remove any remaining artefacts and to check the resulting model quality.

As a preliminary activity, about 73 coded markers were placed around the rooms and their spatial coordinates were measured with an EDM device to develop a matrix ("distortion" or "distance" matrix) for model scaling and validation. The matrix is symmetrical and was made using all the distances (expressed in meters) between markers (distortion matrix).

It is shown in Equation (1):

$$\begin{pmatrix} 0 & \dots & P_j - P_i \\ \vdots & \ddots & \vdots \\ P_i - P_j & \dots & 0 \end{pmatrix} \quad (1)$$

Where: " $P$ " is the vector containing the coordinates of the " $i$ " marker inside the reconstruction relative space and " $j$ " is the total number of markers (73).

A Python script was used to transfer the distance data to the photogrammetric software to reduce transcription errors. The markers were 12-bit coded and placed in the target rooms (E and F) and in rooms (A, B, C) that connect the entrance with the target rooms. Table 2 reports the total number of markers used, their location in the rooms and the number of the resulting calculated inter-distances.

Table 2. Distribution of coded markers, number of resulting distances and location

Room	Markers Total number	Distances Total number	Location
E	10	45	Target area
F Antechamber	13	78	Target area
F	5	10	Target area
A	18	69	Secondary area
B	6	15	Secondary area
C	20	99	Secondary area
D	4	6	Secondary area

It must be noted that the maximum number of distances is different from the theoretical maximum due to the visibility between the markers that reduces the number of distances directly measurable by the EDM.

About 70% of the distance data were imported to the photogrammetry software to obtain a correct scaling of the model, while the remaining parts were used to validate the model by comparing their values with the corresponding measured distance in the developed 3D model.

During the photographic campaign, colour checkers and a grey-white balance target were used to support the colourimetric accuracy of the reconstruction and to balance the white temperature in the photos.

This was particularly critical because of the presence of different types of lighting sources, both natural and artificial (i.e., openings, windows and artificial lighting systems).

Artificial lighting sources had to be used in rooms/spaces where a too-low level of illuminance was detected by a lux meter to avoid dark areas in the photos.

An example of the visual environment with its different light sources and the checkers' position in the target rooms is reported in Figure 4.



Figure 4. Visual environments with different light sources and white-grey-colour checkers.

The photographic dataset was populated with 7360 x 4912 pixels photos in TIFF format with EXIF metadata; this format is suitable for photogrammetric processes due to its lossless quality and the metadata containing GPS information to help the software in the reconstruction process. The photos were taken with a very large overlapping area (~70%) to capture the same detail in at least three different images.

As a function of the environment, a parallel or circular close-image technique was used to improve the quality of the reconstruction and to evidence the details of the objects (Figure 5).

During the campaign a full-frame Nikon D810 camera was used, set at a fixed aperture and focus length, but with variable exposure time, to produce shots as uniform as possible. The lens used was a calibrated and stabilized Nikon AF-S 20mm 1:1 ED. Moreover, more photos were taken of important details, such as paintings, mosaics, opus sectile floors, and relevant architectural features.

The photos for the target rooms were taken at a mean distance of about 2-3 m, while for the less relevant surfaces (secondary areas and other rooms/space) the maximum distance was less than 5 m; the correspondent GSDs (Ground Sample Distance) were calculated on the base of the following Equation (2):

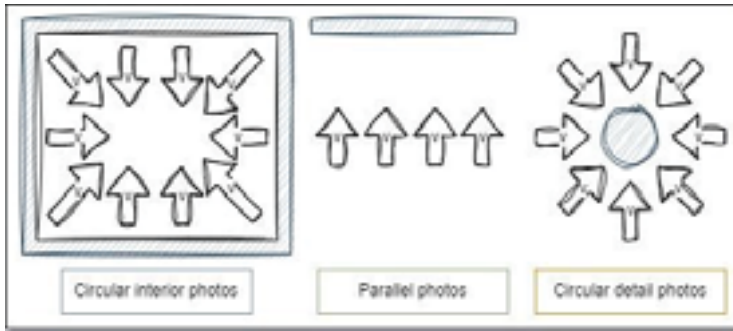


Figure 5. Different close-range image techniques.

$$GSD \left[ \frac{mm}{pixel} \right] = \frac{Distance[m]}{Focal\ length[mm]} * \frac{Sensor\ dimension[mm]}{Image\ resolution\ [pixel]} \quad (2)$$

The calculated GSD values for the target rooms are in the range of 0.5÷0.8 [mm/pixel] with a maximum of 1.4 [mm/pixel]. The number of photos taken for each room/space is reported in Table 3.

Table 3. Indicative distribution of photos among rooms/spaces

Spaces	N. of Photos	Location
Room E	295	Target room
Room F Antechamber	280	Target room
Room F	170	Target room
Connections to target rooms	390	Secondary area
Other rooms & miscellanea	1200	Secondary area

To exclude poorly focused images from the photogrammetric database it was manually analysed. The areas with over/under exposure were masked using a Python script and direct inspection, then the photos that were too dark or bright were excluded by the photogrammetry process (area with a luminance  $H < 0.1$  or  $H > 0.9$  in hue colour space). The remaining 2237 photos were loaded to the photogrammetry workspace and organized according to their content.

After the importing process, 70% of the distances were calculated and imported to the photogrammetry software to scale the environment.

The screenshot in Figure 6 shows the full sparse cloud model after photo alignment and scaling; as can be noted, the cloud is wider than the area interested in the project and the blue areas are the position where the photos were taken and reconstructed by the software; the software correctly aligned 2225 of the 2237 photos.

After the sparse cloud generation, a dense cloud model was generated by using the depth maps from the photos. The dense cloud model was then filtered using the number of correspondences in the photogrammetry database and removing the points that were not connected to the main cloud (artefacts).

Moreover, to reduce the elevated number of points (in the order of billions) the cloud was filtered to have no more than one point every 1.5 mm.



Figure 6. Screenshot of the full Sparse Cloud model with shooting positions (blue areas).

After the dense cloud processing, a complete 3D model was generated interpolating the point cloud, as can be seen in the screenshot in Figure 7; the red line encloses the secondary area and the yellow line the target rooms.

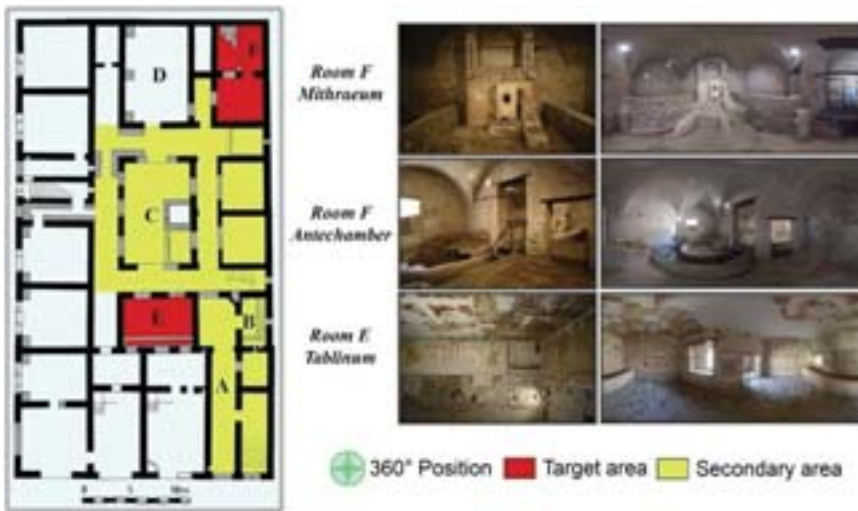


Figure 7. 3D interpolated model screenshots (primary target area is red coloured, secondary is yellow coloured).

To produce files suitable for virtual applications, the complete model was scaled again to a congruous number of points to reduce the number of polygons (from about 160M to about 13M points) and texturized with normal and occlusion maps from a high poly model (8 of 8K texture files); normal and occlusion maps are useful to give the depth information lost during the decimation process to the gaming engine.

After a visual inspection of the 3D model, it was revealed that there were no missing elements or artefacts in the interested rooms.

#### 4.1. Model validation and quality

To evaluate the quality of the output a validation of the final 3D model for the target rooms (E and F) was developed by in-depth three-dimensional methodology, which considers dimension, colour, and perceived structure.

The methodology, developed by the authors, has already been used for other sites, showing its capabilities [12–14]. It involves not only the absolute pixel colour value from a singular pixel analysis but also considers the interrelation between pixels to analyse the “true” representation of an object and the clearance and discernibility of its details. This methodology is useful where dark areas and hidden details may degrade the quality of the representation.

To develop the methodology, the following indices were considered:

- Mean Absolute Percentage Error (MAPE) [15];
- Perception-based Image Quality Evaluator (PIQE) [16];
- Structural Similarity Index Measure (SSIM) [17];
- Signal to Noise Ratio (SNR) [18];
- Peak Signal to Noise Ratio (PSNR) [18];
- Mean Squared Error (MSE) [18].

The SNR, MAPE and PSNR parameters are more useful for comparison purposes between different types of reconstruction of the same model; moreover, they do not consider the perceived quality but only the difference between the original photo and virtual model. SSIM and PIQE, instead, are specifically developed to consider the perceived quality of an image by comparing the image structure. Instead, MAPE was used to evaluate the dimensional error of the virtual model if compared to the real site. This was done using the distances measured, using the distance matrix (Equation 1).

The MAPE parameter was calculated as a vectorial analysis using the following Equation 3:

$$MAPE = \frac{100\%}{n} \sum_{t=1}^n \left| \frac{(A_t - F_t)}{A_t} \right| \quad (3)$$

Where  $A_t$  is the real measured value and  $F_t$  is the distance in the virtual model. This geometrical analysis is compared to a structural analysis which compares the information related to shapes and colours between two images (a real photo and a screenshot taken from the 3D model at the same coordinates and with the same lens characteristics). It must be noted that the “screenshot” is produced by the software using the same colour space as the original photo, not making a screenshot of the display), the indexes used for structural analysis in the present work are SNR, PSNR, MSE, PIQE and SSIM.

The following methodology was used to compare the 3D digital model with the corresponding photos: the camera position calculated by photogrammetric software, which is the point where the photos are supposed to be taken, is used to render an image of the virtual model. Then, the real photos and the screenshot were scaled to the same resolution (800 x 600 pixels) and converted into RGB colour space before applying the metrics. It is not necessary to operate with high resolution due to the greater importance of shapes over the number of pixels since the metrics are considered “full reference”. Finally, the calculations were made using uncompressed images (TIFF - Tagged Image File Format).

The Signal-to-Noise Ratio is a widely diffused index used in science and

engineering to compare a signal to the level of background noise and is expressed in decibels (dB) as shown in Equation 4. The calculation formula for SNR is the following:

$$SNR_{dB} = 10 \log_{10} \left( \frac{P_{signal}}{P_{noise}} \right) \quad (4)$$

The Mean-Squared Error (MSE) measures the average squared difference between the real values and what is estimated. Given a noise-free  $M \times N$  pixel monochrome image  $I$  and its noisy approximation  $K$ , MSE is defined as shown in Equation 5:

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i, j) - K(i, j)]^2 \quad (5)$$

PSNR is another metric which is formulated as SNR, but it evidences the maximum difference between a signal and the environmental noise. It can be defined through the MSE (Equation 5) as shown in Equation 6:

$$PSNR_{dB} = 10 \log_{10} \left( \frac{MAX_I^2}{MSE} \right) \quad (6)$$

Where  $MAX_I^2$  is the absolute maximum possible pixel value in bits, PSNR is expressed in dB as for SNR. In this work, the signal is the value of the RGB channels of the real photo, and the noise is the colour difference between the real photo and the screenshot.

Structural similarity is a model for predicting the perceived quality of digital content; it is a perception-based metric that considers image degradation as a perceived change in structural information. It is based on the idea that pixels have strong inter-dependencies when they are spatially close. The index is usually used for measuring the similarity between two images, one compressed and the other uncompressed, but in this project, it is used as a metric for evaluating the quality of the 3D model. To calculate the SSIM the virtual model is compared with a section of reference photos. The SSIM can be formulated as showed in Equation (7):

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad (7)$$

Where  $x$  and  $y$  are the two sample images (real and virtual) of the same size in pixels;  $\mu$  is the average value between pixels of  $x$  and  $y$ ;  $\sigma$  is the variance of  $x$  and  $y$  as stated by subscripts;  $\sigma_{xy}$  is the covariance, and  $C_1$  and  $C_2$  are two variables used to stabilize the denominator defined as shown in Equation (8):

$$C_1 = (k_1 L)^2, C_2 = (k_2 L)^2 \quad (8)$$

Where  $K_1 = 0.01$  and  $K_2 = 0.03$ ,  $L$  is the dynamic range of the pixel as in Equation 9:

$$L = (2^{bits \text{ per pixel}} - 1) \quad (9)$$

The index is symmetrical; hence  $x$  and  $y$  can be changed in order. The three components, of which the index is made, can be calculated separately:

- Luminance  $l$ , Equation 10:

$$l(x, y) = \frac{2\mu_x\mu_y+c_1}{\mu_x^2+\mu_y^2+c_1} \quad (10)$$

- Contrast  $c$ , Equation 11:

$$c(x, y) = \frac{2\sigma_x\sigma_y+c_2}{\sigma_x^2+\sigma_y^2+c_2} \quad (11)$$

- Structure  $s$ , Equation 12:

$$s(x, y) = \frac{\sigma_{xy}+c_3}{\sigma_x\sigma_y+c_3} \quad (12)$$

Where  $C_3$  is expressed in Equation 13, and SSIM in Equation 14:

$$C_3 = C_2/2 \quad (13)$$

$$SSIM(x, y) = [l(x, y)^\alpha * c(x, y)^\beta * s(x, y)^\gamma] \quad (14)$$

The three constants  $\alpha$ ,  $\beta$  and  $\gamma$  are weights that can be reduced to 1 to obtain the form shown in equation (5).

The SSIM can be applied both in the luminance space (Grey scale) or in the RGB colour model space; in the present work all indices have been analysed in the RGB space. A SSIM value of 1 indicates a perfect match between images and a SSIM  $\geq 0.65$  indicates a good match between images [17]. The last metric used for validation purposes is PIQUE. It calculates the no-reference quality score for an image through a block-wise distortion estimation and a Gaussian noise analysis. The evaluator generates a spatial quality mask that indicates the high spatially active blocks, noticeable artefact blocks, and noise blocks in the image. It is also possible to visualize the spatial quality masks by overlaying them on the image. The evaluator is useful to assess if the output image is of good quality and if each part is discernible. The formulation of this index is complex, therefore, to avoid a more detailed discussion of the topic it is possible to refer to the author's original article for more insight [16].

For this study, the quality threshold for SSIM is given in Table 4, a low score value indicates high output quality and a high score value indicates low output quality.

Table 4. PIQUE quality score range.

Quality scale	Score range
Excellent	0-20
Good	21-35
Fair	36-50
Poor	51-80
Bad	81-100

The expected values of the three-dimensional methodology indices are reported in Table 5.



Table 5. Expected values for the three-dimensional methodology indices.

Parameter	Range	Expected value
MAPE	0 ÷ 100 %	≤ 5%
SNR	≥ 0 dB	≤ 30 dB
MSE	≥ 0	≤ 1500
PSNR	≥ 0 dB	≤ 35 dB
SSIM	0 ÷ 1.0	≥ 0.5
PIQE	0 ÷ 100	≤ 50

Other metrics can be used to define the quality of the output such as BRISQE (Blind/Referenceless Image Spatial Quality Evaluator) [19] and NIQE (Naturalness Image Quality Evaluator) [20], but they use models trained specifically for compression issues and are not directly suitable for evaluation between a virtual model and a photo.

#### 4.2. Results of the reconstruction process

To assess the developed 3D model quality, a comparison between 50 randomly selected original photos and the corresponding photogrammetry model was used to estimate the quality of the virtual reconstruction. The evaluations on a reduced database of photos and correspondent “high-resolution” virtual reconstructions, covering the main features of the site, were performed by MATLAB scripts.

The results are reported in Table 6. As examples, Figures 8 and 9 show the PIQE evaluator output with spatial quality masks (Figure 9) for one of the images taken in Room E.

Table 6. Quality evaluation of 3D models by in-depth “three-dimensional methodology”

Parameter	Range	Expected value	Room E	Room 23-24	Mean
MAPE	0 ÷ 100 %	≤ 5%	1.01%	2.05%	1.53%
SNR	≥ 0 dB	≤ 30 dB	20.84 dB	22.05 dB	21.45 dB
MSE	≥ 0	≤ 1500	535.62	412.98	474.98
PSNR	≥ 0 dB	≤ 35 dB	11.34 dB	12.01 dB	11.67 dB
SSIM	0 ÷ 1.0	≥ 0.5	0.865	0.846	0.856
PIQE	0 ÷ 100	≤ 50	34.55	38.16	36.35

The output shows the noticeable artifact blocks, and the noise blocks in the image. Instead, Figure 10 shows the local SSIM value (large values of local SSIM appear as bright pixels); regions with large local SSIM correspond to uniform regions of the reference image, where blurring has less of an impact on the image.

After quality evaluation, the model was post-processed using Open-Source software to remove any remaining unrelated objects (i.e. markers, extraneous objects, and artefacts resulting from the photogrammetry process), to directly verify visual output

quality after the shader applications (two examples are reported in the renders of Figures 11A and 11B).



Figure 8. PIQE evaluation (original image on left and reconstructed image on right).

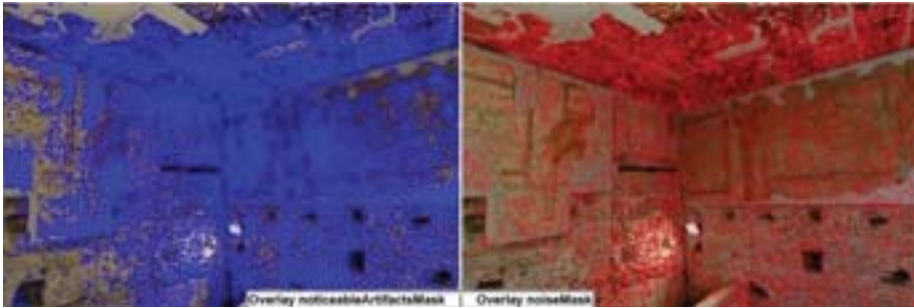


Figure 9. PIQE masks (Noticeable Artifact Mask on left and Noise Mask on right).

Finally, it was necessary to simplify the models by reducing the 3D polygonal mesh to fewer faces to avoid excessive computational loads on the hardware (Figure 12A).

The procedure is called mesh decimation (or simplification) and concludes with a visual inspection of the results to grant optimal accuracy and visual quality. During the process, the creation of new visual artefacts resulting from an oversimplification by the algorithm is avoided.

The tool used for this step was “the simplification of the planar algorithm” of the Blender software and was chosen as it shows good results [21].

The simplification process is fundamental to creating an adequate resulting model suitable not only for 3D gaming engines but also for storing data for documentation purposes inside archaeological park databases. Having an undecimated model results in a big dimension occupied on storage hardware (in the order of many gigabytes) with only negligible advantages. The use of gaming engines permits the tourist to visit the site as if it were a game, moving freely and interacting with the information content. Figure 12B shows an example of the 3D models obtained from the photogrammetric reconstruction. The model was also exported for further elaboration. The chosen formats were: *.obj* for the mesh, and *.TIFF* for the textures. The use of standard file formats to export data is a usual practice to ensure compatibility with different 3D engines, meshers, and visualization software. A render of the target rooms separated from the core model is also reported in Figure 12B to show the final output.



Figure 10. SSIM values.



Figure 11A. 3D render of the cleaned and shaded model (Room E, in front of the entrance door).



Figure 11B. 3D render of the cleaned and shaded model (Room E).

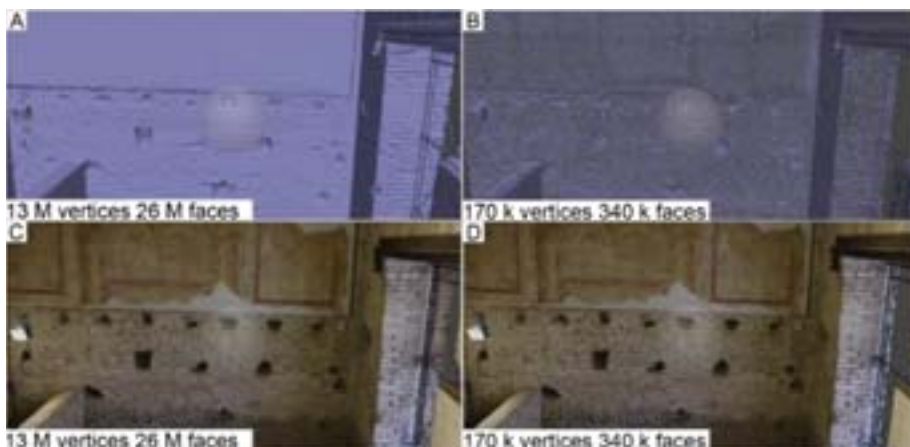


Figure 12A. Room E high-quality mesh with 13M vertices (A and C) and low-quality mesh with 170k vertices (B and D), wireframe render (A and B) and texture render (C and D).



Figure 12B. Rendered images from the 3D model for the target rooms (E on top and F on bottom).

## 5. The VADUS application

Photogrammetry was used to develop 3D models for the VADUS application aimed at resolving the problem of accessing unreachable archaeological sites. The latest innovations in telecommunication technologies and the introduction of the 5G network allow for the creation of virtual tours using remote servers enabling users equipped with a tablet or smart devices to access it through real-time data streaming. The idea beyond the application is to store the 3D models of a virtual asset remotely on a cloud database with all the inherent informative layers and GIS data in one place.

The database itself has two uses:

- Sharing the data with stakeholders for site monitoring and content updating.
- Linking the data to a rendering server containing a cloud application for virtual tours.

The rendering cloud server can share the virtual tour with users present on the archaeological site using the 5G network. Users could be tourists who buy tickets in advance to visit unreachable sites inside the archaeological park, enriching their tours with more content, which is usually difficult or impossible to access. Moreover, the application can be used by stakeholders interested in studying the site or programming maintenance routines. The GIS data coming from mobile smartphones can be used to show the nearest virtual tour in the park, if there are many of them, and is also useful to increase tourist involvement by taking them to the physical entrance of the virtual tour and contextualising the visit. Another use for the tool is for people with mobility disabilities, as they can visit areas that are usually unreachable for them.



Figure 13. Unreachable site application conceptual scheme.

Moreover, thanks to the link to the database it is possible to update the virtual tour content with the latest discoveries and information, dynamically. The use of a remote render device also permits the development of a small-weight application (in terms of space on the disk and the computational load on smartphones) that does not contain heavy 3D models and data. The application also works on a 4G network with some trade-offs such as input lag and streaming resolution and was developed by "NEXT ingegneria di sistemi"<sup>®</sup>, an Italian enterprise which aims to develop innovative solutions linked to space assets. A conceptual scheme of the tool is shown in Figure 13 where the different blocks show the data flows.

Thanks to the scaling possibilities of cloud computing the application is also simple

to expand and scale to more users and more archaeological sites with little effort. Moreover, cloud computing has another advantage, its computational power.

Thanks to the latest improvements in graphical hardware, it is possible to render a good quality 3D model which is difficult to achieve for mobile phones without limitations, such as having a reduced number of polygons, low-quality textures, a lack of depth and normal mapping, etc. Cloud computing can dynamically adjust its performance in function of the number of connected users and their disposition in different locations worldwide, this is a major issue when considering other solutions such as centralized server facilities. The cloud infrastructure was developed by TIM® (*Telecom Italia*) using the Google Cloud® platform. The application needs information layers to enrich the content shown to tourists, therefore, the creation of a storytelling characterized by reliable and scientifically correct information is of mandatory importance.

The use of different layers allows for a "conscious" visit, enjoyable for everyone, according to the cultural level and interests of the user through the possibility of accessing graphic, audio, video and textual information through just a few interactions on the device.



Figure 14. Screenshots of the unreachable site application showing map layer (A), info layer (D), 360° photo of site entrance (B), a frame from the video layer (E), a connective (C) and Room E (F).

Furthermore, the presence of different information layers permits a connection between what surrounds the user and the content they are viewing, without experiencing any sensation of "fiction" or "spectacularizing". To conclude, the storytelling must be multilanguage and the contents scalable in terms of time duration and available information, leaving the user the choice of what to see and what to skip.

Figure 14 shows some screenshots of the application's internal layout with icons, informative layer (video and images), map and textual content.

## 6. Conclusions

An innovative experience for cultural heritage virtual tours in unreachable sites can be offered by merging 5G networks, cloud infrastructure and satellite assets, as well as by developing a cloud-dedicated app supported by high-definition photogrammetry models and high-quality multimedia information layers. The importance of creating high-quality content is of mandatory importance for the wide diffusion of any digital application. This process involves the creation of informative layers, 3D models and a visualization pipeline. In the present work the building, *Casa di Diana*, inside the archaeological park of Ostia Antica was used as a case study to show a methodology able to reach the project goal of creating a quality virtual tour for unreachable sites.

The process started with the collection of information inside the site. Through proper communication with stakeholders and an in-depth analysis of the park's archives and scientific literature, it was possible to develop high-quality informative layers, created also considering the specific needs of tourists with different levels of culture and time. After site identification and definition of the perimeter for the virtual visit, a photogrammetry campaign was carried out to create an accurate 3D model of the site. To assess the quality of the site, structural and geometrical mathematical indices (MAPE, SNR, MSE, PSNR, SSIM, PIQE) were used showing good-quality results.

Then, the model was simplified and optimised so as to integrate quality information with the informative layers inside a cloud gaming engine to stream the virtual tour in real-time to remote mobile devices (such as smartphones and tablets) creating a virtual visit. With the use of a gaming engine, the user can move inside the tour, view the informative content and visit the unreachable site from outside identifying its characteristics. Once developed, the application was tested onsite showing good appreciation among the tourists and the involved stakeholders. Moreover, the use of cloud computing permits the number of connected devices to be scaled easily, while the 5G network permits smooth high-resolution streaming, making the application state-of-the-art.

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### Summary

Digital technologies are today used in many museums and archaeological sites. With the passing years, the diffusion of virtual tours, interactive projections and information totems has increased in all cultural places. Nowadays, new digital materials to be included in visits are very often developed during periods of renovation or the creation of new exhibitions. However, the addition of new material rarely includes what is unreachable and it is usually limited to the main content of the site. The present work aims to overcome this limit, making sites that are difficult to access or that are unreachable, virtually accessible. The creation of high quality and culturally accurate virtual tours can make sites that are usually closed to the public, enriching and enjoyable for visitors. To develop such tours, it is necessary to create 3D models, informative layers and to use appropriate communication devices. Photogrammetry can be used to create

3D models which can be evaluated using structural and geometrical analyses. Appropriately chosen video, textual and image material can be used to create the informative layers, considering tourists' needs and the specificity of the site. 5G networks and cloud computing can widen the possibility of implementation enabling a mobile application to bring the best quality to the tour. The case-study presented within the paper is the *Casa di Diana* inside the archaeological park of Ostia Antica.

### Riassunto

Le tecnologie digitali sono ad oggi ampiamente utilizzate in musei e siti archeologici. Con il passare degli anni è aumentata la diffusione dei tour virtuali, delle proiezioni interattive e dei totem informativi. Ad oggi, parchi e musei archeologici durante il processo di ristrutturazione o durante la creazione di nuove mostre spesso sviluppano nuovi materiali digitali da includere nelle visite. Tuttavia, l'inserimento di nuovo materiale raramente include ciò che è irraggiungibile e di solito è limitato al contenuto principale del sito. Questo lavoro ha l'obiettivo di superare questo limite, fornendo una metodologia per rendere visitabili tutti i siti di difficile accesso e irraggiungibili. La creazione di tour virtuali di alta qualità può rendere accessibili siti solitamente chiusi al pubblico arricchendo e ampliando la visita di un sito culturale. Per sviluppare tale percorso è necessario creare modelli 3D, layer informativi e utilizzare opportuni dispositivi di comunicazione. La fotogrammetria può essere utilizzata per creare modelli 3D, da valutare mediante analisi strutturali e geometriche. Il materiale video, testuale e le immagini possono essere utilizzati per creare livelli informativi, tenendo conto delle esigenze dei turisti e della specificità del sito. Infine, le reti 5G e il cloud computing possono ampliare le possibilità di implementazione consentendo di sviluppare applicazioni mobili atte a migliore qualità del tour. Il caso studio presentato in questo lavoro è la "*Casa di Diana*" all'interno del parco archeologico di Ostia Antica.

# THE COLORS OF MZAB CITIES: HERITAGE, CULTURE AND SYMBOLISM

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*Keywords:* color, Mzab, visual harmony, identity, symbolic

## 1. Introduction

The Mzab region has been a UNESCO World Heritage Site since 1982 [1]. Its quality and beauty lie in its highly distinctive architectural and chromatic character. In Algeria, with the transformation of the urban landscape due to the transition from the traditional to the contemporary world, the traditions and heritage of the past are gradually losing their importance, with the result that architectural heritage is being replaced by modern, standardized construction. In addition, industrialization has diminished representativeness at a time when housing should consider the cultural norms of society, local climatic factors and architectural heritage.

Mozabite cities have long preserved their architectural appearance, but this architectural heritage has unfortunately deteriorated in recent years. The inhabitants, however, are keen to preserve their visual and built environment and to respect the architectural and chromatic character of the region. Painting is one maintenance method that is accessible to all and offers the inhabitants of this area considerable chromatic potential, since from a practical point of view, it allows them to maintain and preserve the original appearance and color of their building cladding. Thus, by generally adopting the sandy tone of the original material the inhabitants of Mzab create a close relationship between the color of the site and that of their dwellings.

## 2. The Mzab: presentations and retrospectives

The Mzab (Ghardaïa) is located in a stony desert around 600 km south of Algiers, the capital of Algeria, in a valley of almost 40,000 km<sup>2</sup>. Its inhabitants, the Rostemide Ibadites, survivors of *Isedraten*<sup>1</sup>, settled in this virtually untouched valley in the 11th century A.D.<sup>2</sup>, and were able to implement the requirements of religious, philosophical, and social morality continuously for 10 centuries. From the year 1011 A.D. to 1347 A.D., they designed an urban ensemble with three constituent elements: a series of fortified towns (*ksour*), palm groves with their summer cities, and cemeteries. These traditional settlements were shaped by the Oued Mzab and its tributaries.

Despite their modest means, the Mozabites achieved the essence of beauty, harmony and rationality in their settlements [2]. Their architecture was designed for communal living while respecting family structures. In this way, they established the region of the Mzab, an undisputed national and international heritage.

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The series of *ksour*, called *Pentapolis* (in Arabic *Chebka*) (Figure 1), is located on the edge of the Algerian Lower Sahara, between the oases of Laghouat to the north and Ouargla to the south [4].

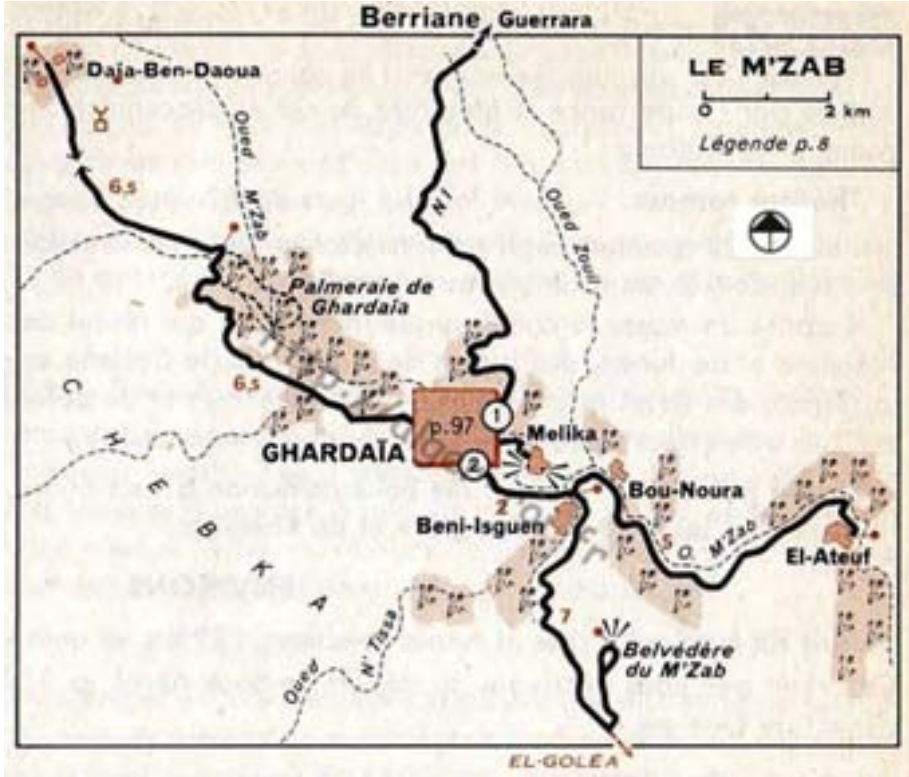


Figure 1. Position of the Mzab *ksour* [3].

It is composed of various towns: El-Atteuf (The turning point), Bou-Noura (The luminous), Beni-Isguen (The Saint), Melika (The Queen) and Ghardaïa, which are isolated by ramparts or fortified houses. The *Pentapolis* is 20 km long and 2 km wide, with altitudes ranging from 300-800 m. The Mzab *Pentapolis* also includes two other *ksour*: Berriane, located 50 km to the north and Guerrara, located 116 km to the northeast (as the Algerian Sahara is so vast, the towns are far apart from one another). These seven villages, or *ksour*, were established over time as a result of various events.

The neighborhoods are arranged in a concentric configuration around the mosque (Figure 2). Positioned at the summit of the hill, the mosque serves as a landmark [5] (Figure 3).

Mozabite towns developed from top to bottom, following the contours of the rocky outcrops, a military tactic aimed at ensuring that any assailants were exposed in the open terrain during an attack [6]. Conversely, on the nearby arable land, one can find cemeteries and palm groves.



Figure 2. Compact, radio-concentric configuration of the Ghardaïa ksar (© Alain Sèbe images).



Figure 3. At street level, the visual perspective leads to the great mosque (source: author 2023).

The palm groves (*Ghaba*) are separate from the *ksour* and are located on the outskirts of the cities. The dwellings, built on the edge of the palm grove, serve as summer residences (*Dar el Ghaba*), where the inhabitants seek refuge during the hot summer months<sup>3</sup> [7].

The climate of the Mzab region is generally harsh and very arid, with minimal rainfall. However, the system for sharing and distributing water is ingenious. It consists of *seguias*, a system for collecting and distributing water from wells and the flooding of the Oued River.

Belonging to a very conservative Muslim society, the architecture of the Mzab is distinctive and characterized by an organization of space that revolves around the sacred and the profane (mosque and cemetery, market and homes). It is also defined by an interior and an exterior that characterize both the family home and the city, with a clear preference for simplicity. As places of economic activity and exchange with foreigners, markets are situated outside the ramparts [8] (Figure 4).

On the other hand, Mozabites who work in agriculture and construction are also frequent travelers. They temporarily emigrate, especially to the Tell region, where they engage in profitable commercial activities, mainly in food and textile retailing [9].



Figure 4. Large market square in the ksar of Ghardaïa (source: author 2023).

### 3. The palette of the site

“Simple, well-thought-out architecture can bring happiness; it must logically be pleasing. Architecture that presents a unity of thought does not go out of fashion: it becomes the expression of a civilization, a real one” [10]. The landscape of the Mzab is an admirable homogeneous organization of site conditions within the framework of the physical environment.

The color of the site is one of the peculiarities of the valley. What strikes the observer upon first contact with the Mzab is the general unity of the chromatic landscape which is in harmony with the surrounding area (Figure 5). Similarly, in the urban environment, color is more attractive than form. Urban color is a strong point in the spectacle of the city as well as within buildings [11]: “Polychromy is an integral part of the architectural environment. It brings together, in different lights, the components of the urban fabric, natural built landscapes, outdoor pavements and the design of street furniture” [12]. The tonalities of the site represent those of:



Figure 5. General view (valley and surrounding area) (source: author 2016).

- The colors of the natural environment, composed of valleys (sandy, stony sites) and palm groves. The colors are those of warm, luminous materials, such as the monochrome sandy tone of the valleys.
- The colors of the built environment include those of the *ksour*, which rise above the valleys. It also includes buildings outside the *ksour*, such as palm grove houses, mosques, cemeteries, markets, dams and other structures. The overall color scheme is sandy, similar in tone to the natural context (Figure 6).
- The appearance of a house is related to the materials used to build it. If we consider the causes that produced this or that color, we may be able to contribute to the data of morphology, climate, botanical geography, and human geography [13].
- The color of sand is due to oxidation. Older and more immobile sand exhibits a more pronounced color; golden-yellow sand is found only on the wind-exposed edges of ergs, where the sand is mobile. Rubbing grains of sand together causes the oxidized part to disappear [14].
- Overall, the color of the site is a sandy tone, similar to that of the original material. The green of the palm groves against the ochre-sand background enhances and embellishes the chromatic composition (Figure 6).



Figure 6. Palm groves and houses near Beni-Isguen ksar (source: author 2023).

### 3.1. The color of site features

In the past, before the introduction of paints by the Mozabites, the color of the buildings was expressed by the material or coating used. The architectural aspect of Mozabite constructions is egalitarian and respects a strict religious morality, has no decorative elements and disregards any state of prestige.

- The material used, rubble of various sizes, was extracted from the same site. Where the exterior walls are in direct contact with neighbouring buildings, the sandy rocks are not coated with gypsum (a type of locally extracted plaster). The coating is only used to fill gaps that are too deep.
- For their buildings and facade cladding, local residents use natural materials such as rubble stone, sand and gypsum (see below). The use of natural materials respects and reproduces the tonalities of the site: the yellow ochre, the sandy tone.
- On the façade, plaster<sup>4</sup> is applied to the walls. As a natural element, plaster is obtained from the abundant gypsum deposits on the site. It hardens quickly and can be applied with bare hands, without using any tools.
- The color of the sand and plaster used in the mortar determines the color of the coating, which ranges from yellow ochre to pink (due to the iron oxide in the silica) [15]. Sometimes, when coatings are made with plaster alone<sup>5</sup>, the resulting color is gray.
- In addition to its isothermal properties, gypsum plaster has aesthetic qualities because it can be handled and shaped by hand, just like earth, without the need for a trowel, as with lime and cement. In fact, gypsum's quick-setting properties allow it to be shaped in a variety of ways. For example, this type of coating sometimes reveals hand marks on the walls. A "Tyrolean" effect can be achieved by whipping the plaster with palm leaves. It is also possible to achieve a honeycomb texture<sup>6</sup>. With these different processes, the texture can range from rough to smooth, from gritty to fine.
- These different textures bring out the delicate harmonies of plaster-based coatings. The play of light and shadow creates different aspects, such as a matte and/or textured appearance. A creamy matte finish gives the wall a warm presence which is added to the ambience of the place. Walls harmonize with different reflections and sunlight brings out warm tones.
- In some buildings (palm grove houses, mosques, cemeteries, etc.), the walls were regularly whitewashed with lime, which has purifying and protective properties.
- Sometimes one or more coats of whitewash are applied to the plaster. The latter is either left naturally white or lightly tinted yellow, ochre or blue [16].
- As for the surrounding walls, the ramparts are made of stone, so they have a natural color.

However, with industrialization and the advent of paints, the inhabitants of the Mzab, eager to adapt to the new rhythm of the world, today use various shades of mineral paints available on the market. This allows them to renovate and give a fresh look to their buildings. "Color affects environments, forming and transforming them. In towns and cities, it confers magic to everyday life and experience" [17].

Tinctorial paints are easy to apply and allow for regular color changes. As a result, residents gain the freedom to manage their living environment. The simple act of repainting a home produces immediate and remarkable results at a relatively lower cost than other types of treatment or renovation.



However, despite the considerable chromatic potential of the paints, inhabitants generally opt for the sandy color of the base material (with a few touches of white, blue or green for architectural details such as doors).

The paints used for the houses are tinted in shades of yellow and red ochre, creating a vibrant spectrum of warm colors. These tones are very similar, with slight differences in hue, saturation and clarity. Total harmony is achieved through this “*nuancement*”<sup>7</sup> [18] when the same color is used in different tones (Figure 7).



Figure 7. Front of ksar Melika made of rampart houses, in a cameo of sandy tones (source: author 2016).

In fact, the color schemes are based on ancient harmonies, rather than being dictated by precise specifications. The whitewashes and renderings are in subtle gradations that resonate with the surrounding tones. Ochre and sand tones dominate the overall color palette. Today, the perimeter walls are tinted ochre to reflect the natural color of the material used.

### **3.2. Chromatic dynamics inside the ksour**

The streets of Mozabite towns are narrow but surprisingly bright due to the intensity of the sun's rays in this region of the Sahara. “The daylight reflected by the vertical walls, or the ground, illuminates the space and gives a special quality to the colors of these alleys” [19].

Mزاب architecture is coherent and very simple, representing austerity itself without any additional decoration or artifice. “The remarkable unity and harmony of the Mزاب is no accident. Reason, rigor and the essential have been chosen. And from this chosen rigor, beauty has emerged” [20].

Unity and social equality are abundantly expressed here; there are no palaces, and all the houses are the same height, as is the mosque. “The Mozabites, for their part, have been at ease for ten centuries in this absence of art - in the Western sense of the word -... pure architecture...” [21]. This austerity is expressed throughout the buildings:

their dimensions, spaces, details and colors. Likewise, color is less expensive than molding and relief decorations and can be achieved with little money, which is why it is becoming increasingly popular with residents.

In fact, on the pedestrian streets, the refusal to decorate, for the sake of equality desired by the Mozabites, has been replaced by a nuanced chromatic dynamic. Inside the *ksour*, paint covers the plaster. Paint is the main coating for the facades, serving as a means of protection and maintenance while also offering an exceptional range of colors (Figure 8).



Figure 8. Market square inside ksar Melika (left) and a street in ksar Ghardaïa (right) showing shades of warm pastel tones (source: author 2023).

The combination of materials, such as stone and plaster coated with either paint or natural lime, is now harmonized in a palette of natural colors to create the sober decor of Mzab architecture. However, the purity of form of the architectural details, enhanced by the warm colors and materials, gives the whole an abstract character “of great plastic and pictorial strength” [22]. In general, the tones of the paints used reflect the natural color palette, with yellow-ochre blending in perfectly with the surrounding architecture. Various shades of warm, luminous ochre, red and sometimes pastel shades of pink, blue and green adorn the lower part of the houses and, at times, even the entire house. Architectural details, such as the doors (usually made of tall, wide planks of palm wood assembled with wrought-iron nails), are highlighted and emphasized by a warm-cold contrast due to their blue color against the ochre background of the houses (Figure 9).

Sometimes, to stay in tone, the wooden doors are painted in the same warm hue, creating a tone-on-tone effect with the color of the building. Brighter and more saturated, the tone of the doors, nevertheless, still forms a light-dark contrast against their background. In addition to the architectural details, the various contrasts enhance the texture and highlight the building materials. Moreover, the intensity of natural light and the high temperatures of this Saharan region directly influence the choice of colors for these homes. “Over time and distance, variations in urban color appear to be influenced by their geographic locations ... City color in diverse parts of the world shows a distinct relationship between locale and palette, a variance in spectrum shaped by light” [23].

In narrow, winding streets, colors energize the pedestrian’s path. They are expressed in yellow tones and in shades of ochre-red and ochre-yellow (Figure 10). The colors used by the inhabitants enliven the Mozabite space, where old and new buildings merge in form and color.



Figure 9. Cold-warm contrast of the blue of the door against the ochre-yellow background of the house (source: author 2023).

### 3.3. Interior color

In the Mzab, traditional houses always face south to ensure they do not block daylight from their neighbors. They benefit from oblique rays in winter and vertical rays in summer [24]. There are no large patios in Mzab houses; the lower level is completely covered, with only a zenithal opening of about one square meter (a *chebeq* in Mozabite terms) (Figure 11). This solution reduces the amount of sunlight and light entering the interior. It also creates a large plateau of terraces (useful during winter days and hot summer nights) on the upper level, where there are almost no windows.



Figure 10. Street inside a ksar; chromatic dynamics in warm-cold and light-dark contrasts and texture enhance the journey (source: author 2023).

“On the other hand, in the Mzab, the light needed for the shelter is taken from its center. The need to look out is satisfied by the oculi on all the facades, which allow air to pass through” [25]. In the past, terraces and walls were often painted with whitewash over a layer of plaster to accentuate the refraction of light.

To restore their interior spaces, today's residents use paint coatings. Despite the ample choice of shades, they tend to retain the light, luminous ochre tones, evoking the authentic hues of the house while providing the spaces with an illuminated ambience.



Figure 11. Palm house with chebek, whitewashed over a sand-colored patina that highlights the dark red of the wooden beams (left). The entrance to a chicane house, painted in luminous yellow and white tones (right) (source: author 2016).

However, there is an attempt to liven up the interior by diversifying the tones. For example, the chicane entrance<sup>8</sup> was painted yellow and white as for the rest of the house (Figure 11).

On residential terraces, the railing height is 1.50m to protect the privacy of residents and prevent overlooking onto neighbouring terraces. Ventilation slots and manholes are provided. These terraces have been patinated in the same shades as the exterior paintwork: yellow, red ochre, pink and, sometimes, blue and green.

Mozabite builders abandoned the ornamental motifs of their original society, focusing solely on what was essential to their constructions, so moldings were replaced by varied textures and dynamic colors.

### 3.4. Other spaces and building colors

Similar to the austere architecture and cladding of their homes, Mozabite mosques are stripped bare of all decoration and ornament. “What is admirable and exemplary, and not found in any other society, is that the arches of the mosques are of the same workmanship as those of houses or public galleries. They are neither more regular nor more decorated, neither higher nor wider” [26].

Today, tinctorial paints are usually used as part of the maintenance work in places of worship and even cemeteries. These spaces are embellished and renovated with new colors, as seen in the mausoleum in the Cheikh Belhadj cemetery, which is

adorned with broken pottery and objects that once belonged to the deceased. The mausoleum was repainted a bright yellow to preserve its original color (Figure 12).

The Cheikh Bassa mosque is only used occasionally, during festivals and religious celebrations. Its naturally shaped arches and columns, the result of palm bending, are covered with several layers of stratified coatings; the large plaster-coated rubble stones have been painted yellow and then whitewashed (Figure 13).

Warm, pastel colors respect the sober, refined unity of the premises, reflecting the tones of the natural materials. Mosque interiors are often whitewashed to purify the sacred space. Occasionally, they are also painted green, the symbolic color of Islam.



Figure 12. Cheikh Belhadj cemetery, where the color of the renovated mausoleum contrasts with its surroundings (source: author 2016).



Figure 13. The Sheikh Bassa mosque (on the left) and Koranic school in Ghardaïa (source: author 2016).

### 3.5. Ghardaïa and Timimoune the Red

In Algeria, several cities are designated by their colors, such as Timimoune the 'red', so called due to the color of its earthen buildings. Indeed, Timimoune<sup>9</sup> is an architectural heritage complex built of earth and located in the Western Sand Sea:

The Grand Erg Occidental of the Sahara. It is endowed with a large groundwater table, where a particular system of water distribution, known as the *foggara*, uses ingenious underground water collection techniques. It has been used since the 2nd century A.D. for optimal and rational distribution between dwellings and oases.

Just like Ghardaïa, Timimoune is organized as an oasis composed of a *ksar*, a palm grove and a water catchment system. These elements have been the most suitable response to desert constraints for several centuries. Over time, human ingenuity has been able to build quality architecture using only local resources [27]. The designation, Timimoune the red, represents the general chromatic aspect of the constructions, which are in total harmony with the surrounding natural context (Figure14).



Figure 14. The ksar of Ighzer, Timimoune, a testimony to the architectural genius of the Zenetes of Gourara (source: [30]).

Indeed, just like Ghardaïa, the color is that of the materials sourced from the site and preserved over time.

Due to its availability and advantageous thermal properties, earth is often used in construction in Timimoune. The most adopted technique is adobe, composed mainly of earth and natural fibers. The earth bricks, in adobe, are joined together using the same material and the wall is then coated with earth [28].

Adobe is a mixture of clay and sand and is a combination of the generally sandy earth, often found in situ, and clayey earth. Clay is added to the sandy earth to obtain an adequate mixture. The main materials (sand and clay) are red due to the

phenomenon of oxidation, mainly iron oxide. Storm rains, charged with carbonic acid, have overoxidized the iron salts that existed in the clays and consequently reddened them [29]. In Ghardaïa, as in Timimoune, constructions, whose materials are sourced from the site, blend and harmonize perfectly with the surrounding landscape. Rehabilitating constructions with such materials, or building new ones, maintains and transmits ancestral knowledge.

The architectural quality and harmonious chromatic aspect of the constructions show that earth, rubble, stones, water and palm trees can combine and offer an inexhaustible vector of architectural and chromatic creativity over time.

#### **4. The divine significance of colors, from denotation to connotation**

In Islamic architecture, colors carry profound metaphysical connotations, representing the beyond. They bear symbolic, far-reaching, stable meanings [31]. Similarly, the *Koran* has been an important source of inspiration for all the arts, with architecture and the world of color being just one facet [32].

The *Koran* mentions colors on several occasions, and *Koranic* verses on the meaning of colors make them an important factor in the field of symbolism.

##### **4.1. The blue of ksar houses, from profane to sacred**

In the *ksar*, the ochre sand color is punctuated by a few houses painted in luminous shades of blue and green as can be seen in Figures 2, 6, and 15.



Figure 15. The overall appearance of the Ghardaïa ksar is punctuated by houses in blue and green.

These rather cool colors enhance the overall effect, creating a warm-cool contrast with the yellow-ochre background. This contrast produces a magical and mysterious effect, representing simultaneous contrast. The law of simultaneous color contrast was extensively exploited by Impressionist painters at the end of the 19th century, including Renoir, Monet, Van Gogh and Seurat. This law is an optical phenomenon related to our perception of color. When the eye perceives a color, it simultaneously demands its complementary color, and if it doesn't receive it, it creates it itself [33].

Blue, green and white are primarily expressed inside the terraces and courtyards of the houses to maintain the general chromatic appearance of the *ksar* (Figures 2, 6 and 15). The selection of colors for homes is characterized by green, blue and yellow-ochre, aiming for the right balance between warmth and coolness. However, the reason is more than just aesthetic: the aim is ostentatious and deeply symbolic. These blue- or green-painted houses are meant to convey the message that their owners have fulfilled the fifth pillar of Islam: the pilgrimage to Mecca. But what is the meaning of blue?

For the inhabitants, the choice of blue for the buildings is symbolic, representing the color of the sky and its reflection in heavenly waters - the source of life and the spiritual mirror of the heart [34]. The blue hues of the constructions create a transition between the building and the sky, as if the construction is unified and extends toward the celestial vault. The explanation originates from a "mythological vision of the color of the vault of heaven and the refraction of the color of Mount *Qâ'*" [35]. This mountain surrounds the earth like a ring of azure-blue, which is reflected in the sky and thus represents the celestial vault.

#### **4.2. Green: analogies and metaphors**

Similarly, green represents the houses of people who have made the pilgrimage to Mecca (Figure 15). It symbolizes the immaterial and metaphysical world. Green is highly favored by desert dwellers seeking greenery. It evokes nature, water, earth and sky [36], and the lush vegetation and oases that are so cherished in arid countries.

The combination of blue-green sky and green plants makes green a soothing and satisfying color for the eyes [37], providing psychic restfulness, especially in its nuances.

According to the inhabitants, inspired by the *Koran*, the green color of the houses signifies the color of Paradise and its lush vegetation. Green is associated with vegetation and specifically with the garden of bliss promised to Muslims [38], representing the gardens of Eden - a place adorned with fruit trees, silk robes, luxurious carpets and brocade sofas. While transient on earth, it is eternal in the afterlife, as described in verses like: "These [companions] will be wearing garments of fine green silk and brocade, and they will be adorned with bracelets of silver..." and "They will be reclining on green cushions and beautiful carpets of rich fabric" [39].

Green is the color of Islam and its flag.

Yellow-ochre, on the other hand, symbolizes light, the sun, gold, sparkle, luxury and distinction. The chromatic ensemble of the *ksar* provides a harmonious blend: yellow and blue come together to form a balanced mixture of green.

#### **4.3. White: purity and light**

The white of Mozabite homes is also expressed through whitewash, a practice observed in some mosques as well (Figure 16). For the inhabitants, white embodies purity, tranquility and serenity.



The white walls of the mosques suggest and symbolize "absolute" light. Light, which is symbolically perceived as white, descends from the sun and represents divine unity [40]: "God is the light of heaven and earth"<sup>10</sup> [41].

In the Islamic culture of the Mzab, white is an ostentatious color. Religious figures and those who have completed the pilgrimage to Mecca dress in entirely white *burnous*.

The sobriety of white represents a mantle of faith and the purity of the body, both in life and in death, as it serves as a shroud for the deceased and symbolizes the purity of the elect on the day of resurrection.

The Prophet emphasized the importance of white attire, stating, "Dress in white, for it is purer and more beautifying, and dress your dead in it" [42]. This attire reflects the color of *ihram*<sup>11</sup>, the garment pilgrims wear when entering the *haram* of Mecca.

In the *Koran*, white is associated with the light that shines on the faces of the believers and the chosen on the Day of Judgment, signifying their purity. It also symbolizes the joyful countenances of the inhabitants of Paradise. "As for those whose faces will be radiant (white in the text), they will be in the bosom of divine mercy for eternity"<sup>12</sup> [43]. Thus, whiteness is linked to the luminosity of Paradise.



Figure 16. White and luminosity inside the mosques, Ghardaïa on the left and Beni-Izquen on the right (source: author 2023).

According to Abdelwahab Bouhdiba [44], white is not strictly considered a color, but rather the synthesis of all colors.

The term "*bayadh*" encompasses everything that can be described as white: milk, day, light, clarity, the moon, the eye, the heart, the sword, water, and more. Another significant aspect of white comes from its association with hair whitened by age, symbolizing wisdom and knowledge. White beards, white turbans, and, incidentally, white clothing, serve as the distinguishing marks of *sheikhs*, professors, theologians, judges (*kādīs*), jurists (*muffīs*), *imāms* and *Koran* readers.

## 5. Conclusion

A popular tradition, color remains an inseparable emblem of architectural and cultural heritage. It distinguishes the Mozabite landscape from other urban landscapes and serves as a hallmark of the specific cultural identity of this region and its people. Amid globalization, Mozabites preserve their original building colors. Through this process,

they revive and restore the values of old neighborhoods and perpetuate their flavors, knowledge and cultures.

In this era of universal and global architecture, residents relate to color as a bearer of meaning and identity. Its goal is to provide visual satisfaction by integrating architecture into the environment, as well as having the objective of conveying spiritual messages that represent a synthesis of the universe emanating from God.

It is therefore important to support this attribute for its role as an element of architectural, social and cultural heritage, with the aim of determining, in different regions, the color palettes to be assigned to new constructions and the rehabilitation of old buildings. This allows for the respect and enhancement of urban landscape quality on a large scale, without limiting interventions to mere sporadic color treatments.

## Notes

<sup>1</sup> Sedrata (in Berber *Isedraten*) is an ancient Berber Ibadite city located southeast of present-day Ouargla, in the Algerian Sahara.

<sup>2</sup> Corresponding to the 4th century A.H.

<sup>3</sup> Most of the inhabitants have a house in the palm grove, where they take refuge in the summer because of the coolness of the vegetation.

<sup>4</sup> *Timchent* of the *chebka*, in Mozabite terms.

<sup>5</sup> Plaster is characterized by its greyish color.

<sup>6</sup> To obtain this effect the mason holds a broom in his right hand and a stick in his left; he then strikes the broom handle against the stick to project the plaster onto the wall.

<sup>7</sup> Meaning: composition between several adjacent tones or around a central tone whose brightness and saturation are fairly close.

<sup>8</sup> This entrance to the house does not offer a direct view of the interior, with the aim of preserving the privacy of the dwelling and gradually discovering the interior space [45].

<sup>9</sup> Timimoune is a Saharan oasis, the capital of Gourara and, a city - a relay between Touat and Mzab, there are more than 62 archaeological monuments, ten mausoleums, and eight places of worship, buildings made of Toub, including old ksours, mosques, mausoleums and forts, scattered throughout the Gourara territories [46].

<sup>10</sup> *Koran En-Nour*, The Light (No. 24), verse 35.

<sup>11</sup> Pilgrims are dressed in a white *izār* veil.

<sup>12</sup> *Koran, Al Imrān*, The Family of Imran (No. 3), verse 107.

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### Summary

In Algeria, the habitat of the Mزاب, a UNESCO World Heritage Site, is considered a remarkable model for the use of color in its architecture. Its chromatic physiognomy is a unique example of visual harmony, quality and simplicity, where color contributes to the identity and image of the place. In the past, Ibadite buildings were either white-washed or their color was expressed through the original material: sand. This allowed them to blend in perfectly with their surroundings.

However, technological progress and the development of industrialization have provided residents with an unlimited number of colors and the market today offers a wide

variety of paint colors. As a result, they have greater freedom of chromatic choice when renovating their homes.

So, in the face of globalization, how have building colors evolved in the Mزاب? How do residents use this variety of colors to maintain the facades of their homes? Do they always preserve the original hue of the building material?

The on-site research is based on interviews with local residents, observations over time, and photographic images of the buildings. It shows that today's increasingly diverse building colors are appropriate to the climate and the cultural, symbolic, and economic circumstances of the inhabitants. They carefully preserve the identity of the place and express the austerity of the buildings, as well as traditional Mozabite values.

## **Riassunto**

In Algeria, l'habitat del Mزاب, patrimonio mondiale dell'UNESCO, è considerato un modello di riferimento per l'uso del colore nell'architettura. La sua fisionomia cromatica è un esempio unico di armonia visiva, qualità e semplicità, dove il colore contribuisce all'identità e all'immagine del luogo. In passato, gli edifici ibaditi venivano imbiancati oppure il loro colore veniva espresso attraverso il materiale originale: la sabbia. Ciò ha permesso loro di fondersi perfettamente con l'ambiente circostante.

Tuttavia, il progresso tecnologico e lo sviluppo dell'industrializzazione hanno fornito ai residenti un numero illimitato di colori e oggi il mercato offre un'ampia varietà di vernici. Di conseguenza la popolazione ha una maggiore libertà di scelta cromatica quando ristruttura la propria casa.

Quindi, di fronte alla globalizzazione, come si sono evoluti i colori urbani del Mزاب? In che modo i residenti utilizzano i colori per mantenere le facciate delle loro case? Viene considerata sempre la tonalità originale del materiale da costruzione?

La ricerca presentata si basa su di una serie di interviste ai residenti, osservazioni nel tempo e immagini fotografiche degli edifici. Ciò dimostra che i colori degli edifici di oggi, sempre più diversi, sono adatti al clima e alle circostanze culturali, simboliche ed economiche degli abitanti. Preservano attentamente l'identità del luogo ed esprimono l'austerità degli edifici, così come i valori tradizionali mozabiti.



# FEM STRUCTURAL ANALYSIS FROM UAV PHOTOGRAMMETRY PROJECTS. CASE STUDY: TWENTY EYES AQUEDUCT IN THE WADI OF CARCAUZ (ALMERIA, SPAIN)

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*Keywords:* UAV photogrammetry, HBIM, FEM, structural simulation, cultural heritage

## 1. Introduction

The traditional approach to structural modelling and simulation of historical constructions presents numerous difficulties, such as the acquisition of geometric data in the field, the accuracy of the resulting 3D models or the oversimplification of the structural models due to the geometric complexity of the work under study. However, the task of reconstructing, protecting and conserving our heritage has been significantly facilitated by recent advancements in photogrammetry, which relies on images captured by Unmanned Aerial Vehicles (UAVs). These advancements also encompass the development of integrated Building Information Modelling (BIM) models and the enhancement of computational performance in modern computers for simulating the structural behaviour of complex constructions [1-2]. With the growing popularity of UAVs, commonly known as drones, fields such as engineering and architecture have leveraged the opportunity to achieve a high degree of accuracy in the information collected through photogrammetric flights with UAVs and to address the limitations of traditional technology for reconstructing buildings or civil works that constitute our historical heritage [3]. Similarly, the significant progress made in computers and software facilitating three-dimensional (3D) modelling has provided an ideal platform for the virtual reconstruction, conservation and public exhibition of our cultural heritage [4-9].

Since the beginning of the 21st century, significant advancements have taken place in Terrestrial Laser Scanners (TLS) [10] and UAV photogrammetry [11], greatly facilitating the generation of 3D models. Thanks to the combination of modern computers and photogrammetry [12], it is now possible to use photos taken at various heights and angles to create 3D models based on point clouds derived from these images.

This process can be accomplished using a variety of computer programs, even when photos are captured using traditional cameras. This transformation is enabled by a cost-effective method called Structure from Motion (SfM), developed in computer

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vision, which can convert a series of images taken from different angles into a 3D representation [13]. The SfM algorithm generates a point cloud representing the object under study, along with the position and orientation of the camera photographs. SfM incorporates stereoscopic techniques from various views (Multiview Stereo Matching) [14], which produce a 3D structure through the overlap between photographs taken from multiple locations and angles, related by means of a Scale Invariant Shape Transformation and bundle adjustment. Following this algorithm's processing, a point cloud is obtained without scale and in relative coordinates, typically requiring georeferencing with an official reference system, either through direct methods using geolocation data from photographs or indirect methods using Ground Control Points (GCP) [15]. According to various studies, the results obtained through the SfM algorithm provide 3D information with similar accuracies to those obtained through TLS [16-17]. The morphology and accessibility of the feature or study area define the most suitable technique: TLS or UAV photogrammetry [18]. Indeed, one of the primary challenges of TLS is inaccessible areas. In such cases, UAVs efficiently and economically facilitate data collection [19-20]. In addition, a straightforward approach to enhancing results obtained with SfM photogrammetry is by using oblique photographs, enabling the visualisation of details that may remain hidden in plain view images, without the need for ground photographs [21-22]. However, there may also be accessibility challenges for UAVs in small geometries, such as long, narrow corridors.

The development of the BIM model commences with the availability of the dense point cloud or 3D mesh of the complex under study, along with CAD files, other design materials or using in-situ measurements.

BIM allows for the collaborative creation and management of a building or civil engineering project throughout its life cycle. Its aim is to reduce time and resources in asset design, development and management, while minimising errors by centralising all project information into a digital model produced by all stakeholders [23]. BIM represents an evolution from traditional plan-based design systems, as it incorporates geometric (3D), time (4D), cost (5D), environmental (6D) and maintenance (7D) information [24]. Another crucial aspect of BIM is its interoperability, facilitating information sharing among all project entities (Construction Operations Building Information Exchange). Although BIM methodology has been primarily used in the construction sector since the turn of the century [25], it has recently gained momentum in historical heritage management and documentation [26-27]. When applying BIM methodology to digitise existing information about artistic or historical works of heritage value, it is referred to as Historic Building Information Modelling (HBIM). This term was initially coined by Professor Maurice Murphy of the Dublin Institute of Technology [28]. The primary goal of HBIM is to obtain BIM models of existing buildings, modelled from parametric objects containing various types of information that can be easily updated, replaced or aggregated. The implementation of HBIM undoubtedly facilitates the dissemination of built heritage. However, since each building is unique and may have anomalies in morphology and constituent materials, the application of this methodology to historical reconstruction depends on the specifics of each building. For the creation of these models, historical information on the building, in addition to data provided by TLS or photogrammetry for model digitisation, is of great assistance. This process, known as 'Cloud-to-BIM' or 'Scan-to-BIM', allows for the realistic reconstruction and visualisation of the modelled building [29-32]. The quality of the model will be related to the level of detail aimed for during the modelling phase. In the case of heritage elements in a dilapidated state, this level will also depend on the existing information on geometry and other original features. The ability to employ Finite Element Models (FEM) to replicate the structural behaviour of buildings is one of the primary challenges currently confronting the



3D digital modelling of our heritage. ‘BIM-to-FEM’ refers to the process of converting a BIM or HBIM into a structural FEM [33-34]. Indeed, with the increasing development of interoperability between BIM models, the same model can serve multiple purposes, with structural analysis being one of them. Specific BIM plugins exist for generating FEMs, such as CSiXRevit. Although exchanging information between a 3D architectural model and its corresponding FEM may appear straightforward, when dealing with complex geometries, the current software interoperability does not always allow for discretisations compatible with elements readable by the main calculation programs (Staad.Pro, SAP2000, SOFiSTiK, Robot, etc.). Therefore, it is crucial that from the outset of the modelling phase the analyst considers not only the accurate reproduction of the assembly but also the fulfilment of the requirements necessary for generating a correct FEM, distinguishing between small irregularities and complexities that may influence structural behaviour and those that are inconsequential [35].

The aim of this project is to develop an HBIM of the Twenty Eyes Aqueduct (Acueducto de los Veinte Ojos) in the wadi of Carcauz, situated between the municipalities of Felix and V́icar (Almería), using a point cloud acquired through UAV photogrammetry. This endeavour will enable a thorough analysis of the aqueduct’s structural behaviour and serve as a starting point for future research into recovery and conservation strategies. This process is summarised in the innovative two-step methodology termed Cloud-to-BIM-to-FEM.

## 2. Materials and methods

The methodology employed in this study is founded on the examination of historical data and the precise location of the Carcauz Aqueduct. Additionally, a survey of the current condition of the aqueduct was devised, accomplished through UAV photogrammetry. Using this data, an HBIM of the heritage structure was generated, employing specific software for processing photogrammetric data (Agisoft Metashape) and for designing the HBIM (Autodesk Revit 2022). The accuracy of the BIM model was verified using geometric validation software (CloudCompare). Finally, the 3D geometry of the BIM model was converted into shell elements (2D finite elements) compatible with the software used for structural analysis (SAP2000), wherein the structural behaviour of the aqueduct is assessed. The workflow employed for the creation of this document is outlined in Figure 1.

### 2.1. Study site

The Carcauz Aqueduct is a hydraulic structure stretching approximately 3.2 km along the slopes of the Carcauz-Casablanca wadi. Situated on the southern slopes of the Sierra de Gádor in southeastern Spain, it lies within the province of Almería, bordering the municipalities of V́icar and Felix [36].

This study focuses on the Twenty Eyes Aqueduct, a component of the hydraulic complex mentioned above, as depicted in Figure 2. The coordinates in UTM projection, Huso 30 N and ETRS89 datum for the location of the aqueduct are as follows:

- Southwest (526.450, 4.075.645)
- Northeast (526.470, 4.075.688)

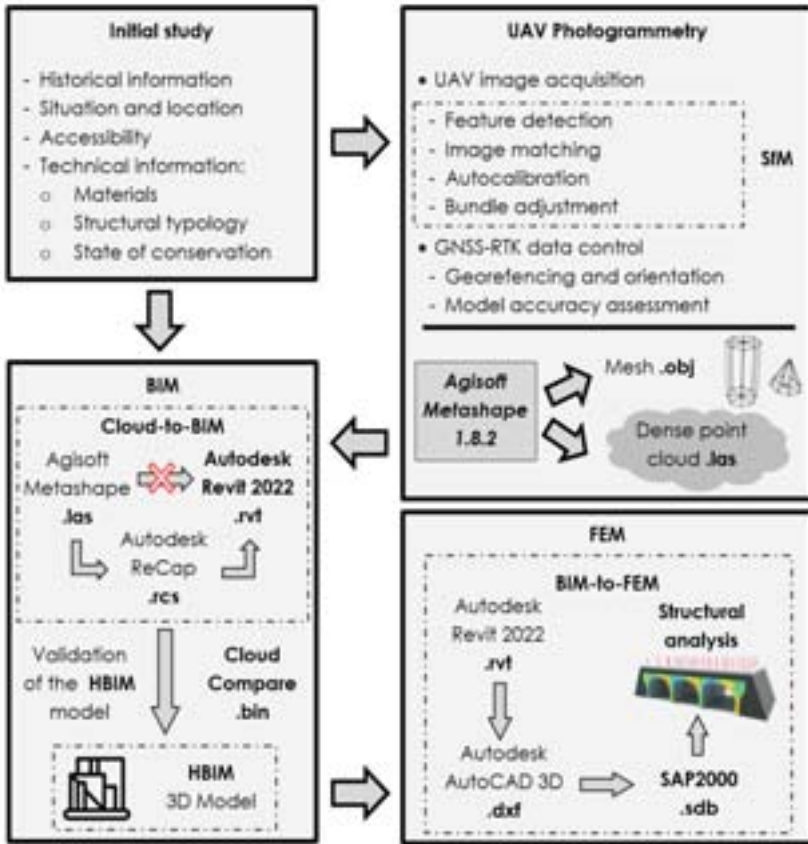


Figure 1. Workflow implemented in this study.

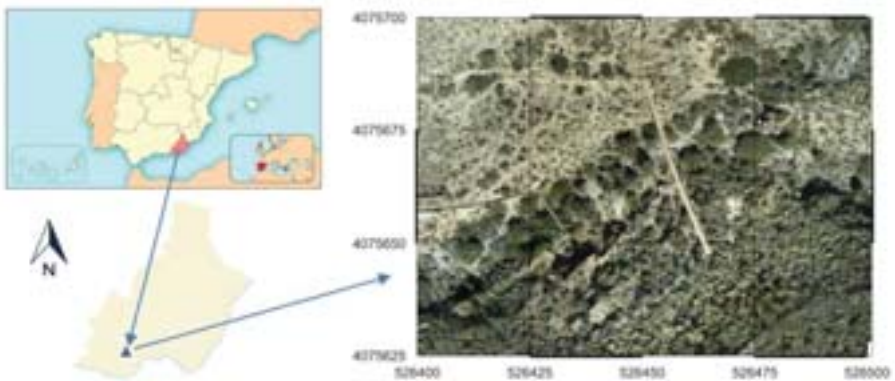


Figure 2. Location of the aqueduct under study.

## 2.2. Historical information

Although the aqueducts documented by Gil Albarracín have been assigned a Roman origin, this dating is controversial, or at least doubtful, as it is based solely on the chronology of the surrounding sites. The construction characteristics, such as concreted masonry, the presence of mechinales (drainage elements) and stucco cladding, are more typical of the Islamic Middle Ages. However, it is plausible that the aqueduct existed during Roman times and underwent repairs or expansion at later periods [37]. The irrigation infrastructure has been extensively described and studied from historical and construction perspectives [36-39]. Alternatively, some historians propose an 18th-century construction date for the aqueduct [38]. The aqueduct can be regarded as one of the most valuable elements of popular civil engineering in the region, despite its need for improved conservation. Figure 3 shows the current state of the aqueduct.



Figure 3. Current conservation state of the aqueduct.

Recently, on 23 June 2022, the Regional Ministry of Culture and Historical Heritage initiated the procedure for inscribing the aqueduct in the Catálogo General del Patrimonio Histórico Andaluz (CGPHA) as a heritage asset of cultural interest (Bien de Interés Cultural, BIC), with the typology of Monument, granting it the highest degree of protection.

## 2.3. Structural description

Above the bed of a tributary of the Carcauz wadi, one can catch a glimpse of the aqueduct arcade popularly known as the Aqueduct of the Twenty Eyes which stretches over a length of 42 m and reaches a maximum height of 9.50 m above the tributary bed. This monument is strategically positioned in a narrowing of the ravine, effectively maintaining the water level at approximately 370.8 m above sea level. The aqueduct derives its name from the 20 arches comprising its elevation. The following components of the aqueduct can be distinguished:

The base and foundations: these consist of the rocky outcrops of limestone of the ravine.

The elevation or arcade: this features three levels and twenty vaults formed by semicircular arches.

The arch on the first level, positioned at the midpoint of the structure, facilitates the passage of water of the stream through the vertical wall of the aqueduct. It stands at approximately 1.70 m from the ground to the keystone, with a span of 2.30 m. A wall is built on top of it, which is 1.12 m high above the lowest arch. Above the aforementioned first level, which rests on the limestone walls of the riverbed, a second level is defined by seven rectangular-section piers, ranging in dimension from 1.75 to 1.96 m in length and 0.80 to 1.0 m in width. These piers support eight arches of similar height. Notably, the central arch was modified by adding another arch at mid-height, approximately 1.0 m above the wall, to reinforce the structure. The third level consists of nine rectangular-section piers, measuring about 60 cm in length and 0.80 to 1.0 m in width, supporting 10 arches and their accompanying walls until they merge with the limestone walls of the ravine. These arches vary in height from 1.05 to 1.35 m and in span from 2.17 to 2.58 m, with the northernmost arch being the smallest. It seems likely that these arches were reconstructed at some point in the past, either due to damage from the passage of time or erosion caused by seismic tremors. At the crown of the aqueduct lies the water channel, with a base width ranging from 30 to 40 cm and a height of approximately 34 cm, contrasting with the 60 cm width of the irrigation channel before it enters the arcade. Notably, sediment has settled on the channel's bottom, suggesting potential modifications to the channel at a later date. The channel walls are constructed of masonry with lime mortar and are approximately 25 cm thick at the edges [40].

## **2.4. Photogrammetric survey of the aqueduct's current state**

### *2.4.1. Topographic survey for subsequent geo-referencing of photogrammetric outputs*

A traditional topographic survey was conducted using a Global Navigation Satellite System (GNSS) to accurately geo-reference the photogrammetric project and evaluate the obtained results. The survey resulted in a total of 14 targets distributed across the study area, as depicted in Figure 4c. These targets, shown in Figure 4a, were A3 format (420 mm x 297 mm) and divided into four quadrants, with two quadrants coloured orange and two black. The 3D coordinates of these targets were measured using a GNSS receiver operating in Real Time Kinematic (RTK) mode and receiving differential corrections from a base station located at the north end of the aqueduct, as illustrated in Figure 4b. Prior to this, the base station was statically positioned, and its coordinates were determined using differential corrections from the Calar Alto Station of the RAP Network (Andalusian Positioning Network) for a duration of 10 minutes. This network offers high-precision positioning across the entire Andalusian territory through free services of differential corrections and Receiver Independent Exchange Format (RINEX) files. In RTK mode, both the GNSS base and receiver receive readings from different satellite constellations, maintaining a constant data link between them in real-time, differing from the kinematic post-processing (PPK) mode.

The GNSS receiver and base station used were Emlid Reach RS2 systems. For RTK mode measurements, this multi-band geodetic receiver provides a manufacturer-stated accuracy of  $\pm 7$  mm +1 ppm for horizontal RMS and  $\pm 14$  mm +1 ppm for vertical RMS. Considering the distance between the base station and the study area was approximately 50 m, the horizontal and vertical errors are estimated to be around 7 mm and 14 mm, respectively.

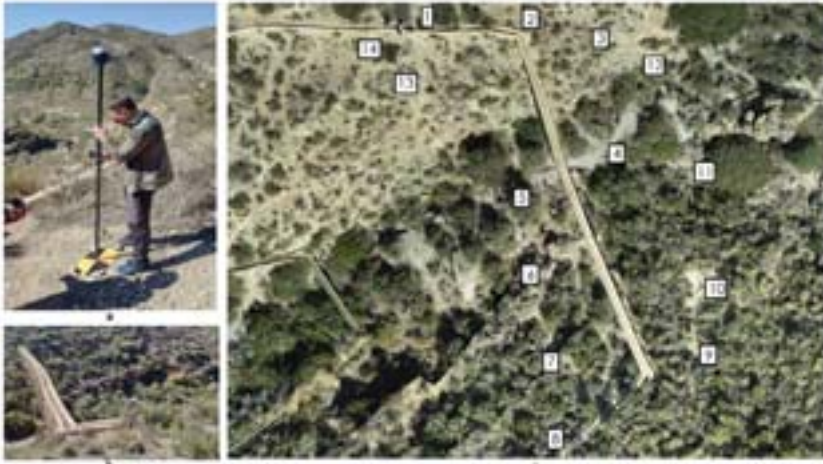


Figure 4. (a) Targets used in this study. (b) GNSS base. (c) Distribution of targets across the study area.

#### 2.4.2. Image acquisition

The images used in this project were captured using a four-rotor DJI Phantom 4 RTK UAV drone. This UAV is equipped with both GLONASS and GPS navigation systems. Additionally, it features front, rear and bottom vision systems that enable obstacle avoidance within a range of 0.2 to 7 m, as well as surface detection under defined patterns and adequate illumination. The Phantom 4 RGB camera has a 20-megapixel (5472 x 3648) 1-inch sensor, which can be manually adjusted from F2.8 to F11. The lens offers an 84° field of view and a fixed focal length of 8.8 mm.

The photogrammetric flight was autonomously planned and executed using the DJI GS RTK app. This application enables the implementation of double-grid 3D photogrammetric flights, ensuring that images of the subject are captured from various angles and inclinations. Figure 5 illustrates the trajectory followed by the drone during the photogrammetric flight. The flight, which included a total of 315 photos, was scheduled to take place at a height of 40 m from the take-off point, positioned on the north side of the aqueduct. This configuration yielded an equivalent Ground Sample Distance (GSD) of 1.22 cm/pixel. In order to enhance the precision of the photogrammetric project, the aircraft was configured to capture oblique images at a 45-degree angle as well as zenith images. Adjustments to the shutter speed were made to minimise the blurring effect on the photos, taking into account factors such as flight altitude, UAV speed and lighting conditions during the flight. The camera was activated every two seconds, and the flight speed was regulated to achieve a longitudinal and transverse overlap of 70%.

Once the flight concluded and the photographs were downloaded, the geolocation data of the cameras was corrected to enhance accuracy. For this purpose, the UAV's RTK system allows for the preservation of satellite observation information for PPK. In this instance, RINEX data at 1-second intervals, provided by the Calar Alto Station of the Andalusian RAP Network, served as the basis for corrections. Atygeo V1.8 software was used for this procedure, as it enables the correction of photo metadata from base observation and navigation files, as well as from the drone navigation file (.obs).



Figure 5. Flight path performed by the drone.

### 2.4.3. Photogrammetric process

Once the geolocation data from the cameras had been corrected, the photogrammetric process was carried out using Agisoft Metashape Professional© version 1.8.2 software. This software conducts the photogrammetric process in multiple steps using the SfM algorithm. Initially, the software identifies and matches homologous points across all photos to align them. During this process, the focal length value of the camera (extracted from the EXIF data of the photos) serves as the starting point for estimating internal and external camera parameters, including non-linear radial distortions. This step was conducted with high accuracy settings for this study. When the program concludes, it produces a sparse point cloud that includes the geometry of the aqueduct environment, each camera's specific position, orientation and an estimated set of calibration parameters. Using the geolocation data of the photographs taken by the drone, the resulting point cloud is directly georeferenced. However, this georeferencing is of low accuracy, and the use of GCP is required to improve it. At least three control points are necessary to enhance this accuracy [41-42], increasing it by using a higher number of control points. Seven (even numbers) and seven (odd numbers) of the 14 targets that were set during fieldwork will be used as GCPs and quality check points (CPs) for the completed work, georeferencing the point cloud in the ETRS89 datum and UTM Huso 30N projection. The software reoptimizes the camera calibration model and adjusts the resulting sparse point cloud after receiving the GCP to be used. Subsequently,

any anomalous points that may have emerged in the model are manually removed to create a dense point cloud comprising 11,779,429 points, thereby densifying the sparse point cloud. A highly detailed, dense point cloud constitutes the final product.

From this dense point cloud, various products can be derived, including: the triangulated mesh of the surface, onto which the texture obtained from the photographs can be applied; the Digital Surface Model and elevation model; an orthophoto of the environment; or the XYZ coordinates in .txt format of each point comprising the dense cloud created. It should be noted that a classification of the dense point cloud was carried out, combining the internal classification algorithm implemented in the Agisoft Metashape software with manual classification of certain points, such as those belonging to the aqueduct. Three classification groups were established: terrain, vegetation and aqueduct. Subsequently, the points classified as aqueduct were exported in .las format, serving as a foundation for the generation of the HBIM.

### **2.5. 3D modelling using HBIM methodology**

The BIM of the aqueduct was conducted in Autodesk Revit 2022, one of the most widely used BIM software in the world [25]. Agisoft Metashape and Autodesk Revit 2022 can be interconnected through the use of Autodesk ReCap, an additional program necessary for the Cloud-to-BIM process.

Prior to converting the project file to .rcs format, which is a point cloud format readable by Autodesk Revit, the dense point cloud obtained through UAV photogrammetry must be imported into Autodesk ReCap in .las format, containing the point cloud classified as an aqueduct. The point cloud imported into Autodesk Revit is depicted in Figure 6.



*Figure 6. Point cloud imported into Autodesk Revit.*

The incorporated information comprises a cloud with thousands of points and their associated RGB colour, showcasing the details of the actual aqueduct, from irregularities in the morphology of the vaults of the arches to variations in the thickness of the walls or their collapse along the aqueduct's directrix.

This allows us to use the visualised point cloud as a guide and reference to establish the parametric model. To complete the modelling, it was not necessary to generate libraries of parametric objects specific to the aqueduct.

Although Revit lacks automated recognition of 3D geometry from the point cloud, it

does offer tools to generate 3D objects with commonly used geometries in today's construction industry [43]. While these tools may not be typically suitable for modelling historical heritage [44] due to their specific geometries (such as ribbed vaults, cornices and lintel ornaments), they are appropriate for the HBIM intended to be generated in this work. In recent years, significant efforts have been made to generate 3D geometries through automatic point recognition. Before proceeding with the aqueduct modelling, it is essential to define the level of detail to be achieved, which closely aligns with the research objectives and required precision level.

From a graphical standpoint, three degrees of model definition can be distinguished: Grade 1 (Coarse), Grade 2 (Medium) and Grade 3 (Fine) [45].

The aim of this paper is to create a FEM for the aqueduct's structural analysis, so reaching a 3D representation level between Grades 1 and 2 will suffice. According to the terminology established by the American Institute of Architecture, we can set the Level of Development (LOD) of our BIM model between levels LOD200 and LOD300. This choice is based on simulating the aqueduct using a structural wall with a constant thickness of 0.90 m, leaning towards safety for the ensuing structural analysis.

Once the structural wall has been created, referencing the plan layout of the aqueduct, we proceed to open the aqueduct's eyes using the empty and cutting shapes tool to subtract the 'eyes of the aqueduct' from the main modelled volume. This ensures seamless interoperability between the parametric objects of the BIM model and their transformation into finite element shells for use in the structural calculation software.

## **2.6. Validation of the fit between point cloud and HBIM**

To validate each parametric object created for the HBIM, it is essential to measure the distances between the point cloud of the photogrammetric model and the mesh of the parametric object. For this validation process, the Autodesk Revit model was exported in .obj format, and together with the .txt file containing the point cloud of the aqueduct obtained from Agisoft Metashape, imported into the CloudCompare software [46]. Using the "Cloud to Mesh Distance" command in CloudCompare, the distance between both elements can be calculated. Since there is no common criterion among existing scientific literature for HBIM validation [47], the following criteria, as per Martínez-Carricondo et al. [48], were established in this research:

- The mean distance between points should be close to 0 m (between -0.10 m and 0.10 m).
- The standard deviation of the distance between points should be less than 0.10 m.

## **2.7. From building information modelling (BIM) to Finite Element Modelling (FEM)**

FEM is a numerical approximation method derived from the Matrix Method, transitioning from a 'discrete' to a 'continuous' mode. The accuracy of the FEM hinges on the size and shape of the elements into which the part is discretised. Moreover, the inclusion of 2D and 3D elements provides significantly higher accuracy in result derivation compared to a model solely comprised of 1D bars.

FEM is mathematically more complex than other linear methods, such as the matrix



method. However, it offers greater precision and, notably, enhanced capacity to model structures beyond the scope of bar elements. While its mathematical manipulation may be cumbersome, we are fortunate to have numerous software applications capable of swiftly generating and solving the numerical equations inherent in this method. This allows designers to discern the true behaviour of their structures, reducing their workload to inputting initial data and analysing results. For this project, the SAP2000 software developed by Computers & Structures, INC. was used.

The objective of this research was to develop a FEM to enable the study of the structural behaviour of the Twenty Eyes Aqueduct.

To achieve this, it was imperative to convert the HBIM into a 3D model with geometric elements compatible with SAP2000. This software was selected because it allows the import of solid 3D elements or 2D shells geometry, followed by discretisation or meshing. Given the linear nature of the structure in this project, it was decided to model it using 2D shell-type elements. The primary advantages of this approach include minimising structural calculation times and simplifying stress analysis.

Starting from a 3D HBIM to generate the finite element calculation model saves considerable time in the development phase of the FEM. Additionally, it leverages the advantage of having greater detail compared to the typical simplified models often adopted for such purposes [35]. The process to generate the FEM involved several steps. First, the BIM model of the aqueduct was exported to .dwg format for further processing in AutoCAD 3D. The resulting product consisted of polyface meshes defining the entire geometry. The polyface meshes were then subdivided into smaller secondary meshes, both horizontally and vertically, each bounded by four edges. To achieve the desired final discretisation size for accurate structural analysis, the aqueduct was manually divided into 10 sections.

Finally, these secondary meshes were decomposed into 'Cara 3D' elements, facilitating their import into the SAP2000 software as 'shell' elements. Once the 3D face elements were imported into SAP2000, the FEM depicted in Figure 7 was obtained, consisting of 4,170 area or shell elements. To control the model's complexity and ensure efficient computational performance, the average mesh size was set to less than 0.50 m, guaranteeing high-quality results.



Figure 7. Model imported into SAP2000.

Once the geometry of the model is available in SAP2000, it is essential to input all the required initial information for the software to perform the calculations.

This includes defining the mechanical properties of the stone-mortar assembly constituting the aqueduct, specifying the external loads acting on the structure and establishing the boundary conditions affecting its structural behaviour, particularly its support on the ground.

### 2.7.1. Characteristics of the materials

The masonry construction of the Twenty Eyes Aqueduct consists of a series of stone pieces assembled and bonded with mortar. The composition of the masonry primarily comprises the characteristics of the stone pieces and mortar, the latter sometimes being absent [49]. For this study, no destructive characterisation tests were conducted on the aqueduct structure. Instead, a visual and geological analysis of the area was performed. Considering the limestone nature of the rock found in the ravine of the Carcauz wadi, the properties of the stone material constituting the aqueduct were estimated. The mechanical properties of the masonry were determined based on its elastic modulus, Poisson's coefficient and the specific weight of the material.

According to J. A. Martín Caro [49], the specific weight of limestone ranges between 20 and 26 kN/m<sup>3</sup>. However, the specific weight of the masonry composite material is determined by the weighted average of the components based on their respective proportions in volume. Considering that in stone masonry constructions, the volume of mortar is significantly lower than that of stone, we can estimate the specific weight of the composite material to be 20 kN/m<sup>3</sup>, adopting a conservative value. The modulus of elasticity ( $E_b$ ) of limestone falls between 17,000 and 76,000 N/mm<sup>2</sup>, with a Poisson's ratio ranging from 0.15 to 0.20. For lime mortar, a modulus of elasticity ( $E_m$ ) is considered to be between 400 and 2000 N/mm<sup>2</sup>, with a Poisson's ratio of 0.2. While mortar, being less rigid, primarily contributes to the masonry's deformability, understanding the modulus of elasticity of both components is important, as it influences the composite material's behaviour. Equation 1 provides an indicative value for the longitudinal deformation modulus (E) of the part-mortar assembly.

$$E = 0,50 * E_b = 0,5 * 17000 \text{ N/mm}^2 = 8500 \text{ N/mm}^2 \quad (1)$$

A Poisson's ratio of 0.15 will be adopted for the entire masonry structure.

### 2.7.2. Structural loads

Below are descriptions of all the actions acting on the aqueduct, along with justifications for the values adopted and an analysis of the suitability of the loads taken into account:

- Permanent loads: the dead weight of all masonry elements was calculated based on their geometrical characteristics, considering a specific weight of the masonry of 20 kN/m<sup>3</sup>.
- Variable loads: treating the aqueduct as a vertical wall with several openings subjected to wind action, wind pressure was calculated following Eurocode 1 (UNE 1991-1-4:2005), resulting in a value of wind pressure on the external surface:

$$w_e \approx 1,00 \text{ kN/m}^2$$

This action was applied to both facades of the aqueduct, acting in one direction for the 'Wind +' scenario and in the opposite direction for the 'Wind -' scenario.

- Accidental loads: Seismic action was considered by conducting a modal-spectral analysis with SAP2000, following the recommendations of the Seismic Resistant Standard NCSE-02.

### 2.7.3. Combination of loads

The load hypotheses considered are formed by combining the calculation values of the actions whose effects may be simultaneous (concomitant actions), according to the general criteria prescribed in the Technical Building Code of the Spanish Ministry of Housing, for both Ultimate Limit States and Serviceability Limit States.

The following table shows the combinations of load assumptions for the Ultimate Limit States of Stability and Strength of the aqueduct (ELU) and the Serviceability Limit States of Deformation (ELS), indicating the coefficients of action magnification. For stability checks, the global loads provided by the software for each individual scenario were used.

### 2.7.4. Boundary conditions

The aqueduct rests directly on the rocky outcrops visible in the riverbed, as determined by the field visit and visual inspection of the aqueduct foundations. Additionally, a continuous footing, also composed of masonry, could have been laid at those valley locations where there was a superficial layer of fill.

Table 1. FEM calculation combinations

Combination	Simple hypotheses					Analysis
	Dead-weight	Wind X+	Wind X-	Seism X	Seism Y	
1-ELU	1,35	1,50	-	-	-	Resistance
2-ELS	1,00	1,00	-	-	-	Deformations
3-ELU	1,35	-	1,50	-	-	Resistance
4-ELS	1,00	-	1,00	-	-	Deformations
5-ELU	1,00	-	-	1,00	0,30	Resistance and Deformations
6-ELU	1,00	-	-	0,30	1,00	Resistance and Deformations

*ELU = Ultimate Limit States of Stability and Resistance*

*ELS = Deformation Service Limit States*

Based on observations, the foundation of the aqueduct base appears to be between that of a simple support and an embedment. Given that a significant portion of the aqueduct wall is inserted into the limestone rock massif, it makes sense that contour conditions would be used throughout the entire lower edge of the aqueduct model to simulate an embedded support in order to reach the level of analysis required for this investigation. In order to fulfil the purpose of the present work, it was sufficient to analyse the model described with the boundary conditions of embedment at the base of the aqueduct.

### 3. Results

#### 3.1. Results of the photogrammetric process

In the established workflow, the first results we obtained were those of the point cloud of the aqueduct area. The accuracy of the photogrammetric project is shown in Table 2, where the error obtained in each CP is displayed.

Table 2. Errors obtained in the Check Points (Agisoft Metashape Report)

Check Point	Error in X (cm)	Error in Y (cm)	Error in Z (cm)	Total error (cm)	Image Error (pix)
2	1.66399	-3.1027	0.0259657	3.52084	0.311 (188)
4	0.341269	-3.91809	1.57669	4.2372	0.257 (235)
6	-1.25744	2.02388	-0.218058	2.39265	0.263 (213)
8	-1.44521	1.09357	-2.4372	3.03718	0.292 (219)
10	2.0657	1.23115	-2.28027	3.31397	0.297 (224)
12	0.482149	-1.82293	-1.0632	2.16471	0.301 (207)
14	1.22377	-4.85691	1.01957	5.11143	0.277 (169)
Total	1.3391	2.89577	1.50445	3.52733	0.286

#### 3.2. Results of the HBIM

In the established workflow, after classifying the points of the cloud in Agisoft Metashape and exporting the points classified as 'aqueduct', a point cloud with a total of 284,779 points was obtained and imported into the Autodesk Revit software for the creation of the HBIM.

According to the methodology described in the previous section, the geometric characteristics of the aqueduct were modelled using the point cloud as a guide.

Figure 8 shows the model created in Autodesk Revit 2022 and its overlay with the point cloud.

#### 3.3. Results of the HBIM validation

Once the HBIM was created, it was necessary to validate the accuracy of the adjustment made in relation to the point cloud. Figure 9 shows the results of the comparative analysis between both elements carried out using the CloudCompare software. The mean of the differences detected between the HBIM object created and the photogrammetric model (point cloud) is 0.022 m, with these differences centred in the majority of points within the range of -0.10 m to 0.10 m. The standard deviation obtained is 0.08 m. The results are represented on a colour scale that highlights the differences,

with points showing the worst correspondence in red and those with the best representation in the generated model in green.



Figure 8. Model created in Autodesk Revit 2022 overlaid with the point cloud.

### 3.4. Results of the structural calculation

The last step in the workflow described in section 2 is the generation and analysis of the FEM. This analysis was carried out by a computer with Intel(R) Core (TM) i7-8700K CPU 3.70GHz and 16 Gb RAM in a time of eight seconds. The model is composed of 4,627 points and 4,170 area or shell elements. After analysing the stability of the assembly in the event of overturning and sliding, the tensile and resistant behaviour of the masonry and the deformations produced in the vertical wall of the aqueduct, the following results were obtained. The stability of the construction was determined by calculating the coefficients of safety against overturning (CSV) and sliding (CSD), assuming that the assembly behaves as a rigid solid.

The following reactions were obtained from the calculation model in SAP2000:

- The overall Z-reaction due to the self-weight of the aqueduct is 2979.4 kN.
- The overall reaction in the X-direction (perpendicular to the aqueduct wall) due to the wind effect is 163.3 kN.
- The overall reaction in the X-direction (perpendicular to the aqueduct wall) due to the effect of seismic activity is 447.9 kN.
- An average height of  $h = 3.40$  m was determined for each section of the aqueduct, which is the position at which the forces resulting from wind and earthquake are applied for the purposes of the stability checks. A coefficient of friction between the ground and the structure of  $\mu = 0.55$  was estimated. Furthermore, the aqueduct wall has an average thickness of 0.90 m.

A CSV and a CSD value were found for the most unfavourable stability combination involving wind action:

$$CSV = \frac{\text{Stabilising momentums}}{\text{Destabilising momentums}} = \frac{2979,4 \text{ kN} * \frac{1}{2} * 0,90 \text{ m}}{163,3 \text{ kN} * 3,40 \text{ m}} = 2,41$$

$$CSD = \frac{\text{Stabilising strengths}}{\text{Destabilising strengths}} = \frac{2979,4 \text{ kN} * 0,55}{163,3 \text{ kN}} = 10,03$$

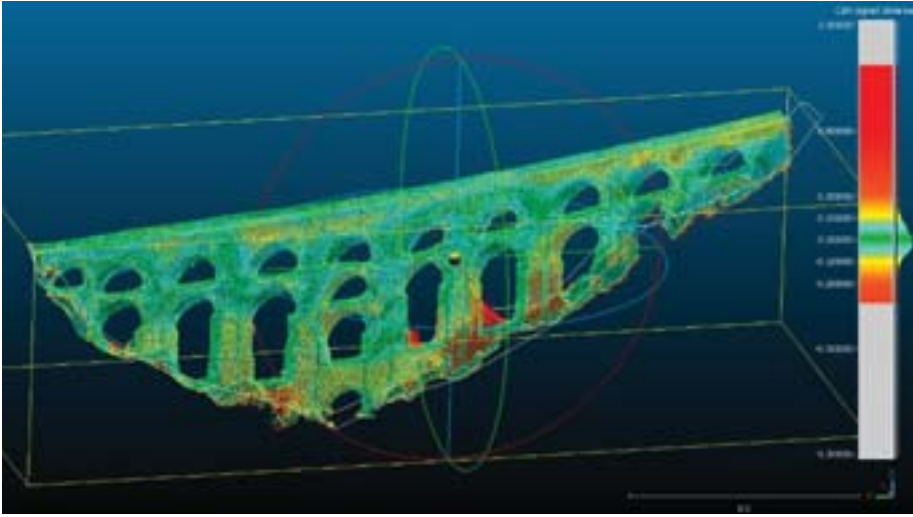


Figure 9. Validation of the HBIM of the aqueduct in CloudCompare.

For the worst-case stability combination involving earthquake action, a CSV and a CSD value were obtained:

$$CSV = \frac{\text{Stabilising momentums}}{\text{Destabilising momentums}} = \frac{2979,4 \text{ kN} * \frac{1}{2} * 0,90 \text{ m}}{447,9 \text{ kN} * 3,40 \text{ m}} = 0,88$$

$$CSD = \frac{\text{Stabilising strengths}}{\text{Destabilising strengths}} = \frac{2979,4 \text{ kN} * 0,55}{447,9 \text{ kN}} = 3,66$$

To analyse the structural stress and resistance of the aqueduct, without being exhaustive, the stresses induced in the aqueduct walls were extracted from the SAP2000 model according to the combinations indicated in section 2.7.3.

For the simple deadweight hypothesis, the following horizontal (Figure 10) and vertical (Figure 11) axial stresses were obtained:

In Figure 11, a maximum compression value of -315.8 kN/m is observed, with practically zero tensile stresses.

The horizontal actions of wind and earthquake are mainly characterised by bending and shear forces at the base of the aqueduct wall. For the combinations that consider the action of wind (1-ELU and 3-ELU), the forces obtained in the shell elements in which the aqueduct has been discretised are those shown in Figure 12 (moments) and Figure 13 (shear). For the combinations that contemplate the action of the seismic activity (5-ELU and 6-ELU), the stresses obtained are those shown in Figure 14 (moments) and Figure 15 (shear).

In Figure 10, a maximum compression value of -65.6 kN/m and a maximum tensile value of 79.7 kN/m can be observed.

In Figure 12, a maximum bending moment at the base of the aqueduct of 37.1 kN\*m/m is observed.

In Figure 13, a maximum shear value of 15.6 kN/m is observed.

In Figure 14, a maximum bending moment at the base of the aqueduct of 133.2 kN\*m/m is observed.

In Figure 15, a maximum shear value of 47.8 kN/m is observed.

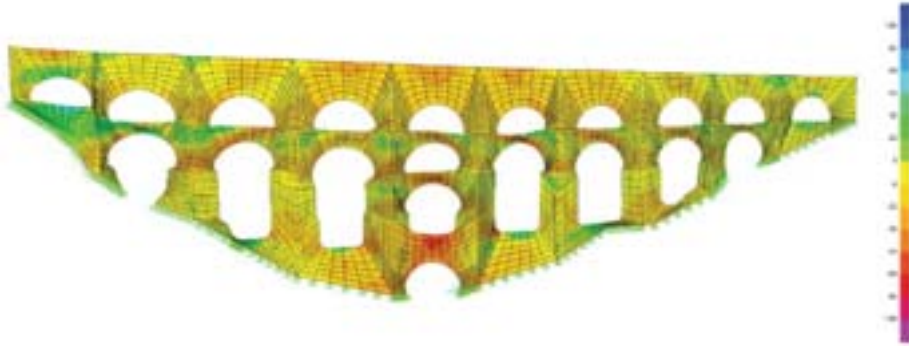


Figure 10. Horizontal axial stresses due to deadweight.

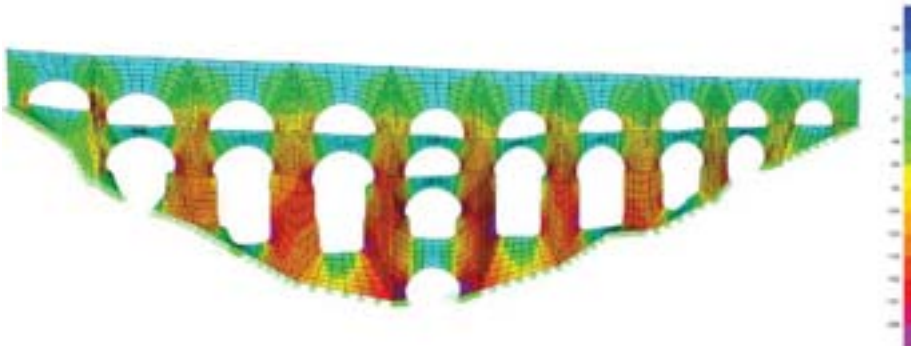


Figure 11. Vertical axial stresses due to deadweight.

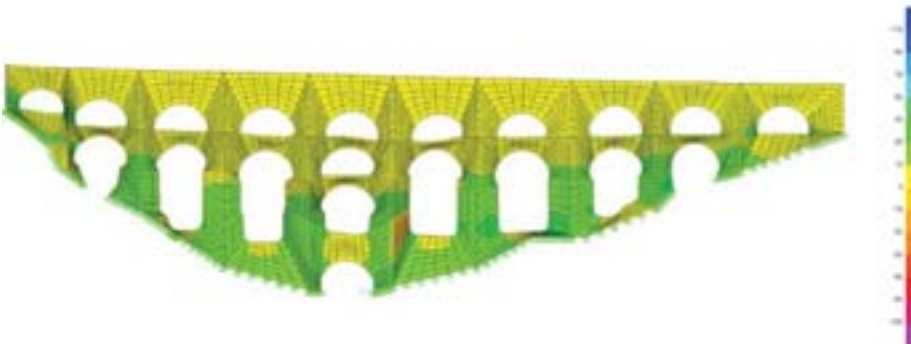


Figure 12. Bending stresses for the 1-ELU combination.

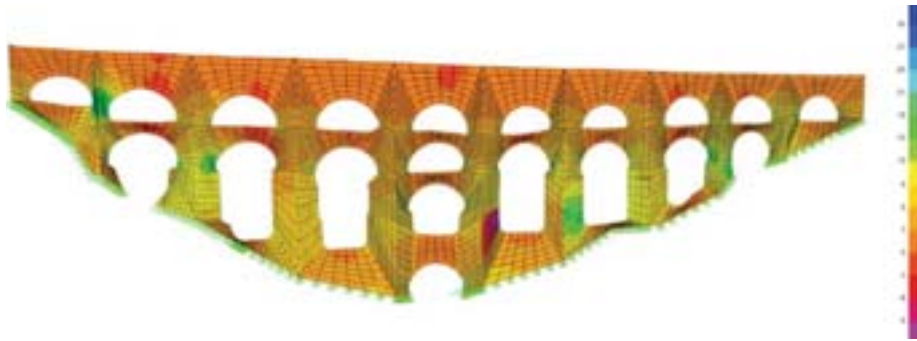


Figure 13. Shear stresses ( $V_{max}$ ) for the 1-ELU combination.



Figure 14. Bending stresses for the 5-ELU combination.



Figure 15. Shear stresses ( $V_{max}$ ) for the 5-ELU combination.

Finally, the resulting deformations in the structure due to the combinations considering the action of wind in the Serviceability Limit State (2-ELS and 4-ELS) and earthquakes (5-ELU and 6-ELU) are presented.

Figure 16 shows a maximum aqueduct crown displacement of 1.6 mm.

Figure 17 shows a maximum aqueduct crown displacement of 6.2 mm.



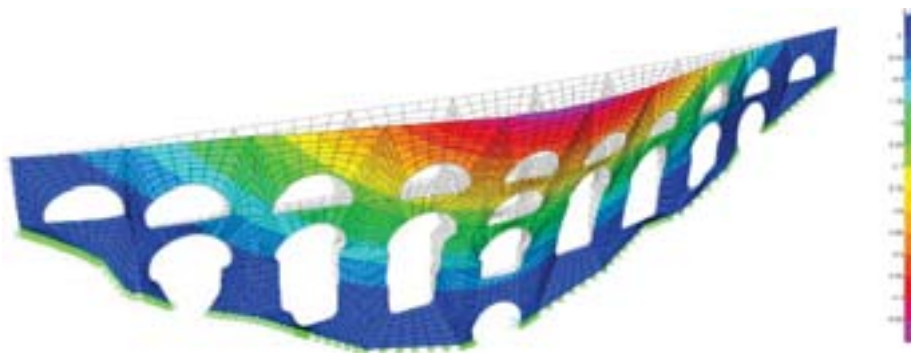


Figure 16. Horizontal offsets for the 4-ELS combination. Scale increased by x500.

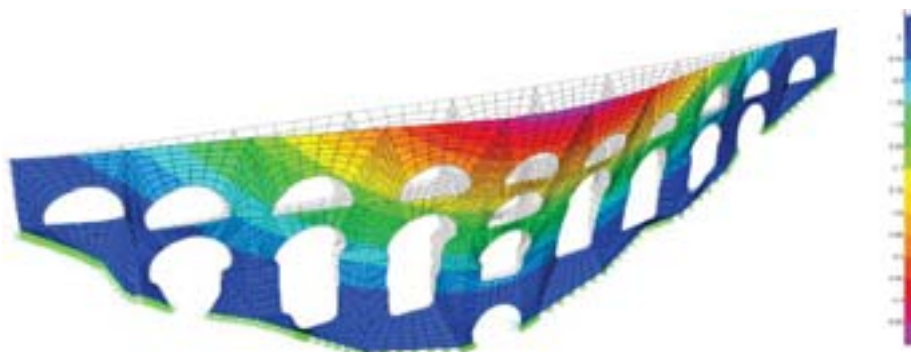


Figure 17. Horizontal offsets for the 5-ELU combination. Scale increased by x500.

#### 4. Discussion

The maintenance of antique infrastructures, particularly those lacking original project documentation, presents a significant challenge, as previously noted. Regardless of the infrastructure type, understanding its structure is crucial for effective maintenance and to ensure operational functionality throughout its lifecycle, as seen in various environments such as ports and maritime settings [50]. In cultural heritage elements like the one examined in this study, analysing structural stability is paramount to prevent infrastructure collapse. The reverse engineering process conducted through UAV photogrammetry or laser scanning has been applied in numerous building restoration projects [51-53]. However, this study added complexity by requiring precise modelling of the arches' eyes, necessitating the use of oblique images and flights in various directions and at different altitudes.

##### 4.1. Accuracy of the photogrammetric project

The values obtained in the photogrammetric project align with several practical applications examined by Clapuyt et al. [54], who compared 10 cases of 3D topographic

reconstructions based on the SfM algorithm under conditions similar to those at the aqueduct site. Additionally, other studies which focused on historical heritage have tolerated errors of up to 15 cm [30, 48], with accuracy typically measured within a cm.

In this research, the total error in the georeferenced model is 3.53 cm and is considered sufficiently accurate for the type of analysis conducted, even comparable to results achievable with TLS analysis [17].

#### **4.2. Use of oblique images**

The enhancement of accuracy and detail in point clouds acquired through UAV photogrammetry with oblique photography has been demonstrated in numerous studies [55, 56]. In this study, the photogrammetric project used photographs captured at a close distance to the object, with camera tilt angles of 45° and 90°, eliminating the need for ground photographs. These conditions resemble the approach in a study of the Piedmont monastery in Italy [55], where high accuracy was also achieved. Undoubtedly, the use of photographs taken at varying angles proved beneficial in obtaining a more precise point cloud of the aqueduct.

#### **4.3. Accuracy of the HBIM**

According to the specific scientific literature, there are no established accuracy limit values for HBIMs created through a point cloud. The level of accuracy should be selected based on the type of intervention or analysis to be conducted, aiming to generate a model that is easy to manage and interpret [2]. In this study, limits were set to ensure the accurate structural interpretation of the aqueduct model and to facilitate the transformation from the HBIM to the FEM without significant simplification. Most observed differences do not exceed 10 cm, primarily resulting from default assumptions, such as considering smaller structural sections than those actually present, ensuring a conservative approach in analysing the structural behaviour. Additionally, factors such as landslides and material accumulations in the aqueduct's eyes, while not structurally significant, contribute to minor adjustment differences in some areas.

#### **4.4. Accuracy of the FEM**

The accurate representation of the aqueduct's geometry in the HBIM poses challenges in creating an exportable object readable by SAP2000 calculation software. Therefore, certain aspects, such as the variability in wall thickness and observed overhangs, were simplified to facilitate information exchange between software platforms. These simplifications, while necessary for interoperability, were implemented with minimal impact on the analysis results, prioritising safety in structural analysis and maintaining high geometric accuracy in the model. Interoperability issues encountered between Autodesk Revit and SAP2000 led to the development of the FEM using Autodesk AutoCAD 3D software, an area of ongoing research to enable automated transitions. The average mesh size in the FEM was deemed adequate for this study, with the maximum distance between nodes on the same edge of shell elements not exceeding 50 cm.

Finer meshing may not significantly alter conclusions [57-58] but would increase computation times, so larger elements were maintained for efficiency.

#### 4.5. Structural behaviour of the aqueduct

Based on the assessment of the aqueduct's stability against external forces, it appears that the structure is adequately resistant to wind and gravitational forces, mitigating both overturning and sliding risks. However, its stability against overturning would be compromised in the event of a seismic disturbance. According to the Ministry of Housing's CTE standards, the CSV coefficient should exceed 2, while the CSD coefficient should surpass 1.5. However, the obtained CSV value for seismic actions is 0.88, falling short of the unit and significantly below the CTE requirement. Consequently, further investigation into potential reinforcement strategies for the monument is needed to ensure its stability under various scenarios specified by existing regulations.

Regarding the distribution of stresses induced in the aqueduct due to its own weight, the model's outcomes are consistent. Horizontal compressions are evident in the arch vaults, while vertical compressions are observed in the piers, with their magnitude increasing towards the base. This aligns with the typical structural behaviour expected from such constructions. Regarding the maximum axial forces resulting from the aqueduct's weight, it is noteworthy that the compressive stresses observed in the masonry are considerably lower than the characteristic compressive strength of both limestone (ranging between 25 and 130 N/mm<sup>2</sup>) and lime mortar (between 0.5 and 2 N/mm<sup>2</sup>). Similarly, tensile stresses are also notably lower than the tensile strength of the stone, which various sources estimate at around 5% of the characteristic compressive strength [49].

$$\sigma_{compress} = \frac{N}{A} = \frac{315800 \text{ N}}{1000 \text{ mm} * 900 \text{ mm}} = 0,35 \text{ N/mm}^2$$

$$\sigma_{tensile} = \frac{N}{A} = \frac{79700 \text{ N}}{1000 \text{ mm} * 900 \text{ mm}} = 0,089 \text{ N/mm}^2$$

Where:

$\sigma$ : Stress (N/mm<sup>2</sup>)

N: Axil stress (N)

A: Section area (mm<sup>2</sup>)

However, to derive accurate conclusions regarding the resistance behaviour of the aqueduct, it is essential to analyse the design combinations in greater detail, considering the effects of wind and earthquake. An approximation of the maximum compressive stresses to be endured by the critical section of the aqueduct can be made by applying the Navier formula for sections subjected to bending and axial force:

$$\sigma = \frac{N}{A} \pm \frac{M * y}{I}$$

Where:

$\sigma$ : Stress (N/mm<sup>2</sup>)

N: Axil stress (N)

A: Section area (mm<sup>2</sup>)

M: Bending moment (N\*mm)

y: Distance from the neutral axis to the most compressed fibre (mm)

I: Inertia of the section (mm<sup>4</sup>)

In the seismic scenario, which results in the maximum bending moment at the base

of the aqueduct, there would be an increase in compressive stresses within the section due to the magnitude of the bending moment:

$$\sigma = \frac{M * y}{I} = \frac{133,2 \text{ kN} * \text{m} * 10^6 * 450 \text{ mm}}{\frac{1}{12} * 1000 * 900^3} = 0,99 \text{ N/mm}^2$$

If we add the compressive stress generated by the bending moment in the seismic combination to the compressive stresses arising from the axial forces on the section, the resulting stresses will still be significantly below the characteristic compressive strength of the masonry [60, 61].

Finally, it should be noted that the horizontal deformations observed in the model due to the effects of wind and earthquake remain within the limit values for total collapse established by the CTE and other international regulations.

The total collapse ( $\delta$ ) for combinations involving wind action must not exceed 1/500 of the total height of the aqueduct. In this case, the observed elastic displacement is 1.6 mm, and the maximum height above the aqueduct bed is 9.50 m. Therefore, according to current regulations, a displacement of up to 1.9 cm would be allowed, which is significantly higher than the modelled value.

$$\delta \leq \frac{9,50 \text{ m}}{500} = 0,019 \text{ m}$$

The total collapse ( $\delta$ ) for combinations involving earthquake action must not exceed 1/100 of the total height of the aqueduct. In this case, the observed elastic displacement is 6.2 mm. Therefore, according to current standards, a displacement of up to 9.5 cm would be allowed, which is considerably higher than the modelled value.

$$\delta \leq \frac{9,50 \text{ m}}{100} = 0,095 \text{ m}$$

It is true that these displacements would be higher if non-elastic behaviour of the masonry were considered. However, the values obtained are sufficiently far from the normative limit to consider, for this level of study, acceptable behaviour in ELS of aqueduct deformations.

## 5. Conclusions

The Cloud-to-BIM-to-FEM methodology enables the generation of BIM and FEM models of architectural and engineering works with low cost, flexibility and high-quality results. This makes it an essential tool for the reconstruction, protection and conservation of our historical heritage.

The photogrammetric project carried out has shown competitive results compared to surveys conducted with TLS. The combination of zenith and oblique images has significantly improved the dense point cloud obtained from the photogrammetric process.

The process of generating the HBIM has consistently maintained the final objective of the work in mind, avoiding unjustified simplifications and resulting in a reliable representation of the aqueduct. A validation process was applied to ensure the similarity between the parametric object created in the HBIM and the dense point cloud from the photogrammetric project, ensuring a high geometric fit between the models. This

facilitates the subsequent accurate structural interpretation of the aqueduct.

The HBIM accurately reflects the geometric complexity of the aqueduct, while the FEM captures its irregularities without oversimplifying the structure. This is a significant improvement over traditional simulations, which often rely on overly simplistic models of masonry works.

Future developments will require the implementation of advanced functionalities to automate the conversion from BIM to FEM. Existing BIM-to-FEM solutions are typically applicable only to regular buildings with highly standardised layouts [33, 59, 60].

The structural analysis of the FEM successfully evaluated the instability conditions of the building in the event of an earthquake, although it exhibits satisfactory behaviour in the event of wind. With regard to the tensile behaviour of the aqueduct walls, it is evident that the maximum compressions experienced by the masonry are significantly below the characteristic resistance of the ensemble formed by the masonry pieces and the lime mortar binding them. However, further analysis considering the non-linearity of masonry behaviour will be necessary to determine whether the tensions generated in the walls could lead to unacceptable compressions or instances of rupture in certain sections.

This point paves the way for future research aimed at identifying areas where tension occurs, which must be addressed to ensure the future structural integrity of this cultural heritage asset over the years. Additionally, it sets the stage for drafting a rehabilitation project for the monument. Another intriguing avenue of exploration would involve the realistic virtual reconstruction of the aqueduct, serving as a means to disseminate the rich historical heritage found in the province of Almeria.

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## Biographical notes

**José Manuel Casimiro Bernárdez** holds a degree in Civil Engineering from the University of Granada (Spain). He furthered his studies in the field of seismic-resistant design of structures thanks to an exchange scholarship at the Pontificia Universidad Católica de Valparaíso (Chile) in 2014. Throughout the last 10 years he has dedicated himself mainly to structural design, both for buildings and bridges, as part of the company HL Ingeniería de Estructuras together with his partner José Lavado. In 2022 he obtained a Master's degree in Representation and Design in Engineering and Architecture at the University of Almeria (Spain), which has allowed him to progress in Cloud to BIM to FEM research and to carry out the present analysis. In addition, he currently works as a teacher in training cycles where he teaches subjects related to the structural support of tunnels and geotechnical works, among others.

**Patricio Jesús Martínez Carricondo** began his studies in Civil Engineering in the academic year 1997-98 at the ETSICCP in Granada. From January 2004 to July 2011 he worked on different engineering projects of great importance developed in Spain (urbanization, roads, highways, dams, pipelines, etc.). At the end of 2011 he began a Master in Representation and Design in Engineering and Architecture taught, among others, at the University of Almeria. This marked the beginning of a new stage that led to the completion of a doctoral thesis on the application of photogrammetric techniques with drones. At present, his professional activity is dedicated to teaching, as a professor in the area of Graphic Expression in Engineering, doing research and providing services with drones through the Drone R&D Service of the University of Almeria (Spain).

**Francisco Agüera Vega** is a PhD in Agricultural Engineering and full professor in the Engineering Department of the University of Almeria, Spain. Since 2009 he has been working with RPAS as platforms carrying different types of sensors. His research topics include land use analysis, precision agriculture, image classification techniques, photogrammetry, generation and exploitation of digital terrain models. He has been principal researcher in several projects related to these topics. In addition, he has participated in several projects related to the optimization of agricultural machinery inside greenhouses, and applications of RPAS in agriculture. In 2007 he spent time at the Department of Earth Science and Engineering, Imperial College London, United Kingdom, in the Remote Sensing and GIS group, and in 2019 at the Dipartimento di Ingegneria "Enzo Ferrari", Laboratorio di Geomatica, at the Faculty of Engineering, at the Università degli Studi di Modena e Reggio Emilia, Italy. He has published numerous teaching and scientific publications in high impact journals.

**Fernando Carvajal Ramírez** has been a PhD in Agricultural Engineering and Full Professor of the Department of Engineering at the University of Almeria since 2019. As part of his research work, he has published books and scientific journals of impact and has obtained 2 national awards for entrepreneurial initiatives; he has participated in numerous research projects; is editor of an international scientific journal of maximum impact. His teaching received 'excellent' in the DOCENTIA programme accreditation, and the Rectoral Mention of Teaching Excellence. He has published several teaching publications, and has participated in teaching innovation projects, most of them as principal investigator. In terms of didactic management, he is currently Vice-Rector for Post-graduate Studies and Institutional Relations in the University of Almeria (Spain).

## Summary

The Twenty Eyes Aqueduct stands as a monumental hydraulic structure with a rich history spanning several centuries, poised to be designated as a heritage asset of cultural interest (Bien de Interés Cultural, BIC). This infrastructure poses a significant challenge for structural simulation, given the heterogeneous nature of its materials, geometric irregularities and challenging accessibility. Recent advancements in UAV photogrammetry, coupled with the evolution of BIM and the computational capabilities of modern computers for calculating FEM, present a methodology for simulating the behaviour of structures under applied loads. This approach enables us to address the tasks of reconstruction, protection and conservation of our heritage with unprecedented precision, speed and perspective. In this study, the innovative Cloud-to-BIM-to-FEM methodology is applied, which is capable of converting BIM models generated from point clouds into FEM. Obtaining the point cloud was possible using UAV photogrammetry, during which a 3D survey of the current state of the aqueduct was conducted. The point cloud obtained served as the basis for generating an HBIM that accurately represents the geometry of the aqueduct (Cloud-to-BIM). The HBIM was then transformed into a FEM model that respects the monument's singularity without excessive geometric simplifications (BIM-to-FEM). Finally, various considerations were deduced regarding the stability of the aqueduct and its structural behaviour by applying loads such as wind and earthquake.

## Riassunto

L'Acquedotto dei Venti Occhi è una struttura idraulica monumentale con una ricca storia che abbraccia diversi secoli, pronta per essere designata come bene patrimoniale di interesse culturale (Bien de Interés Cultural, BIC). Questa infrastruttura rappresenta una sfida significativa per la simulazione strutturale, data la natura eterogenea dei suoi materiali, le irregolarità geometriche e l'accessibilità difficile. I recenti progressi nella fotogrammetria UAV, insieme all'evoluzione del BIM e alle capacità computazionali dei moderni computer per il calcolo FEM, presentano una metodologia per simulare il comportamento delle strutture sotto carichi applicati. Questo approccio ci consente di affrontare i compiti di ricostruzione, protezione e conservazione del nostro patrimonio con precisione, velocità e prospettiva senza precedenti. In questo studio viene applicata l'innovativa metodologia Cloud-to-BIM-to-FEM, in grado di convertire modelli BIM generati da nuvole di punti in FEM. L'ottenimento della nuvola di punti è stato possibile utilizzando la fotogrammetria UAV, durante la quale è stato condotto un rilievo 3D dello stato attuale dell'acquedotto. La nuvola di punti ottenuta è servita come base per generare un HBIM che rappresenti accuratamente la geometria dell'acquedotto (Cloud-to-BIM). L'HBIM è stato poi trasformato in un modello FEM che rispetta la singolarità del monumento senza eccessive semplificazioni geometriche (BIM-to-FEM). Infine, sono state dedotte diverse considerazioni riguardanti la stabilità dell'acquedotto e il suo comportamento strutturale all'applicazione di carichi quali vento e sisma.



# **S**USTAINABLE TOURISM AND CULTURAL HERITAGE: A QUANTITATIVE INTERDISCIPLINARY APPROACH BASED ON VISITOR PROFILES

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*Keywords:* cultural memory heritage, Spanish Civil War Shelters, history pedagogy, urban sustainability, quantitative methodology

## **1. Introduction**

This study addresses the impact of visits to the Civil War shelters in Alicante on the city's cultural memory heritage [1,2]. This analysis is situated within the broader context of how historical sites can serve as powerful vehicles for education, reflection, and the preservation of collective memory [3–5]. The research is part of the Operational Program FEDER Sustainable Growth 2014-2020, which emphasizes the importance of integrating historical and cultural heritage recovery into sustainable urban development [4]. The Civil War shelters in Alicante, rehabilitated and opened to the public, offer a unique window into Spain's troubled past, allowing visitors to connect directly with the experiences of those who lived through that turbulent period. The opening of these spaces aims not only at the physical conservation of the shelters but also at promoting a deeper understanding of their history and the war's consequences on contemporary society, as developed in the field of mnemohistory [6–8]. The main goal of this study is to assess the impact of visits to these shelters on the public's understanding and appreciation of cultural memory heritage. It aims to analyze the profile of the visitors, their motivation for visiting the shelters, and how these visits contribute to historical education and the recognition of cultural heritage. Furthermore, it seeks to identify patterns and trends in visits to offer recommendations that can improve the management of these historical sites in [9–11].

The research hypotheses suggest that the rehabilitation and opening of the shelters have a positive impact on cultural memory heritage, attracting a broad spectrum of visitors and fostering a greater understanding of the history of the Spanish Civil War. The findings are expected to contribute to better management of cultural memory heritage and promote effective communication and education strategies [12]. Considering previous works in the field, this study positions itself at the intersection between cultural heritage management, historical education, and cultural tourism [13–16]. Through the discussion of similar studies and the application of proven methodologies, it seeks to offer a novel perspective on the importance of the Civil War shelters in Alicante as tools

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for stimulating public interest and historical understanding.

The present study adopts an interdisciplinary approach, positioned at the confluence of disciplines such as tourism, cultural heritage management and education. This methodological framework allows for a holistic understanding of the impact of visits to Civil War shelters in Alicante, addressing not only their touristic relevance but also their educational significance and their contribution to the management and conservation of cultural heritage. For instance, from the perspective of tourism, the study investigates how the shelters become tourist attractions that promote responsible and educational tourism, encouraging visitors to reflect on history and collective memory. From the realm of cultural heritage management, it analyzes how the appropriate presentation and interpretation of these sites contribute to their conservation, valorization, and transmission to future generations.

Finally, in the educational domain, the impact of visits on the visitors' awareness and understanding of the historical period represented by the shelters is assessed, emphasizing the importance of integrating these spaces into both formal and informal educational programs. The intersection of these disciplines in our research enriches cultural heritage management by offering multifaceted strategies for its conservation and promotion.

This interdisciplinary approach also underscores the need to adopt management practices that consider the various dimensions of cultural heritage, ensuring its sustainability and relevance to a wide range of audiences.

The relevance of an interdisciplinary approach in studying the impact of visits to cultural heritage has been widely supported by existing literature, covering everything from cultural tourism management to heritage education and conservation [17–20]. In parallel, works such as those by Boyd and Timothy explore the intersection between tourism, education, and heritage management, suggesting that the integration of these fields can significantly enhance the sustainability of cultural heritage [13,21,22]. Furthermore, studies, like that by Richards, emphasize the importance of understanding the profiles and motivations of visitors to design more effective conservation strategies [16]. This approach is reinforced by Leask and Fyall, who argue that an interdisciplinary understanding of tourism and heritage management can lead to more inclusive and participative practices in cultural heritage conservation [23]. The literature also highlights the utility of visitor surveys as a tool for gathering crucial data on public perception and valuation of heritage [10]. These studies demonstrate that surveys not only inform about visitor preferences and behaviors but can also be pivotal in planning educational and conservation interventions tailored to their needs and expectations.

## **2. Research objectives**

The general objective of this study is to assess the impact of visits to the Civil War shelters in Alicante on the city's cultural memory heritage. This analysis seeks to understand how the rehabilitation and opening of these sites contribute to the valorization and understanding of the city's troubled past in the contemporary urban context.

The specific objectives include determining the demographic profile of the visitors, both local and national and international; analyzing visitation trends in different seasons of the year; evaluating the level of knowledge and motivation behind the visits to these shelters; and projecting future visitation trends to improve the management and promotion of these spaces as part of the cultural heritage. Additionally, the study aims to explore the effectiveness of different types of visits (guided, dramatized, etc.) in conveying knowledge about the historical memory associated with the shelters.

### 3. Research hypotheses

The main research hypothesis posits that the rehabilitation and public opening of the Civil War shelters in Alicante have a significant positive impact on the city's cultural memory heritage, increasing public interest and understanding of the historical events these places represent. It is assumed that there is a positive correlation between the offer of cultural and educational activities in these shelters and an increase in visitors, which in turn contributes to a greater awareness and appreciation of the historical and cultural value of these sites.

Furthermore, it is hypothesized that there are significant differences in the visitor profile based on variables such as age, geographic origin, and type of visit, which require differentiated management and communication strategies to maximize the positive impact of these spaces on Alicante's cultural memory heritage. These hypotheses will be explored through a quantitative methodological design, using statistical analysis to interpret data collected during the study period from August 2023 to January 2024.

### 4. Methodology

The study employs a quantitative methodology to assess the impact that visits to six Civil War shelters, which have been rehabilitated and made available to the public in Alicante, have had on the city's cultural memory heritage. Within the framework of the Operational Program FEDER "Sustainable Growth 2014-2020" (CCI: 2014ES16RFOP002, Priority Axis: Urban Development 12), the Alicante City Council, under the supervision of the General Sub-Directorate for Urban Development (D.G. of European Funds, Secretary of State for Budgets and Expenses, Ministry of Finance and Public Function), promoted the DUSI Alicante Strategy "Las Cigarreras Area". This strategy, co-financed by the European Commission and by Order HAP/2427/2015 of November 13 (BOE No. 275 of 11/17/15), aims to encourage sustainable urban development through the integration of the recovery of industrial, religious and military heritage, highlighting its historical and tourist importance. In this context, the rehabilitation and public opening of four Civil War air-raid shelters in Alicante took place in 2022, adding to the two that had previously been opened in 2015 (Figure 1). Following the opening of the Civil War shelters, various activities such as guided tours, dramatized representations and cultural events were scheduled around these spaces.

Throughout the year 2022 and the beginning of 2023, the attendance of 5,229 individuals was recorded, of which 3,472 participated in guided tours and 999 in dramatized activities and lectures on historical memory and the function of the air-raid shelters. After this phase and following the hiring of a new company specialized in guided tours by the Alicante City Council, these activities were relaunched in August 2023, with an expanded scope that now includes more resources and extends over a longer period. Six months into this initiative, the objective is to analyze the generated impact, the profile of the visitors, and prospects, leaving the comparison of historical, current, and future data for subsequent research that can derive optimal conclusions for the management of cultural memory heritage. Through a retrospective longitudinal design, data collected from August 2023 to January 2024 were analyzed, with a particular focus on two visitor segments: the general public and organized school groups, aiming to identify patterns and trends in visits that could contribute to a better understanding of their impact on cultural heritage.

In the current study, a quantitative methodology was adopted to assess the impact of visits to Civil War shelters in Alicante on visitors' perception and valorization of

cultural heritage, specifically focusing on the interplay between the tangible heritage (the shelters themselves) and the intangible heritage (the memories and historical significance associated with them). Data from 407 individuals were collected and analyzed through surveys, focusing on the demographic profile of the visitors, their motivations for visiting, and how these visits contribute to the recognition and appreciation of both aspects of cultural heritage.

The study adhered to the ethical principles of scientific research, obtaining informed consent from participants and ensuring the confidentiality of data (Figure 2).



Figure 1. DUSI Area of the city of Alicante with Civil War air-raid shelters (indicated by red arrows) intended for restoration in the project.





Figure 2. Sequence diagram of the conducted research.

## 5. Results

### 5.1. Descriptive analysis

The survey data reveal a diverse distribution of visitation dates, with daily visitor numbers showing significant fluctuation. The peak visitation date was recorded on December 9th, 2023, attracting 4.4% of total visits, closely followed by other significant dates like April 11th, 2023, and December 28th, 2023, each accounting for 3.4% of visits.

The bulk of visits (85.7%) fall under the category of "General Public," with "School" visits comprising the remaining 14.3%. Analysis of visitor group sizes indicates a predominance of pairs (36.9%), with the frequency of larger groups diminishing progressively. Exceptional instances of notably large groups (e.g., 90 or 98 visitors) typically pertain to organized gatherings.

Statistical measures point to an average group size of approximately 8-9 individuals, despite a median of 3, underscoring a skewed distribution influenced by a minority of large groups. This is further evidenced by a high standard deviation (14.08661) and variance, highlighting substantial variability in group sizes.

The data underscore a skewed visitor group size distribution, with "General Public" visits notably prevalent. Peaks in visitor numbers, particularly on specific dates, often correlate with organized group reservations. This pattern transcends expected increases on weekends or public holidays.

In alignment with the study's aims concerning Civil War shelter visits in Alicante, the survey data facilitated a nuanced analysis of visit timing. Figure 3 illustrates the monthly visitor distribution from August 2023 to January 2024, offering insight into temporal visitation trends to these historical sites (Figure 3).

There is variability in the total number of visitors per month. Some months show a higher influx of visitors compared to others, which could be influenced by seasonal factors, large, organized groups, or holiday periods.



Figure 3. Bar chart of the total visitor distribution by month from August 2023 to January 2024.

While Figure 3 does not detail the specific days, the underlying data and prior analysis indicate that certain dates within these months experienced significant spikes in visitors.

### 5.2. Type of visit and total number of visitors

In this study, a streamlined approach was employed to assess the survey's methodology and findings, with a focus on key insights directly related to the impact of visitors on cultural heritage. The analysis reveals that the General Public (Type 1) comprises 85.7% of visits, underscoring the Civil War shelters in Alicante's widespread appeal and accessibility. This prevalence suggests the site's historical and cultural significance attracts a diverse visitor base with varying interests and historical knowledge levels.

Conversely, School Visits (Type 2) account for 14.3% of total visits, highlighting the site's educational potential and the opportunity to enhance educational programs and partnerships with institutions. This points to the necessity for dedicated resources for this demographic, including tailored educational materials and staff specialized in educational engagement.

The visit types exhibit a mean of 1.1425 with a standard deviation of 0.35 across 407 observations, indicating a predominance of General Public visits with minimal variability.

Visitor group sizes show considerable variation, with a mean of 8.4791 and a standard deviation of 14.08661. The distribution into Small (1-2 Visitors), Medium (3-5 Visitors), and Large Groups (more than 5 Visitors) provides insights into visitor behavior, necessitating a tailored approach to interpretive materials and activities.

The strategic implications for site management include catering to both general and educational visits, with special consideration for the infrequent yet significant occurrence of very large groups.

The strong positive correlation (0.809) between the type of visit and group size underscores the relationship between visit type and visitor volume, informing operational planning and resource allocation (Table 1).

Table 1. Correlations

		Type of Visit	Total Number of Visitors
<b>Type of Visit</b>	Pearson Correlation	1	0,809
	Significance (2-tailed)		<0,001
	Sum of Squares and Cross Products	49,735	1619,211
	Covariance	0,122	3,988
	N	407	407
<b>Total Number of Visitors</b>	Pearson Correlation	0,809	1
	Significance (2-tailed)	<,001	
	Sum of Squares and Cross Products	1619,211	80563,572
	Covariance	3,988	198,432
	N	407	407

The correlation is significant at the 0.01 level (2-tailed).

The analysis revealed that the extremely large effect sizes demonstrate not just a significant difference between the types of visits in terms of the total number of visitors, but also the magnitude of this difference. It indicates that the distinct characteristics and impacts of the two types of visits—general public versus school groups—are substantial. Specifically, the effect sizes calculated from our statistical tests suggest that school visits likely draw much larger groups compared to the general public. This considerable variance in visitor numbers has important implications for how the sites are managed and marketed, emphasizing the need to tailor experiences and educational resources to accommodate and engage these distinct visitor segments effectively (Figure 4).



Figure 4. Bar chart displaying the average number of visitors for the two types of visits: general public (1) and organized school groups (2).

The management of the shelters has logically considered this preference or need for school visits to cater to larger groups. In this regard, strategies have been considered to efficiently manage days with a high influx of school groups, including the assignment of additional guides, and the opening of larger spaces to accommodate these groups, ensuring that the visits are interactive and educational for larger groups. To this end, the War Interpretation Center in Alicante was designed and constructed, precisely next to one of the shelters to be visited (the one at Plaza de Séneca).

This information has also been useful for designing programs and materials that are attractive to educational centers and that can handle the volume and dynamics of a large school group.

A notable case study highlighted in this analysis is the "La Rambla de los Castillos" initiative, where individuals of all ages and backgrounds participated in educational workshops [24] (Figure 5).



*Figure 5. Schoolchildren engaging in creative workshops as part of the 'La Rambla de los Castillos' initiative, which aims to foster a connection with the city's history through the arts and revitalize the collective memory associated with the Civil War shelters.*

The objectives included the participatory reconstruction of the historical narrative, the strengthening of collective identity linked to historical heritage, and the promotion of reflection and consensus in a participatory democracy. The project, executed by Grupo Aranea under our coordination, consisted of two phases. This multidisciplinary group, led by Marta García Chico and Francisco Leiva Ivorra, focuses on creating spaces that encourage minors to engage with and understand public spaces, in this case, more specifically, the Civil War shelters.

The project included interactive sessions with schoolchildren, aiming to spark their interest in the mnemonic heritage and resources of Alicante through playful activities such as drawing, storytelling and theater.

The outcome was the creation of various maps of the shelters that were incorporated into a final city map created by the children, reflecting their discoveries and imagination (Figure 6).

Sessions with schoolchildren also included discussions about cities, presentations of elements of Alicante's identity, and the transformation of these elements into imaginary characters, thus enriching the city's narrative.

Through engaging with the narratives and personal recollections collected during the sessions with schoolchildren, the activity facilitated the preservation of the intangible heritage associated with the shelters.



Figure 6. Various drawings of the city of Alicante's shelters made by students from the state school La Aneja in Alicante.

As children and visitors alike shared and listened to stories and testimonies, they participated in living history, bridging the past with the present. This storytelling approach not only served as a repository for memories but also allowed visitors of all ages to form a personal connection with the historical narrative of the place, fostering a sense of continuity and relevance.

Moreover, the analysis of the preferences and motivations behind the visits reveals that specific educational programs, such as guided tours focusing on the history of the Civil War and its impact on the local community, have a significant impact on the valorization of heritage. These programs not only increase knowledge about the historical period but also promote a more nuanced understanding of the importance of preserving such sites for future generations. The diversified profile of visitors to the Civil War shelters in Alicante plays a fundamental role in the conservation and valorization of cultural heritage. This study demonstrates how different demographic groups interact with and perceive memory heritage, directly influencing the management and promotion strategies of these historical sites. For instance, local visitors exhibit a strong emotional and personal connection to the shelters, considering them as an integral part of their local cultural and historical identity. The deep personal connection fosters greater awareness of the importance of heritage preservation and motivates active participation in conservation activities. In contrast, national and international visitors, attracted by the educational and tourist value of the shelters, contribute to their valorization by spreading knowledge about these spaces through social media and other digital platforms, expanding their recognition globally (Figure 7).

Therefore, it is evident that a cultural heritage management strategy that considers the profiles and motivations of visitors can significantly improve the conservation and valorization of heritage.

By tailoring the activities and programs offered to the needs and interests of different visitor groups, shelter managers can ensure broader and more committed participation, which is crucial for long-term heritage preservation.



Figure 7. Micro-theater performed in the antechamber of the Tabacalera air-raid shelter.

### **5.3. How visitors found out about the shelter visits and the percentage distribution for each**

In this refined analysis, we shift the focus from quantitative details to the broader implications of how visitor demographics and discovery methods influence the conservation and valorization of cultural heritage.

The study highlights a diversity of ways through which people learn about Civil War shelters in Alicante, underscoring the pivotal role of digital platforms, personal recommendations, and institutional promotions in attracting visitors of various ages. Key findings reveal that the internet is the primary discovery tool, followed by unspecified sources, which suggests a wide array of untracked or personal methods of learning about the shelters. The importance of tourist offices and previous visits suggests a significant impact of direct promotion and visitor retention on heritage engagement. Recommendations from friends or family and social media emerge as crucial, yet less dominant, channels. The correlation analysis between the type of visit and discovery methods unveils a moderate positive relationship, indicating that different visitor groups learn about the shelters through varied channels, with school groups possibly leveraging educational communications and the general public being reached more effectively through online advertising. This points to an interdisciplinary approach in heritage conservation, where understanding visitor demographics and preferences can guide more targeted and effective communication strategies (Table 2).

The Pearson correlation between these two variables is 0.296, significant at the 0.01 level. This indicates a moderate positive correlation, demonstrating that there is a relationship between the type of visit and the medium through which visitors learn about them. As the type of visit changes, so does the way in which visitors find out about

them, although the relationship is not strongly pronounced and is not the sole determining factor.

Table 2. Correlations

		Type of visit	How did you find out about the shelter visits?
<b>Type of visit</b>	<i>Pearson Correlation</i>	1	0,296
	<i>Significance (2-tailed)</i>		<0,001
	<i>Sum of Squares and Cross Products</i>	49,735	210,855
	<i>Covariance</i>	0,122	0,519
	<i>N</i>	407	407
<b>How did you find out about the shelter visits?</b>	<i>Pearson Correlation</i>	0,296	1
	<i>Significance (2-tailed)</i>	<0,001	
	<i>Sum of Squares and Cross Products</i>	210,855	10177,912
	<i>Covariance</i>	0,519	25,069
	<i>N</i>	407	407

*The correlation is significant at the 0.01 level (2-tailed).*

That is, while school visits might be more likely to be discovered through educational channels or direct communications to schools, and general public visits through advertising or the internet, this trend is not exclusive or absolute.

The study suggests that while digital and personal referral channels are vital in promoting cultural heritage visits, the diverse discovery methods underscore the need for a multi-channel marketing strategy that can cater to a broad audience spectrum. This approach aligns with an interdisciplinary methodology that not only considers statistical correlations but also integrates marketing, education, and heritage management principles to enhance the appeal and accessibility of cultural heritage sites. Overall, the analysis advocates for nuanced communication strategies that address the demographics of visitors and their discovery behaviors. Emphasis is placed on the importance of both digital platforms and personal interactions in the promotion and preservation of cultural heritage, as demonstrated by the following Tau-b and Spearman correlation graphs between age groups and how they learned about the visits (Figure 8). This interdisciplinary perspective offers valuable insights for tailoring visitor experiences and engagement initiatives, ultimately contributing to the sustainable valorization of cultural heritage.

#### 5.4. Presence in the visit groups by age range

Similarly, we analyzed the relationship between the size of the visitor group and the presence of different age groups in visits to the Civil War shelters in Alicante, with a particular focus on the relevance of these data for the conservation and valorization of cultural heritage.

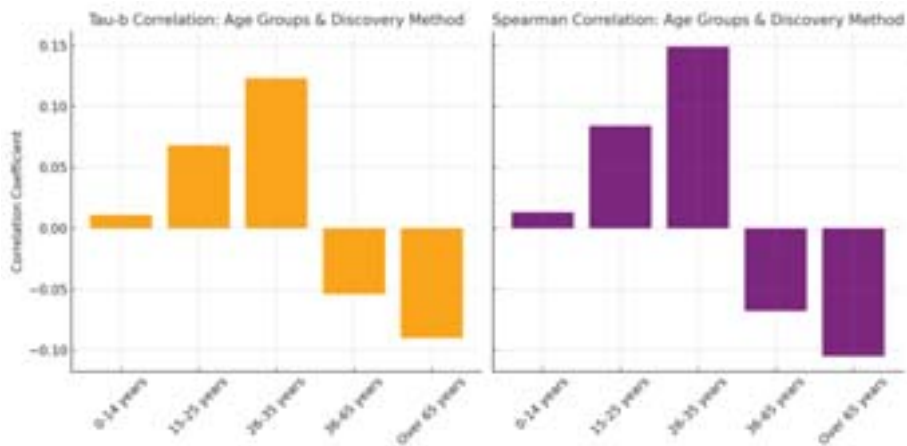


Figure 8. Correlation chart between age groups and how they found out about the visits.

The findings suggest a significant trend: young visitors, especially those between 15 to 25 years of age, tend to participate in larger groups, often organized by educational institutions, which implies a notable interest of this demographic group in the studied cultural heritage. In contrast, groups that include children under 14 years of age or adults over 65 years are less common, which could reflect a lower attraction or accessibility of these visits for such age ranges.

The methodology employed includes ANOVA analysis (analysis of variance) to examine variations in group size among different age groups, revealing statistically significant differences that suggest how the age composition of visitor groups can influence the visit experience and, consequently, the perception and appreciation of heritage. The correlations between the type of visit and the age of visitors indicate that school visits play a crucial role in attracting young people, highlighting the importance of educational programs in heritage conservation (Table 3).

Table 3. ANOVA

Total Number of Visitors					
	Sum of Squares	gl	Mean Square	F	Sig.
Mean Square	23551,288	19	1239,541	8,414	<0,001
Within Groups	57012,284	387	147,319		
Total	80563,572	406			

Note: gl = Degrees of Freedom; Sig. = Statistical Significance.

This interdisciplinary approach, which combines statistical analysis with considerations of heritage management and education, underscores the importance of tailoring conservation and promotion strategies to the demographic characteristics of visitors. Identifying visitation patterns by age can inform the development of experiences and programs that maximize visitor interest and participation, ensuring greater valorization



and sustainability of cultural heritage in the long term. In this sense, the study provides evidence to promote more inclusive and targeted practices in heritage management, which can significantly improve its conservation and appreciation by a broader range of audiences.

## 6. Discussion

Discussion of the findings of this study is enriched by considering previous research that has examined the impact of the rehabilitation of historical sites on cultural heritage and collective memory [13,16,23], as well as those that have used similar methodologies to analyze visitor behavior and profiles [25–27].

These comparisons not only allow the current study to be situated within a broader theoretical and empirical framework but also offer insights into understanding the complexities associated with the management and promotion of cultural heritage in urban contexts.

Previous studies, particularly from the field of mnemohistory, but not exclusively, have shown that the rehabilitation and public opening of memory sites, such as Civil War shelters, can play a crucial role in historical education and in strengthening collective memory [6–8,28–30]. These works underline the importance of integrating historical narratives into the urban fabric to promote a deeper and more nuanced understanding of contentious pasts. In line with these investigations, our study finds that the opening of Civil War shelters in Alicante has generated significant interest among the public, thus contributing to greater awareness and appreciation of the city's contentious past [3–5,24,31–33].

Methodologically, the adoption of a quantitative approach to analyze visitors' profiles and their motivations to visit aligns with similar studies in the field of cultural and heritage tourism. For instance, research employing descriptive and correlational statistical analysis has been effective in identifying visitation trends and visitor preferences at cultural heritage sites [13,23]. Like these studies, our work has applied statistical analyses to better understand the demographic characteristics of visitors, their visitation patterns, and how these factors influence the perception and valuation of memorial cultural heritage. However, unlike some previous studies that focus exclusively on quantitative aspects, our approach also includes a deeper exploration of qualitative aspects to better understand the subjective experiences of visitors and their emotional connection with memory sites. This holistic perspective is essential for capturing the complexity of interactions between the public and heritage sites, as suggested by research that combines quantitative and qualitative methods.

Finally, the discussion of this study benefits from comparison with research that has explored the relationship between tourism development and the conservation of cultural heritage [34]. These works highlight the challenges and opportunities of balancing public accessibility with the preservation of authenticity and historical significance of memory sites. In this sense, our study not only contributes to academic knowledge about the management of cultural heritage in urban contexts but also offers practical implications for tourism and heritage conservation policies.

In sum, by situating our findings within the context of previous research, the relevance of the Civil War shelters in Alicante as active memory spaces and their potential to foster responsible and educational cultural tourism is underscored by scholars such as Carretero and Borrelli, Ciro, and Caro-Lopera, Gutiérrez, Martínez-Rodríguez, et al, Movellán Haro, Pappier and Morras, and Restrepo and Espinosa [35–41].

## 7. Conclusion

After a comprehensive analysis of the collected data on the impact of visits to Civil War shelters on cultural memory and heritage in Alicante, Spain, several important conclusions have been reached. These conclusions facilitate the evaluation of the extent to which the initially proposed research hypotheses have been fulfilled.

Firstly, the results confirm the main hypothesis that the rehabilitation and public opening of Civil War shelters significantly enhance the city's cultural heritage memory (Figure 9).



Figure 9. Four of the shelters rehabilitated in the DUSI Project

This is evident from the notable increase in both local and national/international interest and visitor numbers to these sites since their opening. An increase in visitor numbers reflects heightened public awareness and appreciation of the historical and cultural importance of these spaces, thus corroborating the effectiveness of the rehabilitation strategies and the valorization of heritage related to historical memory. Furthermore, it has been demonstrated that there is a positive correlation between the offer of cultural and educational activities in the shelters and the increase in the number of visitors. Guided tours, dramatized activities, and presentations about historical memory have played a crucial role in attracting the public and in transmitting knowledge about the Civil War period and its impact on Alicante. This confirms the second part of the main hypothesis, indicating that visit modalities enriched with cultural and educational content are essential for enhancing the value of these sites as resources for learning and reflection on the past.

Regarding the specific objectives, the study has revealed significant differences in the profile of visitors based on age, geographic origin, and the chosen visit modality. School groups and young visitors show higher participation in guided tours and educational activities, indicating effective engagement with this segment of the public. On the other hand, individual visitors, or those in small groups, including national and international tourists, display diversified interest in the different visit offerings. This variability in visitor profiles and preferences underscores the importance of developing differentiated communication and management strategies for each segment, to maximize the educational and cultural impact of the shelters.

In conclusion, the study's results suggest that the recovery initiatives and valorization of Civil War shelters in Alicante have been successful in terms of increasing public

interest and enhancing the understanding of Alicante's cultural heritage related to its historical memory. Additionally, these initiatives have facilitated the identification of effective strategies for managing cultural and educational tourism, emphasizing the need to tailor offerings to diverse visitor profiles to ensure enriching and meaningful experiences. It is recommended that the development of educational programs, cultural activities and promotion strategies that highlight the importance of historical memory and encourage active participation from various societal groups, should continue.

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### Biographical notes

**Dr. Pablo Rosser** is a Professor at the International University of La Rioja (UNIR) and an Associate Professor at the University of Alicante (UA), where he teaches in the Faculty of Education and at the Permanent University for Adults (UPUA). Additionally, he collaborates as a Professor at the Open University of Catalonia (UOC). Dr. Rosser holds degrees in Geography and History and a doctorate in Historical and Archaeological Heritage. His research focuses on learning preferences in experimental sciences, gender opportunities in higher education and social e-learning.

His work includes both online and in-person teaching, covering topics such as history, archaeology, cultural heritage, tourism and education. He conducts research on learning styles, emotions, and their relationship with active methodologies, critical pedagogy, and AI, specifically ChatGPT. His findings have been presented at international conferences and published in scientific journals.

Another research area involves cognitive and emotional memory and its relationship with cultural heritage, supported by hermeneutics. He also initiated a pilot project in 2021 with Dr. Seila Soler, evaluating the satisfaction, motivation, cognition, emotions, and well-being of UPUA students. This project has produced results presented at national conferences and has been published in scientific journals. Dr. Rosser's dedication

to improving educational quality for older adults and his extensive research make him a valuable contributor to higher education.

**Dr. Seila Soler** has a cum laude Ph.D. in educational research from the University of Alicante (UA) and is a full-time professor at Isabel I University, where she coordinates master's theses in Secondary Education. She is a member of UNIR's PREFAPLI Research Team, focusing on learning preferences in experimental sciences. Her research aligns with detecting learning style preferences in secondary and higher education. She also contributes to the UA Network for Design and Attention to Gender Opportunities in Higher Education.

With a degree in History, Dr. Soler has worked as an archaeologist and a secondary school teacher. She has conducted teacher training courses at CEFIRE, emphasizing active methodologies. Her research contributions include various published articles and conference presentations on didactic methodologies, critical thinking, and the education of older adults. In collaboration with Pablo Rosser, she initiated a pilot research project on the satisfaction, motivation, cognition, and well-being of UPUA students.

Dr. Soler specializes in the history of education, particularly between the 19th and early 20th centuries. She has developed a novel methodology for analyzing historical educational narratives using QDA software, with significant results in her doctoral thesis and publications. She excels in both qualitative and quantitative analysis for educational statistical analyses and thematic bibliometrics.

## Summary

This interdisciplinary quantitative study offers a comprehensive assessment of how visits to the Civil War shelters in Alicante, which have been rehabilitated and opened to the public, influence awareness of cultural memory heritage in an urban context. The framework of the FEDER Operational Program "Sustainable Growth 2014-2020", delves into how these spaces contribute both to sustainable urban development and to historical understanding in society. Through a retrospective longitudinal design, data from 407 visitors were collected and analyzed between August 2023 and January 2024, aiming to profile the visitors, their motivations, and their visitation patterns. Preliminary findings reveal a positive reception and an increase in awareness of the historical significance of the shelters, suggesting a substantial impact on the appreciation of memory heritage. The analysis provides key insights for managing cultural heritage by proposing enhanced strategies for the communication and promotion of historical legacy. This article is positioned at the intersection of tourism research and cultural heritage studies, exploring the links between culture, sustainable development and tourism through an inter- and transdisciplinary approach that encompasses both social sciences and administrative and business practices.

## Riassunto

Questo studio quantitativo interdisciplinare offre una valutazione completa di come le visite ai rifugi della Guerra Civile ad Alicante, che sono stati riabilitati e aperti al pubblico, influenzano la consapevolezza del patrimonio della memoria culturale in un contesto urbano secondo il quadro del Programma Operativo FEDER "Crescita Sostenibile 2014-2020". Viene inoltre approfondito il modo in cui questi spazi contribuiscono sia allo sviluppo urbano sostenibile che alla comprensione storica nella società. Attraverso

un disegno longitudinale retrospettivo, sono stati raccolti e analizzati i dati di 407 visitatori tra agosto 2023 e gennaio 2024, con l'obiettivo di profilare i visitatori, le loro motivazioni e i loro modelli di visita. I risultati preliminari rivelano un'accoglienza positiva e un aumento della consapevolezza del significato storico dei rifugi, suggerendo un impatto sostanziale sulla valorizzazione del patrimonio della memoria. L'analisi fornisce spunti chiave per la gestione del patrimonio culturale, proponendo strategie avanzate per la comunicazione e la promozione del patrimonio storico. Questo articolo si posiziona all'intersezione tra la ricerca sul turismo e gli studi sui beni culturali, esplorando i legami tra cultura, sviluppo sostenibile e turismo attraverso un approccio inter e transdisciplinare che comprende sia le scienze sociali che le pratiche amministrative e commerciali.





# SHARING, PRESERVING AND EXPLOITING DIGITAL COLLECTIONS AT THE VATICAN LIBRARY

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*Keywords:* digital library, long-term digital preservation, interoperability, machine learning, digital humanities

## 1. Introduction

For centuries, the Vatican Apostolic Library (BAV) has collected, preserved, studied and made available, manuscripts and archival documents, ancient and modern printed books, coins and medals, prints, drawings, photographs, molds and objects of the highest value, true treasures of science, spirituality, literature, music, and art [1-6]. Its main goal is to enable the progress of research and the development of culture. While it is a highly specialized library whose collections require specialized knowledge and skills in subjects such as linguistics, history, codicology, paleography and others, to correctly deal with the BAV collection, the Vatican Library has from its origins always been an open library - an open library endowed with a humanistic and universal vision, dedicated to promoting Gospel values and dialogue between persons, peoples and generations through culture, but first and foremost through its qualified service to scholars who seek and spread the truth in their very diverse fields of investigation [7].

Over the last twelve years, the Vatican Library has promoted a digitization project [8-9] aiming at the digital acquisition of its entire collection of manuscripts, which is composed, excluding archival units, of 80,000 codices mostly from the Middle Ages and humanistic period. The implementation of an interoperable digital library and the exploitation of its data is a challenge of our times and ideally relies on the same original purpose that expressed the humanistic idealism of the age of Popes Nicholas V (1447-1455), Sixtus IV (1471-1484) and Sixtus V (1585-1590), in the 15<sup>th</sup>-16<sup>th</sup> centuries, with the creation of a universal library, open to the public, "for the common benefit of the learned". Today the Vatican Library is still at the service of learned women and men, having evolved during its long history into a modern research library, preserving valuable collections and treasures, which constitute an essential part of the cultural heritage of mankind.

The year 2012 marks the beginning of the digitization project when a preliminary study of the requirements of photographic devices was completed. At the same time, all necessary improvements were made to the Vatican Library's server farm to hold the long-term preservation archive of high-resolution images that were acquired.

The aim of the project was to achieve the twofold objective of long-term digital preservation on the one hand and dissemination of digital contents through a web platform on the other. To achieve both objectives, an action-oriented approach was chosen which focused on the dynamic and innovative application of standards, best practices and shared principles relevant to the domain of international library science.

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The article outlines the most important characteristics of this experience and focuses on the evaluation of digital assets that allow digital humanities to study ancient roots of knowledge in a new way. The availability of such a vast collection of digital objects consequently leads to effective data mining operations for the process of extracting, learning and predicting. The library, in its initiatives for the study of the digital contents produced so far, is promoting case studies relating to computer vision for the automatic detection of iconographic contents in selections of digitized manuscripts of the BAV described below.

## 2. Long-Term Data Preservation (LTDP): Pipeline and FITS Format

In the digital age, the problem of long-term preservation is still a challenge. For the BAV, ensuring data legibility and accessibility to digital resources is deemed essential and forms an important part of its preservation strategy. Long-term digital preservation requires the use of technologies and processes which can guarantee the survival of digital information objects while maintaining their integrity and identity [16]. This is the challenge the BAV faces today.

First and foremost, LTDP requires quality control of the digital objects to be ingested within the archiving system. As a first step of the pipeline, all images acquired at the Vatican Library are checked by a validator, in addition to the human post-production control, which is carried out by the staff of the Library's Photographic Lab. The validator adopted for the analysis of TIFF files produced by acquisition devices is the open-source JHOVE<sup>1</sup>. This tool, typically used during routine operations of digital repositories and for digital preservation activities, is able to identify and validate image files and their related technical metadata.

After quality control of the master copies, the LTDP pipeline for the ingestion of digital objects is structured to undertake different tasks which are automatically tracked thanks to a software controller<sup>2</sup> called Inside [11]. Upon completion of validation by JHOVE, Inside enables the automatic conversion of TIFF master copies into the format that the BAV deems suitable for long-term preservation, which is described below.

In considering the suitability of particular digital formats for the purpose of preserving digital information as a relevant resource for future generations, it is useful to analyze some important factors that could be crucial for making the correct choices.

### 2.1. Seven sustainability factors

The Library of Congress in Washington which, in addition to being the U.S. national library, is a center of excellence for the development of metadata for bibliographic resources and for the best practices of digital preservation, designates seven sustainability factors to be considered when choosing the format to entrust digital assets to<sup>3</sup>.

These factors are relevant because they influence feasibility and the cost of preserving information content; furthermore, they ensure the effectiveness and durability of digital objects over time, beyond any eventual technological changes.

They are significant whatever strategy is adopted as a basis for future preservation actions. It is appropriate to briefly synthesize these sustainability factors in order to understand the format chosen by the Vatican Library for its digital preservation.

1. **Disclosure:** Disclosure refers to the availability of information and instructions for uses related to long-term format management. Preservation is not feasible

without understanding how the information contained is encoded as bits and bytes in digital files.

2. **Adoption:** Adoption refers to the degree of diffusion of the format. A format that has been employed or used by archival institutions provides evidence of adoption.
3. **Transparency:** Transparency refers to the format's ability to be directly parsed with basic tools, including human readability using the simple mediation of a text-only editor.
4. **Self-documentation:** Formats that are self-documenting are a guarantee of long-term readability. If there are explanatory elements within them the risk of obsolescence is reduced. This is a very important feature that is also applicable to the embedded metadata that describes the digital object, in relation to its content, its technical characteristics and the information that specifies its life cycle (e.g. conversions, updates, etc.).
5. **External dependencies:** External dependencies refer to the degree to which a particular format depends on a particular hardware, operating system, or software to render or use, and the expected complexity in managing those dependencies in future technical environments.
6. **Impact of patents:** Patents and licensing costs related to a digital format can affect, if not prevent, the sustainability of that format in the long run. Although the costs for licenses to decode formats are currently low, the existence of patents can slow down the development of open-source encoders and decoders. Furthermore, prices of commercial software for transcoding content into outdated formats can result in high licensing costs.
7. **Technical protection mechanisms:** The techniques used to protect data and documents in an LTDP archive should allow access to file formats in the present as well as in the future. Therefore, if files are protected in an LTDP archive with mechanisms such as encryption, a security system should be implemented to document their possible decryption.
8. It is these principles which inspired the Vatican Library in the choice of digital format to be adopted for the LTDP archive and the reasons for which the FITS (Flexible Image Transport System)<sup>4</sup> format was selected.

## 2.2. FITS Format

FITS [12] is an image and data format widely used in science, mainly for archiving astronomical images, and has been in use for more than 50 years; thus, we may argue that its longevity is undisputed because it has been in use since the 1970s. FITS was conceived as a format to be used for the transfer of data between astronomical observatories and research centers (hence the "T" in the acronym). It was later used as a tool for archiving and analyzing scientific data by institutions such as NASA (National Aeronautics and Space Administration), ESA (European Space Agency), ESO (European Southern Observatory). Its implementation started in 1976 and three years later the format was officially presented in the "International Image Processing Workshop" in Trieste (Italy)<sup>5</sup>. Since then, the format has evolved and the first official version was standardized in 1993 by the International Astronomical Union FITS Working Group, while the last release of the format dates back to 2016. Its development has always been guided by the principle "once FITS, always FITS": no change in the specifications should ever conflict with retrospective FITS files so as to avoid past files becoming potentially unreadable by future reading software.

Outside of these research areas, the FITS format is still not that popular, and is mostly unknown to the general public. In the context of cultural heritage, BAV is one of the early adopters of FITS: interest regarding this format is emerging, following the use case of the Library as demonstrated by the publication of UNI 11845:2022 standard which is described below.

In the scientific world there are huge archives of FITS images: as an example, we can mention the archive of the PAN-STARRS system containing 1.6 Petabytes of data, the ESO archive containing 44.8 million files for a total of 1.01 Petabytes of data<sup>6</sup> and finally the FITS archive of the Vatican Apostolic Library, currently containing more than 8 million<sup>7</sup> FITS images for a total of about 500 Terabytes of data, to be increased due to the ongoing digitization project.

FITS was adopted because it has a series of distinctive characteristics that rely on the sustainability factors and make it especially suitable for the purpose of long-term preservation, particularly for its simple structure: it is made up of two fundamental parts, an initial part with ASCII encoding, called Header Data Unit (HDU), and a binary part containing the data (Figure 1).

```

SIMPLE =                               T / Java FITS: Tue Feb 20 12:36:48 GMT 2024
BITPIX =                               8 / bits per data value
NAXIS =                                 3 / number of axes
NAXIS1 =                                7740 / size of the n'th axis
NAXIS2 =                                10320 / size of the n'th axis
NAXIS3 =                                 3 / size of the n'th axis
UNIQKEY =                               T / Compliant with UNI 11845:2022
EXTEND =                                 T
SCHEMA = "Capp.Giulia.VIII.99_0002_fa_0148a" / Original image filename
SERIAL =                                -1 / The image is part of a group
GROUP = ""                               / File group URI
LONGNAME = "OGIP 1.0"                   / The HDU long string convention may be used
CREATOR = "FITSHeaderConv v2.0.0"       / Software that created this FITS file
INSTRUM = "Phase One IQ190"
PROGRAM = "Capture One 7 Macintosh"
DATE-OBS = "2019-01-10T19:10:11"
DATE = "2024-02-10T13:49:10" / Date and time of FITS file creation
EXPTIME = 0.0080000217648466666 / Exposure Time
REFERENCE = "https://nsl.vatlib.it/view/NGE_Capp.Giulia.VIII.99" / Publication ID
ORIGIN = "Biblioteca Apostolica Vaticana"
OBJECT = "Capp.Giulia.VIII.99"
COLORMAP = "RGB"                       / Colors mapping
CTYPE1 = ""                             / Linear transformation on axis 1
CTYPE2 = ""                             / Linear transformation on axis 2
CTYPE3 = "RGB"                          / Name of the coordinate represented by axis 3
CRPIX1 = 0.0 / Location of reference point along axis 1
CRPIX2 = 0.0 / Location of reference point along axis 2
CRPIX3 = 0.0 / Location of reference point along axis 3
CUVAL1 = 0.0 / Coordinate CTYPE1 at the reference point CRPIX1
CUVAL2 = 0.0 / Coordinate CTYPE2 at the reference point CRPIX2
CUVAL3 = 0.0 / Coordinate CTYPE3 at the reference point CRPIX3
CUNIT1 = "mm"                           / Units of CUVAL1 and CDELTA1
CUNIT2 = "mm"                           / Units of CUVAL2 and CDELTA2
CUNIT3 = "mm"                           / Units of CUVAL3 and CDELTA3
CDELTA1 = 0.004978264978264974 / Coordinate increment at reference point
CDELTA2 = 0.004978264978264974 / Coordinate increment at reference point
CDELTA3 = 1.0 / Coordinate increment at reference point
CHECKSUM = "ZML2MjC2MjC2MjC"          / checksum for the current HDU
DATALEN = "3644749434"                  / checksum of the data records
INSTRUME = "INCH"                       / Resolution Unit
INSTRUME = 462.0 / Horizontal resolution
INSTRUME = 462.0 / Vertical resolution
RAV01 = "Alamize"                       / Contributor
RAV02 = ""                               / Lens model
RAV03 = 11.000140181779688 / Aperture Value
RAV04 = 60 / ISO speed

```

Figure 1. Example of FITS Header.

In relation to sustainability, it is easy to demonstrate its peculiar characteristics of self-documentation, transparency, freedom of use and autonomy.

- **Self-documentation:** The first blocks of information composing the FITS file, which are encoded in ASCII-and therefore easy to access, contain a set of metadata, essential for using the data contained in the file itself. In particular, the first bytes contain the number of bits per pixel, the number of axes and the number of elements per axis in the image contained in the file. This information is sufficient for understanding and accessing the content of the individual HDUs contained in the FITS files.
- **Transparency:** The ASCII encoding allows immediate reading access to all metadata contained in the FITS file header; in addition, the structure of the FITS file makes it possible to point directly to the bytes corresponding to the various pixels of the image by exploiting the information contained in the first bytes of the file. Consequently, the metadata are easily accessible by means of data analysis tools and can be read instantly even through any available hex viewer.
- **Freedom of use:** The FITS format is an open format, so its technical specifications are publicly available and there is no legal restriction on the use of the format. Otherwise, it would not be possible to guarantee the readability of files in the long term.
- **Autonomy:** No special software or hardware is required to use the format. In order to gain access to a file's content, it is sufficient to access the file's binary data.

Therefore, the evolution, or conversely the obsolescence, of the hardware and software, will never jeopardize the use of a FITS file archive.

### **2.3. Requirements for LTDP archives and UNI 11845:2022**

The implementation of the LTDP archive of FITS files revolves around a series of requirements that have been identified for managing the BAV's digital objects. These requirements are closely related to the possibilities that the FITS format offers. They pertain to:

- **Homogeneity:** Homogeneity provides the LTDP archive with efficient management of data validation processes and actions for the recovery of corrupt or truncated data, as well as helping in information retrieval processes. In addition, it facilitates the use of the archive contents even if the documentation describing the archive is itself lost.
- **Validation:** The validation process includes a series of procedures designed to verify the consistency and structure of the data archive and to pinpoint the eventual issue of data corruption or data loss.
- **Conversion:** The long-term versatility and usability of a digital image archive is guaranteed by the ability to convert the FITS files into other exchange formats if requested by end users (e.g.: PDF format, JPEG format, TIFF format). The conversion process is therefore crucial in building a long-term preservation archive.
- **Information retrieval:** The extraction of metadata from the files contained in the archive is an essential process for the maintenance and usability of the archive itself. The LTDP archive allows an efficient metadata extraction by

- accessing only those portions of the FITS file that contain the metadata itself.
- **Origin and history:** Whatever the nature of the digitized object, it is essential to keep knowledge of the file acquisition and creation methods and all modifications undergone by the file itself for the purpose of long-term preservation. This information is an essential part of the image archive, and it is invoked or directly stored in the FITS files.
  - **Semantic content:** Whatever the nature of the digitized object, a basic description has to be included either as referenced or wrapped data, in relation to the semantic content that can therefore enable the archived data to be interpreted in the long term.
  - **Structural models:** The LTDP archive “FITS format based” can preserve the logical relations between the digital data and the related metadata, as well as between the digital data itself when there is a need to keep memory of the configuration pertaining to physical and/or logical arrangement of the data represented and managed in one or more FITS files. This includes, for example, cases such as:
    - Preservation metadata (history of the data) and descriptive metadata (semantic content): typically implemented as XML files in specific namespaces, these metadata can be embedded as binary files in specific HDUs of the FITS file.
    - Embedding of multiple objects into a single FITS file.
    - Relationships between multiple FITS files.

These requirements and the related technical documentation have been standardized and published by the body for Italian National Unification: the official Italian Standardization Body entrusted with the development, publication and promotion of national and international standards<sup>8</sup>.

The creation of UNI 11845:2022 [13] within the UNI Technical Commission “Documentation and information”<sup>9</sup> occurred according to the principles and rules of international standards. The technical committee that carried out this work was attended by experts, in addition to the BAV, from the Italian Ministry of Culture (Directorates of Library and Archival Heritage), academic institutions and scientific bodies (University of Rome Tor Vergata, National Institute for Astrophysics, European Space Agency), Italian national associations of archivists and librarians, the archive of the Bank of Italy and Italian companies specialized in LTDP and the preservation of digital assets.

LTDP requirements stated in this standard are paving a new way in the technical evaluation of LTDP archives, especially for cultural assets and are, moreover, demonstrating a change of paradigm: from the conception of a long-term archiving that provided for the ingestion of data considered as inert and closed in the preservation system, to an archive structure where access to the data implies constant data curation (Figure 2).

This means that access is high-performance, enabling data analysis for the preservation of documents and data that can be updated and documented with the semantic content of the original objects.

### 3. The digital library and its discovery services

The second objective of the Vatican Library's digitization project concerns implementation of the digital library platform [14].



Figure 2. Example of conversion: from FITS format to a derivative format by using the BAV application.

The conceptual design of the functional architecture is mostly focused on enhancing the discovery services for the digital collection. The implementation of a digital library platform is not a mere display of digitized images nor a way of linking bibliographic records in a catalog. Firstly, a dissemination pipeline must solve the problem of the image aggregation of complex digital objects, such as books. A folder stored in a file system physically contains all the files of a distinct semantic unit (e.g., images of a manuscript, per each folio) however its unitary structure is obviously inadequate for a viewer to represent the digital object in its aggregation. Folders contain files whose ordering is simply by file name and not according to the physical or logical sequences of contents. So even just viewing one image after another, to digitally compose the volume requires the application of standardized procedures. The physical sequence of a manuscript, for example, may involve different numbering or irregularities that should be documented and managed for viewers. Physical as well as logical sequences (about the structure and contents of the digital object) are typically managed by metadata syntax. Without going into technical details of the standards that manage the aggregation of data in complex digital objects, behind the scenes of digital library functions there has been a METS profile<sup>10</sup>, designed by the BAV, since the first generation of the online digital library<sup>11</sup> and is now used for the DVL (DigiVatLib)<sup>12</sup> (Figure 3). The DVL, therefore, offers navigation of the digitized contents per each of its distinct collections and each of these refers to descriptive syntaxes, which are peculiar to each type of resource. For example, searching for a digitized manuscript entails indexes corresponding to the specific elements describing codicological information along with the individual works within a codex, but a table of contents is also included as a pointer to browse the digitized resource. The DVL therefore provides dual access to information, which includes both the consultation of images and the consultation of all the information associated with a digitized resource, in its native description, including any bibliographic references.



Figure 3. DVL – DigiVatLib home page.

Another widely used service is the online availability of inventories and finding aids. These references constitute an individual collection with its specific search menu and their permalinks are included in the descriptive metadata of manuscripts, in order to connect the description to the related references in inventories. The ingestion into the DVL of each digital object implies its automatic connection to the bibliographic records available in the online catalogs. The recognition of the structure of the persistent identifier, associated to the digital object, allows the DVL to direct the objects in each collection: manuscripts, incunabula, graphics, coins and medals, printed books<sup>13</sup>.

This is one of the main tasks performed by the back-end system, called DWF (DigiWorkFlow), which is responsible for orchestrating the complete workflow, i.e. from the ingestion of digital images to the structuring of the METS, along with the association of descriptive and structural metadata and the viewer. The latter conforms to the specifications of the interoperability protocol IIIF (International Image Interoperability Framework)<sup>14</sup>.

The DVL was implemented in 2016 and at that time, its most innovative feature was the adoption of the IIIF [15], which radically changed the paradigm of use of digital objects. The Vatican Library's scientific interest in the IIIF data model<sup>15</sup> dates back to 2015. At that time, many digitization projects that libraries were implementing, provided access to valuable collections but considered them as individual repositories, like *silos*. Access to these rich collections held in cultural heritage institutions was crucially dependent on each database configuration and service functions. A means to break down these barriers was to employ the techniques of the semantic web able to interconnect repositories of digital objects (Figure 4). In essence, the IIIF data model is based on the semantic web approach to allow scholars to compare and study digital objects by using tools able to offer a simultaneous display of resources despite their different provenances.

The term "interoperability" in the IIIF acronym stands for the technological effort that seeks to meet this need, to express the opportunity of exchanging information or services between IT systems, by facilitating their mutual interaction. The interoperability of digital libraries began in 2012 at Stanford University Libraries. A group of experts from the Digital Library Systems and Services Division studied how to access digital images of manuscripts on the web, along with all the data and documentation pertaining to them (the description of a catalog, detailed notes commenting on particular elements, transcription of folios, etc).





Figure 4. DWF – DigiWorkFlow: example of the Archival Information Package (general information).

This study led to the creation of a standardized "interoperability protocol" for the free circulation of digital data and images in the web, directly traceable through search engines and independent from the repositories of individual libraries.

In a nutshell, by using an IIIF-compliant viewer, it is possible to display a digitized manuscript on a laptop, simply by calling up its web address (what is technically called URI: Uniform Resource Identifier of the digital object) and then placing it alongside another manuscript (or even several others) for all relevant comparisons. The application of the interoperability protocol to the world of manuscripts immediately appeared of great interest for studies of philology, bibliography, paleography, with particular regard to critical editions and the possibility of carrying out virtual reconstructions of collections dispersed in various libraries or simply of fragmentary materials preserved in different places.

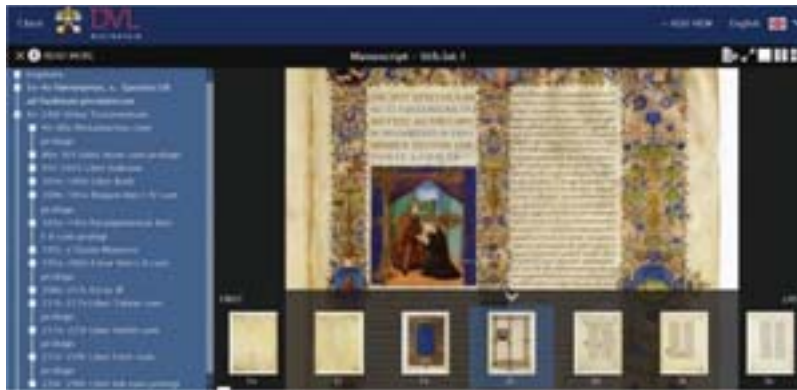


Figure 5. DVL: example of a digital resource.

The Vatican Apostolic Library (Figure 5) is one of the most prominent early adopters of IIIF technology [10]. In 2015, the experimentation of a small but significant first case study by the BAV was completed which involved applying the protocol on a small number of digitized manuscripts and managing the annotations: transcriptions, notes, and marginalia on folios. After this first pilot project, only a year later, the DVL was

implemented, fully compatible with the IIIF. In the years 2016-2019, the Vatican Apostolic Library promoted a special research activity on some specific groups of manuscripts, the results of which were available in the said “IIIF-mode” by comparing and annotating on the folios of the manuscripts transcriptions, comments on the texts, glosses and illuminations, identification of copyists, illuminators, and owners. The Andrew W. Mellon Foundation, the New York foundation that supported the development of the IIIF in its most significant applications, sponsored this three-year research. The initiative made use of the technical consultancy of the same Stanford experts who first studied this revolutionary conception of cultural heritage, which became, in its digital expression, a sort of unified heritage, a “mare magnum” on the open horizon of knowledge. An innovative service in which the Vatican Library can express its mission, confirming its centuries-old tradition. The outcome of this research was the implementation of a platform capable of managing selections of resources with the main purpose of producing annotations (transcriptions, comments, comparative analysis of texts and images) performed by curators. The peculiar characteristics of this implementation have demonstrated how IIIF capabilities can be used to study manuscript collections. Furthermore, the features required in this project were consistent with the design patterns and development practices embraced by IIIF communities to be integrated in open-source tools.

```

@context: "http://iiif.io/api/presentation/2/context.json"
@id: "https://vial.net/iiif/it/CL_006_let_1/manifest.json"
@type: "sc:Manifest"
articleid: []
label: "006_let_1"
description: ""
thumbnail[]: []
viewingdirection: "left-to-right"
viewinglist: "paged"
attribution: "Images Copyright Biblioteca Apostolica Vaticana"
logo: "https://vial.net/iiif/it/resource/006/006_let_1.jpg"
sequences:
  - id:
    @type: "sc:Sequence"
    canvas: []
    viewingdirection: "left-to-right"
    viewinglist: "paged"
  structures: []
  seek[]:
    - "https://vial.net/iiif/it/006/006_let_1"

```

Figure 6. Example of an IIIF manifest of a digitized manuscript.

#### 4. Thematic Pathways on the Web

The BAV use case on IIIF annotations is entitled *Thematic Pathways on the Web*<sup>16</sup> (which produced over 26,000 annotations<sup>17</sup>). As previously mentioned, this is an implementation carried out in collaboration with Stanford University Libraries for manuscripts selected under a specific theme. The project platform has implemented software such as Mirador<sup>18</sup> and Spotlight<sup>19</sup>. The latest is an open-source app based on the Ruby on Rails framework,<sup>20</sup> for managing platforms with search functions that exhibit collections and objects taken from digital libraries.

The content of all annotations (created in Mirador) is indexed along with the

metadata (exposed as URI-addressable resources through the OPAC (Online Public Access Catalog) and read by Spotlight), thus constituting a semantically enriched system that allows scholars to carry out integrated searches for all the available information related to a resource, as well as managing the narrative part of the thematic pathway. Each of these is a sort of virtual exhibit through texts, images and through the discovery of content in the innovative ways offered by the IIIF. Essentially, a thematic pathway in the BAV Spotlight platform is composed of three different types of information:

- A general description (introduction, historical information, etc.) of the chosen theme that represents the narrative in which the thread of the discourse is intertwined with the contents enjoyed via IIIF.
- A set of descriptive and content metadata for each manuscript chosen.
- A large pool of annotations, comments, insights on detailed parts of a manuscript (e.g. texts, commentaries, miniatures, etc.) and transcriptions of information units.

Above all, the objective is to deal with themes identified in the digital collections and showcase the selected digital resource, so as to conceive an exhibition itinerary. These digital exhibitions promote a new perspective to the study of manuscripts by means of web communication and IIIF (Figure 7). The first four exhibits carried out in the three-year research period focused on the following topics:

A. Course in Paleography (Greek and Latin, from Antiquity to the Renaissance)

The rich collection of manuscripts preserved in the Library makes it possible to follow the evolution of the Greek and Latin scripts all the way from antiquity to the Renaissance. A careful selection of images of the manuscripts, accompanied by transcriptions and comments (such as IIIF annotations) is offered as teaching material for a course in Greek or Latin. The availability of online manuscript images, together with the possibilities offered by the IIIF API (Application Programming Interface), enables a complete transformation of teaching practice in this field.



Figure 7. Thematic Pathways on the Web: example of page.

## B. Latin Classics

The Vatican Library owns one of the most important collections of manuscripts with texts by Classical Latin authors, many of them richly illustrated. The aim of this pathway is to describe 81 manuscripts directly from the original codices: metadata and annotations pertaining to the study of texts and illuminations have been provided. The work throws light not only on the illustrations of the texts but especially on the relationship between text, illuminations, comments and glosses regarding the main text in a manuscript (marginal or interlinear notations).

## C. Vatican Palimpsests

The Vatican Library has identified more than 380 manuscripts in its own collections, which include palimpsests, that is, erased then recycled parchment folios. This pathway intends to present this rich and scarcely explored material to the public by making in-depth archaeological research on the palimpsests of twenty-four select manuscripts and recover their lost identities with the help of IIF technology.

## D. The Library of a "Humanist Prince"

The library of Federico da Montefeltro (1422-1482), Duke of Urbino (from 1474), is known as a typical humanist collection. In the first years, Federico bought or ordered manuscripts in Florence (both in writing and in illumination), but later preferred Ferrara or Paduan artists and scribes active in Urbino. This pathway points out the characteristics of the two schools, very different in style, and the most important artists (half of the chosen manuscripts is representative of the Florentine school while the other half of the Ferrara and Paduan schools). The *Thematic Pathways on the Web* platform can be used for hosting many digital contents. The most recent virtual exhibitions in the web showcase are: *Super Hanc Petram* (of the Vatican Medal Collection) and more recently *Traveling with Dante*<sup>21</sup>.

## 5. Beyond AI, again IIF

The adoption of artificial intelligence, computing vision and machine learning is rapidly growing. The impact of these new IT frontiers in the world of digital humanities means there is an increasing number of experiments and services: from the improvement of optical character recognition of texts to new services for data analysis of digital collections.

The Vatican Library is promoting experiments both in the field of character recognition<sup>22</sup> and in research related to the machine learning potential of a convolutional neural network [17]. A convolutional neural network (ConvNet/CNN) [18] is a deep learning algorithm that is particularly useful for acquiring input images and analyzing them against an associated dataset, in order to recognize known *patterns* by identifying objects, classes and categories (while in the training phase it builds the *reference patterns*). The artificial neural network experiment focused on the automatic detection of iconographic content of a selection of digitized manuscripts. The most advanced content of this case study is strongly related to interoperability, giving it an innovative feature since the machine learning carried out is proposed as IIF annotations. This result is not only remarkable from a mere technical point of view but above all for the opportunity that it offers to integrate current discovery tools with data mining aimed at detecting the contents of digital objects.

### 5.1. YOLO and its biases: a case study

The convolutional neural network that was implemented made use of YOLO (You Only Look Once)<sup>23</sup>: an algorithm capable of detecting objects present in images. YOLO “looks once” at the image because it can predict its meaning after just one interpretation. The detection is carried out in accordance with the instances of objects belonging to a specific class recognized within an image. The algorithm basically recognizes the existence of objects in an image using bounding boxes and assigns types or classes to the identified objects. For example, it takes an image as input and generates one or more bounding boxes, each labeled as a reference class. In principle, a convolutional neural network can handle classification, multi-class localization and detection of objects with multiple occurrences. Image classification algorithms predict the type or class of an object in an image (input) from a predefined set of classes for which the algorithm has been trained. The output is a class or label that represents a particular object, accompanied by a confidence index of that prediction<sup>24</sup>.

Object localization algorithms detect the presence of an object in the image and represent its position in a bounding box. The Vatican Library implemented the YOLOV5 version (using PyTorch<sup>25</sup>). YoloV5 is one of the most relevant pre-trained networks that uses COCO (Common Objects in COntext)<sup>26</sup>, i.e. a large dataset of images: over one and a half million instances of objects segmented within images, corresponding to 80 categories of objects. The artificial neural network was able to identify and frame the iconographic contents with the limit of the identification of COCO classes.

In the application of COCO in the domain of illuminations, this case study highlighted the issue related to the needs of a dataset consistent with the corpus of data to be analyzed: the current datasets available in pre-trained networks do not have classes corresponding to the categorization of the objects identified in illuminations or iconographic details within manuscripts. With regard to the choice of manuscripts (the images to be segmented): instead of establishing selection criteria, for the purpose of this case study, it was preferred to opt for a random selection by considering only two aspects:

- A quantity of images adequate for the training of the artificial neural network.
- The availability of descriptive metadata of the manuscripts to be processed.

The data sample consists of 1,874,999 images, corresponding to 5,186 manuscripts. The successful segmentation process led to the detection of 54,629 objects. For each, the network added a specific probability index.

The manuscripts were divided into the following groups, in order to proceed with the analysis of the results or the relevance of the classification of the iconographic content identified in the segmented images:

- Manuscripts (115 in total) with at least 100 records,
- Manuscripts (232 in total) with at least 50 entries,
- Manuscripts (483 in total) with at least 20 records,
- Manuscripts (747 in total) with at least 10 records,
- Manuscripts (1054 in total) with at least 5 records.

The sample analyzed, based on the presence of illuminations, is 75 manuscripts belonging to the first group<sup>27</sup>, in which the artificial neural network identified and classified 21,933 objects.

The interpretation of the network, depending on the COCO dataset, obviously

classified iconographic contents corresponding to the classes to which it belongs. It is important to dwell on the attribution of classes corresponding to shapes, in analogy to the patterns of the images of which COCO is composed.

As for an example of biases, we may refer to the selection of circular or ovoid details found in the digitized folios, such as halos or stamps, but also holes in parchment subsumed by the artificial neural network under inconsistent categories with respect to their real meaning (Figure 8).

The systematic human validation of the results obtained from the automated neural network was limited to some specific categories. From a quantitative point of view, at the end of these checks, the data obtained were the following:

- 2575 overall total results of which:
  - 1260 results were actually consistent with the class assigned by the network (approximately 49% of the total);
  - 1315 results with class reassignment or with class added from scratch and, if applicable, related box from scratch (approximately 51% of the total);
  - 1034 results (irrelevant and later deleted);
  - 309 new classes added.



Figure 8. Example of segments interpreted in YOLO using COCO as 'Frisbee'.

From a qualitative point of view, the errors (1315+1034) that required human intervention are obviously interesting. In the group of irrelevant and, therefore, deleted results, these were mostly cases of outlines or shapes interpreted as iconographic content. Classes that were reassigned or added, are either due to the failure of the network, a lack of the corresponding class in COCO or a mismatch of concepts (Figure 9).

## 5.2. From results of the artificial neural network to automated IIF annotations

The results of the artificial network relating to the 75 selected manuscripts (with at least 100 objects detected, as previously reported) - which for each segment (object) denotes the class and the probability index (*confidence*) of this prediction - were

transformed into IIIF annotations and indexed within the Spotlight platform in which the aforementioned BAV's *Thematic Pathways on the Web* are disseminated.



Figure 9. Example of biases.

While in the latter the annotations for each thematic pathway are part of a curatorial project that sees the commentary, transcriptions, classifications as manually filled annotations, in this case study, the script (called AI4I<sup>28</sup>) converted the output of the artificial neural network to an annotation that is integrated into the set of all data collected, using IIIF, on that specific digital object.

The assigned class is transformed into the IIIF annotation tag (which is preceded by a source-specific prefix: 'AI4I (neural network)' while the body of the annotation reports the result in its original form.

The coordinates of the segmented images become the IIIF annotation region that the script transforms into canonical annotations<sup>29</sup> (Figure 10).

```

tag="person"
testo=" class: person<br> confidence: 0.5682786703109741"
canvas="https://digi.vatlib.it/iiif/MSS_Urb.lat.1/canvas/p0003"
x=400
y=500
w=300
h=500
coordinates="xywh="+str(x)+" "+str(y)+" "+str(w)+" "+str(h)
coordinateshtml="M"+str(x)+" "+str(y)+"h"+str(w/2)+"v0h"+str(w/2)+"v"+str(h/2)+
"v"+str(h/2)+"h"+str(w/2)+"h"+str(w/2)+"v"+str(h/2)+"z"
manifest="https://digi.vatlib.it/iiif/MSS_Urb.lat.1/manifest.json"
id="Urblat1ann14"
color="#ff8c00"
strokewidth="3"

```

Figure 10. Example of transformation: data from YoloV5 and the relation to the IIIF 'json manifest' of the manuscript to which it belongs.

The *AI4I* script transforms these values into the information shown in Figure 11.

```
{
  "@context": "http://iiif.io/api/presentation/2/context.json",
  "@type": "oa:Annotation",
  "motivation": {
    "oa:tagging",
    "oa:commenting"
  },
  "resource": {
    {
      "@type": "oa:Tag",
      "chars": "+tag+"
    },
    {
      "@type": "dctypes:Text",
      "format": "text/html",
      "chars": "+testo+"
    }
  ],
  "on": {
    {
      "@type": "oa:SpecificResource",
      "full": "+canvas+",
      "selector": {
```

Figure 11. Example of an IIIF annotation.

The *AI4I* script also includes other elements that are taken from the descriptive metadata of the manuscripts, such as context-specific information: shelfmark, dates, provenance, language of the manuscript.

The opportunity of integrating an environment of indexed data with the results produced by an algorithm could lead to improving a corpus of images and classes consistent with the domain of the original resources: to date, a corpus focused on illuminations is not yet available.

The success of this experiment can be found in the ability to use artificial intelligence within an integrated IIIF system, where automatic processing is only a tool to facilitate the retrieval of data and scholars' research within a hybrid environment, in which the data produced by human intelligence determine the use of artificial intelligence data (and not vice versa). In itself, the recognition of an illuminated content by a 'machine' does not add anything if a human being is already able to recognize it.

However, the value of these data can be found in their association with other elements such as descriptive metadata in order to enable data mining analysis to identify, with the help of algorithms, the evolution of styles, or schools or to recognize different manuscripts/illuminations.

## 6. Conclusion

The aim of this paper was to illustrate the process of production, conservation, development and increasingly wide sharing of the collections and digital resources of the



Vatican Apostolic Library, an institution of ancient origin that also today “is an outstanding means for the Church to contribute to the development and dissemination of culture, in support of the work of the Apostolic See. Through its various sections, it is responsible for collecting and preserving a vast patrimony of learning and art and of making it available” [19].

The evolution of the Vatican Library's digital services in the span of a decade fosters knowledge of the collections made possible by a complex technological world that exploits data analysis. If, previously, access to the collections was only through an OPAC, the integration of bibliographic information with digital objects opens up a varied scenario where the interoperable vision of the IIF for the sharing of research and resources breaks in. With growing awareness of the value of digital assets, the long-term preservation of heritage data and documents is considered as indispensable for the usability of the digital library.

The world of artificial intelligence has so far seen in the BAV experimental cases aimed at achieving objectives related to an integrated use of algorithms, in the coexistence of metadata, content production (such as IIF annotations) and human-generated research tools. In particular, the experimentation described in its workflow, demonstrated a method for setting up an 'AI-to-IIF' pipeline capable of ensuring: an efficient image partitioning method (the construction of a segmentation algorithm independent of YOLOV5), the ability to implement a CNN, the transformation of the results into *canvas* within an 'annotation list' in the IIF manifests of the selected manuscripts, the incorporation of annotations in the Spotlight platform. The annotations obtained, led to two important results. The first, a precious 49% of success of the artificial neural network without any human intervention, and the second, an equally relevant 51% of new attributions: corrections, reassignments of categories, new identifications that constitute an important element for a new training of the network for the detection of segmented images, using more consistent classes based on the aforementioned results. As is known, a heuristic method of machine learning initially proceeds through trial and error: what is defined as 'supervised learning'. In this type of learning, the artificial intelligence is trained to provide a known answer: the values are entered and compared with the correct answer. In this way the algorithms can gain experience in order to avoid previous errors and adapt their response for subsequent values, so that results are gradually improved until they give an accurate answer. The results of this case study are available at: <https://ai4mss-poc.vatlib.it>. On this web site (which is conceived as one of the thematic pathways of the exhibits included in the BAV Spotlight) scholars can evaluate all the annotations, tags, metadata of the manuscripts, analyses of the results, as well as groupings by century and provenance of the identified classes.

The current challenges and opportunities that the development of advanced technologies and cybernetics pose to our culture and society today, starting from humanistic institutions such as libraries, make us responsible, for the "cultivation of the human spirit", and the commitment, especially towards the new generations, of promoting and "protecting wisdom, in other words, knowledge that is human and humanizing" [20-22].

## Notes

<sup>1</sup> The original JHOVE project was a collaboration between JSTOR and Harvard University Library with funding from the Andrew W. Mellon Foundation for the Electronic-Archiving Initiative. JHOVE is currently maintained by the Open Preservation Foundation; Cf. <https://github.com/openpreserve/jhove> [Accessed: Jan. 28, 2024].

<sup>2</sup> Inside, on the one hand, pertains to check long-term preservation procedures and,

on the other, tracks the process of dissemination of digital collections. It was designed and implemented by the Coordination of IT Services of the BAV.

<sup>3</sup> Cf. Library of Congress:

<https://www.loc.gov/preservation/digital/formats/sustain/sustain.shtml> [Accessed: Jan. 28, 2024].

<sup>4</sup> “FITS Standard Web site: “FITS Standard Document: The official reference document that defines the requirements for FITS format data files”. Available at: [https://fits.gsfc.nasa.gov/fits\\_standard.html](https://fits.gsfc.nasa.gov/fits_standard.html) [Accessed: Jan. 28, 2024].

<sup>5</sup> Cf. [https://archive.stsci.edu/fits/users\\_guide/node8.html](https://archive.stsci.edu/fits/users_guide/node8.html) [Accessed: Jan. 28, 2024].

<sup>6</sup> Cf. <https://www.eso.org/public/science/archive/> [Accessed: Jan. 28, 2024].

<sup>7</sup> Total amount of FITS files at the time of writing of this article (January 2024).

<sup>8</sup> The UNI is recognized by the Italian State and by the European Union and is one of the national bodies of the International Standards Organization (ISO) and European Committee for Standardization (CEN).

<sup>9</sup> Cf. <https://www.uni.com/normazione/organi-tecnici/dettaglio-commissione/?id=37> [Accessed: Jan. 28, 2024].

<sup>10</sup> Metadata Encoding and Transmission Standard. It is the well-known administrative metadata schema, developed by the Library of Congress and internationally adopted in best practices for digital libraries.

<sup>11</sup> The first implementation, thanks to the support of Heidelberg University, was the DWork: an application able to manage the process flow of digitization and web presentation of the digitized works.

<sup>12</sup> Cf. <https://digi.vatlib.it> [Accessed: Jan. 28, 2024]. The DVL (DigiVatLib – Digital Vatican Library), as well as its back-end application, the DWF (DigiWorkflow), were designed by the Coordination of IT Services of the BAV and engineered by NTT Data Company (Japan).

<sup>13</sup> At the time of writing of this article (January 2024), the collection of printed books, currently composed only of cropped images related to details of pages in rare books, is evolving to manage a complete flow of digitization of printed books.

<sup>14</sup> International Image Interoperability Framework. Cf.:

<https://iiif.io> [Accessed: Jan. 28, 2024].

<sup>15</sup> Cf. <https://iiif.io/api/model/shared-canvas/1.0/> [Accessed: Jan. 28, 2024].

<sup>16</sup> Cf. <https://spotlight.vatlib.it> [Accessed: Jan. 28, 2024].

<sup>17</sup> It is the largest experimentation with annotations produced so far.

<sup>18</sup> Cf. <https://projectmirador.org/> [Accessed: Jan. 28, 2024]. Mirador is an open-source image (and recently video) viewer with the ability to zoom, view, compare and annotate digital assets compatible with the IIIF protocol.

<sup>19</sup> Cf. <https://github.com/projectblacklight/spotlight> [Accessed: Jan. 28, 2024]

<sup>20</sup> Cf. <https://rubyonrails.org/> [Accessed: Jan. 28, 2024]. Ruby on Rails is an open-source framework for web applications written in the Ruby programming language.

<sup>21</sup> Exhibit on the occasion of the 7th centenary of the death of Dante Alighieri (1265-1321) curated by the Vatican Library, promoted by the Dante Scientific-Organizational Committee (Pontifical Council for Culture) and supported by the Cortile dei Gentili.

<sup>22</sup> An optical recognition project of Greek writing, for the achievement of a dataset of one million characters. The project, led by the Japanese company Toppan and based on images of BAV manuscripts, is currently underway.

<sup>23</sup> This is the name of an open-source object detection algorithm that processes images very quickly, in virtually real time. Cf. <https://github.com/ultralytics/yolov5> [Accessed: Jan. 28, 2024].

<sup>24</sup> The probability index is between 0 and 1: the closer it gets to 1, the more certain

the prediction is considered by the network.

<sup>25</sup> PyTorch is an open-source software. It is a machine learning framework based on the Python programming language and the Torch library used to create artificial neural networks.

<sup>26</sup> Cf. <https://cocodataset.org> [Accessed: Jan. 28, 2024].

<sup>27</sup> Manuscripts were considered according to the illuminations detected.

<sup>28</sup> AI4I: Artificial Intelligence for Illuminations.

<sup>29</sup> This includes the connotative properties of IIF annotation (with the values, in the motivation, related to 'commenting' and 'tagging'. Cf. Simplest Annotations <https://iif.io/api/cookbook/recipe/0266-full-canvas-annotation/> [Accessed: Jan. 28, 2024].

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## Biographical Notes

**Paola Manoni** is the Head of the Coordination of IT Services at the Vatican Library. Her research and work areas are focused on metadata, digital libraries, interoperability, machine learning and long-term preservation for cultural heritage. She is currently chairing the UNI Technical Committee for "Documentation and Information" as well as the Sub Committee for "Technical interoperability" in the same organization. She represents the Vatican Library in many international initiatives such as the IIIF Consortium and, in this context, she is also co-chairing the "IIIF Design" Working Group.

**Mauro Mantovani** is the current Prefect of the Vatican Library. A Salesian Catholic priest, he is Professor of Theoretical Philosophy at the Salesian Pontifical University, where he was Dean of the Faculties of Philosophy and of Social Communication Sciences, and Rector Magnificus (2015-2021). His research focuses on borderline issues between philosophy, theology and science. He is a Councillor of the Pontifical Academy of St. Thomas and Member of many other Pontifical Commissions and Scientific and Academic Committees.

## Summary

This article outlines the two main purposes of the Vatican Library digitization project

(long-term digital preservation and dissemination of contents), focusing on the exploitation of digital assets and providing the humanities with a new way to study the ancient roots of knowledge. The article describes the LTDP (Long Term Data Preservation) pipeline, and the choice of preservation format based on sustainability factors and focuses on the LTDP archives requirements in light of the UNI 11845:2022 standard. The dissemination pipeline describes the digital library platform and demonstrates the Vatican Library's adoption of the IIF protocol (International Image Interoperability Framework). Finally, the article describes a pilot project relating to the use of AI for the recognition of iconographic details in illuminations, with the peculiarity of managing the results of the artificial neural network within IIF annotations.

### **Riassunto**

Questo articolo delinea i due principali scopi del progetto di digitalizzazione della Biblioteca Vaticana (conservazione digitale a lungo termine e diffusione dei contenuti), concentrandosi sulla valorizzazione del patrimonio culturale digitale. Il processo di digitalizzazione consente alle discipline umanistiche una nuova via per lo studio delle antiche radici della conoscenza. L'articolo descrive quindi la pipeline LTDP e le scelte del formato di conservazione effettuate in base a fattori di sostenibilità. Vengono inoltre discussi i requisiti degli archivi LTDP alla luce della norma UNI 11845:2022. La pipeline di diffusione descrive la piattaforma della biblioteca digitale e dimostra l'adozione da parte della Biblioteca Vaticana del protocollo IIF (International Image Interoperability Framework). Infine, l'articolo descrive un progetto pilota relativo all'utilizzo dell'AI per il riconoscimento di dettagli iconografici nelle illuminazioni, con la peculiarità di gestire i risultati della rete neurale artificiale all'interno delle annotazioni IIF.



# CULTURAL HERITAGE PRESERVATION THROUGH ONTOLOGY-BASED SEMANTIC SEARCH SYSTEMS

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## 1. Introduction

For centuries, the Angkor civilization has been a dominant influence in Mainland Southeast Asia (MSEA). It is generally known as the antecedent of the Funan Empire and Chenla Empire cultures, which bestowed the area with several awe-inspiring architectural heritage sites. It was these cultures that influenced the architectural establishment in this region, based on the beliefs and traditions of that period. The two Empires systematized the creation, design, and construction of the buildings and structures, and encompassed the architects, builders, designers, and craftsmen who collectively shaped the architectural landscape based on the prevailing styles and techniques of that particular period and culture. The architecture also included a number of temples, monasteries, once-lost cities, and an extensive network of canals, reservoirs, bridges, and road infrastructures.

Thousands of these heritage sites existed and were scattered throughout Cambodia, Laos, Thailand, and across the Mekong River to Vietnam. Owing to their geographical position some of the enormous temples, such as the Banteay Chhmar temple and Preah Khan temple, with entire temple cities, such as the Koh Ker temples and Sambor Prei Kuk temples, were protected because they were built in isolated areas, nestled in the jungle and hidden from mass commercial tourism. Over the years, mosses have gradually covered and almost obscured these structures, as they are often found in out of the way areas. This rich tapestry of historical evidence is a testament to the grandeur

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and complexity of the civilization which once prospered in this region [1–4].

The primary objective of this study was to integrate digital humanities methodologies into constructing ontology for the shared knowledge of the Khmer civilization in the Greater Mekong Subregion (GMS) countries. The ontology highlights the tangible cultural heritage (TCH) in these countries and is designed to serve as a pivotal resource for information congregation (i.e. gathering, categorizing, and analyzing) and retrieval. Hence, the study delineates the core aspects of this research for developing ontologies, especially for stone castles in the GMS countries.

As mentioned above, the Khmer civilization once had great influence in the Greater Mekong Subregion, dominant evidence being found in the form of the Khmer stone castles. As opposed to temples, these stone castles are noteworthy for several reasons, including their historical significance, architectural uniqueness, and cultural impact.

- 1) Historical significance: Khmer stone castles, also known as citadels or fortresses, played a crucial role in the defense and governance of ancient Khmer territories.
- 2) These structures served as military strongholds, administrative centers, and symbols of power and authority for the Khmer Empire, which flourished in Cambodia and neighboring regions during the medieval period. Their construction and strategic placement reflected the Khmer rulers' geopolitical dynamics and expansionist ambitions.
- 3) Architectural uniqueness: Khmer stone castles are renowned for their impressive architectural features, including massive stone walls, intricate carvings, and sophisticated hydraulic systems. These structures showcase the advanced engineering skills and artistic craftsmanship of the Khmer civilization, demonstrating their ability to harness natural resources and to adapt to diverse environmental conditions. The design and layout of Khmer castles exhibit a blend of indigenous Khmer styles with influences from neighboring cultures, resulting in a distinctive architectural heritage that continues to captivate scholars and enthusiasts alike.
- 4) Cultural impact: beyond utilitarian functions, Khmer stone castles hold immense cultural significance as symbols of Khmer identity, resilience, and ingenuity. These monumental edifices served as focal points for religious rituals, royal ceremonies, and communal gatherings, reinforcing social cohesion and spiritual beliefs among the Khmer populace. Moreover, the presence of Khmer castles in the GMS countries reflects the broader cultural exchange and diffusion of ideas across regional networks, highlighting the interconnectedness of the GMS countries' civilizations during the medieval period.

Thus, to effectively organize the knowledge for the ontology, the scope classification, elucidation, concepts, and structural intricacies relevant to the stone castles in the GMS were first constructed, then examined. This classification was instrumental in enhancing understanding and facilitating the search for information regarding these historical structures. Knowledge organization and ontology development were employed in the research methodology to enable the systematic networking of related information to foster data-sharing efficacy. Furthermore, semantic search capability implementation allows users to access and utilize this data more effectively [5]. Therefore, the developed ontology is able to play a significant role in enhancing semantic search system development. This advancement was a crucial step towards addressing and bridging semantic gaps in the subsequent phases of this research for the Khmer stone castles in the GMS countries.



## 2. Methodology

This study aimed to develop an ontology for knowledge relating to the Khmer stone castles across the countries of the Greater Mekong Subregion (GMS). With the goal of delineating knowledge scope and fostering an inclusive understanding of the Khmer stone castles in these nations, this ontology was an introductory step in enhancing semantic search systems. The study employed the Uschold and King methodology for domain ontology development [6] as the directorial framework and encompassed several key processes as follows:

- 1) Definition of the objective and scope;
- 2) Ontology development;
- 3) Subsequent evaluation and
- 4) Semantic search system development.

As indicated in the research objective, the study highlighted the findings and insights gained during the ontology development.

In delineating classification, the study results indicated that there were seventy-two (72) classes comprised of ten (10) primary classes which were: *Castle*, *Location*, *Country*, *Khmer art*, *Art type*, *Castle size*, *Castle type*, *Material*, *Religion*, and *Condition*. The study affirmed that the Khmer Stone Castle was interconnected with all other classes as outlined in the Semantic Web Table Specification and adhered to the W3C's RDF standards [7]. The data within the ontology were meticulously organized and presented following the format of a descriptive example, as illustrated in Table 1 and Figure 1. This structured approach facilitated a comprehensive and systematic representation of the information, aligning with best practices in data organization and semantic web standards.

Table 1. List of main classes and definitions

Class/Concept	Definition
<b>Castle</b>	A castle in the context of the Khmer stone castle ontology refers to a fortified structure or complex primarily built during the historical period of the Khmer Empire. These structures, predominantly constructed from stone and characterized by their architectural features, cultural significance and historical value, served various purposes, including religious, administrative, and some residential functions.
<b>Location</b>	This class specifies the geographical coordinates or regional area where the castles are located.
<b>Country</b>	This class indicates the specific country or region within the GMS where the castles are located.

Class/Concept	Definition
<b>Khmer art</b>	This class covers the diverse range of artistic expressions and creations that originated in or are associated with the Khmer culture, primarily in Cambodia. This art form is known for the unique characteristics which emerged over the centuries, particularly during the Angkor period.
<b>Art type</b>	This class describes the specific architectural characteristics and influences evident in the castle's design.
<b>Castle size</b>	This refers to the physical dimensions or scale of Khmer stone castles within the Greater Mekong Subregion (GMS) countries. This class covers the quantitative aspect of the castle's characteristics, including area, the amount of space it occupies, or any other relevant measurements that indicate the overall size of the structure.
<b>Castle type</b>	This refers to the categorization of Khmer stone castles based on distinct architectural styles, historical periods, functional purposes and design characteristics unique to the Greater Mekong Subregion (GMS) countries. This classification helps in the identification, comparison, and analysis of various castle structures within the ontology.
<b>Material</b>	The primary materials used for castle construction include various types of material components, such as wood, brick, and stone (e.g. sandstone, laterite).
<b>Religion</b>	The religious significance or usage of the castle, such as Buddhist or Hindu practices.
<b>Condition</b>	The present state of preservation of the structure.

The Khmer Stone Castle ontology was conducted within Hjørland's knowledge organization concept [8]. The primary focus involved the identification of knowledge categories by delineating concepts and semantic relationships while establishing their connections with relevant concepts. Systematically presenting the outcomes, we organized the data on principal concepts into a hierarchical structure based on related content groups through classification schemes. Subsequently, the data structure underwent further refinement into an ontology.

The domain of ontology development adhered to Uschold and King's conceptual framework [9], encompassing three distinct processes: defining purpose and scope, ontology development, and ontology evaluation.



Figure 1. The Khmer Stone Castle ontology

Notably, Noy and McGuinness's seven-step methodology for ontology development [10] was employed, utilizing the Hozo Ontology Editor in this study. Hozo, a graphical ontology editor, was designed in Japan to construct substantial ontologies. The

collaborative effort involved the Department of Knowledge Systems (Mizoguchi Laboratory) and ISIR-Osaka University in conjunction with Enegate Co. Ltd. (Osaka, Japan) [11]. The development and evaluation processes were conducted under the scrutiny of domain experts and application-based evaluation methods.

The approach involved a meticulous process of categorizing knowledge, where the initial steps revolved around identifying the key concepts and their interrelations. These relations were then mapped with relevant concepts, leading to the formation of comprehensive classification schemes. The resultant data hierarchy was a visual representation of the interconnected concepts, laying the foundation for the subsequent development of an ontology. Ensuring a systematic ontology development process, the implementation of Uschold and King's conceptual model [9] involved commencing with the definition of purpose and scope, progressing to the actual construction of the ontology, and concluding with a rigorous evaluation. Noy and McGuinness's well-established seven-step protocol [10] served as a guiding framework throughout this developmental phase. The Hozo Ontology Editor was the instrumental tool employed for its user-friendly graphical interface and ability to handle the intricacies of constructing robust ontologies.

The study utilized WIDOCO [12] to showcase the created ontologies and involved the following steps:

- 1) Choosing a template for the Ontologies Web Languages file;
- 2) Inputting metadata, and
- 3) Uploading the textual data.
- 4) Upon completion of the preparation, all files relating to the Khmer Stone Castle ontology were uploaded and made accessible at <https://is-school.kku.ac.th/owl/index-en.html>, as illustrated in Figure 2.



Figure 2. The Khmer Stone Castle ontology by WIDOCO

In this research methodology, an application-based OAM (Ontology-based Application Management) framework was utilized to develop a semantic search and ontology evaluation system that works on web-based technology.

The collected data were processed and analyzed with the application using web-based technology as the data originated from different sources; this technique was adapted for assessing the structure, content, and usability for the ontology development. We developed the semantic search system prototype through the OAM Framework [13], a tool renowned for providing reusable and configurable application

templates for building prototypes.

As a result, the rapid prototyping and hypothesis-testing capabilities of these application templates were particularly noteworthy. Additionally, the OAM framework was integrated with a Web API to enhance the scope for more advanced application development. In the ontology evaluation, moreover, the study employed key information retrieval metrics, such as precision, recall, and F-measure as the crucial metrics for evaluating the accuracy and efficacy of the semantic search system. Correspondingly, in a pivotal aspect, the study adopted information retrieval metrics to evaluate the efficacy of the process of information retrieval in the semantic search prototype.

This evaluation provided insight into the prototype's performance and facilitated the refinement of the approach to ensure appropriate function and user satisfaction. Based on the ontology, this prototype was designed to test and demonstrate how effectively the semantic search system could retrieve relevant information. Therefore, during the study, various tests were conducted to measure key performance indicators such as precision, recall and overall user experience in information retrieval.

### 3. Results

The aim of this research was to present ontology development designed to encapsulate knowledge of the Khmer stone castles in GMS countries. The ontology was meticulously crafted to define concepts of tangible cultural heritage and to elucidate its relationships, and was dedicated to investigating in-depth cultural heritage content, particularly the Khmer stone castles located in Thailand, Laos, Vietnam and Cambodia. As a pioneer study, this investigation tried to discover and analyze architectural characteristics and historical backgrounds which would contribute to a broader understanding of the regional cultural heritage.

Furthermore, to heighten capacity, a semantic search application was implemented to demonstrate the practical utility of ontology development, which was evaluated by the ontology specialists accordingly. In addition, several complex queries were designed during the evaluation to leverage the relationships among the ontological classes.

As a result, results were obtained with pin-point elements and high accuracy. This evaluation focused on assessing the ontology's efficacy, particularly highlighting the hierarchical structure of the ontology knowledge and emphasizing how this structure enabled the ontology to effectively represent and confirm its effectiveness within the particular domain of knowledge it aims to address. In essence, it suggests that the hierarchical organization of the ontology played a crucial role in ensuring its accuracy and usefulness within the designated area of expertise.

Thus, the evaluation process emphasized the ontology's effectiveness and, in particular, its hierarchical knowledge structure and relations. It also aligned well with delineating and confirming its effectiveness within the specific knowledge domain.

For ontology validation, the study employed a comprehensive ontology evaluation process to validate its structural integrity and precise descriptive elements as follows. Initially, we invited three specialists in ontology development to conduct an in-depth analysis focused on ontology aspects such as hierarchy, relationships, and terminology consistency. This evaluation enhanced standards to eliminate complexity and enhance clarity. The results were systematically compiled and are presented in Table 2.

Apart from structural evaluation, applicability and effectiveness in real-world scenarios were also evaluated because this stage involved creating prototypes and hypothesis experiments in various contexts.

Table 2. Khmer stone castle ontology evaluation

<b>Aspects</b>	<b>Mean</b>	<b>Meaning (Degree)</b>
<b>Scope determining</b>	4.65	High
<b>Classes /Concepts defining</b>	4.60	High
<b>Properties defining</b>	4.50	High
<b>Instances creation</b>	4.50	High
<b>Future development and application</b>	4.85	High
<b>Total</b>	4.62	High

Hence, we designed real-world scenario evaluations to test ontology functionality and, in particular, its ability to facilitate information retrieval and integration in a dynamic environment. With the aim of practical capacity, we carefully selected the scenarios to stimulate potential real-life applications for credible adaptability and utility.

Thenceforth, results from these practical evaluations were both qualitative and quantitative and contributed insight into the ontology's performance under different conditions and contexts, as shown in Table 3. These dual approaches featured evaluation—combining specialists' evaluation and practical application—to ensure that the ontology accurately reflected theoretical concepts in the real world, facilitating practical and effective implementation of semantic search systems.

Table 3. Knowledge retrieval efficiency results (F-measure)

<b>Retrieved</b>	<b>Relevant</b>	<b>Irrelevant</b>	<b>Overall</b>
Semantic searching	Relevant meaning	Non-relevant meaning	Overall meaning
Able	62	0	70
Unable	0	12	-

### 3.1. The Khmer stone castle semantic search system

The semantic search significantly enhanced contextual search capabilities by intelligently interpreting the relationships between ontological schemas and the contextual meanings. Compared to general search systems, which rely predominantly on character comparison methods to sift through data or documents, this semantic search delves deeper into grasping the underlying concept and intention of a query. This is because the search system allows the query to transcend the limitations of basic keyword matching, which often misses the mark in accurately representing the user's intention. Consequently, the semantic search reduced the retrieval of cognate results which were irrelevant attributes or inaccurately manifested and authorized a more precise and contextually relevant search experience. These challenges were primarily raised due to the semantic gap between computer interpretation and human understanding [13]. We developed the system as a web-based application and considered a multitude of factors

to deliver meaningful search results, as well as easier accessibility. These included searching contexts, a word variation arrangement (corpus), and a comprehensive synonyms list. The semantic search also accommodates generalized and specialized search queries to cater to various informational needs, including those of experts, in concept matching, ensuring the results align closely with the user's intended meaning. Concept matching is crucial for professionals and researchers who require precise and relevant search results within specific domains of knowledge because they often work with complex concepts that may not be directly mentioned in the texts or documents they are searching through. Thus, they rely on the search system's ability to understand the context and the relationships between concepts to find the most relevant information.

Additionally, it was equipped to direct natural language queries, which provided a more intuitive and user-friendly search experience. This sophisticated approach endorsed relevant, richly contextualized, and highly accurate search results. Similarly, the software enabled the recognition of distinctions between the tangible cultural heritage sites so as to deliver the most relevant results. This semantic approach delivered these advantages based on a contextual and intelligent understanding of the meaning of the information developed for the semantic search system.

In this study, two primary characteristics of the semantic search system were developed for the Khmer stone castles in the Greater Mekong Subregion (GMS) to enhance capacity and accessibility as follows:

- 1) *Web Browser Programmability*: we designed the semantic search engine to be easily programmable via a web browser interface. This feature certifies that users can conveniently interact with the system without needing specialized software. With this flexibility and user-friendly attributes, the search facilitates customization and adaptation of the search engine to meet various user requirements. This web-based approach also improved system accessibility from different devices and platforms as well as enhancing utility and user-friendliness.
- 2) *Versatile Search Capabilities*: the system was equipped with robust search engine functionality to enable users to conduct searches using multiple approaches and to search by class properties. These functions are also able to add an enquiry option based on specific characteristics or categories defined in the ontology, such as location, era, architectural style, or material used. Additionally, the two search methodologies include both simple and advanced semantic searches, and the system also supports searches using the name of a specific Khmer stone castle or relevant keywords.

### 3.1.1. Aspects of the system's semantic search capabilities

The simple search function involved common information retrieval and was suitable for general queries, while the advanced semantic search function offered deeper, more complex, and more distinct data exploration, making it ideal for specialized information retrieval or detailed inquiries. To illustrate the system's capabilities and user interface, we have included a semantic search system prototype in Figure 3. The prototype provides a visual and functional representation of the system's operation, showcasing the practical application of the theoretical concepts underpinning this research. The system prototype incorporeally demonstrated how users can explore and access information about the Khmer stone castles in the GMS, which highlighted its value as a tool for researchers, historians, and enthusiasts interested in cultural heritage.



Figure 3. Prototype of a Khmer stone castle semantic search system.

For this research, we utilized an existing database containing information about Khmer stone castles, which is predominantly in the local language (Thai). Subsequently, we developed an ontology to establish a mapping with the database, enabling the creation of a semantic search system.

As a result, queries made through our system display information in the Thai language, consistent with the data stored in the database (we have made the detailed Khmer Stone Castle ontology created in this study available for users and can be accessed via the Internet at <https://ischool.kku.ac.th/owl/index-en.html>, as referenced in the body text preceding Figure 1).

### 3.2. Semantic search system performance evaluation

In this stage, an application-based ontology evaluation was conducted to assess ontology structure efficacy and evaluate information retrieval effectiveness through a semantic search prototype. An Ontology Application Management (OAM) framework was adopted to develop this semantic search system prototype, which provided versatile, reusable, and configurable templates ideal for rapid prototyping and hypothesis testing. This framework also included a Web API to be more sophisticated in application development. To measure the effectiveness of the ontology, the key information retrieval metrics were conducted in addition to precision, recall, and F-measure [14]. The evaluation involved calculating three critical metrics:

- 1) The precision value, which indicated the proportion of relevant documents retrieved;
- 2) The recall value, which represented the proportion of relevant retrieved documents;
- 3) The F-measure, which calculated a specific formula.
- 4) The performance analysis in the semantic search system yielded precision, recall, and F-measure values at 0.885, 0.756, and 0.815, respectively. These results provided valuable insights into the efficacy of the search system and highlighted areas for potential improvement.



Table 3 shows the advanced search performance evaluation results, explicitly focusing on the F-measure, a metric combining precision and recall. The data shows an average F-measure of 0.815 for the advanced search. This figure was particularly noteworthy because it indicates a high level of effectiveness in the semantic search system based on ontology knowledge. The F-measure was a balanced metric for considering the precision (the accuracy of the results returned) and recall (the system's ability to retrieve all relevant results). An F-measure of 0.815 suggested that the system not only retrieved a high percentage of relevant results (high recall) but also confirmed that these results were accurate and pertinent to the query (high precision). Thus, they were especially significant in the semantic search, suggesting that these elements carried significant weight in semantic search scenarios, where the ability to comprehend context and queries was paramount for a successful outcome.

The exceptional browsing efficiency highlighted by this F-measure indicated that the semantic search system was proficient at interpreting and processing complex queries in the domain of cultural heritage. This efficiency is critical for researchers and scholars who rely on precise and comprehensive search results to conduct their work effectively. The system's ability to interpret the queries accurately and retrieve highly relevant information was demonstrated in the successful application of the ontology knowledge base to enhance search capabilities. Generally, a high F-measure highlights the success of the ontology in bridging semantic gaps and improving the search experience by making it a valuable tool for exploring and researching the cultural heritage in the ontology.

#### 4. Conclusions

In conclusion, this study focused on developing a semantic search system for the Khmer stone castles in the GMS countries, adhering to UNESCO's policies for preserving cultural heritage. According to these guidelines, compiling a list of tangible cultural heritage, encouraging research, and gathering related documents or evidence for effective safeguarding measures and educational purposes were crucial. Consequently, we proposed the creation of a database for Khmer stone castles featuring high-quality data verified by specialists for validation.

Following the organization of the data in the database, a systematic approach was employed to establish a comprehensive knowledge base for educational and research purposes. This entailed structuring the data coherently to facilitate easy access and utilization by educators, researchers, and other stakeholders interested in the domain covered by the database. Additionally, efforts were made to ensure that the knowledge base met the standards and requirements for its intended use, enhancing its value and applicability in the field. Regularly updating and interlinking data also effectively helps to disseminate knowledge when it is easily accessible, forming a key cornerstone in managing tangible cultural heritage.

The study results demonstrated the significant outcomes and high level of effectiveness of the semantic search system for accessing information about the Khmer stone castles in the Greater Mekong Subregion (GMS) countries. This system has the potential to act as a benchmark for other cultural information search systems and significantly improve information retrieval in specialized domains. Furthermore, this study also laid the groundwork for the creation of similar search systems in different areas of study to enhance methods for knowledge storage and retrieval. From a broader perspective, this research can open new paths, igniting further investigation of ontology for supporting the preservation of cultural heritage, particularly relevant in the context of

developing sustainable web-based information search systems that utilize semantic networks. The implications of this study were far-reaching, offering valuable insights and methodologies in the ongoing effort to conserve and make our rich cultural heritage accessible to everyone.

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### Summary

The aim of this study was to develop a semantic search system for Khmer stone castles in the Greater Mekong Subregion (GMS), in alignment with UNESCO's cultural heritage preservation guidelines. The proposed database, curated with verified, high-

quality data, serves as a comprehensive knowledge base for educational and research purposes. The semantic search system demonstrated high effectiveness, showcasing its potential as a benchmark for cultural information retrieval. The study contributes to establishing similar systems in diverse domains, paving the way for ontology-driven approaches to support cultural heritage preservation and sustainable web-based information search systems. The far-reaching implications offer valuable insights for the conservation and accessibility of cultural heritage.

### **Riassunto**

Questo studio mira a sviluppare un sistema di ricerca semantica per i castelli in pietra Khmer nella sottoregione del Grande Mekong (GMS), in linea con le linee guida per la conservazione del patrimonio culturale dell'UNESCO. Il database proposto, curato con dati verificati e di alta qualità, funge da base di conoscenza completa per scopi didattici e di ricerca. Il sistema di ricerca semantica ha dimostrato un'elevata efficacia, mostrando il suo potenziale come punto di riferimento per il recupero delle informazioni culturali. Lo studio contribuisce a stabilire sistemi simili in diversi domini, aprendo la strada ad approcci guidati dall'ontologia per supportare la conservazione del patrimonio culturale e sistemi sostenibili di ricerca di informazioni basati sul web. Le implicazioni di vasta portata offrono spunti preziosi per la conservazione e l'accessibilità del patrimonio culturale.

# NOTRE-DAME CATHEDRAL IN CINEMATIC INTERPRETATIONS

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*Keywords:* historical heritage, great buildings, image, cinema, Gothic architecture

## 1. Introduction

The modern commitment of the French state to the preservation of Notre Dame is part of the country's history, art, and culture. At the time of mass tourism during the 20<sup>th</sup>-21<sup>st</sup> centuries, the Cathedral became one of Paris' most significant images and was noted by the highest authorities in the heritage field. As a result, in 1991, it became part of the property of "Paris, Banks of the Seine" and was included in the UNESCO World Heritage List [1-3]. This gem of Gothic architecture, a witness to the evolution of art for more than nine centuries, attracts at least thirteen million visitors a year, making it the most visited monument in Europe. Its partial destruction was the result of a fire in April 2019. It reverberated around the world because, in addition to its quality of being a symbol of France, it is a place where you can find religious, national, and historical values that are held dear by the French [4,5]

The Cathedral was opened in 1182 and became a cultural, artistic, historical, and religious building. Today it is known as the most important Catholic building in Paris. This was demonstrated by the fact that hundreds of devotees gathered after the tragedy of 2019 to pray together. Notre Dame, a living heritage structure is, of course, a cathedral and can be valued as a place of worship. However, it can be visited as a museum and this connection forms the uniqueness of this structure [6,7].

The importance of Notre Dame for Parisians - and not only for them - is explained by the formalities of majestic religious holidays and the important civil ceremonies held there in the past, such as the marriage of Mary Queen of Scots and the French Dauphin François (1558), the marriage of the French Princess Elizabeth of Valois (Elisabeth de Valois) and the Spanish King Philip II (Felipe II) (1559), as well as the marriage of Napoleon III (Charles Louis Napoléon Bonaparte) (1853) or his son's baptism in 1865. In 1302, the Cathedral became the place where significant political events happened, such as the opening of the States General - the first Parliament of the Kingdom of France - by Philip IV (Philippe IV le Bel). Notre Dame also has a dark side, as it became the place where both the writer Dominique Venner in 2013 and a young intellectual in exile in Paris in 1931, committed suicide [8-10].

Over the years, its great influence and mysterious beauty have made Notre Dame Cathedral a source of inspiration for artists and writers. A work that cannot be overlooked is, obviously, "The Hunchback of Notre Dame", Victor Hugo's masterpiece of 1831, which tells the dramatic story of the bell ringer Quasimodo and the gypsy Esmeralda. It has also served as inspiration for various cinematic performances, including the very successful Disney classic, The Hunchback of Notre Dame. Luc Plamondon

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and Riccardo Cocciante were also inspired by Victor Hugo's novel and wrote and composed the music for the play "Notre Dame de Paris", which debuted on September 16, 1998, in Paris under the direction of Gilles Mahe. The director followed the author's wishes, so, instead of developing the action theatrically, as in a musical, he arranged a performance in a semi-scenic form.

The scenery and costumed singers interacted only partially, and the play was interpreted in an almost concert form: the play's action alternated with songs and dances that, sometimes, were performed separately. The songs "Vivre", "Le Temps des Cathédrales" and "Belle" were released as singles in France and achieved great success. "Live for the One I Love", the English version of "Vivre", was recorded by Celine Dion.

The overwhelming success of the Paris production prompted the authors to export the show, adapting it in many countries. From 1998 to 2008, the performance took place in France, South Korea, Belgium, Switzerland, Canada, Russia, Spain, Italy, Great Britain and the USA. The 1996 Disney film, *The Hunchback of Notre Dame* and the 1998 theatrical performance, to the music of Riccardo Cocciante, were inspired by the aforementioned Hugo novel [11, 12].

Notre Dame is one of the greatest historical buildings not only in France, but also across the whole world, having an impact on various spheres of life: religious, cultural, architectural, national, etc. In this study, the aim was to study the influence of Notre Dame Cathedral on cinema by analyzing its representation in various films.

## 2. Materials and methods

This study is theoretical and was aimed at confirming the thesis that the Notre Dame Cathedral has had an impact on art due to its monumental architecture and historical background.

This is an aspect that has been reinforced and, in some ways, created by Victor Hugo and his novel; the main theme in this case study is consequently Notre Dame and related cinema heritage. Theoretical research is any cognitive procedure that is defined as a systematic structure, the main purpose of which is to answer the question posed in front of the researcher or to clarify the hypothesis underlying the study. This type of research allows one to expand their knowledge on a specific topic, promotes an approach to the truth, can give us a possibility to correct mistakes made in previous studies or to break the myths that could be created around the studied object or phenomenon. So, the main purpose of this theoretical research was to gain knowledge. To implement the research and achieve its goal, appropriate theoretical methods were chosen such as synthesis, descriptive, comparative and historical analyses, systematization, and generalization.

### 2.1. Study approach

The base of the research was created by analysis and synthesis which were used throughout the study to implement different tasks, as described below.

- *Descriptive analysis* was used to collect and systematize information about Notre Dame Cathedral, which resulted in a description of the characteristics of the structure both from the standpoint of its appearance, architectural composition, and from the standpoint of its significance in the cultural and historical

context.

- *Comparative analysis* was used to determine the role of the Cathedral in various cinematic interpretations and to determine how the structure was used in a particular production and how decisive its appearance was in the film production.
- *Historical analysis* was used to construct a chronology of the main events of Notre Dame: from its foundation till today. This made it possible to assess its influence on art throughout time, as well as to trace the stages of acquiring the status of a renowned World Heritage site.

The method of *analysis and synthesis* was used throughout the study in various forms. This approach is characterized by two different processes that logically complement each other. The analysis involved dividing the object into separate elements. The selected elements were then viewed from different sides and the goal was to share the most significant cultural and historical meanings of the Cathedral from the author's subjective viewpoint. Synthesis is the opposite of analysis, assuming a single integer combination of the studied elements and the target sides such as the impact of Notre Dame on the cultural and historical heritage of both France and the world. In the course of analysis and synthesis, the interrelations of the studied processes and phenomena, cause-and-effect relationships are naturally observed. The process of forming the concept developed during the research is based on the integrity of the process of analysis and synthesis. Analysis and synthesis are independent stages, but they are not separated from each other by scientific research. At each stage of the study, they take place as a whole, reflecting the relationship between the part and the whole, and they cannot be effectively used separately. It was for this reason that this method was chosen as the basis of the study. The material basis of the research was cinematic works, such as "Esmeralda", "Notre Dame de Paris", "The Hunchback of Notre Dame", and "Breathless".

### **3. Results and discussion**

#### **3.1. Architecture of the Cathedral**

Notre Dame de Paris is a majestic Catholic church on the island of Cité in the center of Paris. This outstanding monument is widely known in art and is one of the most famous places of worship in the world. Every year from 13 to 14 million tourists visit Notre Dame to see the rising Gothic silhouette decorated with fancy, stained glass windows and fantastic gargoyles. The architectural greatness of this cathedral can be imagined due to Figure 1 with its impressive spires and columns, but the beauty of Notre Dame cannot be fully imagined looking at the plan without feeling the soul of this building.

Notre Dame Cathedral is the geographical center of both Paris and the whole country. It is here that the so-called "zero kilometer" is located and from which all distances in France are counted. The church of Notre Dame de Paris is located on the site of ancient Romanesque, Christian and Merovingian shrines.

The construction of the magnificent building began in 1163 under King Ludwig VII, who devoted his whole life to the church. The Parisian bishop, Maurice de Sully, was the initiator of the Gothic cathedral creation, while Pope Alexander III had the honor of laying the foundation stone of the cathedral.

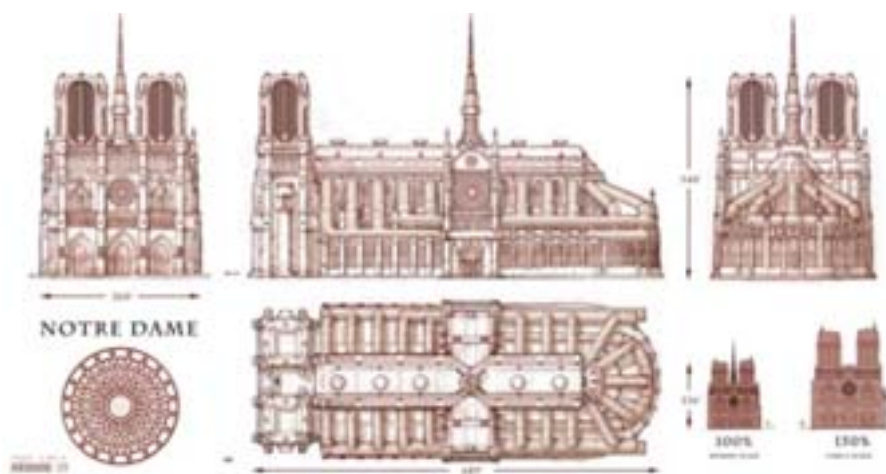


Figure 1. Architecture plan of the Notre Dame de Paris.

The construction lasted almost two centuries and was completed only in 1345. Many architects supervised the construction, helping them to build one of the most magnificent temples in the world. The cathedral is made in Gothic style, diluted with Romanesque elements. The ugly exits from the rain pipes were accompanied by gargoyles through which streamed the rainwater [13-15].

### 3.2. Notre Dame's historical context through time

The value of the majestic building lies not only in the incredible architecture, Gothic style and mythical sculptures. New royal families were formed under the arches of the cathedral, knights were blessed, and rich Parisians preserved their values.

In Notre Dame de Paris, Napoleon became king of the French Empire. In addition, the pastors of the cathedral helped the poor. The legendary trial of Joan of Arc took place in the temple, but after the girl's death the court acquitted her completely. Adjacent to Notre Dame, there is an annex – a treasury. Christian relics are kept here: a crown of thorns, a fragment of a cross and religious works of art.

### 3.3. Restoration of the cathedral

During its existence, the cathedral has seen thousands of battles. The French Revolution left the Catholic Church in disrepair. The precious artefacts of the temple were looted, and the sculptures were destroyed and beheaded; the building was in dire need of repair. In 1831, after Hugo published his novel in its honor, urging the nation to love the architecture of their homeland, the building was restored within 23 years (1841-1864). The novel "Notre Dame de Paris" made the Cathedral the center of the plot, evidently helping and promoting the repair work to be carried out. The work not only glorified the author, but also made him realize the value of the temple. Soon, Notre Dame was to be rebuilt under the guidance of the architect Viollet-le-Duc.



The restoration work lasted 23 years. Galleries of gargoyles and other sculptures were restored, chimeras were installed. The architect did not forget the cathedral tower either, destroyed by revolutionary actions in 1793 when Notre Dame became a Temple of Reason [16,17].

In the 20<sup>th</sup> century, the cathedral survived the Nazi occupation, and received nine new bells and a reconstructed organ in the new millennium for its 850th anniversary.

On April 15, 2019, flames engulfed Paris' Cathedral, the largest historical monument not only of France, Europe, but also of the whole world, praised by Victor Hugo in the famous novel "Notre Dame de Paris" and Osip Mandelstam in the poem "Notre Dame" of 1912. The fire, which raged for several hours, brought down the tower designed by the architect Viollet-le-Duc and built in the 19<sup>th</sup> century. Its frame was made of 500 tons of wood covered with 250 tons of lead sheets. The roof, built with 1300 oaks in the 13<sup>th</sup>-14<sup>th</sup> centuries (the cathedral towers were finished in 1245 and the whole building completed in 1345), was also severely damaged, as well as part of the interior decorations [10,18]. But even before the building was rebuilt, several works of art were sent to the city hall for storage.

In particular, 16 copper statues around the base of the tower were removed for restoration. The crown of thorns of Jesus Christ and the Saint King Louis IX chiton were saved from the fire. Fortunately, two large rose windows in the south and north of the transept and sculptures by Antoine Coisevox, Guillaume the Elder and Nicolas Coust were not damaged by the fire.

Two of the cathedral's towers, medieval stained-glass windows and an organ were also preserved. 400 firefighters were involved in extinguishing the fire. People from all over the world responded to try to find a solution to the problem. State chiefs, international figures, and organizations expressed their condolences.

A few billionaires allocated hundreds of millions of euros for the cathedral restoration (Figure 2). Bells rang everywhere in solidarity with the French people, and people with flowers walked past French embassies around the world. And, of course, many remembered the tragedy of September 11, because the towers were filmed as often as Notre Dame.

### **3.4. Notre Dame in cinema art**

Notre Dame can be seen in a great many films (Figure 3) and the Lumiere brothers were the first to film the cathedral. Against its background, the characters of films, such as "Is Paris burning?", "Charade", "Amelie", "Angel-A", "Before Sunset", "Julie and Julia", "Paris, I love you", "Say I love you", and "Midnight" appeared before our eyes in Paris. The Cathedral is also reflected in computer games; for example, the Irishman, Sean Devlin in the action adventure "Saboteur" and British spy, Violette Chabot in the stealth action "Velvet Killer", see Notre Dame in German-occupied Paris; in the sci-fi thriller "Remember Me", Nilin fights against the backdrop of the cathedral of the future; and in Assassin's Creed: Unity, Arnaud Victor Dorian, lived in Paris at the time of the French Revolution.

It is noteworthy that an Ubisoft employee, Carolyn Miousse, the senior artist who worked on the aforementioned game helped in restoring the damaged cathedral due to the detailed model she created, which took more than a year to complete (14 months). Her model was used in recreating Notre Dame in real time. However, an Ubisoft spokesperson noted that the model had not been created as a historical reconstruction, so some differences in terms of scale occurred. In addition, Ubisoft donated €500k towards the reconstruction [19,20].



Figure 2. Cathedral restoration process after the fire in 2019.



Figure 3. Still from the film 'Notre-Dame on Fire'. France (2022).

Many people are familiar with Notre Dame Cathedral due to Victor Hugo's novel, which influenced both the fate of the building and impacted the world's cultural heritage, but the novel has also been adapted for the stage. In 1836, Louise Bertin wrote the

opera “La Esmeralda”, which was staged in Paris on November 14 of the same year, based on a libretto by Hugo in four acts. In the early 1840s, Alexander Dargomyzhsky wrote another opera ‘Esmeralda’ which was first performed at the Bolshoi Theater on December 5, 1847 (December 17, according to the Julian calendar). Caesar Puni and Jules Perrault created a three-act ballet “Esmeralda” set in the middle of the 19<sup>th</sup> century. Modern theatergoers are probably also familiar with the musical “Notre Dame de Paris” by Richard Cocciante and Luc Plamondon, written in France in 1998 together with Garou and based on “Quasimodo”. In 2002, the musical performance of Julius Kim was adapted for the Moscow Operetta Theatre, and since then, such actors as Anton Makarsky, Alexander Marakulin, Valery Yaremenko, Svetlana Svetikova, Vyacheslav Petkun, Eduard Shulzhevsky, Theona Dolnikova, Anastasia Stotskaya, Alexander Postolenko, Anna Nevskaya, Sergey Li and many others, have performed various roles in it. There are about two dozen film adaptations of the novel. The first was “Esmeralda” (1905) by the French directors, Alice Guy-Blaché and Victorin Jasset: Dennis Becke was Esmeralda and Henri Vorin, Quasimodo. In 1911, Albert Capellani’s “Notre Dame de Paris” was released with Henri Krauss and Stasia Naperkovskaya. In 1917, Teda Bara became Esmeralda in the version by Gordon Edwards. In the 1923 “The Hunchback of Notre Dame” the great and terrifying Lon Chaney was portrayed as Quasimodo in a horror drama thanks to the efforts of director Wallace Worsley and producers Carl Laemmle and Irving Thalberg (Figure 4).



Figure 4. ‘The Hunchback of Notre Dame’, 1923. Dom Claude (Nigel De Brulier) restrains Quasimodo (Lon Chaney) from violence.

According to the plot, the beautiful dancer, Esmeralda, bought by gypsies in early childhood, attracted the attention of Jehan, the vicious younger brother of Archbishop Claude Frolo. Overcome with passion, he decided to kidnap the dancer with the help of the ugly hunchbacked Quasimodo. Quasimodo’s makeup took an hour and a half to put on, using a 36-kilogram rubber pillow, a flesh-colored rubber suit, and a corset to

simulate a hump. A special device in the actor's mouth simulated suitable teeth. The cathedral itself was presented in the picture in the form of a detailed model with a height of about 75 m and a width of 50 m.

In 1939, William Dieterle directed the film of the same name (Figure 5). In this version, Maureen O'Hara appears as Esmeralda and Charles Laughton as Quasimodo, while Edmond O'Brien became a poet, Pierre Gringoire. Sir Cedric Hardwicke acted as Quasimodo's guardian and the Archdeacon, Claude Frollo. Loved by Esmeralda, Alan Marshal acted as the captain of the Royal Guard, Phoebus de Chateaupher. Views of Paris, as well as details of the interior of the Cathedral, can be seen in this film in the sets that were constructed by Van Nest Polglase. Many of the scenes were shot at the RKO Encino Ranch and those of the interior of the bell tower were shot at the University of Southern California's Mudd Hall of Philosophy.

One of the most famous "Notre Dame de Paris" adaptations that received the Cannes Film Festival Grand Prix, was staged by Jean Delannoy (1956) and shot by French and Italian cinematographers. A number of scenes showing the Cathedral were included in the film, but some of the movie scenes were filmed in pavilion. One more asset was the use of luxurious costumes in the film.

The film owes its success to the great Gina Lollobrigida (Figure 6) who decided to play barefoot even though the heroine of Victor Hugo had shoes. For this role she received the Bambi Award. The film takes us to medieval Paris, where the whole action unfolds and where a gypsy girl drives men crazy with her beauty. Claude Frollo, a strict priest of Notre Dame Cathedral, secretly falls in love with her, as does his disciple, the hunchback Quasimodo.



Figure 5. Charming Esmeralda and skillfully embodied Quasimodo. Still from 'The Hunchback of Notre Dame' by William Dieterle, 1939.



Figure 6. Esmeralda as Gina Lollobrigida in the film by Jean Delannoy (1956).

But the girl remains loyal to an aristocrat named Phoebus. Enraged by jealousy, the priest wounds him and Esmeralda is accused of committing a crime; the judges sentence the girl to death by hanging. Phoebus does nothing to save her, but the hunchbacked Quasimodo comes to the rescue of his beloved. The ending of the film is different from Hugo's novel's ending. In the movie, Esmeralda is killed by an arrow during the storming of the cathedral, and her last words are: "Life is beautiful". In this cinema version, it is worth mentioning that Anthony Quinn played Quasimodo (Figure 7) and Alain Cuny, Frolo.

The 1960 film "Breathless" is not dedicated to Notre Dame, but it was shot in Paris, so the architecture of the famous building is often seen in it. The film was directed by Jean-Luc Godard, starring Jean-Paul Belmondo, who played a young student who fell in love with another young student.

Directed by Michael Tuchner and Alan Hume, "The Hunchback of Notre Dame" (1982) was produced by Norman Rosemont and Malcolm J. Christopher and created by the United Kingdom and the United States of America cinematography group at the Pinewood Studios. The script of the film was based on Hugo's novel (Figure 8).

The role of Quasimodo was acted by Sir Anthony Hopkins (Figure 8) who fought for the love of Leslie-Ann Down, an Emmy nominee, and his opponent was Derek Jacobi as Frolo. Claude Frolo finds an ugly child at the foot of Notre Dame and decides to adopt him, giving the child the name, Quasimodo. After 20 years, Quasimodo becomes the bell ringer of the Cathedral, notices the dancing gypsy Esmeralda in the square and falls in love with her.

But Frolo, Gringoire and Captain Phoebus also fall in love with the gypsy. In the end, after some unhappy events, Esmeralda is sentenced to death, making Quasimodo kill Frolo; Quasimodo then falls from the tower to his death.



Figure 7. Anthony Quinn as Quasimodo. Still from the Jean Delannoy film (1956).



Figure 8. Esmeralda gives water to Quasimodo. Still from the film 'The Hunchback of Notre Dame', 1982.

The film also features such brilliant British actors as David Suchet and John Gielgud.

Notre Dame was used as the main location for filming, so, this film adaptation became the first that used the Cathedral locations for most of the scenes.

Moreover, the current adaptation was the first which was closely based on the plot of Hugo's novel.

Several cartoons have been created based on Victor Hugo's novel but the most famous of them is the Disney one directed by Kirk Wise and Gary Truesdale. The cartoon won an Oscar and a Golden Globe thanks to the music created by Alan Menken. The characters are voiced by Tom Hulce, Kevin Kline, Demi Moore, and Jason Alexander.

A sequel to the cartoon was made later, as well as a video game 'The Hunchback of Notre Dame' (Topsy Turvy Games) which came out in 2002. Disney is currently developing a remake of the game "The Hunchback" in which the focus is on the beautiful gypsy dancer Esmeralda, the powerful and influential judge Claude Frollo, who pursues her and secretly falls in love with her, the hunchback Quasimodo, and the young captain Phoebe who is also in love with Esmeralda. Of course, there is less cruelty in it than in the original and there is a happy ending here.

The Notre Dame Cathedral is present in the painted form. A year after the Disney version, during the success of Salma Hayek, Peter Medak shot "The Hunchback of Notre Dame" with this wonderful Mexican actress in the role of Esmeralda (Figure 9). Little known to the general public, Mandy Patinkin became Quasimodo (Figure 9), and Richard Harris, who later appeared as Albus Dumbledore in Harry Potter, became Claude Frollo.



Figure 9. A still from the screen adaptation of Hugo's novel by Peter Medak, 1997.

The plot of the film adaptation shows a strong discrepancy with the book. Quasimodo and Esmeralda, in particular, are older than the book heroes, and in the finale the

gypsy avoids death. Esmeralda was tried for a murder that she did not commit and found guilty after being tortured. Quasimodo tries to save her by taking her to Notre Dame which cannot be attacked by the authorities, as it is the home of God. Quasimodo and Esmeralda become friends and take care of one another, which does not please Frollo. Frollo consequently denounces Esmeralda to the authorities which means death for the girl and she is sentenced to death. Quasimodo cannot come to terms with this and gets a confession from Frollo about her not being guilty. Everyone in the square hears it, so the gypsy girl is acquitted. The archdeacon, completely distraught, attacks Esmeralda with a dagger in the Cathedral, but the hunchback protects her and throws Frollo off the cathedral tower. However, during the fight, Quasimodo is wounded and, bleeding, dies to the sound of the cathedral bells; Gringoire and Esmeralda are ringing the Notre Dame bells in tribute to Quasimodo.

In the famous 1998 blockbuster “Armageddon”, in which Bruce Willis once again heroically saves the world, in one scene flying debris falls on Notre Dame and destroys the Cathedral. Most likely, the director wanted to emphasize that the forces of nature can destroy man-made things in seconds, though, as it turned out in real life, it was not an asteroid.

In 1998, the musical “Notre Dame de Paris” was released on DVD and became the brightest film adaptation of Hugo’s famous novel (the composer is Riccardo Cocciante, while the author of the libretto is Luc Plamondon). The songs from this musical became so famous that the main hit “Belle” was named one of the best songs of the second half of the 20<sup>th</sup> century. The song is sung by the main characters in the musical (Daniel Lavoie, Garou and Patrick Fiori), and has been translated into other languages, including Russian. In the original version, the musical toured Belgium, France, Canada and Switzerland. The same musical debuted at the French theater “Mogador” in 2000, but with some changes. These changes were followed by Italian, Russian, Spanish and several more versions of the musical. In the same year, an abridged American version of the musical was launched in Las Vegas, and an English version in London. In the English version, almost all the roles were played by the same artists as in the original. The musical was presented on Broadway in May 2001, premiered in Moscow on February 26, 2002, and by December 2017, more than 11 million viewers had watched the musical in 8 languages.

On the eve of the new century, French director Patrick Timsit staged the comedy “Quasimodo” based on the novel, in 1999, transferring the plot to modern Paris. Quasimodo is hunchbacked, bald, deaf, wears size 47 shoes and lives in the city of El Paris. The story tells of Quasimodo’s parents who, considering him to be ugly, abandon him to Archdeacon Frollo and adopt a Cuban girl Esmeralda, as their own daughter. Twenty years pass, and the city of El Paris is terrified: a freak maniac has already killed 18 women. The chief of police, a stupid erotomaniac Phoebus, investigates the case without even getting out of his polished Jeep and immediately begins to suspect Quasimodo. Each of the heroes has a goal. Quasimodo is trying to get rid of suspicions, Esmeralda is trying to reward Quasimodo for his suffering, Frollo wants to find out the truth and maybe hide it, and Phoebus simply has no time for trifles. Years later, Esmeralda (Melanie Thierry), the governor’s daughter, learns that Quasimodo (Timsit) is her parents’ true heir. Richard Berry played Frollo in the film which, in this case, had a happy ending.

In the cult comedy “Amelie” of 2001, a significant place that appeared was Norm-Dam. Although the film takes place in Montmartre, it has an iconic scene associated with the cathedral. Little Amelie and her mother go to the temple to pray for the family, but when they leave, a tourist jumps off the roof of the building and kills the woman. It did actually become the site of a bloody drama when writer and historian, Dominic



Venner, committed suicide at the same place in 1913. In the 2004 Steven Sommers film “Van Helsing”, about the most famous fighter of evil spirits, Van Helsing and the villain, Mr. Hyde, fight along the walls of Notre Dame Cathedral. During the battle, the hero breaks a pink glass window, which is one of the few remaining giant stained-glass windows of the 13<sup>th</sup> century. The most amazing thing is that in reality, they were not affected by the fire, which could be considered a great miracle and a matter of good luck. Another exciting 2011 film, “Midnight in Paris” is about a dream and a return to the past, in which Notre Dame de Paris is also shown as one of the integral attractions of Paris. The main character, played by Owen Wilson, incredibly finds himself in Paris in the past, where he meets the most famous representatives of French bohemia – Dali, Fitzgerald, Gertrude Stein and many others.

Gargoyles are one of the symbols of Notre Dame de Paris. These chimeras were installed in the upper part of the building in the 1840s with the light hand of the architect Eugene Emmanuel Viollet-le-Duc who was known for his innovative approach to restoration. Moreover, gargoyles became a well-known symbol elsewhere and were used separately in diverse cultural spaces. For example, they became central characters in the film “I am Frankenstein” and were not just statues, but active participants of the film plot. According to the film, they are the members of the secret Gargoyle order formed in Notre Dame. Its members appointed Archangel Michael as the founder of the order, whose duty it was to protect people from the legions of demons released by Satan from Tartarus. Gargoyles, were powerful warriors, created to fight the constant battle against evil and to save civilization. In “The Musketeers” of 2011 by Paul W. S. Anderson, D’Artagnan (Logan Lerman) and Rochefort (Mads Mikkelsen) are seen fighting on the roof of the cathedral. Despite the fact that it was a set, since the whole picture was shot in Germany, these frames help the audience to be transported to Paris, to the walls of Notre Dame Cathedral.

#### **4. Conclusions**

Depicting great historical buildings that have an impact on various spheres of society is an important task as it helps to preserve their heritage for future generations. Notre Dame Cathedral is one of the places of worship that has significance both in history and in art. Its image formed the basis of the cult work “Notre Dame de Paris” by Victor Hugo which, in turn, formed the basis of many cinematic interpretations of the novel. Moreover, its history, art heritage, and architectural execution are a source of inspiration for creativity. With the passage of time and in the aftermath of destructive events, the interior and exterior of buildings often lose their original appearance, and in some cases can be completely destroyed, so it is important to pass on history from generation to generation, capturing it with the help of various types of art forms and expressions. The events that took place in April 2019 and their consequences showed that Notre Dame Cathedral in Paris is more than a monument. It is a symbol of power and a reflection of French self-esteem. Over the years, millions of tourists have been there, they have visited it throughout its existence and continue to do so today, despite the destruction and recent reconstruction of the roof and spire. Built in the architectural style of early Gothic, Notre Dame de Paris is one of the oldest European cathedrals and is visited annually by millions of tourists and pilgrims from all over the world. For some reason, this structure is an exception, unique in the history of Gothic cathedrals. The influence of this historical structure on people is so great that it has become the object of literary and cinematic works, becoming a participant in events both in the foreground and at the level of secondary roles. The main work inspired by the image of Notre Dame is Victor Hugo’s novel “Notre Dame Cathedral”, which eventually formed

the basis of more than 20 cinematic interpretations, the entourage of which to one degree or another shows the external and internal performance of Notre Dame Cathedral.

Promising areas for future research on the topic are the following: consideration of the image of some other great architectural structure in cinematic interpretations; and the study of the image of Notre Dame Cathedral in other forms of art, for example, in literature, or painting.

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### Summary

Notre Dame de Paris is a building with a huge architectural and artistic wealth, but at the same time, it is very mixed in its influence on the surrounding world, since the structure performs historical and cultural as well as political and national functions. The purpose of this study is to study the role of Notre Dame in cinema and analyze its representation on the big screen. We have chosen the following theoretical research methods: analysis and synthesis, descriptive analysis, comparative analysis, historical analysis, systematization, generalization. In the course of the study, the appearance, architectural composition, cultural and historical significance of the Cathedral was analyzed. A comparative analysis of various cinematic interpretations was also carried out, where the image of Notre Dame Cathedral was used. The study, moreover, created a chronology of the main events that have taken place there, from its foundation to today. It was found that Notre Dame Cathedral is a source of inspiration for artists, as it is one

of the greatest buildings not only in France, but also in the whole world, the cultural and historical heritage leading to the creation of art works expressed in different forms dedicated to Notre Dame or indirectly using its image. The research materials may be useful for specialists in the field of cinematographic art or historians whose subject of research is Notre Dame Cathedral.

### **Riassunto**

Notre Dame de Paris è un edificio di enorme ricchezza architettonica e artistica, ma allo stesso tempo è molto eterogenea nella sua influenza sul mondo circostante, poiché la struttura svolge funzioni storiche e culturali, nonché politiche e nazionali. Lo scopo di questo studio è quello di studiare il ruolo di Notre Dame nel cinema e analizzare la sua rappresentazione sul grande schermo. Sono stati scelti i seguenti metodi di ricerca teorica: analisi e sintesi, analisi descrittiva, analisi comparativa, analisi storica, sistematizzazione, generalizzazione. Nel corso dello studio sono stati analizzati l'aspetto, la composizione architettonica, il significato culturale e storico della Cattedrale. È stata inoltre effettuata un'analisi comparativa di varie interpretazioni cinematografiche, in cui è stata utilizzata l'immagine della Cattedrale di Notre Dame. Lo studio, inoltre, ha creato una cronologia dei principali eventi che vi si sono svolti, dalla sua fondazione ad oggi. Si è scoperto che la Cattedrale di Notre Dame è una fonte di ispirazione per gli artisti, in quanto è uno dei più grandi edifici non solo in Francia, ma anche in tutto il mondo, il patrimonio culturale e storico che porta alla creazione di opere d'arte espresse in diverse forme dedicate a Notre Dame o indirettamente utilizzando la sua immagine. I materiali di ricerca possono essere utili per gli specialisti nel campo dell'arte cinematografica o per gli storici il cui oggetto di ricerca è la Cattedrale di Notre Dame.

# **D**IGITALLY DOCUMENTING BUILT HERITAGE USING T. L. SCANNING. THE MAI EIDAAN COURTYARD, LAHORE, PAKISTAN

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*Keywords:* digital documentation, TLS, Mai Eidaan Courtyard, conventional model, virtual model

## **1. Introduction**

Historic monuments and open spaces are fragments of urban built heritage that play a vital role in the sustainable development of historic cities. Unplanned urbanization has deteriorated the urban fabric of old cities, and modern interventions have entirely transmuted the historic environment [1]. The constant deterioration of landmark properties due to natural occurrences and human activities has forced the conservation community to find new technical and concrete solutions for the conservation, restoration, rehabilitation, regeneration, and redevelopment of architectural and urban heritage [2].

The urban built heritage of the historic core of Lahore is in danger due to various factors, such as environmental, climatic, botanical, biological, and entomological issues [3]. In addition to these natural agents, human activities also damage the historic character of the old city of Lahore [4]. The historic city of Lahore has been used by intruders and invaders adaptively, resulting in the loss of precious stones and metals [5]. However, the cultural and historical values of the city articulate the stories of the past and educate the future generation about the progress made by earlier generations. Whatever remains is a national asset and must be safeguarded to maintain our national identity [6]. The historic urban landscape (HUL) and form of historic cities are transformed due to the changes in life patterns and responses to various cultures and communities [7]. For ages, cities have been a source of history, art, architecture, culture, and rituals because cities are not just physical places to live in; they are vivacious entities and dynamic spaces that showcase human achievements through art, architecture, and cultural heritage. The historic environment needs to balance the heritage

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conservation with socio-economic development in the area [8].

For the last few decades, conservation experts have inevitably been using digital technologies to get the maximum from the digital collaborative environment and minimize the constraints of conventional methodologies [9]. Historic Building Information Modeling (HBIM) is an effective method for designing conservation projects and managing and documenting invaluable cultural heritage [10]. It can support the project designing, restoration, management, and monitoring of activities at heritage sites through 3D Models and auto-generated orthographic drawings in a systematic manner [7]. Virtual databases can be reviewed using portable devices to develop guidelines for constituting theoretical and methodological frameworks to document architectural heritage accurately [11]. Physical dimensions are based on tangible cultural heritage, and social dimensions are related to non-tangible values. At the same time, time dimensions deal with the scheduling and implementation of conservation projects within the designated time frame [5]. The historic city of Lahore needs a holistic approach to conserving and refurbishing landmark buildings and urban heritage spaces, applying digital tools, methods, and software. The walled city of Lahore functioned as an administrative center during the Mughal Empire (1526-1799). The Mughal Emperor Akbar shifted the capital to Lahore in 1585 A.D. to maintain control in Kabul, and the city also sustained its position as the seat of power during the Sikh Kingdom (1799-1849) [12]. After British annexation, it came under the control of "The East India Company" in 1849 and was added to the British Empire in 1858 [13]. Being the royal seat of the Mughal, Sikh, and British Empire, the historic core of Lahore has a great wealth of historical monuments, urban heritage sites, and archaeological remains which direly need to be conserved and rehabilitated according to the demands of the modern age [14]. Urban conservation concerning the historic city of Lahore has been studied with physical, social, and time dimensions [15]. The Mai Eidaan courtyard, the selected case study, is located on Fort Road, now part of Food Street, with an additional entrance accessible via Nicha/Neewan Chait Ram Road. The courtyard is surrounded by a cluster of residential buildings of high architectural, tourist, and commercial value in terms of original and adaptive reuse. The cluster of buildings around the courtyard comprises an Imam Bargah (a congregation hall for Shia Muslim commemoration ceremonies), two restaurants, some houses, and two residences functioning as shoe factories (Figure 1).



Figure 1. Plan of the Mai Eidaan courtyard with buildings surrounding the courtyard (Basemap WCLA and modified by authors).

It is an example of the historical context; in the historic city of Lahore, there are hundreds of spaces with buildings listed in three categories based on architectural values: high, middle, and low. It has become a challenge for stakeholders to revitalize the historic environment of religious, social, and architectural values. Therefore, it is necessary to schedule conservation projects with digital technologies to revive the urban built heritage environment, focusing on minimizing the restrictions of conventional methods [16]. As a pilot case study in this research, the Mai Eidaan courtyard was selected - due to its location in the historical context and tourist value - for scanning with a terrestrial laser scanner (TLS), and the scanned data was processed to develop an HBIM model through Autodesk Suite (Autodesk Recap 360 and AutoCAD 2016) for surveying, mapping, and documenting, to achieve precision and accuracy, in addition to saving time and human resources. HBIM can provide an integrated platform for stakeholders to share and access building information during conservation projects. HBIM permits multiple team members to use the same model simultaneously, permitting real-time coordination of numerous conservation activities. It can also reduce the probability of errors and rework. HBIM also incorporates metadata to provide comprehensive details about building components, such as the degree of deterioration, previous interventions, maintenance schedule, etc. Metadata in historic building information models can facilitate effective management by providing multilayer information [2].

The research follows the digital mapping of a selected site by using TLS with built-in digital 360 cameras and the development of an HBIM model and auto-generated orthographic details with the help of multiple software, such as Faro Scene 2019, Autodesk Recap 360, and AutoCAD 2016, to achieve a high level of precision and accuracy.

It explores the potential and scope of digital technologies, such as TLS, concerning conservation techniques and practices. The also research contributes to the development of an understanding of digital heritage documentation, management, and monitoring by investigating the constraints of conventional methods and their application in heritage preservation.

## **2. Literature review**

Historic cities are living examples of past human activities and are real connections to records of certain endeavors. For years, historic conservation has faced various challenges in preserving historic monuments and heritage sites due to conflicts of interest between stakeholders [17]. A rigorous process is required to safeguard historic assets from further decay without compromising their authenticity and integrity. Historic conservation is a process of maintaining, managing, and monitoring heritage assets for the sustainable development of historic cities [18]. The process needs appropriate identification of heritage sites, accurate documentation, assessment of damages, and treatment methods, and it can only be done with the help of HBIM approaches [19].

### **2.1. Conventional v/s virtual methods**

Architectural buildings with rich geometric and ornamental details provide multilayer information for future architects and planners to solve issues regarding function and design aesthetics. Documenting historic buildings and urban areas is a critical step in conservation. Conventional methods are generally inaccurate and are often time-consuming, devour human resources, and present the possibility of human error. Visual

and pictorial surveys of the site need to be conducted before conservation to record the current status of the historic monument in its context, to make a record of previous interventions, and to develop documentary evidence of conservation procedures applied at the site and, after conservation, to maintain and monitor the life cycle of the conserved sites [20].

Historic cities are losing their heritage assets due to natural agents, human neglect, and new constructions. Conventional recording tools, such as measuring tapes, tachometers, etc., provide various formats for documentation needs. Measured orthographical drawings provide accurate dimensions of the features and open spaces in and around the buildings, with chances of human errors being made due to issues of accessibility and complexity. Perspective drawings represent the buildings appearing to the human eye, presenting realistic spatial depth and proportion. [21]. Photographic records present data about the general outline, quality of light, and appearance of materials. Sketches produce an environment in an artistic format, whereas videos with sound effects are records of a live visit to a place in a 3D context. A physical model shows 3D aspects of a building. Written documentation describes visual representations and unseen data concerning building materials, owners, and constructors [22].

On the contrary, virtual methods (digital) provide more accurate multilayer information than conventional methods (manual workings). An HBIM model of a building based on a digital database can also support the development of a database for CAD drawings, providing metadata such as horizontal and vertical measurements and building materials (color and texture). Digital databases can also be shared globally for analysis, comparison, and discussion, with minimum ambiguities and discrepancies. Architectural plans, elevations, sections, and perspectives can easily be generated from digital databases [23]. In addition, digital databases can provide a base for walkthrough analyses and virtual reality tours. Modern technology is a way forward to more accurate and authentic multilayer digital data and to help reduce the time needed to complete the task [24].

## **2.2. Digital conservation and the HBIM collaborative environment**

The digital conservation of heritage sites and historical monuments using modern 3D measurement technologies has been devised as an efficient and well-organized tool for the purpose of surveying, mapping, and documentation solutions [25]. Conventional methods such as simple manual measurement, tachometry, and photography have been lagging due to their constraints in quality, accuracy, precision, chances of error, and time span [26]. According to current practices, applying Total Station and Terrestrial Laser Scanners is becoming the most commonly used technique because of its comprehensiveness, accuracy, and rapidity. However, Terrestrial Laser Scanning is the most rapid of the digital technologies [27].

The HBIM approach supports various stages in the process of cultural heritage conservation. The first step is the remote collection of survey data using a TLS technique combined with other image-based survey technologies such as digital 360 cameras and photo rectification. Another step is to monitor the behavior of historic environments over time during and after the conservation of architectural heritage [24]. The specific application of HBIM in the area of refurbishment was introduced by Murphy et al. in 2013, who termed it Historic Building Information Modeling for the first time [28]. Afterward, in 2014, Volk et al. identified causes of decay, deterioration modeling (a process of simulating the deterioration of materials and structures over time), uncertainties of building conditions, and incomplete documentation prevailing in existing structures, with the



help of HBIM [29]. In 2018, Bruno et al. produced methodological advancements in HBIM in the form of a structured and integrated model as a database of semantic information [25].

The latest progress in the field of HBIM is to raise the transmissibility of multilayer data through the most modern techniques of virtual and augmented reality (VR-AR). These 3D models are based on TLS scanning and image-based survey techniques to digitize and accurately represent the built heritage [26]. The scan-to-BIM process introduces a new paradigm of the complexity of historical monuments and urban-built heritage, as well as its tangible and intangible values in the field of conservation in terms of information contents and knowledge accumulated in the last decades [9]. Currently, these 3D models have themselves become a research tool, allowing non-destructive operations of investigation and analysis to be carried out on buildings, thus facilitating examination of the deterioration of materials, the geometry of their elements, and their conservation state. The 3D reconstruction of surviving objects can then be integrated with what has been damaged through virtual methods, giving a complete virtual image of the building [30].

Autodesk has been considered a comprehensive suite of HBIM software solutions, including Autodesk Revit, AutoCAD Recap 360, AutoCAD Architecture, Navisworks, and others. For the current project, Autodesk Recap 360 and AutoCAD Architecture were selected as they are easy and compatible in terms of measurement of the metadata of buildings, such as height and width, and door and window details, the identification of any damage, their user-friendliness and interoperability, and their ease of sharing with other stakeholders [27].

The application of HBIM for existing structures differs from its use for new projects. Scan data can be converted into AutoCAD & Autodesk Revit files to get accurate and authentic metadata based on 3D models, auto-generated orthographic drawings, and as-built drawings with details of materials and construction techniques [31]. All the processes of digital conservation also help in the adaptive reuse of historic environs to fulfill current community needs.

### ***2.3. Interoperability within different software environments in HBIM a chances of errors***

HBIM creates a collaborative environment among historians, architects, engineers and conservation experts, facilitating them to jointly document and preserve historical building metadata such as construction dates, architectural styles, previous modifications, etc. [7]. A collaborative environment enables stakeholders to share their expertise in the digital documentation process, confirming the capture of all relevant information and integration into the HBIM model. In addition, it enables the sharing of information among stakeholders working in different fields, leading to an understanding of historical building materials, construction techniques, and cultural significance [31]. It also provides material specifications, including their composition, age, condition, and provenance, thus supporting conservation efforts and preservation projects [30]. The key support given by HBIM models is briefly described below.

- HBIM platforms are designed to integrate with heritage documentation tools, such as laser scanning, photogrammetry, and 3D modeling software, allowing historical data to be seamlessly incorporated into the BIM model.
- HBIM promotes interoperability with conservation software tools for structural

analysis, material testing, and restoration planning, enabling informed decision-making in heritage conservation projects.

- Interoperability in HBIM facilitates data exchange with cultural institutions and heritage organizations, ensuring that historical building information is shared and preserved for future generations.

TLS is a modern and powerful technology for capturing the 3D data of historic monuments and heritage sites, but similar to any other technology used for measuring, it is also subject to chances of errors in terms of precision and accuracy. These errors can be due to instrument calibration errors, target reflectivity and surface properties, range noise and signal attention, scan registration errors, geometric distortions, point density and sampling errors, data processing, and filtering. By considering these possibilities of error, TLS users can reduce them through careful calibration, data processing, error modeling, quality assessment, and uncertainty estimation techniques.

#### **2.4. Digital documentation within the historic core of Lahore**

The historic core of Lahore is comprised of a variety of building types and historic urban open spaces, reflecting a distinctive and comprehensive pattern of spatial development. It was divided into nine districts termed Guzars at the time of Emperor Akbar [32]. They were named after the administrator or the activity being performed in the area. The buildings have been classified under three categories: high, medium, and low [33] by the Walled City Lahore Authority (WCLA), depending on their architectural characteristics and construction period. Patrick Geddes (1854-1932), after a short visit to Lahore in 1917, gave an idea of “conservative surgery” based on the improvement of old buildings and the construction of quarters rather than demolition and reconstruction [34].

It has remained a challenge for the authorities to protect this urban heritage due to the constraints and limitations of conventional tools. New technologies have introduced fast-track and authentic surveying, mapping, and documenting of significant historic buildings. At the same time, a process of accurate preservation has helped to give new life to old structures, as adaptive reuse is not a new phenomenon but a process that started with the development of the built environment [35].

The TLS technique was introduced in Pakistan by Dr. Murtaza Taj from LUMS University, who digitally documented six sites using a Leica Scan Station P20. The selected six sites included Mosque Wazir Khan Lahore, the Temple of Shiva Johi, Daddu, Takhat-e-Bhai Mardan, Darewar Fort Bahawalpur Multan, Mosque Khudad Daddu and stupa at Julian Huripur. Mosque Wazir Khan was digitally documented in collaboration with the Walled City Lahore Authority (WCLA) in 2015 [36]. TLS technology was adopted by the Agha Khan Cultural Services of Pakistan (AKCSP) for the documentation and conservation of built heritage after LUMS and AKCSP completed several successful projects in collaboration with WCLA. The most significant were the Conservation of the Chauburji gateway, the Picture Wall at Lahore Fort, and the Façades of Wazir Khan Mosque [37]. WCLA has identified zones of special value in the walled city of Lahore. Out of these identified zones, Bazaar-e-Hakeema and Jogi Mohallah were documented with TLS in 2016 [38]. As a World Heritage Site, Lahore Fort was also documented with TLS under the umbrella of WCLA [38].

Conservation projects completed from 2015 to the present have encouraged WCLA and the conservation community to adopt modern technologies to overcome the limitations of conventional methods and to apply speedy and accurate documentation within

the Walled City of Lahore. According to the information provided by WCLA, the TLS, Faro Focus<sup>s</sup> point cloud owned by WCLA is one of the latest versions from Faro Industries with the combination of a 360 digital camera, helping to expedite the digitizing of cultural heritage of Lahore.

### 3. Case study: the Mai Eidaan Courtyard

#### 3.1. Location and Context

The site of the case study is accessible from Fort Road and Nicha/Neewan Chait Ram Road, located in the Shahi Mohallah, Lahore, which is now part of Food Street. The selected site, “Mai Eidaan Courtyard,” is located in the historical context of Lahore Fort, with religious and commercial activities and comprises a courtyard surrounded by a group of buildings of various typologies. The main access to the site is from Fort Road through a street situated in front of the entrance in the south wall of Badshahi Mosque used by the Nikah Khawan (a person who solemnizes marriages) (Figure 2).



Figure 2. Mai Eidaan courtyard with its context (source: WCLA – modified by author).

In the north, on the entrance street from Fort Road to the courtyard, Andaaz Restaurant is located on the right side, and Royal Dreamland Restaurant is on the left side. These rooftop restaurants present a view of the courtyard of the historical Badshahi Mosque. Mai Eidaan Imam Bargah is situated on the opposite side of the courtyard, in the south, and is accessible from the Nicha/Neewan Chait Ram Road. The first floor of the Imam Bargah serves as a mosque and is used for prayer five times a day by 15 to 20 people of the Shia sect. There are shops on the three sides of Imam Bargah that generate a source of income (such as shop rents) to cover the expenses of the Imam Bargah and Mosque (e.g. salaries, maintenance, etc.). Mai Eidaan was the lady who donated her land for the construction of the Imam Bargah. Her house is situated on the opposite side of the Imam Bargah at the Nicha/Neewan Chait Ram and was recently sold by family members.

The structure on the west side of the Mai Eidaan Imam Bargah is utilized for

commercial purposes, for example, there is a shoe factory, as a shoe market is located in the nearby premises. There are, moreover, houses on the east and west sides that have architectural value.

### **3.2. Historical background**

During the reign of Akbar, Lahore was divided into 36 districts (guzars) and 09 of them are in the old city of Lahore. The selected site is located in the Guzar Shehbaz Khan, which is also famous as Guzar Mang Khan and named after Muhammad Shahbaz Khan Kamboh, a Rajput Kamboh was a military general and tutor of Emperor Aurangzeb and famous for his generosity, due to which the area is also called Guzar Mang Khan [32].

Guzar Shahbaz Khan is located in the immediate premises of the southern wall of Badshahi mosque and Lahore Fort and was a place of residence for royal family members, administrators, and nawabs during the Mughal Empire and Sikh Monarch. The area is accessible from the Texali gate from the west, the Masti gate from the North, and the Bhatti gate from the South [12, 39]. The community also used the place and included intellectuals dedicated to pleasing the Royal throne with their performing art skills, such as music and dance [39]. Muhammad Iqbal, Advocate of the High Court and president of Ustad Damon Academy, Texali Gate Lahore, stated in an interview that Chait Ram was a Hindu nobleman famous for his charity to the poor and needy people. The road is dedicated to his name because he used to sit at a place named "Takya of Chait Ram," located on it, to guide the community in their noble spiritual actions.

Architectural elements of the structures indicate that the area was developed during British rule and occupied by performing artists, musicians, qawwals (a local term for singers), poets, etc. The prostitutes started to reside in this area during the period of Ahmad Shah Abdali, their presence solidified by the British soldiers. One of the shop tenants of Mai Eidaan Imam Bargah said that he had been an eyewitness to all past activities that went on in the area until a ban was called by President Zia ul Haq to crack down on prostitution and to get rid of the "Tawaiif" culture. After this ban, most of the prostitutes had to shift to another area to continue their activities, and the vacant houses were purchased by traders, who opened restaurants, factories, and the like. This ban was an initial step towards the commercialization of the Shahi Mohallah. Today, traders and wholesale manufacturers have transformed the residences into commercial places by adaptive reuse. The consequences of this shifting and adaptive reuse of the residences into commercial hubs have enhanced the commercialization of the area. Archaeologists have shown interest in protecting this area to identify its tourist value and to develop it for foreign tourists and visitors [12].

### **3.3. Architectural and cultural significance**

Mai Eidaan was a devotee of the Shia sect. She purchased a piece of land in front of her house, located on the Nicha/Neewan Chait Ram Road, running parallel to Fort Road, and started mourning processions during Moharram (Islamic month in which the grandson of the Holy Prophet Muhammad was martyred), in memory of the martyrdom of Hazrat Imam Hussain. Afterward, an Imam Bargah was constructed in 1954 (as written in the description at the front door of the building). The Mai Eidaan courtyard is sandwiched between some restaurants and the Imam Bargah and is accessible from Fort Road and Nicha/Neewan Chait Ram Road through 15'-0" wide roads. There are

shops on the western and southern sides of the Imam Bargah to meet the running expenses of the Imam Bargah and mosque. The administrator of the Imam Bargah rents the shops, which are utilized to pay salaries and the maintenance of the Imam Bargah.

Due to its location and religious activities, the precinct is considered a historic and religious environment. Another function is commercial activity. However, as one of the buildings is utilized as a shoe factory, it damages the historic character of the open spaces. The residents in this area also use this courtyard as a private space for drying clothes in the sun and leisure activities. However, people dining at the rooftop restaurants have beautiful views overlooking the courtyard of Badshahi Mosque.

The courtyard can be accessed through Fort Road, Lahore, which is near the UNESCO World Heritage Site, Lahore Fort. The courtyard is an open space inside Shahi Mohallah, famous for performing arts in past decades. Due to its location in the historical context, it was a favorite place for royal family members, nobles, and royal servants during the Mughal and Sikh Empires, being one of the principal sites for the people who had to attend the Royal court to please the Mughal Emperors with music and dance. Due to its relevance for the royal throne, the area is known as Shahi Mohallah, the residence of people associated with the royal seat [40]. Once upon a time, it was a hub of cultural activities that stopped after Independence. Most of the structures have abandoned their original use and are adaptively being used to fulfill contemporary requirements. As an example, two residences in the Mai Eidaan courtyard have been transformed into restaurants, and two of the residences have adaptively been used as shoe factories, thus accommodating the contemporary needs of the residents.

The group of buildings around this courtyard is comprised of a Mai Eidaan Imam Bargah associated with religious functions, therefore maintaining its original use; two residences have been adaptively reused and transformed into rooftop restaurants, the Andaaz Restaurant and Royal Dreamland restaurant, bearing architectural and tourist value, with beautiful views of the courtyard of Badshahi Mosque; two of the houses have been converted and are now shoe factories with a commercial value; and the remainder of the buildings are used as residences. The Mai Eidaan Imam Bargah reflects the religious environment, especially during the month of Moharram and Safar (Islamic months) for the Moharram proceedings, and the place was dedicated to the memory of the martyrdom of Hazrat Imam Hussain by Mai Eidaan. Initially, it was open land, but after an extended period, a building was constructed on the ground floor, the Imam Bargah, and a mosque on the first floor. Mai Eidaan's residence is on the Nicha/Neewan Chait Ram road, a side road of the Imam Bargah; however, her family members were moved to another part of the city for personal reasons.

### ***3.4. On-site terrestrial laser scanning at Mai Eidaan Courtyard and the HBIM model***

The Mai Eidaan courtyard was digitally documented using TLS by a team from WCLA to record and evaluate the operational stages of the TLS surveying, mapping, and processing of scanned data to develop 3D models, which auto-generated 2D measured drawings. The TLS device can survey hundreds and thousands of positions per second. The scanned data is in the form of point cloud data in XYZ format. 3D scanning and producing point cloud data are used to acquire large volumes of accurate data. Conventional surveying methods, such as measuring tapes and digital surveying with theodolite and total station, can never compete with the accuracy and speed of a TLS, which is 976000 points per second in the case of the Faro Focus S70 laser scanner (Figure 3) [28].



Figure 3. The Faro Focus S Laser Scanner shows spheres (targets) and scans surveyed at the site.

For the selected case study, the Mai Eidaan Courtyard, a Faro Terrestrial Laser scanner was used (the Faro Focus is owned by the Walled City Lahore Authority). An architectural plan was drawn up with the help of data collected during the visual and pictorial surveys to fix the target points in the courtyard for the scanning of the facades of the surrounding structures. With the help of “spheres,” Artificial Common Reference Objects (targets), four points were fixed to define the range of scanning for the facades.

The scanned data was combined using the Scan Manager of the software Faro Scene 2019 to transform it into a single file. This software gives a 3D model of the scanned site. After converting scanned data into a 3D model, it is possible to delete unwanted elements from the scanned data (Figure 4).

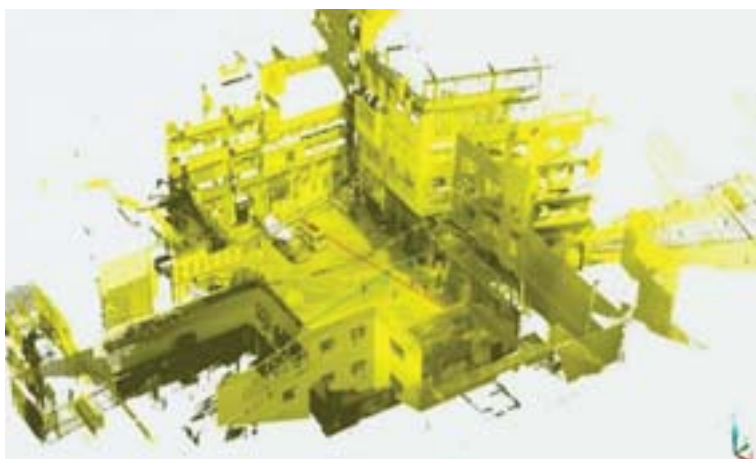


Figure 4. Showing Faro scans of the Mai Eidaan Courtyard

The distance between the target points and objects to be scanned can affect the wavelength of laser beams. Four scans were done with the help of Terrestrial Laser Scanners to cover the facades of the buildings facing the courtyard and the streets linking the courtyard. Each scan is 10 minutes in duration. The target points are shown in Figure 5. The site was scanned with the help of the TLS of Faro S70, and the scanned data was registered with the help of the “Faro Scenes 2019” software. The registered data, in the form of a Recap file, was then transformed into 3D models showing all the details with a high level of accuracy in the minimum time. All the scanning was done in 04 scans, each of 10 minutes, consuming 40 minutes of scanning time and almost 10 minutes for the preparation between the scans. The whole processing from the start of the task till the end was almost 03 hours, after which the file was ready to import into an AutoCAD model to get the multilayer data (Figure 6). The scanned data was combined with the help of Faro Scene 2019 software. The file format is .rcp, and it is ready to export to Autodesk Recap 360 software. These .rcp files can be imported into Autodesk Recap 360 to develop a Building Information Model of the scanned site (Figure 7).

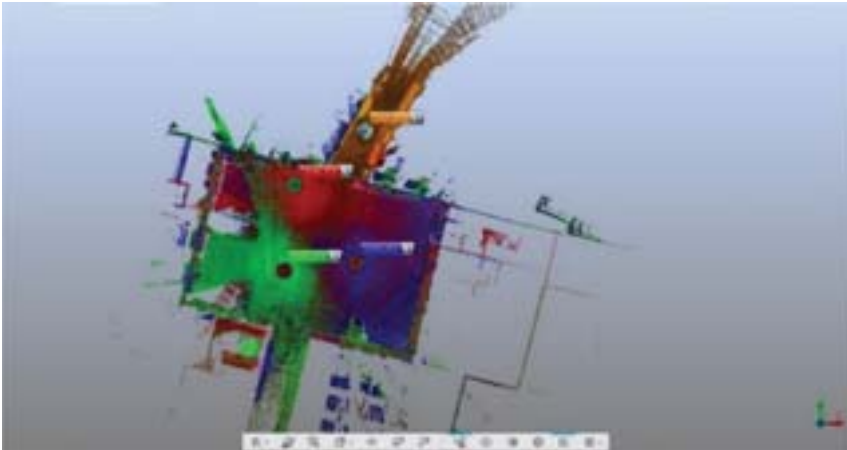


Figure 5. A view from above of the Mai Eidaan Courtyard showing the location of the targets (spheres), using TLS with scenes no.875, 876, 877, and 878.



Figure 6. Details of the processing of scanned data in 3D model (Figure A) and details of files (Figure B).

### 3.5. From scan data to building information modeling

Files edited in “Scenes” in \*.rcp format were exported to Autodesk Recap 360 Pro to develop 3D models with multilayer information in RGB colors.



Figure 7. Details showing 3D Models in the Recap support files.

Figure 8A shows a model, while Figure 8B (see upper right-hand corner) shows how the placement and orientation of the targets can be traced to view the desired model. Autodesk Recap can help to develop HBIM models to provide details beyond the limits of conventional methods. The key feature is using the limit box to visualize the details of the facades in the HBIM model (Figure 9A and B).



Figure 8. RGB 3D model of the selected site (A); and real view of the site in Autodesk Recap 360 (B).

Measurements can also be taken from these HBIM models, saving time and energy. It takes many days to develop measured plans using manual drawings, but HBIM models can be developed, saving time and money (Figure 10 A and B).

In-depth details can be extracted from the HBIM model and can be measured, and the present condition of the deteriorated elements can be recorded with a high level of accuracy and precision for the development of digital models.





Figure 9. HBIM Model (A) and use of limit box (B).

The HBIM database provides accurate and precise details about the deterioration of materials and causes of decay, as compared to the database of any other conventional technique, such as manual drawings and sketches, photographs, etc. (Figure 11A and B). Building heights are also measured through the expression of colors. Autodesk Recap has the option of obtaining the heights of buildings.

The image in Figure 12 shows the heights at 319-350 meters at a focal length of 50mm. The software can also support “cropping” unwanted objects from the model.



Figure 10. The HBIM model shows key features for extracting markups (A); and measurements (B).



Figure 11. HBIM model (A) with extracted details of historic doors of high architectural value (B).

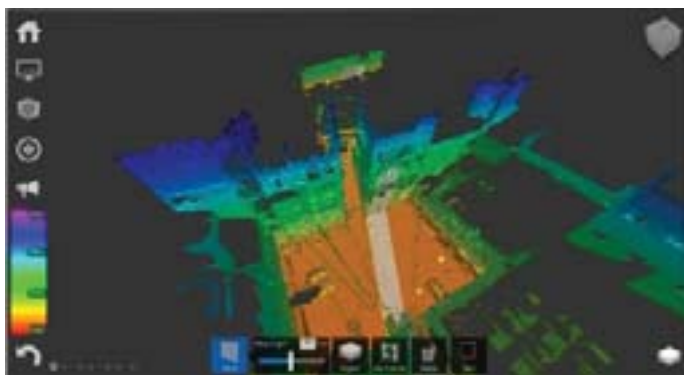


Figure 12. The image captures the building's complete inner view.

### 3.6. HBIM models in AutoCAD

The files of Autodesk Recap can be opened in AutoCAD and Revit, using an icon to import a point cloud to develop 3D models to execute projects such as as-built drawings and digital documentation of heritage sites [18] (Figure 13).



Figure 13. Elevation of the northern façade of the Mai Eidaan Courtyard.

## 4. Research methodology

The key objective of the research is to evaluate the potential of scanning and mapping heritage sites and historic buildings using the Faro Focus application (Terrestrial Laser Scanner). It is a valuable tool due to its many merits, including ease of use, chances of error reduction, time and money saving, and the highest quality of work. The environment in which the scanning is done is very significant, as it can influence measurement errors. The temperature difference of 10°C or a change in air pressure of 35 hPa can cause an error of 1mm/100m [41]. With all the benefits, there are a few constraints and limitations regarding applying the Faro Focus scanners at the site. It is pertinent to mention that there is a limitation related to its function in high temperatures as it can impact the wavelength of the laser beam, and, in addition, there are chances

of error due to the thermal expansion of the objects being measured. Rain, dampness, moisture, or dusty environments can also influence performance accuracy, and care should be taken to ensure the instrument is protected at all times to avoid accidents (e.g., storing it in congested spaces).

Considering all the constraints and limitations, the site for the case study was carefully selected in a historical context, encompassing various categories of buildings based on their function and architectural characteristics. To ensure the validity of the research, a comprehensive strategy was developed for documenting the selected area, leaving no stone unturned in our pursuit of accurate and reliable data.

- Archival data was collected from the Walled City Lahore Authority and local libraries to identify the site's historical and architectural value and context. From the historical context, it was evaluated that the site's conservation and refurbishment can enhance the courtyard's tourist value, in addition to the additional religious value deriving from the Imam Bargah.
- A visual and pictorial survey with DLSR was conducted to develop an initial inventory of the buildings surrounding the courtyard.
- The present status of the buildings was recorded in terms of age, architectural characteristics, and damage spanning the period of their existence.
- Interviews were conducted with the residents, employees, shopkeepers, and visitors to evaluate previous interventions
- The selected time for scanning at the site was 8 a.m. to avoid human traffic and high temperatures, as the site is outdoors, so the work could be completed before noon. The time span was almost 03 hours. The scan data was saved in a memory card inserted in the scanner (by default). Four scans were captured at various points with the help of spheres, termed targets. The scan data was in the form of high-resolution point cloud data.
- A video was made to maintain a record of the on-site scanning and to evaluate the whole activity.
- After the scanning was completed at the site, the rest of the work was completed at the office workstation. The scanned data, saved on a memory card, was registered to the computer with the software application "Faro Scene 2019."
- After registration of the scan data in .rcp format, the files were transferred to AutoCAD Architecture 2016 files through Autodesk Recap 360 to provide the opportunity to share the data among stakeholders. This software can support files to measure the site's dimensions, visualize the detailed images, and describe minute details regarding damage and construction materials.
- The 3D models and auto-generated orthographic drawings were prepared to develop conservation and rehabilitation plans for the urban built heritage, maintaining its authenticity and accuracy.
- Finally, the data can be transformed to AutoCAD Architecture and Autodesk Revit to achieve a high level of accuracy in the documented drawings. However, Autodesk Revit requires a high level of proficiency in data acquisition and data management.

## 5. Results and discussion

Digital technologies play a significant role in the building industry in getting the best resource outcomes regarding accuracy, time, and money. The heritage conservation

community is also trying to convert its processes and practices from conventional to digital to preserve historic buildings, urban heritage, and archaeological sites. There are various phases in the conservation process, and documentation is one of the most crucial and substantial parts. Conservation experts are consequently constantly trying to find the most authentic methods to document built heritage with the help of digital tools and software.

The journey of remote sensing for the digital mapping of heritage sites started from a total station to Terrestrial Laser scanning in order to save multilayer data in terms of intrinsic architectural details, in-depth damage valuation, surface deterioration, and structural damage, and it would not have been possible without the application of these digital technologies. The application of Terrestrial Laser Scanning has revolutionized the heritage community through the opportunities it offers to scan urban built heritage in depth. Furthermore, it provides scan data that can be processed to obtain AutoCAD orthographic drawings, Autodesk Revit 3D models, and metadata in terms of how old buildings are, their height and current status, their material deterioration and climatic impact, all data that can be used in the preparation of conservation plans (Figure 14A and B).

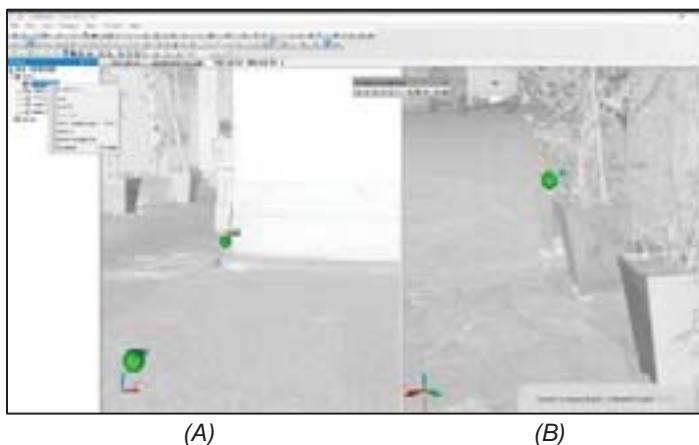


Figure 14. Terrestrial laser scanner scanned images using point cloud data (A and B).

The scan data provides accurate data that takes a minimum of time and converts it into AutoCAD and Revit files, which are technical solutions to obtain accurate measured details while drawing horizontal and vertical measurements. The data capture for the courtyard was completed in only three hours, but it can take a couple of weeks if done manually, with chances of human error. Other than human resources to document the facades of the buildings encompassing the courtyard, different equipment is needed for measuring the multistory structures.

However, the orthographic projections and decorations such as kashi kari, mosaic, and engravings cannot be measured. Still, they can be scanned with high-resolution point cloud data, and measured drawings can also be prepared by converting point cloud data into 3D CAD and Revit models. These measured drawings are helpful in project planning and execution at the site. Finally, digital technologies also help to develop a digital archive of projects entertained by various conservation agencies.

In this research, digital tools, methods for their application, and software for

converting scan data to Auto CAD files were studied as an integrated approach to exploring the scope and potential of Terrestrial Laser Scanning and HBIM approaches for preserving architectural and urban heritage in Pakistan. Figure 15 shows the recap file processed from scan data illustrating the architectural details of the courtyard which can subsequently help in preparing appropriate conservation plans in the future.



Figure 15. Recap data processed from point cloud data.

The process, once completed in several weeks, can now be done in a few hours at the site, and the work at workstations can also be done in the shortest time with maximum details. Although there are possibilities of errors, they can be minimized through accurate measuring and experience in diverse skills. There is a big challenge regarding the cost of the equipment, but it can be justified based on the number of projects and the type of heritage sites in Pakistan.

The scan data can provide in-depth structural and surface damage details and help manage and monitor heritage sites. Equally, it can be used to prepare a digital archive that is usable for future projects, with data that can be utilized for the sustainable development of historic cities to protect and save the heritage of Pakistan.

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**Neelum Naz** was born in April 1956 in Gujranwala District; her educational journey commenced in Dipalpur, culminating in a Matric certificate from the Govt. Pilot Secondary High School Sahiwal. After completing F.Sc. (Pre-Engineering) at the Government College for Women, Gujranwala, studied Architecture at the University of Engineering and Technology (UET), Lahore, in 1974. Following her Bachelor of Architecture in 1980, she served as an Assistant Director at the Lahore Development Authority (LDA). Joining the Department of Architecture as a Lecturer in Jan. 1983, she was promoted to Professor in 2004. After earning her Ph. D. from the University of Sheffield in England in 1997, she returned to Pakistan to serve her Alma Mater. In 2005, she delved into post-doctoral studies at the Middle East Technical University, Ankara, Turkey. After dedicating 34 years to UET, she honorably retired in 2016. At present, she proudly holds the esteemed title of the first female Professor EMERITUS at the Department of Architecture, UET, Lahore.

**Yusuf Awan** has a Ph.D. from the University of Sheffield, UK. He is also a Higher Education Commission (HEC) approved PhD Supervisor and is currently serving as Dean for the School of Architecture, Design, and Urbanism at the Institute for Art and Culture, Lahore. He has 48 years of experience in teaching, research and administration. He served as Chairman of the Department of Architecture at the UET (University of Engineering and Technology), Lahore, and strengthened programs of B. Arch, M. Arch, and PhD Arch. After retirement from the UET, Lahore, he served as Dean at the School of Architecture and Planning, UMT, Lahore. He launched four bachelor programs, two programs for Master's Degrees, Master of Architecture and MS-Housing and Community Development, and one program for PhD Architecture. He has published more than 22 research papers and supervised more than 40 M. Arch theses and more than 700 B. Arch Projects. He has also successfully established a research journal, the Journal of Art, Architecture and Built Environment (classified in the Y- Category) and is approved by the HEC as Chief Editor.

## Summary

This study uses a Terrestrial Laser Scanner (TLS), focusing on the Mai Eidaan Courtyard in Lahore, Pakistan, to present a systematic approach to digitally documenting historical monuments and urban built heritage. The architectural and urban heritage is facing accumulative pressure regarding the sustainable development of historic cities. The preservation of cultural heritage is becoming an urgent task for the conservation community if it wants to ensure it survives for generations. The case study is located in the historic center of Lahore. It comprises great historical value, serving as a noteworthy example of adaptive reuse within a historical context and attracting high tourist interest. Using a systematic methodology, this study evaluates the efficacy of TLS in documenting intricate architectural details and spatial characteristics, thereby contributing to the broader discourse on digital preservation strategies for historic urban environments. The methodology integrates terrestrial laser scanning (TLS) as an emerging remote survey data collection tool for mapping systems and documenting the monuments. Heritage documentation and virtual modeling play crucial roles in identifying, protecting, and preserving historic structures, enabling monitoring and maintenance, and providing multi-layered information necessary for conservation efforts. Overall, this

research aims to bridge gaps in the literature on digital heritage documentation and highlights the significance of interdisciplinary collaboration for safeguarding urban-built heritage for future generations.

### **Riassunto**

Questo studio propone un approccio sistematico dedicato alla documentazione digitale dei monumenti storici e del patrimonio costruito urbano utilizzando tecnologie basate su Laser Scanner Terrestre (TLS). In particolare, si presenta il caso di studio del Cortile Mai Eidaan. Ad oggi, il patrimonio architettonico e urbano si trova ad affrontare pressioni continue e cumulative dovute allo sviluppo sostenibile delle città storiche. La conservazione del patrimonio culturale è un'esigenza per la comunità e garantisce benefici per le generazioni future. Il caso di studio si trova nel centro storico di Lahore e comprende un gruppo di edifici di significativo valore religioso, commerciale e storico, che costituiscono un virtuoso esempio di riutilizzo adattivo di un contesto storico, inoltre attirano un elevato interesse turistico. La metodologia proposta in questo studio permette di valutare l'efficacia delle scansioni TLS al fine di documentare dettagli architettonici complessi e caratteristiche spaziali, contribuendo così al discorso più ampio sulle strategie di conservazione digitale per ambienti storici urbani. La metodologia integra l'uso della TLS come strumento di raccolta dati da remoto al fine di produrre una mappatura e la relativa documentazione per i monumenti storici analizzati. La documentazione e la modellazione virtuale svolgono un ruolo cruciale nell'identificazione, protezione e conservazione delle strutture storiche, consentendone il monitoraggio, la manutenzione, fornendo le informazioni multilivello necessarie per gli sforzi di conservazione. Nel complesso, questa ricerca mira a colmare le lacune nella letteratura internazionale in merito alla documentazione del patrimonio digitale ed evidenzia l'importanza della collaborazione interdisciplinare per la salvaguardia del patrimonio urbano costruito per le generazioni future.

# **T**RACING “ORIENTALISM” THROUGH ARCHITECTURE AND ART DURING THE FRENCH COLONISATION OF ALGERIA

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## **1. Introduction**

Algeria holds a prominent position as one of the key countries in North Africa. Its extensive territory, along with its ethnic and cultural mosaic, has provided fertile ground for the emergence of a diverse urban and architectural heritage. This heritage forms the basis for expressions of identity, serving as a background that vividly illustrates the nation's cultural diversity.

The French colonisation of Algeria (1830-1962) left a significant urban and architectural legacy that characterises most of its present-day cities. Initially, the French established themselves in the territory by creating military installations with fortifications and defensive structures based on the specific features of the traditional urban fabric of each region. Their main goal was to subdue the local population. Thus, over time, many colonial cities and public facilities were developed throughout Algeria [1-3].

During this historical period of colonisation, notable architectural styles emerged, including the “conqueror style” and the “protector style” [1-2, 4]. From 1830 until the end of the 19th century, the conqueror style dominated throughout the Algerian territory and encompassed three primary architectural tendencies: neoclassicism, post-revolution design, and eclecticism. As for the protector style, also known as “Arabisance,” “Jon-nart’s style,” or “neo-Moorish,” it unfolded during two distinct periods. The first is associated with the construction of official buildings between 1900 and 1930, while the second emerged after the Second World War (1945) [2]. The protector style embodies an Orientalist trend, the adoption of which varies in Algeria depending on factors such as local architecture (including building techniques and materials), the architect's sources

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of inspiration, and external influences. Orientalism is a movement that reflects Western fascination with the Orient [5]. When viewed from a Western standpoint, it refers to a way of looking at and representing the cultures, societies, and histories of the Eastern world, primarily the Middle East, Asia, and North Africa. The term gained prominence through the work of Edward W. Said, a Palestinian-American literary theorist, in his influential book "Orientalism," published in 1978 [6]. In Said's analysis, Orientalism is not just an academic field or a set of scholarly practices, it is also a form of Western cultural and intellectual imperialism. He argued that Western scholars, writers, and artists often approached the East with preconceived notions, stereotypes, and biased perspectives, constructing a distorted image of the Orient that served to justify colonial and imperialist agendas.

While the Orient has been a source of inspiration for artists and writers for centuries, it was not until the 19th century that a true infatuation emerged. In the early 20th century, specifically between 1900 and 1930, French Algeria experienced a shift in policy that deviated from seventy years of conqueror-style austerity. This new policy in Algeria aimed to foster a distinct national identity by searching for design references from the Islamic heritage, particularly through the adoption of a regional architectural style that sought to reconcile Western and Eastern elements. Architects incorporated traditional elements and motifs extensively into their designs, resulting in the construction of numerous "modern" buildings across Algeria with an Oriental-inspired aesthetic. These structures, including railway stations, post offices, city halls (Figure 1), churches, and other facilities, responded to evolving needs and introduced new functions that did not exist in traditional heritage [7-9]. This period is significant historically, as it marked the establishment of an Arabising architectural tradition and facilitated an unprecedented fusion of modern programmes with traditional architectural styles, reviving Islamic aesthetic qualities.

The word "aesthetics" is originally Greek and means perception. The science of aesthetics, in the broadest sense of the word, examines the methods of feeling the environment and the position of the individual within it. Aesthetic in architecture refers to the branch of architectural design that prioritises and emphasises a structure's visual and sensory aspects. Thus, the focus extends beyond mere functionality to encompass beauty, harmony, and deliberate consideration of the emotional and perceptual experience of those interacting with the built environment. Historically, the topic of aesthetics has its roots in the art and architecture of different cultures around the world. The aesthetic of each nation has developed in line with its theoretical wisdom, tastes, ideals, and cultural beliefs, reflecting its identity and distinctive ethnic and national traits [10-11]. Therefore, the perception of beauty is a multidimensional phenomenon that can activate observers' internal and external senses, intellect, and intuition. The state of this colonial heritage, which has left a significant mark on today's urban landscape, is alarming. On the one hand, some colonial buildings have been preserved and restored, particularly in major urban centres. Some of them have become public institutions, museums, hotels, or cultural spaces. These buildings are valued for their historical and architectural value and contribute to Algeria's cultural identity.

On the other hand, many colonial buildings are in a poor state of conservation due to neglect, lack of maintenance, and deterioration. Certain buildings have undergone radical transformations that have altered their original appearance. Preserving colonial heritage is a complex challenge because of its controversial history and the feelings associated with colonisation. The Algerian government and heritage associations are working to preserve and restore some of these colonial buildings, but much remains to be done to ensure long-term protection for this architectural heritage and to strike a balance between heritage preservation and contemporary urban development needs.

## 2. Selection of case study, objective, and methodology

To better understand the subject of this paper, the city hall in Biskra city was selected as a case study (Figure 1). This historic edifice was designed in 1896 by the architect André Pierlot of Constantine and built under the supervision of the contractor Auguste Vigliano of Batna, as confirmed by an inscription on the building. With its monumental dome, porticos, arched openings, colonnettes, and wooden balconies, it is an appealing example of neo-Moorish style. Notably, it stands as the most splendid structure in the French colonial city of Biskra [13]. Despite being officially listed on the supplementary inventory<sup>1</sup> for protection and conservation in 2010 and 2023, with each designation spanning ten (10) years, the city hall is now in a lamentable condition. Over time, the building's conservation state has deteriorated, raising concerns about the potential fate of this historically significant structure. Certain distinctive features of the city hall have been transformed or have disappeared, such as the wooden balconies (Figure 2). Unfortunately, the city hall appears to be following a trajectory similar to that of other noteworthy monuments in Biskra city, with the Sahara Hotel standing as a poignant witness. In 2023, the Sahara Hotel was demolished by the local authorities. This significant event prompted a heartfelt and impassioned response from the citizens and civil society associations of the city of Biskra. They expressed their sentiments through an open letter addressed to the President of the Algerian Republic, dated April 4, 2023 (Figure 3). The demolition of this iconic hotel, with its historical and cultural significance<sup>2</sup>, raises questions about the rationale behind such a decision and the broader implications for the preservation of Biskra's architectural heritage. This event is visually documented in Figure 4. Using a historical approach, this article aims to highlight Algeria's significant contribution to the history of architecture by shedding light on a pivotal period: the period of French colonisation. It establishes the connections between Islamic aesthetics and French colonial architecture in order to critique the multiple references to colonial architecture in Algeria.



Figure 1. Old postcards of some city halls in Algeria with different colonial styles: A) Bel-Abass; B) Oran; C) Buir; D) Colea; E) Setif; F) Annaba (Bone); G) Skikda (Philippeville); H) Batna; I) Biskra [12].



Figure 2. The rear façade of Biskra city hall: A) Old postcards showing the wooden balconies [14]; B) Current view showing the transformation of the wooden balconies.



Figure 3. Open letter addressed to the President of the Algerian Republic regarding the preservation of the heritage of Biskra city. This letter was published in the independent daily newspaper "L'Est Républicain" [15].

Furthermore, the article encourages the local authorities to preserve this building, which attests to one of the styles that have marked the history of architecture in Algeria, specifically in the region of Biskra. The outcome of this endeavour will be an essay that meticulously unravels the heritage value inherent to Biskra city hall.



Figure 4. Demolition of the Sahara Hotel in 2023 [16].

### 3. The neo-Moorish style in Algeria: the revival of Islamic aesthetics

In the early 20th century, the French colonial administration in Algeria launched a series of significant architectural projects to forge a distinctive Algerian cultural and architectural identity through the reinterpretation and valorisation of pre-colonial architectural heritage [8]. French colonial structures integrated elements from Islamic architecture and art, such as minarets, domes, rooftop terraces, poly-lobed or horseshoe arches, intricate stucco decorations, stalactites, and zelliges, albeit in a whimsical and "decontextualised" manner. Inspirations were drawn from various regions including the Maghreb, the Middle East, Cairo, Cordoba, Constantinople, and Jerusalem [17]. Neo-Moorish architecture exhibited a range of forms and variations, from faithful reproductions of Islamic architectural elements to reinterpretations or conceptual recompositions guided by the rationality of refined geometry, which contributed to the first manifestations of Art Deco [18-19].

Initiated in the 1840s, a discourse emerged in Algeria about the need for an architectural approach that resonated with the local cultural ethos and, crucially, the climatic conditions. Figures such as Alexis de Tocqueville (1805-1859) raised concerns over the importation of European architectural models ill-suited to Algeria's environmental context [17]. Even at the official level, there were advocates for "Arab" architecture characterised by features like terraces, patios, and courtyards. The aesthetic inclinations of the colonists reflected a degree of appreciation for this idea. However, it was not until the early 20th century, marked by economic growth and the official adoption of "Arab" architectural elements, that these notions became more widespread. This official endorsement was followed by the issuance of circulars, largely due to the efforts of Charles Jonnart (1857-1927), who aimed to introduce an oriental style to public buildings [17]. In 1905, he established an architectural department tasked with studying, managing, and overseeing the construction processes and restoration of public buildings. The architect Albert Ballu (1849-1939), who had been the chief architect of Historical Monuments in Algeria since 1889, was entrusted with the management of this department. His long-standing role had given him a deep appreciation for the local

heritage. The neo-Moorish style gradually left its imprint on private architecture and eventually became synonymous with the architecture of Algerian cities, often referred to as the "Jonnart style" [20].

Jonnart's policy, much like the subsequent policy of Lyautey, was strongly influenced by practical considerations, especially in response to economic needs. The impetus for the development of tourism and, more crucially, the drive to "revive" local arts, significantly shaped aesthetic policies [17]. In pursuing its new policy objectives, France sought to adopt an image that better suited its protective role (the idea of a protectorate), opting for a "paternalistic stance." The aim was to reflect a France respectful of traditions and capable of reconciling differences in the interests of all [21].

The reinterpretation of the architectural language of previous periods is commonplace in architecture and art history. Over centuries, architectural thinking has consistently oscillated between two distinct trends: consciously revisiting historical styles or deliberately deviating from them to endorse innovative design forms [22]. For example, Bacha [23] reported that in the 19th century, the architect-restorer and theorist Emmanuel Eugène Viollet-le-Duc (1814-1879), considered Gothic architecture a foundation for modern architectural renewal, particularly for churches. This perspective stemmed from the belief that the Gothic style best suited French customs, climates, and habits. In the 19th-century European context, the local environment and historical influences played a significant role in architectural design. This period was marked by a historicist attitude, resulting in so-called "neo" architectures, such as neo-Romanesque, neo-Gothic, neo-Classical, and neo-Moorish. The prefix "neo" is synonymous with a revival within an ancient order. The term "Moorish" has a longstanding reference in Europe to Muslims from Mauritania to Spain [24]. The neo-Moorish style, thus, represents a revival of the "Moorish" style, which found its way to Algerian territory with the Andalusian influence from Spain. Zerrouki [25] noted that the Moorish style evolved into a "Turco-Moorish" aesthetic under Ottoman rule in Algeria before taking on a new expression following the French colonisation. Western architects like Benjamin Bucknall (1833–1895), Toudoire Denis Marius (1852–1922), Georges Guiauchain (1840–1912), and Albert Ballu (1849–1939) were instrumental in practicing architectural "Arabisation," later identified as neo-Moorish in 1905 and called "arabisations" by François Béguin [21] in his book, *Arabisations: décor architectural et tracé urbain en Afrique du Nord (1830-1950)*, published in 1983. In Algeria, Moorish architecture is the embodiment of an ancestral art that is almost omnipresent in historic cities such as Algiers, Constantine, and Tlemcen, which boast stunning examples of Moorish architecture, including mosques, palaces, and madrasas (Islamic schools). This architecture imbued with a rich history and diverse cultural influences, is distinguished by its unique aesthetic features, skillfully fusing Islamic, Berber, and Andalusian elements. Among the remarkable examples of Moorish architecture is the Great Mosque of Tlemcen.

French colonisation in Algeria stimulated visits by painters by providing a conducive environment for artistic exploration. The increased interest in exotic landscapes, supported by institutional backing and the promotion of colonial tourism, attracted French artists in search of new subjects. Colonial authorities often encouraged these visits by providing subsidies and organising artistic expeditions. Art exhibitions in France also helped generate interest in Algeria by showcasing works inspired by the country. As a result, Algeria became a coveted destination for artists seeking inspiration, thus shaping the visual representation of the country and its culture.

Orientalism played a significant role in the artistic representation of the country by painters. European Orientalist painters often travelled to Algeria to capture its landscapes, inhabitants, and culture, portraying them from an idealised European perspective. Their works helped shape the image of Algeria in the Western imagination, often



glorifying French colonisation and legitimising the colonial enterprise. However, it is worth noting that not all artistic representations of Algeria during colonisation necessarily followed this Orientalist trend; some artists also attempted to capture the everyday reality and cultural diversity of the country with more authenticity and nuance.

In 1886, the Swedish Fritz Ludwig von Dardel (1817-1901) painted the courtyard of the Great Mosque of Tlemcen, depicting its aesthetic and architectural elements in the late 19th century (Figure 5).



Figure 5. Watercolour by Fritz von Dardel, dated 1886, depicting the courtyard of the Great Mosque of Tlemcen, Algeria [26].

Using the watercolour painting technique, von Dardel's artwork captured the intricate details of arched apertures, doors, and ablution fountains, offering an interesting visual testament to Muslim culture, in which ablution remains an important practice. Ablution, known as "*wudu*" in Arabic, typically involves washing the hands, mouth, nose, face, arms, and feet with water in a prescribed manner. It is considered a symbolic cleansing of impurities, both physical and spiritual, in preparation for engaging in acts of worship. Although some architects, like Georges Guiauchain, critiqued Jonnart's policy, hybrid architectures in 19th-century Algeria predominantly comprised ornamental decor assembled from local references, with no specific logic, as evidenced in many buildings like the Algerian Dispatch (1906) or the Grande Poste (1910) [17] (Figure 6). Architects were at liberty to repurpose elements from the past, irrespective of their original function. This period was marked by eclecticism and historicism in architecture that gradually permeated throughout Algeria [7]. Eclecticism was initially introduced towards the end of the 19th century within the context of French colonisation and was part of the Western fascination with Islamic art, following an Orientalist trend. Hence, the neo-Moorish style is classified among the "historicist styles" and finds favour among Orientalists. It emerged in Algeria towards the late 19th century, reached its zenith in the early 20th century, and saw a decline in the 1930s with the advent of new forms aligned with the modern movement. It is a result of acculturation—a fusion of two cultures and their architectural languages, giving rise to a new stylistic expression.



Figure 6. A) Old postcard showing the Algerian Dispatch (in front) and the Grande Poste (in back) [27]; B) Old postcard showing the Grande Poste [28].

#### 4. The neo-Moorish style in Biskra city: some benchmarks

Focusing specifically on the neo-Moorish style in Biskra city, its manifestation seems notably eclectic, drawing inspiration from a diverse array of sources in terms of ideas, style, and taste. This implies that the architectural language adopted was external to the context of Biskra. Indeed, the pre-colonial architecture in this city, whether residential or religious, was devoid of any decorative details and did not extensively use components that, together, shaped the neo-Moorish style. Notably, the traditional religious buildings, of which mosques are the main edifice, were mainly characterised by blind façades dominated by the minaret and the dome covering the mausoleum [9, 29-30]. Consequently, the local architectural language of Biskra was not a major source of inspiration for architects during the colonial period. The city's local minarets and domes seem to be the key elements reinterpreted by Western architects. Many architects involved in designing new projects in Biskra sought inspiration from the northern regions of Algeria, where Moorish architecture was prevalent, which may explain the exogenous stylistic aspect of many colonial buildings in the city.

Delving into old postcards from the French colonial period unveils distinctive characteristics of the neo-Moorish style in Biskra. One of its prominent hallmarks is its commitment to symmetry, creating a visually balanced and harmonious aesthetic. In addition, the neo-Moorish style is marked by the strategic incorporation of key elements, including minarets that punctuate the skyline, domes that add grandeur to the structures, arches that create an engaging visual rhythm, colonnettes contributing to the ornate detailing, and monumental entrances that serve as impressive focal points. This deliberate integration of architectural elements reflects meticulous attention to detail and an effort to evoke the intricate beauty associated with Moorish influences.

Among the most captivating examples exemplifying the neo-Moorish style in Biskra are the Casino-Hotel Palace complex (1893) and the Hammam Es-Salihine (1896-1897). These architectural landmarks were built on the initiative of the Compagnie de Biskra et de l'Oued Righ (CIBOR) [31], a financial power that contributed a lot to the construction of the new commercial and tourist establishments in the city of Biskra before 1900 [32]. Indeed, in the early 1890s, the influx of tourists to Biskra was so great that it necessitated the construction of new establishments to satisfy tourist requirements [33, 34]. The Hammam Es-Salihine (Bath of the Saints) was located 7 km north-west of the French colonial city of Biskra. It was built on thermal springs dating back to Roman times. Unlike the Casino-Palace Hotel complex, this hammam has now disappeared. The Casino-Hotel Palace complex (Figure 7A, B, and C) and Hammam Es-

Salihine (Figure 7D) were designed by the same architect, Albert Ballu, who, according to Encyclopædia Universali [35], was a French architect, and General Inspector of Muslim Buildings in Algeria for over thirty years.

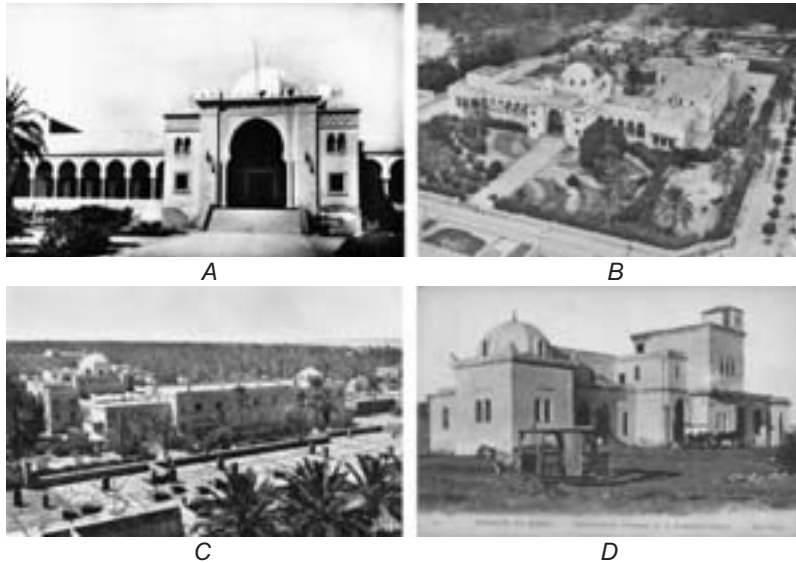


Figure 7. Old postcards showing projects drawn by Albert Ballu in Biskra city: A) the main entrance of the Casino of Biskra [37]; B) view of the Casino of Biskra [38]; C) the Palace Hotel [39]; D) the Hammam Es-Salihine [40].

He also studied the Arab and Roman historical monuments in Algeria. Albert Ballu entered the École des Beaux-Arts in Paris in 1868 and was a student of Auguste Magne and his father, Théodore Ballu (1817-1885). For her part, Oulebsir [36] confirmed that Albert Ballu, whose inspiration from local architecture is one of the hallmarks of his works, adopted a didactic architectural principle to explore and promote local styles. Roger [32] added that around 1890, Ballu visited Biskra, sketching three of its traditional mosques in pencil and studying the ancient door of the Sidi Okba Mosque. The casino of Biskra holds the distinction of being the first casino established in Algeria [31]. Its architecture intentionally incorporates elements such as columns, capitals, doors, and arches, reminiscent of Ottoman Islamic art in Algeria. Albert Ballu drew inspiration from the ornate features found in the palatial structures of the Casbah of Algiers. Examples include the Aziza Palace, Hassan Pacha Palace (Figure 8), Mustapha Pacha Palace, Dar El Hamra, Dar Mami Amaout, and Khdaouedj El Amia. Additionally, Ballu was influenced by the domed architecture of the Ali Bitchine Mosque in designing the Casino. Neo-Moorish architecture often emphasises rhythm in its design, creating a harmonious and balanced composition. The Casino exhibits this principle, contributing to its architectural beauty. Moreover, a journalist reported in *L'Algérie hivernale* (September 25, 1896) that the casino of Biskra was reminiscent of certain parts of the palaces of Ahmed-bey in Constantine, and even the Alhambra in Granada, Spain [32]. In Algeria, alongside the Casino-Hotel Palace complex and Hammam Es-Salihine, Ballu also designed two other significant projects, the Medersa of Constantine (1909) and the railway station of Oran (1913). In addition to the arched openings, the madrasa, like the railway

station, features a monumental dome, a common feature of Ballu's design style in Algeria (Figure 9). The stylistic features of the Casino of Biskra exhibit similarities to Ballu's previous projects in France, such as the Algerian pavilion at the Universal Exhibition in Paris (1889) and also the Algerian pavilion at the Trocadero Palace (1900).



Figure 8. A) Postcard of Hassan Pacha's Palace in Algiers [41]; B) Postcard of Ahmed Bey's Palace in Constantine [42].



Figure 9. Old postcards showing projects designed by Albert Ballu in Algeria: A) general view of the Madrasa of Constantine [43]; B) the railway station of Oran [44].

The first pavilion was regarded at the time as a pastiche of various famous monuments in Algeria: the minaret of the pavilion was inspired by the Sidi Bou-Medine Mosque in Tlemcen, as well as the Sidi Abd-er-Rahman Mosque and Jamaa al-Jdid (or Pêcherie Mosque) in Algiers. In the same stylistic approach, Ballu designed a Moorish city for the Algerian pavilion at the Universal Exhibition in 1900 [32] (Figures 10 and 11). According to Boufassa [45], a simple comparative observation of these two great exhibition pavilions of 1889 and 1900, reveals a diversity of high architectural elements between towers, minarets, spires, and observatories.

At these exhibitions, the towers and minarets were landmarks and served as panoramic vantage points from which to appreciate the landscape. Recognising the minaret as an emblematic element of the mosque and Islam, it represents a mysterious and distant world for European audiences unfamiliar with the Islamic faith and culture, embodying the broader concept of Orientalism where the East is often viewed as exotic and inscrutable.

As such, the use of the minaret as an architectural element referring to a religious function in a secular building was certainly a source of curiosity for the organisers and visitors of the exhibition.



Figure 10. Views of the Algerian pavilion at the Universal Exhibitions in France: A) exhibition pavilion of 1889 [46]; B) exhibition pavilion of 1900 [47].



Figure 11. Old postcards showing mosques in Algiers: A) minaret of the Sidi Abd-er-Rahman Mosque [48]; B) Jamaa al-Jdid (or Pêcherie Mosque) [49].

It is a mixture or confusion between two different antagonist cultures. Furthermore, the perception of the mosque as symbolising the "Otherness" of Islamic civilisation contributes to its allure and perceived inaccessibility for Europeans. It seems that the adoption of the neo-Moorish style predates Governor Charle Jonnart's cultural promotion policy in the early 20th century. This suggests that the inception of what was then called "neo-Moorish" can be traced back to earlier instances, as evidenced by the examples in Biskra. While some scholars, like Béguin [21], attribute its emergence to Jonnart's political decision, others argue that it evolved as a culmination of architectural experiments already underway in the 19th century [45].

## 5. Case study: the city hall in Biskra

The city hall (*Hôtel de ville* in French) occupies an entire urban rectangular-form island in the French colonial city of Biskra. Spanning an area of 1200 square meters, it measures 40 meters in length and 30 meters in width (Figure 12). Locally known as "Baladiat Souyda," meaning "the municipality of the lions," a reference to the statues of two lions on either side of the main entrance of the building.

These statues, reminiscent of the Atlas lions, have been shifted to inside the portico bordering the building's patio (Figure 13). At the beginning of 1879, Jules Béchu, the first mayor of Biskra, requested credits<sup>3</sup> for the construction of a city hall in Biskra.

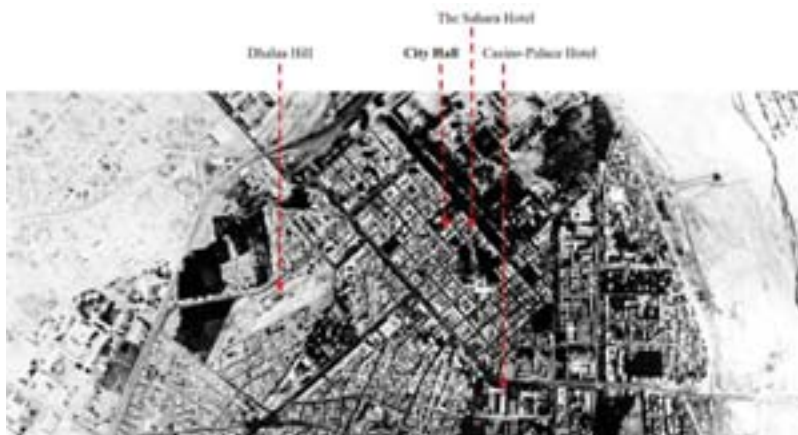


Figure 12. Aerial view taken in 1987 shows the French city of Biskra, and the location of the city hall, the Sahara Hotel, the Casino-Place Hotel complex, and Dhalaa Hill [51].



Figure 13. Old postcard showing the main façade of the city hall in the French city of Biskra. A) Two lion statues on either side of the main entrance [52]; B) After shifting the statues from the main façade [53].

Indeed, in 1896, the city hall in Biskra was erected by the Vigliano company of Batna based on a design by the architect André Pierlot from Constantine [50].

In Algeria, Pierlot was responsible for the design of various public buildings, including Souk Ahras city hall. He received a silver medal for his architectural contributions at the Universal Exhibition in Paris in 1889. In addition, Pierlot designed the civil hospital of Souk Ahras and the boys' school (*école des garçons*). André Pierlot's architectural style was influenced by the prevailing trends of the time, which often included a fusion of European and Moorish elements.

His designs aimed to merge French architectural traditions with local Algerian influences, resulting in buildings that reflected colonial aspirations while incorporating elements of the local culture and environment. The Musée d'Orsay archives provide invaluable insights into the art history, as well as the cultural and social landscape of the 19th and early 20th centuries.

According to some documents, the city hall of Biskra was the subject of an architectural competition, won by a French architect of Constantine, André Pierlot, who was renowned for his Baroque style [32]. The general design of Biskra's city hall was presented at the tenth Universal Exhibition in Paris, held from 5 May to 31 October 1889,

the theme of which was the French Revolution, to commemorate its centenary. Interestingly, the Eiffel Tower was also erected for this historic exhibition.

In 1893, the British politician Alfred Edward Pease described the city hall in his travelogue “Biskra and the oases and desert of the Zibans with Information for Travellers”; he wrote: “The hôtel de ville [city hall] is an almost extravagantly large and decorated pile. It is built in an exaggerated Eastern style, but the whole appearance of the building, with its court, its arcades, its columns, its façades, the whole surmounted by a great white cupola which rises above the town, and can be seen shining from afar amidst the dark green foliage around, is pleasing and effective.

Two large red marble lions guard each side of the entrance within finely ornamented iron screens and railings.” [54].

A brief description of the city hall of Biskra is given below. It highlights its spatial layout and the stylistic features of the façades, which are perfectly representative of the neo-Moorish style (Figure 14).

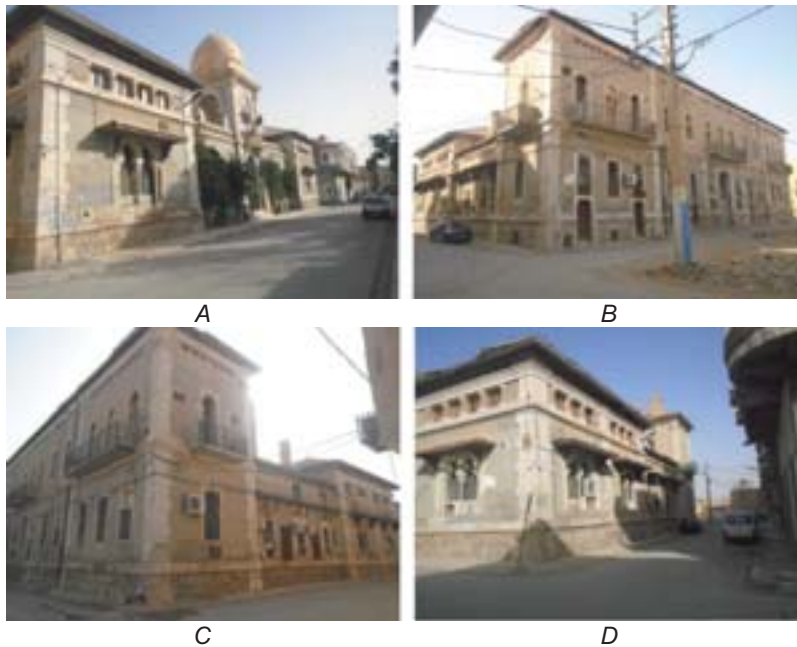


Figure 14. Current views of the city hall in Biskra: A) the main façade; B) the rear façade; C) and D) lateral façades.

### 5.1. Spatial organisation

The spatial layout of the city hall of Biskra was designed differently from the traditional French one, to align with local traditions [55]. It stood as a magnificent structure in a purely oriental style [50].

The city hall consists of two above-ground levels and one underground level. Access to the ground floor is provided through the north façade (the main façade). The entrance features a wrought iron double gate, leading into a spacious portico.

This portico, designed to accommodate up to a thousand people, protruded from the three elevations overlooking the patio and was covered with a sloping tiled roof (Figure 15.A).

The city hall's layout, symmetrical to an axis passing through the main entrance, encompassed three wings: the left wing housed all the administrative services, a council chamber, a security office, a mayor's office, an architect's office, and a registrar's office. In the right wing, there was a courtroom, a clerk's office, an interpreter's office, and a judicial office. The central wing included civil status offices, two archive rooms, and a police station with three offices.

There was also a garage and a service door, accessed from the rear façade. According to a note on the graphic document of this city hall: «Drawing inspiration from Arab style and customs, the architect placed its [referring to the city hall] services around a patio or inner courtyard opening onto all the building's doors [...]»<sup>4</sup> [56]. The underground level at the back of the building contained one cell and two gaols.

The first floor included three flats that shared a common circulation gallery and were reserved for the secretary-general, the architect, and the police commissioner [57]. These flats were directly accessible from the outside through the door on the south facade (rear facade), via a separate stair vestibule on the ground floor. They were also accessible from the door opening onto the patio (Figure 15.A).

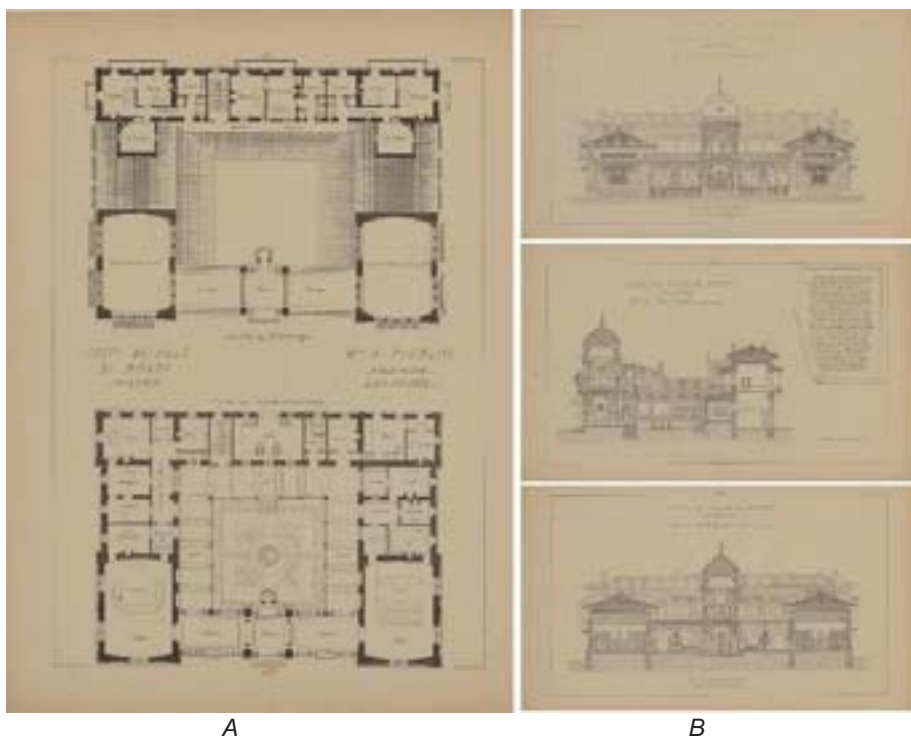


Figure 15. Graphic drawings of the city hall of Biskra: A) plans of the ground and first floor; B) above, the main façade, and below, two sections [56].



## 5.2. *Façades and elevations*

The position of the city hall, which occupied an entire urban island in the French city, meant it had four façades aligned with the streets (Figure 15.B): a main façade oriented to the north; a rear façade oriented to the south; and two lateral façades oriented to the east and west.

The main and rear façades followed axial symmetry. According to a note in the graphic document specific to this monument: "The external bays are topped by a canopy, while those that light up the main rooms have a covered balcony reminiscent of the Spanish miradors and Arab mouchrabiehs designed to prevent blinding light from penetrating directly into the interior. A very high dome, serving as a campanile, gives the [main] façade a monumental appearance befitting a municipal building."<sup>5</sup> [56].

The campanile is the most remarkable feature of this building.

It takes the form of a 10-meter-high dome with a clock manufactured in Paris. It crowns the main entrance to the city hall, giving it a monumental aspect. A lightning rod attached to the dome extends down to the subterranean level, where it is immersed in the running water of the "segua" (water canal) [50, 57]. Figure 16 shows details of the distinctive elements that compose the façades.

As for the construction of this municipal building, different systems were used. Its foundation is 1.50 metres by 0.8 metres up to ground level. For the superstructure, the contractor Vigliano used dressed stone extracted from Dhalaa Hill (southwest of the French colonial city of Biskra) for the base (Figure 12 and Figure 17). The façades are made of softer white stone extracted from quarries in the village of El-Kantara (52 km from the north of Biskra). The bricks from Batna (116 km from Biskra), and the tiles from Marseille. The first floor is made of adobe (mud bricks). The structural framework is made of timber from northern Algeria.

As reinforced concrete was not yet used at that time, iron tie rods were used in the building [50, 57]. The city hall has undergone a notable transformation. In the 1930s, restoration efforts were carried out, notably altering the appearance of the portico bordering the patio. This structure, which extended from the façades overlooking the patio, saw its original columns replaced with rectangular pillars. In addition, the sloping tiled roof was replaced with a flat roof, creating a rooftop terrace on the upper floor

## 6. Biskra city hall, a heritage treasure to be safeguarded and conserved

Biskra city hall, built in 1896 by the architect André Pierlot, stands today as a reference displaying a part of the French colonial period in Biskra, and Algeria in general. Far from being a mere administrative building, this building embodies an exceptionally rich architectural heritage, bearing witness to the evolution of styles and the harmonious fusion of Western and Eastern influences.

The city hall stands out for its imposing presence; the architectural elements such as the horseshoe arches, the monumental campanile, the arched openings, and the delicately worked wooden balconies, all contribute to making it a tangible witness to the oriental influence. The city hall has become a work of art in its own right, rooted in the very fabric of the region (Figure 18).

The building's aesthetic appeal echoes a complex and controversial time. As a witness to political, economic, and social change, the city hall of Biskra embodies the changing attitudes and architectural policies of the colonial period. Conserving this structure is crucial to safeguarding a unique heritage for future generations.



Figure 16. Graphic drawings showing details of the distinctive elements of the city hall of Biskra: A) main façade; B) details of the campanile; C) covered vestibule and lion statue; D) the wooden balconies [56].



Figure 17. Old postcard showing Dhalaa Hill in Biskra, a source of building materials. In the background, the French colonial city, and the public garden [58].



Figure 18. View of the entrance portico of Biskra city hall. On the right, the lion statues after shifting [59].

## 7. Conclusion

This article deals with Orientalism in architecture through the case study of the city hall in Biskra City (Southeastern Algeria). Adopting a historical approach, the findings revealed that at the end of the 19th century and the beginning of the 20th century, Algeria experienced an important period that marked the country's architectural history. The period was known for revisiting pre-colonial architectural language (often Moorish) to create a new stylistic expression, the neo-Moorish style. This style is classified among "historicist styles" and was appreciated by Orientalists. It takes up the features of Islamic architecture from the Maghreb, the Middle East, Cairo, Cordoba, Constantinople, and Jerusalem. It appeared in Algeria at the end of the 19th century and flourished in the early 20th century, as the result of a phenomenon of acculturation, in which two cultures and two architectural languages merged to produce a novel stylistic expression.

The examination of Biskra's city hall has revealed a distinct oriental aesthetic, characterised by architectural elements that stand apart from the traditional context of Biskra. Notably, the building's design reflects influences from the Moorish style, which was not prevalent in the pre-colonial architecture of Biskra, whether in residential or religious structures. This suggests that Biskra did not serve as a primary inspiration source for Western architects during the colonial period. Instead, the architect of the city hall, André Pierlot, reinterpreted the Moorish architectural heritage found in the northern regions of Algeria. Thus, the stylistic aspect of the town hall seems exogenous to the local context of Biskra.

The neo-Moorish style embodied in this city hall reflects the architectural choices of a colonial past and persists as a significant aspect of the local cultural identity. While Orientalism is often associated with negative stereotypes and biases, not all Western depictions of the East fall into this category. Contemporary scholars have continued to explore and critique the complex interactions between East and West, seeking a more nuanced understanding of cultural exchanges and influences.

The perspective of this article is promising, as it ultimately encourages local authorities to safeguard and preserve the city hall in Biskra, a building that attests to one of the styles that have marked Algeria's architectural history.

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## Notes

<sup>1</sup> According to Art. 8 and Art. 10 of Law N° 98-04 of 20 Safar 1419 corresponding to June 15, 1998, on the Protection of Cultural Heritage, [Algeria](#), the immovable cultural property includes three (03) categories: 1) historic monuments; 2) archaeological sites; 3) urban or rural complexes. Immovable cultural property, whatever its legal status, may be subject to one of the protection regimes set out according to its nature and the category to which it belongs: 1) inclusion in the supplementary inventory; 2) classification; 3) creation of "protected sectors". Immovable cultural property that does not warrant immediate classification but which is of interest from the point of view of history, archaeology, science, ethnography, anthropology, art, or culture requiring preservation may be entered into the supplementary inventory. Immovable cultural property entered on the supplementary inventory list that is not definitively classified within ten (10) years is removed from the said inventory list. According to this law, the supplementary inventory serves as a temporary protection measure for ten (10) years. Any immovable cultural property listed in this inventory that has not been definitively classified within this timeframe is removed from the supplementary inventory list. To be reinstated, a new application must be prepared per the aforementioned law.

<sup>2</sup> The Sahara Hotel was built shortly after the arrival of the French colonisation in the city of Biskra, where a modern city was created. It was the first and oldest hotel in the city of Biskra and is thought to be the first hotel built in Algeria using adobe (mud brick). For more information on the architecture of the Sahara Hotel, consult: Dali A.I., Belakehal A. (2019). *Style architectural des monuments de l'époque coloniale: cas de l'Hôtel du Sahara à Biskra, Algérie*. In: D. Pittaluga, F. Fratini (eds.), *Conservation and promotion of architectural and landscape heritage of the Mediterranean coastal sites*, Genoa, 20-22 September 2017. Milano: FrancoAngeli s.r.l., pp.1343-1354. Available at: <https://series.francoangeli.it/index.php/oa/catalog/view/437/244/2113> [Accessed: 11/06/2023].

<sup>3</sup> During the French colonisation of Algeria, "credit" typically referred to the system of financial and economic arrangements established by the colonial authorities. This system involved providing financial resources, often in the form of loans or credit lines, to settlers, landowners, and businesses to support agricultural, industrial, and commercial activities in the colony. The allocation of credit was a crucial tool used by the French colonial administration to promote economic development, encourage European settlement, and exploit Algeria's natural resources for the benefit of France. Credit was often extended to European settlers to purchase land, establish farms, develop infrastructures such as roads and railways, and invest in various industries. However, the distribution of credit during this period was often discriminatory, favouring European settlers over the indigenous Algerian population. Indigenous Algerians were often marginalised



and excluded from accessing credit, contributing to their economic disenfranchisement and reinforcing colonial inequalities. For more information, consult: Fanon, F. (1963). *The Wretched of the Earth*. New York: Grove Press; McDougall, J. (2006). *A History of Algeria*. Cambridge University Press; Ruedy, J. (1992). *Modern Algeria: The Origins and Development of a Nation*. Bloomington: Indiana University Press; Stora, B. (2004). *Algeria, 1830-2000: A Short History*. Ithaca: Cornell University Press.

<sup>4</sup> The original quotation in French is as follows: «*S'inspirant du style et des coutumes arabes l'architecte a placé ses services autour d'un patio ou cour intérieure sur lequel ouvrent toutes les portes de l'édifice [...]*».

<sup>5</sup> The original quotation in French is as follows: «*Les baies extérieures sont surmontées d'un auvent, celles qui éclairent les salles principales sont garnies d'un balcon couvert rappelant les miradors espagnols et les moucharabiés arabes destinés à empêcher l'aveuglante lumière de pénétrer directement dans l'intérieur. Une coupole très élevée servant de campanile donne à la façade [principale] l'aspect monumental qui convient à un édifice municipal*».

### Biographical notes

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**Haroune Ben Charif** is an architect. He has a bachelor's degree in "Architecture" (2013) and a master's degree in "City and Architecture in the Sahara" (2018) from the University of Biskra, Algeria. In 2019, Ben Charif was admitted to a scholarship for a second master's degree in "European Territories-Heritage and Development" within the Erasmus Mundus Joint Master's Degree programme between the University of ELTE in Budapest, Hungary, and the University of Catania, Italy. Ben Charif is currently a Ph.D. candidate in "Architecture, Industrial Design, and Cultural Heritage" at the University of Campania "Luigi Vanvitelli", Aversa, Italy. He is a member of the research group "Knowledge, Valorisation and Digital Communication of Cultural Heritage." His research

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**Amdjed Islam Dali** is a conservation architect and earthen architecture specialist. He holds a bachelor's degree in "Urbanism and Architecture" (2013), and a master's degree in "Urban and Architectural Heritage in the Sahara" from the University of Biskra, Algeria (2015). In 2018, Amdjed Islam Dali was admitted to a scholarship for a second Master's degree in "European Territories-Heritage and Development" within the Erasmus Mundus Joint master's degree program between the University of ELTE in Budapest, Hungary, the University of Catania, Italy, and the EHESS of Paris, France. He was also a postgraduate from ENSAG in France in 2023 with a degree in "Earthen Architecture, Construction Cultures, and Sustainable Development". Dali is currently a Ph.D. candidate in "Architecture, environment, and heritage", at the University of Biskra. His major research interests include the colonial heritage, including hotels and thermal baths architecture in Biskra, Algeria.

## Summary

The reinterpretation of the architectural language of previous periods is commonplace in architecture and art history. Over the centuries, architectural thinking has consistently oscillated between two distinct trends: consciously revisiting architectural styles or deliberately deviating from them to endorse innovative design forms. In this particular context, the present article delves into the manifestation of the concept of "Orientalism" in both architecture and art during the French colonisation of Algeria, specifically spanning the late 19th century to the early 20th century. This historical period was characterised by a historicist approach, giving rise to what is commonly referred to as the neo-Moorish style. The city hall in Biskra (southeast of Algeria) was selected as a case study for an in-depth exploration of the subject of this article. Through a historical approach, this study has a twofold purpose. Firstly, it aims to highlight Algeria's significant contribution to the history of architecture by revealing one of its most important periods, that of French colonisation. Secondly, it seeks to establish a connection between Islamic aesthetics and French colonial architecture, shedding light on the multiple references to colonial architecture in Algeria.

## Riassunto

L'utilizzo di un linguaggio architettonico ispirato ad esperienze di epoche precedenti è una condizione ricorrente nell'intero arco della storia dell'architettura. Nel corso dei secoli, il pensiero architettonico ha sempre oscillato tra due differenti tendenze: quella

di attingere consapevolmente dalla tradizione o deliberatamente discostarsene per intraprendere inediti percorsi di invenzione progettuale. In questo particolare contesto, l'articolo analizza la manifestazione del concetto di "orientalismo" nell'architettura e nell'arte in Algeria durante la colonizzazione francese, in particolare tra la fine del XIX secolo e l'inizio del XX secolo. Quest'epoca storica è stata caratterizzata da un approccio storicista, che ha dato origine a quello che viene comunemente definito lo stile "neomoresco". Il municipio della città di Biskra (sud-est dell'Algeria) è stato scelto come caso di studio per esplorare approfonditamente questo tema. Questo studio ha un duplice obiettivo indagato attraverso uno approccio essenzialmente storico. In primo luogo, mira a mettere in luce il contributo significativo dell'esperienza algerina nel contesto dell'architettura internazionale, mettendo in luce uno dei suoi periodi più importanti, quello della colonizzazione francese. In secondo luogo, il tentativo è quello di individuare le possibili connessioni e le influenze tra il linguaggio autoctono della cultura islamica e quello dell'architettura coloniale francese, sottolineando gli aspetti evidenti di ispirazione presenti in tutta l'esperienza dell'architettura francese in Algeria.



# **B**IODETERIORATION OF HERITAGE BUILDINGS REPRESENTATIVE OF COSTA RICAN CARIBBEAN ARCHITECTURE

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*Keywords:* Limón City, preservation, multi-criteria evaluation, wood, fungi

## **1. Introduction**

In Limón, Costa Rica, Central America, there are buildings with historical value and distinctive structural and aesthetic characteristics which are differentiated from other typologies and styles used in the rest of the country. Costa Rican Caribbean architecture is characterized by vernacular buildings based on models imported by the United Fruit Company with adaptations to the climate conditions of Limón [1]. Although there are similarities with other expressions developed in the Caribbean islands and coastal areas of some Central American countries, Costa Rican Caribbean architecture represents a unique case of adaptation to the context [2]. These representative features are part of the urban landscape of Limón city and are the cultural heritage and identity of this region, but very few of them have legal protection. Furthermore, since research in this area is limited, preservation initiatives need to be implemented to protect this valuable cultural and historical heritage. Limón is a city of port origins that was developed at the beginning of the 20th century. Its history is directly linked to the railroad and banana production because of the United Fruit Company enclave in this Caribbean region in Costa Rica [3]. The main city and the entire province of Limón are characterized by climatic conditions with predominantly high temperatures (21.8 - 29.7°C) and humidity (75.7 - 99.9%) [4]. Limón is also a coastal city, where many of the buildings were built on what was once marshland.

The original buildings representative of Costa Rican Caribbean architecture are rapidly disappearing as a result of biodeterioration, limited resources for building maintenance, and poor recognition of their historical significance. The age of these buildings, their materiality, proximity to the Caribbean Sea, and constant exposure to high temperature and humidity, make these buildings very susceptible to biodeterioration. Biodeterioration can be described as the process in which living organisms damage or

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degrade organic substances or materials such as wood; this process is the result, mostly, of the growth and metabolic activity of microorganisms such as fungi and bacteria [5]. Wood is a common material used in Caribbean buildings due to its hardness, light weight, and availability [6], but its degradation is rapid in houses and buildings in the tropics. The objective of this research was to characterize biological agents responsible for the biodeterioration in two heritage buildings identified as Costa Rican Caribbean architecture: the Casa Misionera de la Iglesia Bautista (the Missionary House of the Baptist Church) and the Antigua Capitanía de Puerto (the Former Port Captaincy), both of which are protected by the Law of Architectural Historical Heritage of Costa Rica (Law 7555 of the Republic of Costa Rica). This research included the architectural characterization of the buildings, an inventory of existing buildings, identification of the areas with damage, isolation, and the molecular identification of possible biodeterioration agents (fungi), through a multidisciplinary approach.

## **2. Materials and Methods**

### **2.1. Definition of the characteristics of Caribbean architecture**

The project focused on buildings located in the oldest sections of Limón City; the historical center and the neighborhood called Jamaica Town, which is considered the first extension of the city.

The main characterization of Caribbean architecture was based on construction materials, and architectural and constructive elements described in the literature [1, 2, 7-10, 11]. These criteria were used to identify the buildings to use for the preliminary phase of the study. A basic template of the characteristics was used to establish an initial list of buildings with a minimum number of architectural elements. The initial list included the geo-localization and photographic documentation of the buildings of interest that were also used to create a map using the free and open-source software QGIS 16.6 (GNU and OSGeo). Buildings were classified into four typologies based on the presence and clarity of the characteristics of Costa Rican Caribbean architecture in each building [7]. The following set of typologies was established: Type 1 (building not modified, minimally modified, and preserves most characteristics); Type 2 (building slightly modified and preserves many characteristics); Type 3 (greatly modified and preserves few characteristics); Type 4 (not eligible for the study, extremely modified and does not preserve any characteristics). Buildings that were not accessible or for which there was a lack of information, were considered "Unclassified".

Based on the typology, a more detailed description of the basic characteristics was conducted. Recurrent and new architectural elements were identified that had not been reported as common characteristics [12] and added to the profile. Additionally, we included each characteristic in an eBook of Costa Rican Caribbean architecture, in which each of the elements identified was defined and illustrated [13].

### **2.2. Inventory of Costa Rican Caribbean architecture buildings**

Based on the typologies that showed more prominent characteristics of Costa Rican Caribbean architecture (Type 1 and 2) an inventory was elaborated to include registration code, location, coordinates, street name, and number/neighborhood name, materials, original and current use, building typology, identification of main architectonic and constructive elements, as well as a general assessment of the preservation state. Any

damage present in the building was also described. The elaboration of the inventory required the design of inventory tabs for the compilation of field data including photographic documentation. A database on Excel (Microsoft, USA) was elaborated using all the information in the inventory tabs. Each one of the buildings was designated with a code that denoted the block in which the structure is located (letter), typology (Type 1 or 2), and the number of buildings in the block. The inventory tabs, the classification using typologies, data gathered on-site, and the database were constantly revised for accuracy and to refine the established inventory.

### 2.3. Multi-criteria evaluation

A multi-criteria evaluation was conducted and is a method that enables the selection of specific decisions by taking into account a vast amount of information, relationships, and objectives, as explained by Munda [14 -15]. A first evaluation was developed with five criteria [16] to evaluate and select the buildings that better represent and preserve the characteristics of Caribbean architecture and are at a higher risk of deterioration due to the presence of biodegrading agents. After the demolition of some of the buildings during the development of this project, a review of the multicriteria evaluation was conducted and a sixth criterion was added to include the current use of the buildings (Table 1). Each one of these criteria was used to calculate a final score by adding the assigned percentages to each criterion. A point scale ranging from 0 to 4 was assigned (Table 1) to evaluate each criterion.

Table 1. Criteria, percentage, and point scale used in the multi-criteria evaluation of the 23 buildings inventoried in Limón City, Costa Rica.

Criteria	Percentage (%)	Point scale
Presence and clarity of characteristics of the Caribbean architecture (Lc)	30	Type 1: 2 points Type 2: 1 point
Declaration of architectural historical heritage (Law 7555) (Dp)	10	Has declaration: 1 point Does not have declaration: 0 points
Preservation condition (Ep)	20	Bad condition (presents a lot of damage, deterioration, and many modifications to the structure): 3 points Regular (presents some damage, deterioration and/or few modifications): 2 points Good condition (presents little to no damage, deterioration, or modifications): 1 point

Accessibility to the building (Da)	20	Access approved to the interior of the building and availability to conduct research work: 3 points Access to the interior of the building: 2 points Access only to the exterior of the building: 1 point
Current use (Ua)	10	Abandoned (more vulnerable): 3 points Non compatible with original use: 2 points Compatible with original use (less vulnerable): 1 point Demolished: 0 points
Property status (Cp)	10	Abandoned (more vulnerable): 4 points: For sale: 3 points Rented: 2 points Occupied by owner (less vulnerable): 1 point

To obtain the final score, the following formula was used:

$$Final\ Score = [(Lc2 * 0.3) + (Dp1 * 0.1) + (Ep3 * 0.2) + (Da3 * 0.2) + (Ua3 * 0.1) + (Cp4 * 0.1)] * 100 \quad (Eq. 1)$$

Where:

- Lc is the presence and clarity of characteristics of the Caribbean architecture
- Dp is the declaration of architectural-historical heritage
- Ep is the preservation condition
- Da is the accessibility to the building
- Ua is the current use
- Cp is the property status

Once all the scores were obtained, we prioritized the evaluation and sampling of the buildings with higher scores.

#### **2.4. Damage documentation, sample collection, and microbial isolation**

From the inventory and the multi-criteria evaluation, two properties considered with higher architectural heritage were selected, the Antigua Capitanía de Puerto (AAA - Type 1 - 01) and the Casa Misionera Iglesia Bautista (W -Type 1 - 01). Visual observations of areas with aesthetic damage, such as the presence of holes or tunnels, dust, sawdust, cracks, and color changes were made and recorded. In addition, structural lesions including any softening of the wooden surfaces, presence of rot, molds, or other organisms were also noted. A written record was made of the location of each identified lesion inside the building, as well as details present in the site regarding the presence



of vegetation, proximity to the Caribbean Sea, and climatic conditions such as temperature and relative humidity; the information was recorded using data loggers (Testo 174H, Instruments Testo S.A., Spain). Selected areas were sampled for isolation of potential microorganisms responsible for wood damage. Inside the properties of interest, each wood segment with visible damage caused by microorganisms was cleaned using 70% ethanol. Two sampling methods were used: a) smaller samples between 0.1 g and 1 g were taken by scraping the surface with a scalpel or, if possible, by taking a small piece of wood containing the damage, the sample was wrapped in sterile aluminum foil, and b) rubbing a sterile swab in the affected area where microbial growth was visible. The collected samples were placed in a cooler until they were transferred to the Laboratory of Forest Pathology of the Forest Innovation Research Center at the Costa Rica Institute of Technology where they were stored at 4°C for further use. For the isolation in laboratory conditions, the wood samples were first disinfected with 1% sodium hypochlorite a. i. for 30 s, washed with 96% alcohol for 30 s, and finally with distilled water for 1 min [17]. Then, the wood pieces were placed on three different solid media to grow fungi present in the samples. Media included potato dextrose agar (PDA), Sabouraud dextrose agar (SDA), and nutrient agar (NA). Then the plates were incubated at 25°C in the dark for 7 days. After 7 days, all colonies from each plate were transferred to obtain single colony cultures. Cultures were stored in 10% saline solution at room temperature and 50% glycerol solution at -20°C [18] for further use.

### **2.5. Molecular characterization**

A QIAGEN DNeasy Plant Kit (QIAGEN, Germany) was used for DNA extraction following the manufacturer's instructions. Polymerase chain reaction (PCR) was conducted using a Promega PCR Master Premix (Promega, Wisconsin), a final reaction with MilliQ water, PCR master mix 2X (Promega M7502, Wisconsin), 5 µM forward primer ITS1F [19], and reverse primer ITS4 [20], BSA 1% and fungal DNA (40ng/µl) [21]. For negative controls, PCR water was used instead of the fungal DNA.

For visualization of PCR products, an agarose gel was made of TAE X1. It was run in an electrophoresis chamber at 150 V for 45 min and then visualized with UV light. Samples that showed a strong band without contamination with limited smears were selected for sequencing. A second PCR was made for LSU, using the forward primer LR3 [22] and reverse primer LROR [22] to compare results and to better identify the fungal isolates. PCR products were sequenced using Sanger sequencing by GENEWIZ (South Plainfield, New Jersey).

The same PCR primers (ITS and LSU) were used to obtain forward and reverse sequences. Sequences were trimmed and edited using Sequencher 4.0 (Genes Codes Corporation, Michigan) and compared via nucleotide blast with the NCBI and UNITE databases for both ITS and LSU sequences. For both programs parameters were E-value 0, score higher than 700, query cover between 80% and 100%, and a percent identity higher than 95%.

## **3. Results**

### **3.1. Definition of characteristics of Caribbean architecture**

Based on the bibliographic review [1, 2, 9-11], a basic profile of main Caribbean architectural characteristics was established [16]. The main features of these buildings

include the use of wood as the main construction material in external and internal structures. The presence of one or more of the following architectural elements was required to be included in the study: wooden or concrete piles, galleries, attics, socles, porticos, wooden rails, wooden grilles or *petatillos*, wide eaves, and similar structures in other areas separated from the roof, balconies, corridors and galleries, thermal control chambers for insulation and skylights. Fieldwork was conducted in Limón City using the basic profile and a list of 101 buildings was established; each building was geo-localized (Figure 1).

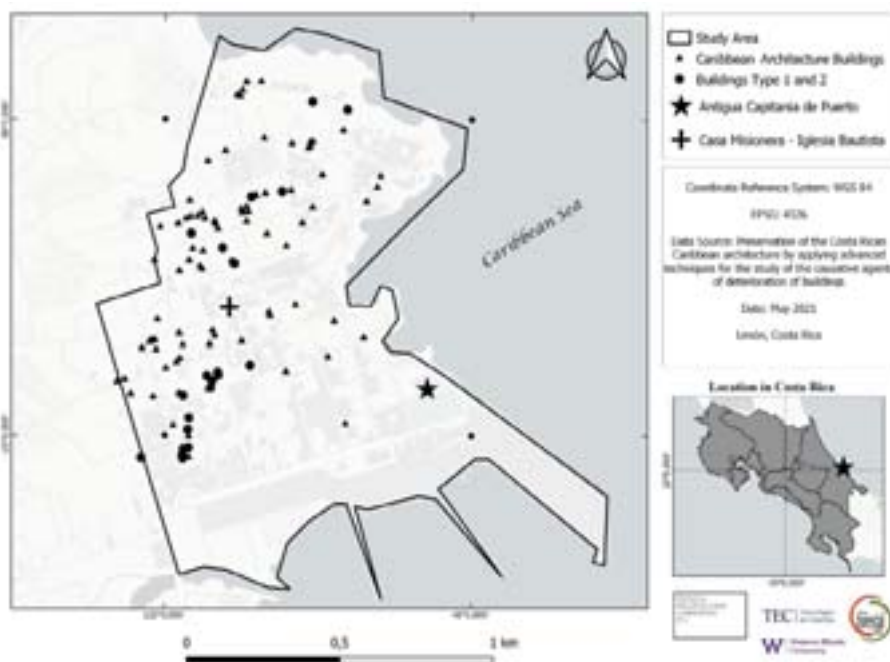


Figure 1. Location of buildings with Caribbean architectural characteristics in Limón City, Costa Rica.

Characterization of the buildings started with the identification of the features described in the basic profile, as well as the identification of the new common elements that were not previously reported in the literature.

For example, buildings in the area presented structural systems, “balloon framing”, passive strategies for climate comfort, a variety of vibrant colors, and different spatial configurations.

A classification based on typology was implemented for the initial list of buildings (101 in total) and buildings were classified using the information in the inventory from the text by Hernández-Salazar, I. et al including the newly identified characteristics and verified field data [7] resulting in 16 buildings in Type 1 category, 7 in Type 2, 37 in Type 3 and 22 in Type 4 (Table 1, Figure 2A-D).

Nineteen buildings were not considered due to lack of information or restricted access to the properties and 11 buildings were listed as demolished following the owner's decision.



Figure 2. The basic facade of typical housing buildings of Costa Rican Caribbean architecture classified according to typology. A) Multi-family dwelling type 1 (TT - Type 1 - 01); B) Attached dwelling type 2 (P - Type 2 - 02); C) Two storey house with concrete base type 3 (JJ - Type 3 - 01); D) Single family house with many modifications type 4 (I - Type 4 - 01). All buildings were located in Limón, Costa Rica.

### 3.2. Inventory of Caribbean architectural buildings

Additional information was obtained for the 23 buildings classified as Type 1 and Type 2. Location, owners' contact information, state of preservation, architectural, structural, and material characteristics were determined, as well as the main aesthetic and structural damage and possible degradation caused by biological agents or damage caused by the building's advanced age. In some cases, more than one visit was necessary to verify the information gathered in the first visit, then the database was updated. The inventory showed that most Type 1 and 2 buildings are in poor condition, putting at high-risk key elements of Limón city's heritage. According to García-Baltodano et al. [23], Limón City has a total of 22 declarations for buildings of heritage importance, of which only three are listed as Costa Rican Caribbean architecture, two of the three are still standing, while the other was lost due to a fire in 2016 (The Black Star Line). The two buildings of heritage importance were registered in this study inventory as Type 1.

### 3.3. Multi-criteria evaluation

Based on the information gathered in the inventory and the score assigned in the multi-criteria evaluation, an order of priority to select representative buildings of

Caribbean architecture and demonstrate the highest risk of deterioration and loss was developed (Table 2).

Table 2. Order of priority based on the final score assigned in the multi-criteria evaluation of the 23 buildings classified as Type 1 and Type 2 of Costa Rican Caribbean architecture present in Limón City, Costa Rica.

Inventory Code	Property Name	Use	Coordinates	Score	Ranking
W-Type1-01	"Casa Misionera de la Iglesia Bautista"	Unoccupied	9.99554, -83.03121	100.0	1
FF-Type1-02	N/A	Unoccupied	9.99364, -83.0319	83.3	2
AAA-Type1-01	"Antigua Capitanía de Puerto"	Institutional	9.99319, -83.0253	72.5	3
A-Type1-01	"Antigua Casa Dr. Argüello"	Unoccupied	10.00117, -83.0309	70.0	4
MM-Type1-01	N/A	Housing	9.99199, -83.03244	65.0	5
M-Type1-01	N/A	Housing	9.99881, -83.02962	62.5	6
TT-Type1-03	N/A	Unoccupied	9.99118, -83.03257	60.0	7
FF-Type1-01	N/A	Housing	9.99325, -83.03177	58.3	8
FF-Type1-03	N/A	Housing and services	9.99367, -83.03161	58.3	9
FF-Type1-04	N/A	Housing and services	9.99359, -83.03157	58.3	10
J-Type1-01	"Casa del Coco"	Housing and commercial	9.99763, -83.03236	58.3	11
L-Type1-01	N/A	Demolished	9.99871, -83.03044	58.3	12
MM-Type1-02	N/A	Housing	9.99215, -83.03249	58.3	13
TT-Type1-1	N/A	Housing	9.99144, -83.03259	56.7	14
TT-Type1-2	N/A	Demolished	9.99147, -83.0325	56.7	15
GG-Type2-01	N/A	Unoccupied	9.99388, -83.03055	51.7	16
P-Type2-02	N/A	Housing	9.99719, -83.03143	50.0	17
EE-Type1-01	N/A	Housing	9.99307, -83.03274	49.2	18
SS <sup>1</sup> -Type2-01	"Casa Familia León"	Housing	9.99123, -83.03386	47.5	19
FF-Type2-03	N/A	Housing and services	9.99325, -83.03177	43.3	20
P-Type2-01	N/A	Housing	9.99675, -83.03119	43.3	21
TT-Type2-1	"Casa Garvey"	Demolished	9.9913, -83.03263	43.3	22
B - Type 2 - 01	N/A	Housing	10.00144, -83.02877	36.7	23

According to the ranks obtained, buildings with scores higher than 60 (six buildings) were selected for additional sampling and analysis.

Nonetheless, it was only possible to work with four of these buildings due to restricted access to two of the properties. In this study, we focused on the two buildings with the highest heritage importance as mentioned above: Casa Misionera de la Iglesia Bautista (W-Type 1-01) and the Antigua Capitanía de Puerto (AAA-Type 1-01) which were ranked as first and third in priority, respectively.

The Casa Misionera de la Iglesia Bautista (W - Type 1 - 01) belongs to the First Baptist Church in the province of Limón and was built in 1887; it was last restored in 2001 and declared architectural heritage in 2002 (Decree No. 30232-C, La Gaceta No. 65 - Thursday, April 4, 2002). Nowadays, the building is in poor condition and mainly used for storage, which further impacts its deterioration. The Antigua Capitanía de Puerto' (AAA - Type 1 - 01) was constructed in 1930.

It was declared architectural heritage in 1995 (Decree No. 24366-C, La Gaceta No. 121 — Monday, June 26, 1995). The building was last restored in 2014 and since then it has been used as a Cultural Center of the Municipality of Limón; despite its recent restoration, the building presents recurring deterioration that affects its overall preservation state.

### **3.4. Damage documentation and identification of biological agents in the properties**

During the onsite visits, damage and tunnels made by insects, such as termites, were observed in both buildings (Casa Misionera and Antigua Capitanía). Nonetheless, it was not possible to find living insects for collection and identification, very likely representing previous infestations. Insect damage was observed in the interior as well as in the exterior of the buildings. In the Casa Misionera de la Iglesia Bautista, 24 damaged areas showed signs of biological activity, 67% of which showed fungal growth or characteristic deterioration caused by fungi and 33% by insects.

Structural damage such as loss of material, change in color, and presence of vegetation was also observed (Figure 3A-D). In the Antigua Capitanía de Puerto, 14 areas with damage caused by biological agents were identified, 79% of the areas that showed visible damage were caused by fungi, and 21% were caused by insects. Aesthetic damage such as a change in color and the presence of vegetation was also observed (Figure 4). In the Casa Misionera de la Iglesia Bautista a relative humidity of 87.4% and an average temperature of 25.5°C with a maximum of 32°C were recorded in one year. In the Antigua Capitanía de Puerto, an average of 25.7°C was recorded with a maximum of 34°C, and relative humidity of 87.34% was also recorded in one year.

### **3.5. Microorganism isolation**

From the samples of the areas showing damage, 36 fungi were isolated from both locations, 19 of the isolates were obtained from the Antigua Capitanía de Puerto and 17 from the Casa Misionera de la Iglesia Bautista. Most isolates were obtained from the PDA medium (26 cultures) from both buildings including *Trichoderma*, *Fusarium*, and *Penicillium*. SDA medium isolates were dominated by the genus *Penicillium*.

Using an NA medium, we were able to obtain a culture of *Fusarium oxysporum* from the “Antigua Capitanía de Puerto” and one of *Penicillium citrinum* from the Casa Misionera de la Iglesia Bautista.



Figure 3. Casa Misionera de la Iglesia Bautista (W - Type 1 - 01). A) Front view. B) Damage caused by insects (termites) (indicated with black circles). C) Damage caused by humidity and fungi (indicated with a black circle). D) Presence of vegetation under the structure (indicated with a black circle).



Figure 4. Antigua Capitanía de Puerto (AAA - Type 1 - 01). A) South and East view of the façade; B) Damage caused by insects (termites) (indicated with a black circle); C) Damage caused by humidity and fungi (indicated with a black circle). D) Presence of vegetation under the structure (indicated with a white circle).

The isolated fungi were stored in either a saline solution or glycerol solution in a fungal collection of the School of Forest Engineering of the Costa Rican Institute of Technology for preservation and further use.

### 3.6. Molecular characterization

All isolated fungi belong to the phylum *Ascomycota*. The most common orders were *Eurotiales*, *Hypocreales*, and *Botryosphaerales*, respectively. The most common genera identified were common environmental fungi including *Trichoderma*, *Fusarium*, *Penicillium*, and *Lasiodiplodia* (Figure 5). *Penicillium* was the most common genus found (21% of the cultures), followed by *Fusarium* with 19%.

The only fungi present in the two locations were *Aspergillus niger*, *Fusarium solani*, and *Lasiodiplodia citricola*.

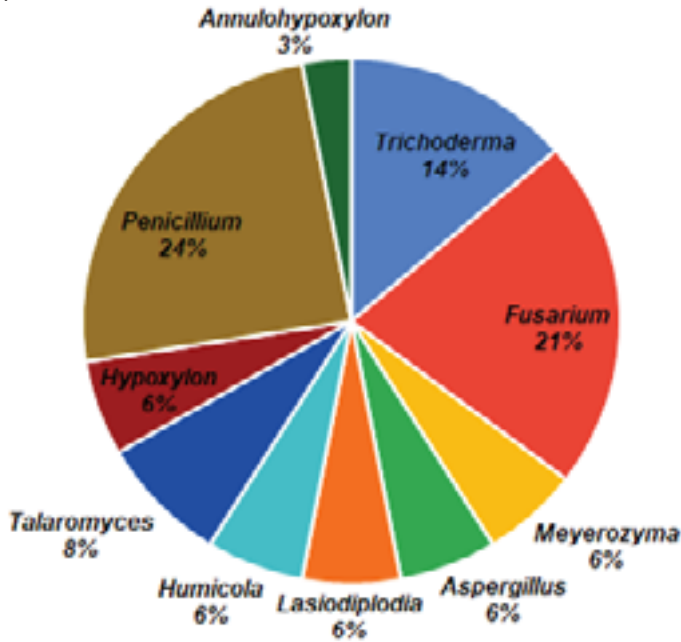


Figure 5. Genera identified from isolates obtained from wood samples from the two buildings (Casa Misionera and Antigua Capitania) studied in Limón City.

A total of 19 different genera were isolated from Antigua Capitania de Puerto, *Fusarium* was the most common isolate with seven of the 19 cultures in this genus (37%). The second most common genus found in this location was *Trichoderma* with four isolates (21%). Additional genera included *Humicola* with two colonies (11%) and lastly *Hypoxylon*, *Talaromyces*, *Lasiodiplodia*, and *Aspergillus*, all of which represented 5.3 % of the isolates.

From the Casa Misionera de la Iglesia Bautista, the most abundant genus was *Penicillium* with nine colonies out of the 17 isolated (53%), followed by *Talaromyces* with two colonies (12%) and lastly *Hypoxylon*, *Fusarium*, *Annulohyphoxylon*, *Trichoderma*, *Aspergillus* and *Lasiodiplodia*, all of these with 5.9% each (one colony per genus).

## 4. Discussion

### 4.1. *Costa Rican Caribbean architecture, heritage at risk*

The buildings included in this study are examples of architecture adapted to a specific context of Costa Rica that have become a significant aspect of the historic urban landscape of Limón City. The Caribbean architecture of Costa Rica is part of the cultural and historical heritage of the city and country, being a key feature of the area.

Despite the heritage importance of these buildings, this type of architecture has not been studied, causing great difficulty on the part of the owners, researchers, and respective authorities to spread awareness of the historical importance and the need to preserve these structures.

The lack of documentation and studies regarding this topic have hindered the proper preservation of these buildings, an aspect that has also negatively impacted the documentation of traditional knowledge on the construction of this type of architecture and increased the risk of losing them completely.

Between 2018 and 2022, 11 buildings representing Caribbean architecture were demolished; eight of them were part of this study in the initial phases of this project and had already been demolished when the inventory was conducted, so it was not possible to further investigate them.

The remaining three, classified as Type 1 and included in the inventory, were demolished later. This represents a loss of 13% of the recorded buildings of Costa Rican Caribbean architecture in Limón city.

In this regard, there is an immediate need to fully understand the importance of this heritage to develop initiatives for the successful preservation of these buildings.

### 4.2. *The need for interdisciplinary investigation for the preservation of heritage*

According to Bertolin and Loli, the existence of a building of historic importance inside the cultural heritage field has an intangible meaning [24]. Cultural and architectural heritage is considered the legacy of our societies and must be managed through good preservation practices.

Heritage management must, moreover, be an interdisciplinary process with the intervention of many groups of experts in areas such as conservation, architecture, engineering, history, biology, chemistry, and other fields [25].

This study was carried out with an interdisciplinary perspective which included researchers from different areas such as architecture, forestry engineering, and biotechnology.

Tools implemented in the study, like multi-criteria evaluation, show the importance of joint efforts to determine risks and develop strategies to decrease the biodeterioration process.

Wood is the oldest construction material, the most used globally [26] and represents the most commonly used material in Costa Rican Caribbean architecture. It is, however, susceptible to deterioration and aesthetic damage caused by environmentally common fungi such as the ones detected in this study.

It is necessary to implement diverse multi and interdisciplinary studies to identify the potential causal agents of biodeterioration present in these buildings and provide possible solutions for their preservation.



#### **4.3. Interaction of factors such as plants, insects, and climate conditions in wood structures**

Wood is commonly treated before it is used in construction to improve its hardness and durability, including simple processes such as drying and treating the wood with varnish. These treatments are also used to reduce the deterioration of the wood known as weathering [27]. In the case of Costa Rican Caribbean architecture, the location of Limón City and the use of wood as the main construction material promotes the growth of wood-degrading microorganisms. Figures 3 and 4 show damage caused by humidity and rain on the outside of the buildings which leads to the attack of fungi, insects, and general wood decay.

Weathering is inevitable. Nonetheless, it is a slow process that normally takes many years to see significant damage in the wood, but if there are favorable conditions for the growth of biological agents, quicker and more severe degradation can occur in less time [28]. The main cause related to timber degradation is the presence of moisture in buildings, this leads to the attack of wood eaters such as termites and fungi [29]. This, alongside the poor maintenance of the buildings, aggravates the process of deterioration, such as in the case of the previously mentioned buildings in Limón City.

The outdoor structures constantly affected by humidity were more susceptible to damage (Figures 3 and 4) and there is a higher presence of fungi on the external surfaces than inside the structures.

Another important point is that fungi can be dispersed by wind or vectors and thus scatter their spores to colonize these buildings. The rate at which wood degrading fungi decompose these materials is majorly influenced by ecological interaction with wood-damaging vectors such as insects that facilitate the entry and penetration of fungi [30]. In many instances where there is damage by insects, like termites or beetles, there is also colonization by fungi. This is due to insects digging holes and permeabilizing the wood surface by removing paint and other protective layers like varnish and, in some cases, the insects may also vector communities of symbiotic fungi [31].

#### **4.4. Ascomycota fungi as common colonizers of indoor and outdoor environments**

Fungi from the *Ascomycota* phylum can also degrade wood components and damage buildings and structures. Any genera belonging to *Ascomycota* have the genes and enzymatic capabilities to degrade cellulose and other wood components [32]. All fungi isolated in this study are from the *Ascomycota* phylum and were present in the damaged areas where samples were taken. White rot and brown rot fungi were not obtained in culture, structural damage characteristic of these fungi was observed. Fungi from *Ascomycota* are normally recovered as environmental fungi, nonetheless, these fungi are more commonly found in anthropic areas, in cities, or villages with trees and wood structures [33] and can cause aesthetic damage, especially in conditions of high humidity.

This is the case in Limón City, where, due to high temperatures and high humidity, many of the buildings are made of wood and are surrounded by vegetation to lower temperatures inside the house. The genus *Hypoxylon* has been reported as very common in wood samples [34] and was present in the buildings of Limón City. *Trichoderma* was another genus that was fairly common in these buildings. This genus is capable of inhabiting wood and degrading its components [35].

## 5. Conclusions

Limón City represents a valuable and unique resource of Caribbean architecture. Many of the buildings that show these characteristics are in danger of disappearing or being destroyed due to damage caused by fungi, insects, climate, and other factors, including poor maintenance. The study and preservation of these buildings of heritage importance have included a multidisciplinary perspective to facilitate a better collection of information and a more complete analysis based on each specific situation. The present study shows the importance of this type of research and how the usage of multi-criteria tools optimized the decision-making to define priorities for the identification and preservation of specific properties. This is the first study on Caribbean architecture conducted in Limón City, Costa Rica, using a multi-criteria and interdisciplinary approach.

All the fungi isolated from the two locations in Limón City were from the *Ascomycota* phylum, with *Trichoderma*, *Fusarium*, and *Penicillium* being the most common genera. These results showed that fungi from the *Ascomycota* phylum are common inhabitants in damaged wood.

The wood also showed structural damage characteristic of white rot and brown rot fungi. Most of the isolated fungi could cause aesthetic deterioration of the structures considering the high temperatures, rain, and humidity experienced in this region. Molecular characterization was shown to be a reliable method to characterize genera and species of the samples isolated in tropical regions, but direct sequencing may be necessary for specific identification of fungi difficult to culture including many of the wood-degrading species not isolated in this study.

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### Summary

The goal of this work was to characterize potential biological agents responsible for biodeterioration in heritage buildings identified as Costa Rican Caribbean architecture using a multidisciplinary approach. First, an inventory of buildings of Caribbean architecture from Limón City was elaborated. Then, a multi-criteria evaluation system was used to define priority scores to select buildings for sampling and analysis. Selected buildings were sampled for potential biological agents responsible for biodeterioration. Wood samples were taken from sections showing visual damage and fungi were isolated and characterized using Sanger sequencing. A basic profile of Costa Rican Caribbean architecture was established. A preliminary identification of 101 buildings that satisfied the basic profile of characteristics was conducted. Subsequently, these buildings were classified into 4 typologies from which 23 buildings belonging to Typologies 1 and 2 were chosen for the collection and registration of data. Applying the multi-criteria evaluation, 6 buildings with final scores higher than 60 points were selected from which the 1st (Casa Misionera Bautista) and 3rd (Antigua Capitanía de Puerto) in the classification were selected for further characterization of biological agents. From the sampling conducted on these two buildings. A total of 36 fungi were isolated. All fungi identified belonged to the fungal group *Ascomycota* phylum, the most common genera being *Trichoderma*, *Fusarium*, and *Penicillium*. The study shows how multidisciplinary studies can improve the process of decision-making in the preservation of heritage with the use of a ranking obtained for each building in the multi-criteria evaluation and the use of advanced techniques for the identification of biological agents.

## Riassunto

L'obiettivo di questo lavoro è stato quello di caratterizzare i potenziali agenti biologici responsabili del biodeterioramento negli edifici storici identificati come architettura caraibica del Costa Rica utilizzando un approccio multidisciplinare. In primo luogo, è stato elaborato un inventario degli edifici della città di Limón. Successivamente, è stato utilizzato un sistema di valutazione multicriterio per definire i punteggi di priorità per selezionare gli edifici per il campionamento e l'analisi. Gli edifici selezionati sono stati campionati per individuare potenziali agenti biologici responsabili del biodeterioramento. I campioni di legno sono stati prelevati da sezioni che mostravano danni visivi e i funghi sono stati isolati e caratterizzati utilizzando il sequenziamento Sanger. È stata condotta un'identificazione preliminare di 101 edifici che soddisfacevano il profilo di base delle caratteristiche. Successivamente, tali edifici sono stati classificati in 4 tipologie tra le quali sono stati scelti 23 edifici appartenenti alle Tipologie 1 e 2 per la raccolta e la registrazione dei dati. Applicando la valutazione multicriterio, sono stati selezionati 6 edifici con punteggi finali superiori a 60 punti, tra i quali sono stati selezionati il 1° (Casa Misionera Bautista) e il 3° (Antigua Capitanía de Puerto) nella classificazione per un'ulteriore caratterizzazione degli agenti biologici. Dai campionamenti effettuati su questi due edifici, in totale sono stati isolati 36 funghi. Tutti i funghi identificati appartenevano al gruppo fungino *Ascomycota* phylum, i generi più comuni sono *Trichoderma*, *Fusarium* e *Penicillium*. Lo studio mostra come studi multidisciplinari possano migliorare il processo decisionale nella conservazione del patrimonio con l'utilizzo di una graduatoria ottenuta per ogni edificio nella valutazione multicriterio e l'utilizzo di tecniche avanzate per l'identificazione degli agenti biologici.

# RETENTION AND EXAM PERFORMANCE BASED ON PRINT BOOK AND E-BOOK STUDY AT UNIVERSITIES IN SRI LANKA

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*Keywords:* higher education, bachelor degree, e-books, professional study, retention

## 1. Introduction

Merkle notes that the rise of the e-book started from its initial introduction to the market in 1971 [1] supported by increased utilization of e-book readers, such as Kindle, actively available on the market [2], and an increased number of books readily available in electronic version [3]. Myrberg [4] declares that the usage of electronic books decreases with age, as well as users preferring larger screens. Customizable e-books provide higher retention for dyslexic readers [5] but was not the case for normal individuals and students who saw significant retention drop after only one week [6], while some claimed retention dropped immediately after reading [7]. Li [8] notes that this is a concern especially in Asian countries where exams are mostly retention based. Wood and Shirazi [9] say most academic questions can be answered using the framework and textbooks provided by lecturers, aggravating the impact of reduced retention from e-books because retention is paramount to achieving academic success and good marks depend on it.

Sri Lanka, a nation rich in cultural heritage, has an impressive historical and artistic tapestry that bears witness to its colorful past. In this study we analyze aspects of higher education as part of the cultural heritage of Sri Lanka, focusing on features in academia and technology. The article provides a comprehensive approach to learning that integrates academic achievement with the depth of our historical and artistic narratives, highlighting the necessity of bringing our cultural legacy into the educational landscape [9].

Sri Lanka's cultural history has long included art in all of its manifestations. From exquisite traditional crafts to breathtaking architecture, students can draw inspiration from our artistic past. The next generation of artists, architects, and inventors can be fostered by universities through the inclusion of creative expression and art appreciation in the curriculum. In addition to preserving our legacy, encouraging students to follow their artistic interests develops creativity and ingenuity, two qualities that are highly valued in today's workforce [12].

It is crucial that we share our cultural heritage with the world community in this age of globalization. Universities can be key players in this effort by setting up joint research projects, exhibitions and cultural exchange programs. Through the exhibition of our cultural artifacts, traditional performances and historical artifacts, we can build a bridge of

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mutual respect and appreciation between cultures. Furthermore, publishing statistics and data about our cultural heritage in scholarly publications can become a significant way for supporting global policymakers and researchers by fostering a global conversation about the significance of cultural integration and preservation in higher education [13]. Including cultural heritage in higher education is a commitment to protecting our identity and creating a future that is firmly anchored in our past, not just a scholarly endeavor. Achieving a balance between technological advancements and cultural preservation is crucial as we navigate the digital age. Universities in Sri Lanka can produce well-rounded people who are not only academically adept but also culturally aware and appreciative by immersing students in the rich tapestry of our history and art. Assuring that our distinctive historical and artistic narratives continue to inspire future generations is made possible by empowering students to become ambassadors of our legacy through the integration of our cultural heritage into education. We can create a harmonious fusion of tradition and modernity by working together and being dedicated to cultural integration. This will enhance the educational experience and make the world a more culturally aware place [5].

This paper paves the way to studying the impact of utilizing e-books among university undergraduates in Sri Lanka, an island in South Asia, and the impact it ultimately has on their exam performance, in addition to other factors such as retention, comprehension and understanding, learner's age, eye strain and effective mode of reading.

## 2. Literature review

Electronic books are generally preferred by younger people. However, there is one big disadvantage to using e-books which is eye strain, a factor that can increase if e-book usage increases. This aspect consequently reduces the efficiency of e-learning for people with any eye impairments, making it difficult for them to positively benefit from their use, considering the many advantages of e-book features (e.g. easy navigating, etc.) [4, 5]. Retention and recalling are found to be higher in print book readers than e-book readers [6], further affirmed recently in a case where the time taken to remember and memory retention were lower with e-books [7]. In addition, the impact on retention, comprehension and understanding when reading from e-books was lower than printed books [10] due to the absence of touching and feeling the book materially and physically. More repetitive reading was also required on the part of e-book readers, as they needed more time to grasp the same content [11]. Li [8] notes that this impacts Asians more due to the fact that their undergraduate exams are retention based. So, according to Wood and Shirazi [9], most examination questions are answerable from a pre-defined framework and academic textbook.

Sri Lankan undergraduate students' academic experiences have been shaped by the introduction of innovative learning materials, especially e-books, through the convergence of technology and education in recent years. Exam performance and retention among e-book-using undergraduates in Sri Lanka is the subject of this study, which also examines a cognitive framework emphasizing the value of print book usage in academic institutions and libraries. It also tries to address the efficiency of the e-tools (books) used in bachelor learning, stressing the integration of cultural history and focusing on the distinct historical and artistic legacy that defines Sri Lanka, and analysing training and higher education, as one of modern Sri Lankan social values [11].

The cultural legacy of Sri Lanka includes a patchwork of varied influences, including interactions with its colonial past, indigenous customs, and ancient civilizations. As guardians of this legacy, our universities uphold and perpetuate the spirit of the past. A



mutually beneficial interaction is established between the academic realm and our historical roots when this cultural legacy is included and integrated into higher education. Students must be aware of their cultural identity in order to build a sense of pride and belonging as the future's torchbearers.

Universities can close the gap between the past and the present by including historical narratives in their curricula. Imparting important knowledge, studying the development of indigenous cultures, the rise and fall of ancient kingdoms and the effect of colonization fosters critical thinking and analytical abilities. Comprehending historical events within the framework of our nation cultivates empathy, motivating pupils to recognize the intricacies of historical accounts and their significance in contemporary globalized society [12-13].

In their research, Harris et al. [12] demonstrate that Walberg's Theory of Educational Productivity explains the relationship between the mode of instruction and student exam performance. Makatjane [13] and Tuah et al. [14] provided data showing that e-books can be a source for self-learning. However, there is not enough information about the efficiency of using e-books in learning or the efficiency of e-books when compared to print variants in learning new data or preparing for exams.

As Trivedi notes [15], the best knowledge retention practices are paramount at universities to achieve better student academic performance. It is through retention improvement [16] that results can be attained, even though pathological retention degeneration is present in old age, as Baddeley et al. [17] notes. But as the majority of university undergraduates are aged less than 24, no impact of degeneration or decrease in the ability to comprehend is due to aging. The majority of students rely on reading electronic, as well as print books, when learning and preparing for exams [18].

According to Zhang [19] scholarly libraries face a paradigm shift from print books to e-books, while Dawkins and Gavigan [20] declare e-book readers are widely adopted among public library networks in developed nations. Buzzetto-More et al. [21] reported that 56.2% of students in the University of Maryland Eastern Shore, United States of America, prefer printed books. Additionally, data by Alsadoon [22] says that eye strain causes health hazards when using e-books. From data given by Alsadoon [22] and Jyotsna and Amudha [23] it was found that there are triggers which can cause Computer Vision Syndrome and motion sickness when traveling, common issues among Kindle users. Furthermore, Park and Lee declare that reading comprehension varies according to the mode of instruction and influences exam performance based on the importance, questioning, visualizing, inferring and synthesizing strategies of comprehension [24]. Nevertheless, comprehension, as stated by Reich et al., is higher in students who read print books [25]. Retention is memorization and incorporation of knowledge, while memorization is transferring from short-term to long-term memory and is associated with significantly higher exam performance, a point which is overlooked when shifting to e-books from printed books.

Most decisions to shift learning to e-tool usage are based on convenience factors without analyzing the efficiency of the student's exam performance [26]. Clark [27] declares that repetition is based on conditioned response that can be explained by Ivan Pavlov's theory of classical conditioning which requires repeated stimuli [27, 28]. Repeated reading of the same content was required several times more than for print books; hence, extra time was required to compensate for the necessity of repeated reading, but time is a rare asset for students [29].

An effective mode of reading is one which can provide higher retention and exam performance for students within a time-effective context to help improve the intellectuality and overall knowledge of students [30] Therefore, this paper studies effective reading modes as being either with an e-book or a print book.

### 3. Methodology

#### 3.1. Study design and Sampling Frame

The presented research was based on the quantitative survey of university bachelor degree undergraduates (384 persons) of Sri Lanka, based on proportionate, simple random sampling covering all UGC (University Grants Commission) recognized government universities (a total of 17 universities). The online survey was sent to 1,011 participants from 153,497 Sri Lankan university undergraduates in total participating in all University courses. and was volunteer-based. Thus, as not all undergraduates completed the questionnaires, the final given response rate was 38%. The patient is the one who knows the disease better than the doctor'. Based on this statement, the reader is the best person to comment on the ease and effectiveness of the reading format, whether e-book or print books [31]. It is, therefore, the perspective of the students which is considered as the basis of the findings of the research. The methodology (conceptual framework) used is illustrated in Figure 1 and was supported both theoretically and empirically, in order to fill the knowledge gap regarding studies on understanding the impact of reading methods on undergraduate exam performance.



Figure 1. Conceptual framework.

#### 3.2. Instrument development

The main constructs, as described in the conceptual framework, were adapted from existing questionnaires from literature and are as follows: Learner's Profile Eye Strain, Comprehension and Understanding, Retention, Effective Mode of Reading, Exam Performance [32-34]. The adopted questionnaire based on the above literature, which contained twenty-three equally weighted questions on a five-point Likert scale, was initially subjected to expert review. Following amendments from subject experts, we proceeded to pilot study among forty participants, where reliability and validity was checked, and further amendments were made before establishing the final questionnaire. The final amended questionnaire was then issued to the target population of the sampling frame.

#### 3.3. Processing and analysis methods

The analysis was mainly performed after data cleaning, and screening and treating missing and/or inconsistent data in the collected data set which was analyzed through

IBM SPSS software and then through IBM SPSS AMOS software for confirmatory path analysis (Figures 2).

Blocks in Figure 2 are related to F1: Eye Strain (ES) F2: Comprehension and Understanding (CU) F3: Retention (RE) F4: Effective Mode of Reading variable (EM) F5: Exam Performance (EP). Sub-elements such as ES2-ES7 for block F1 are the questionnaire items loaded in the model, "e" blocks instead are the error terms for every single item resulting from the analysis [38, 39]. The following metrics were used with a threshold value for the model performance assessment. Normed Chi-Square: < 0.5 Comparative Fit Indices (CFI): > 0.9 Root Mean Square Error of Approximation (RMSEA): < 0.08. The structural model in Figure 2 explains the structural relationship of the data with the model and confirms the pathway. The calculations, as well as performance assessment, were made using IBM SPSS and IBM SPSS AMOS software [39].

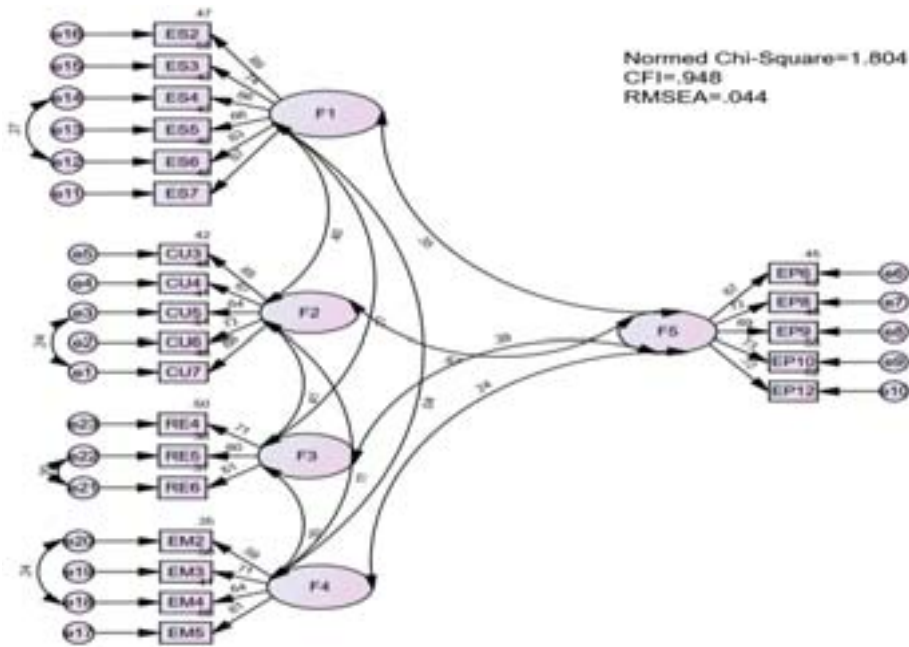


Figure 2. Final measurement model derived from IBM SPSS AMOS software. Keys: F1: Eye Strain (ES), F2: Comprehension and Understanding (CU), F3: Retention (RE), F4: Effective Mode of Reading variable (EM), and F5: Exam Performance (EP).

### 3.3.1. Reliability

We assessed the study process at the Management and Science University using Cronbach's Alpha Reliability Test (CART), where a threshold above 0.7 is considered valid [38] and studied parameters such as eye strain in reading, comprehension and understanding and retention rate, as well as efficiency of the reading mode, and exam performance (Table 1).

3.3.2. *The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's test of Sphericity.*

The Kaiser-Meyer-Olkin (KMO) test was used to examine the strength of the partial correlation where the TVE (Total Variance Explained) threshold is above 0.7 [38]: to test how the factors can explain each other between the variables.

And Bartlett's test of Sphericity was used for testing the null hypothesis [38]: is the correlation matrix present an identity matrix. So, we can see that the KMO was above 0.7 and the Bartlett Test Significance was below 0.05 and they were within the threshold (KMO above 0.7 and Bartlett Test below 0.05 [38]), hence proving the statistical significance of the findings (Table 2).

Table 1. Results according to Cronbach's Alpha Reliability Test

<b>Construct</b>	<b>Pilot Reliability</b>	<b>Final Reliability</b>
Eye Strain	0.860	0.840
Comprehension & understanding	0.853	0.813
Retention	0.788	0.709
Effective Mode of Reading	0.817	0.794
Exam Performance	0.808	0.833

Table 2. Result of the conducted KMO test and Bartlett's Test.

<b>KMO Test and Bartlett's Test</b>	
<i>Kaiser-Meyer-Olkin Measure of Sampling Adequacy</i>	0.853
Approx. Chi-Square	3935.618
<i>Bartlett's Test of Sphericity</i>	df 325
Sig.	0.000

The Total Variance Explained cumulative loading was 60.276% above the 60% threshold [38]. Therefore, all items loaded within respective constructs with loading values or commonalities above 0.6 and where the threshold is 0.5. So, they were assessed as acceptable. Confirmatory Factor Analysis was conducted according to the model described in Figures 2 and 3; the results are presented in Table 3.

Table 2. Model Modification

<b>Tested parameters</b>	<b>Variable</b>	
	<b>Overall Measurement Model</b>	<b>Structural Model</b>
<b>Initial Model</b>		
Normed Chi-Square (<5.0)	1.804	2.740
CFI (>0.9)	0.948	0.884
RMSEA (<0.08)	0.044	0.064
<b>Modified Model</b>		
Normed Chi-Square (<5.0)	No modification required	

CFI (>0.9)	The initial model is according to the modified model fit
RMSEA (<0.08)	
Comments	

So, it must be noted that the model which was included in the research needed no correction or modification because it was equivalent to the initial fitness indice values (presented in Figures 2 and 3) [36].

### 3.4. Hypotheses testing

Comprehension and understanding have significant relationships with exam performance, with an estimated r value of 0.526 and an r-squared value of 0.588 showing a positive moderate relationship. So in this way, if retention and exam performance are significant and have a 0.598 r value and 0.785 r-squared value therefore hypotheses being accepted (Table 4). Table 4 explains the relationships between Exam Performance (EP) and Eye Strain (ES), Exam Performance (EP) and Comprehension and Understanding (CU), Exam Performance (EP) and Retention (RE) and Exam Performance (EP) and Effective Mode of Reading (EM) and their Correlation Estimate, Standardized Estimate (S.E), Composite Reliability (C.R.), P-value of each relationship (P) and Correlation squared value (R<sup>2</sup>).

Table 3. Hypotheses Testing Results

			Estimate	S.E.	C.R.	P	R <sup>2</sup>
EP	<---	ES	0.118	0.040	2.980	0.003	0.153
EP	<---	CU	0.526	0.064	8.173	***	0.588
EP	<---	RE	0.598	0.399	4.011	***	0.785
EP	<---	EM	0.084	0.036	2.322	0.020	0.120

The relationship between exam performance and eye strain was significant. However, it was weak and positive (of 0.118 and a coefficient of 0.153). It was consequently rejected for this study. The efficiency of the reading mode and exam performance also demonstrated a positive relationship at 0.084 and a coefficient of 0.120 but it was lower than the acceptance threshold; for this reason, it was also rejected.

### 3.5. Findings

Table 5 presents the study results based on the data of Table 4: a p-value below 0.05 is considered significant, a correlation value r below 0.2 is weak, 0.5 is moderate, and above 0.7 is significant. If a hypothesis is considered "significant" and the relative "relationship" is moderate or strong while the direction remains valid (positive or negative relation) then the study finding is supported.

## 4. Discussion

Still, with such a high penetration of e-books, print books outsell e-books by 10

times, as Handley [37] notes. Writer, marketer and President Emeritus of Book Baby, the nation's leading self-publishing company Steven Spatz [38] gives data in his blog that even after being in the market for five decades and with major companies such as Amazon investing in printed books, they have not yet assessed the impact on exam performance.

Table 5. The indicated results of the conducted study

H(x)	Hypothesis	Significance	Relationship	Reference and Justification	Finding
H1	Eye strain is negatively related to Exam Performance	Significant	Very weak, Positive	Table 3. Hypotheses Testing	Not supported
H2	Comprehension and Understanding is positively related to Exam Performance	Significant	Moderate, Positive		Supported
H3	Retention is positively related to Exam Performance	Significant	Strong, Positive		Supported
H4	Effective Mode of Reading is positively related to Exam Performance	Significant	Very weak, Positive		Not supported

Moreover, Zhang [19] notes that users still prefer print books, especially for short time reading (for pleasure), posing a need to study this area further.

The findings from this research affirm the fact that the literature which supports Asian students are exam oriented and that most exams are based on a framework and retention of textbook content.

Mangen et al. [10] note that print books give a higher ability to be able to comprehend and understand content through increased retention than e-books. Also, as Mangen et al. [10] and Glass et el. [26] note, the use of print books allows for better data retention compared with e-books; the findings from this research contribute to other findings that show the exam performance of university undergraduates is linked to their comprehension and understanding as well as to retention of the content. There is a significant advantage to comprehension, as it ultimately improves students' performance in the exam through increased retention, which is achieved by utilizing print books instead of e-books.

## 5. Conclusions

Thus, e-Books are considered irrelevant considering the toll they take on students, such as reduced power of retention and the need for constant repetition to grasp the

same material. The findings suggest that eye strain is a negative factor, found when using e-books, which adversely affects the reading time of the students of books, as well as their health. Therefore, the usage of e-books should not be promoted without further conscious understanding of the issues; instead, print books should be promoted. This research has shown that comprehension, understanding and retention are major contributors in the exam performance of undergraduate students, therefore, a mode of reading that produces higher comprehension and understanding capabilities, as well as higher retention capabilities, will positively impact the academic performance of undergraduate students so they achieve significantly better results. Based on previous studies, as well as from this research, printed books are known to have higher retention, comprehension and understanding capabilities. Therefore, using print books as the primary mode of reading for university textbooks by university undergraduates will improve their overall exam performance and will eventually help build a better knowledge society, as well as increase the social intellectuality of the population.

## **6. Practical recommendations**

In conclusion, print books need to be promoted, at least for university undergraduates who regularly use academic textbooks for reading and study purposes during each semester and final examinations, as they have proved to give students a higher ability to retain, comprehend and understand subject matter when they are used.

Libraries should not enforce e-books among students and other academic members. The impact of using e-books for study purposes should be studied thoroughly and, however, print books should be made equally available and ultimately leave the choice to the reader, who ultimately should decide which is best for them.

## **7. Future research scope**

Based on the scope of the research findings, print books currently provide students with better retention and exam performance capabilities than e-books. Therefore, a method of achieving the same results using e-books needs to be found and studied in the future.

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## Summary

The mode of reading plays a vital role in signifying the relationship between reading (getting the information) and remembering, which, in the end, transforms into professional skills formation. We looked at the assessment of the study's success in using different sources of the specialty study information (print and e-Books). The research was based on the analysis of students' exam success in their bachelor's degree. The sampling frame was defined within the undergraduate student population with a simple random sampling method. An online-based survey questionnaire was performed and the data collected and examined. The findings showed a significantly higher level of success in exam performance and retention among students who utilized print books instead of e-Books as a primary mode of reading. It was noted that eye strain becomes a negative factor in using e-Books and adversely affects the reading time of the students. The usage of e-Books should not be promoted without a further conscious understanding of their pros and cons. We present a local assessment of the efficacy of using e-books in the higher education process by analysing student exam performance in Sri Lanka when using print books and e-books. It was concluded that prioritizing and promoting print book usage among universities and libraries improved academic results among undergraduates and that print book usage shows students are better able to comprehend data when compared to e-book usage.

## Riassunto

La modalità di lettura gioca un ruolo fondamentale nel significare il rapporto tra leggere (ottenere informazioni) e ricordare, che si trasforma in formazione di competenze professionali. Abbiamo esaminato la valutazione del successo dello studio nell'utilizzo di diverse fonti di informazioni sullo studio specialistico (stampa ed e-book). La ricerca si è basata sull'analisi del successo degli esami degli studenti della laurea triennale e sul modo in cui hanno ottenuto le informazioni. Il quadro di campionamento è stato definito all'interno della popolazione studentesca universitaria con un semplice metodo di campionamento casuale. È stata eseguita la raccolta dei dati del questionario del sondaggio online. I risultati dimostrano un aumento significativo delle prestazioni agli esami e della fidelizzazione tra gli studenti che utilizzavano libri cartacei anziché e-book come modalità principale di lettura e, di conseguenza, come modalità principale di competenze professionali. Possiamo notare che l'affaticamento degli occhi diventa un fattore negativo riscontrato negli e-book. Sta influenzando negativamente il tempo di lettura degli studenti. L'uso degli e-Book non dovrebbe essere promosso senza un'ulteriore comprensione consapevole dei loro pro e contro. Vogliamo presentare la valutazione locale dell'efficienza dell'uso degli e-Book nel processo di istruzione superiore prendendo l'esperienza della regione asiatica (nello Sri Lanka). Possiamo quindi concludere che dare priorità e promuovere l'uso dei libri stampati tra le università e le biblioteche migliorerà i risultati tra gli studenti universitari. L'utilizzo dei libri stampati mostra una maggiore capacità di comprensione dei dati da parte degli studenti e la loro comprensione rispetto agli e-Book.

# BETWEEN MICHELANGELO AND THE HOLY SHROUD: ARTIFICIAL INTELLIGENCE AND ITS MIRACLES

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*Keywords:* Michelangelo, holy shroud, artificial intelligence, CNN, authorship

## 1. Introduction

The search for a link between the greatest sacred artist in history and the greatest of sacred relics has all the potential to be seen as a need yet to be realized in the science of biography. Nevertheless, this topic is despised in academic circles - and beyond - for various reasons. How so? The lack of materiality is probably the main reason. But would a natural association between Michelangelo Buonarroti (1475-1564) and the Holy Shroud really be out of place?

Just as with Leonardo, perhaps the total lack of documentary evidence associating Michelangelo with the Shroud is due to something justifiable (the reason for which is hidden from us) or simply mere chance – but "absence of evidence" should not be confused with "evidence of absence". Incidentally, there is also no documented personal evidence that Michelangelo was homosexual or that Leonardo painted the *Mona Lisa*.

One must consider that, not only for these two artists, but (virtually) for any other Renaissance artist, no relationship with the Shroud of Turin was ever evident - as if the subject of the "Shroud" was something to be naturally kept a secret. Could it have been simply because they were unaware of it, or because they had never come across the Shroud? Hard to believe, since the fame of this relic in Europe (and particularly in Italy) was widespread; moreover, the close relationship between ecclesiastical and political authorities and many of these great artists was a constant, a natural consequence of the importance of their activities. Suffice it to say that 96% of Michelangelo's works were commissioned by popes and cardinals [1].

An obvious explanation for such silence might be the fact that, if a connection between the artist and the Shroud had been revealed, it would have been suspected that the relic was, in fact, a fake. Obviously, society would not have tolerated such frauds, and even if there were "official" copies of the Shroud on display, these would already be recognized as replicas<sup>1</sup>.

As an intellectual attentive to religious symbolism and scientific questions of human anatomy, it would have been extremely unlikely that the Shroud would have gone unnoticed by Michelangelo - he, who frequented the most cultured circles between Rome and Florence, eager to understand God's creation and how evolution had sculpted the shapes and volumes of the "human machine". Learning from the very nakedness of the Son of God was for him a journey to the divine, the transcendental.

With these notions in mind, I decided to undertake research making use of all the

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material we have available, to bring more of it to light, and to try to answer the question: if there was indeed a relationship between Michelangelo's art and the Shroud, where would the evidence that would confirm it be? Evidence that is often embedded within the art of the one who is called "The Divine".

An analysis of his ideas, codified in the artistic production that immortalized him [2], and in his writings [3], could offer us clues capable of revealing a new perception of the inner sacredness of the genius. Below, I will outline some arguments in support of a probable link between the greatest sacred artist in history and the greatest of sacred relics as represented by the overlapping sections shown in Figure 1. I would also like to point out that this study was approved by Barrie Schwartz, the world's foremost authority on Shroud research and dissemination, editor and founder of the Shroud of Turin Website ([www.shroud.com](http://www.shroud.com)) and the official photographer for the Shroud of Turin Research Project (STURP) between 1978 and 1981 [4].

## 2. The Shroud at the center of the Pietà

It cannot go unnoticed that the presence of the Shroud - more or less explicit - ended up being a constant in Michelangelo's work, given the level of attention the artist devoted to the theme of the dying Christ.

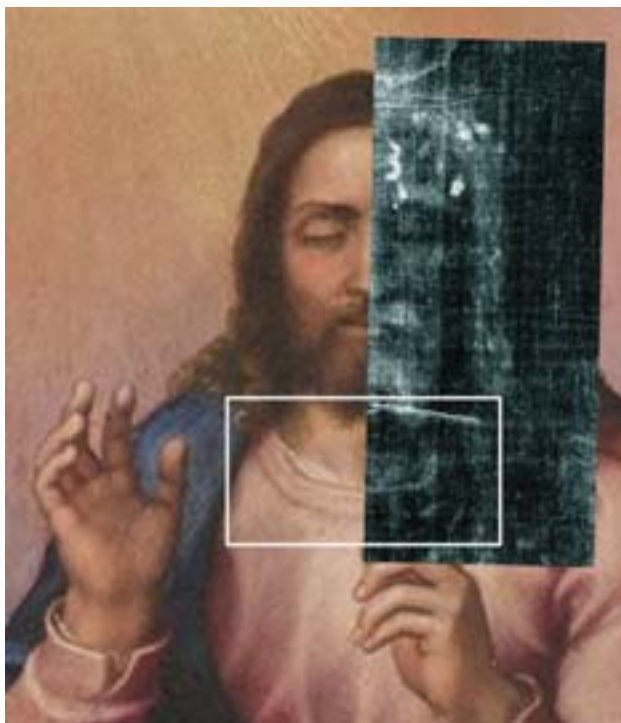


Figure 1. The face of Christ (detail) in a painting by Marcello Venusti based on a drawing by Michelangelo and the face of the Shroud. The perfect correspondence of the facial features and the line of the neckline is striking. (Source: Átíla Soares / Massimo Gaudio / Wikimedia Commons)

In the iconic *Vatican Pietà* (Figure 2), the Sacred Shroud is present at the very center of the composition, in the wide drapery covering the legs of Mary, who holds her dead Son on her lap.



Figure 2. Michelangelo Buonarroti's "Pietà", St. Peter's Basilica in the Vatican (1497-1499). (Source: Wikimedia Commons)

The Shroud is also depicted in paintings on the theme of the "Deposition of Christ" based on preparatory drawings by Michelangelo. Figures 3 and 4 give a clear example; the two paintings belonging to Marcello Venusti and Jacopino del Conte are based on Michelangelo's drawings.



Figure 3. "The "Deposition" with the Shroud: a "gloomy" version in a painting by Marcello Venusti (left), and another similar one Figure 4 by Jacopino del Conte (right) based on drawings by Michelangelo. (Source: Accademia di San Luca, Rome / Palazzo Barberini, Rome)



Figure 5. "Illuminated" version of the "Deposition" (Michelangelo, 1500-1501, National Gallery) and the nudity of Christ: a constant in Michelangelo's depictions. (Source: National Gallery / Wikimedia Commons)



Figure 6. There is a high level of correspondence between the faces of Jesus in the "Bandini Pietà" (left) and in his last, unfinished work (right), the "Rondanini Pietà", and the face of the Holy Shroud: would Michelangelo have known about or had closer contact with the greatest treasure of Christendom? (Source: Private Archives - Átíla Soares da Costa Filho / Mdig.com / Renata Testa)



Figure 5 is in contraposition with the classical representation of Christ, because Michelangelo painted him nude. On the theme of the Pietà (Michelangelo made four of them), it is possible to find another element that directly evokes the Shroud, except for the "Palestrina Pietà", where it is not very evident. Thus, besides the fabric representing the Shroud in the *Vatican Pietà*, two of the other three variants show the face of Christ, very similar to that of the relic.

The *Bandini Pietà* (Figure 6), commissioned by Francesco Bandini in 1547, features Michelangelo's self-portrait as Nicodemus supporting the lifeless body of Christ. The sculptor and architect, Tiberio Calcagni (1532-1565) was commissioned to restore the (usual) signs of fury that Michelangelo had left on the marble in this massive work [5]. The work conveys a spiritual and dramatic atmosphere to us, given the advanced age of its author, and today it is preserved in the Museo dell'Opera del Duomo, Florence, Italy.

The *Palestrina Pietà*, made of marble and belonging to the Barberini family, probably dates back to 1556. It depicts the exact moment the body of Jesus is lowered from the Cross and supported by his Mother and her followers - something revolutionary in the art of sculpture up to that time. As mentioned, it is the only version that has no obvious connection with the Holy Face (Turin). It was once located inside the church of Santa Rosalia in Palestrina, but now belongs to the collection of the Galleria dell' Accademia in Florence.

And finally, the *Rondanini Pietà*, also in marble, begun in 1552 and left unfinished due to Michelangelo's death in 1564. It is interesting to note that, in addition to approaching a Gothic style - choosing to represent pain rather than beauty - in this version, it is the Son who seems to support the Mother, when seen from another point of view<sup>2</sup>. His last *Pietà*, extraordinarily moving, is preserved today in the Castello Sforzesco Museum in Milan.

### 3. A "sacred technology" - the "Luminari" method

It is possible that the mere fact that the Son of God was completely naked in the Shroud called Michelangelo's attention. The union of Christ's pure divinity with his human, male bodily dimension would have been a perfect event in terms of synthesizing the greatest values and spiritual interests of his mind and soul: a miracle that had materialized before him. Indeed, virtually every time the artist decided to depict the adult Christ, he presented him naked or half-naked, whether in drawings, paintings, or sculptures.

The most famous image is the Christ-Apollo figure at the center of the *Last Judgment* (1535-1541), in the Sistine Chapel. It was later covered (along with the other nude figures) with a strip of cloth by the brush of Daniele da Volterra, his greatest disciple [6].

Also noteworthy is the Crucifix of Santo Spirito, which he sculpted in 1492, at the age of 17, for the convent of the same name in Florence.

Incidentally, Buonarroti's fondness for the body of the Messiah was so great that there is a curious fact regarding the preparatory sketch of the *Pietà* for Vittoria Colonna. The drawing (now in the Isabella Stewart Gardner Museum in Boston) was executed in 1538 by the master as a gift for his Platonic muse and great intellectual companion, the poetess Vittoria Colonna, marchioness of Pescara. However, there is great debate whether the related painting has come down to us [7]. In 2010, the media broke the news of a strong candidate for the privately owned "lost original" in Buffalo, New York. In 2023, I had the opportunity to perform an analysis on some good reproductions of

the painting using an artificial intelligence program developed, in part, by me, while an interesting aspect was revealed concerning the body (described later in the text). This particular methodology - named "Luminari" [8] - includes a series of tests performed using Machine Learning engineering, following rigorous academic standards. In essence, it is a system with convolutional neural network architecture, specifically suited to performing predictive tasks in the field of artwork. The engineering includes multiple layers, from correction codes to "Max Pooling". The processed images are then converted into a one-dimensional vector with "softmax" activation.

#### 4. The challenge of small datasets for artworks

One of the great difficulties of Artificial Intelligence (AI) systems that specialize in artwork attribution lies in the fact that, in many cases, they deal with possible artists whose output is very sparse. The reason is obvious: the premise of Machine Learning is that the more examples there are to build a database - or a library - the better. It is on this data that a digital signature will be built for each artist. How then to deal with certain painters (or draftsmen) who have done little, who have been sparsely prolific, and whose output is not compatible with the minimum satisfactory number of 100 works<sup>3</sup> to be analyzed? How will this "algorithmic signature" be formed? To give an idea, Leonardo da Vinci (1452-1519), the author of the two most famous works in history, the *Mona Lisa* and the *Last Supper*, has 15 universally accepted and authenticated works. And, like Leonardo, there are other geniuses at the other end of the spectrum - Michelangelo, with 48 (including 40 in the Sistine Chapel alone), Jan Vermeer (1632-1675) with 34, and Hieronymus Bosch (1450-1516) with 25, to name a few<sup>4</sup>.

One of the faculties of the Luminari method is that it predicts such a situation and is able to readily create the possibility of providing a solution. The formula, a private and exclusive technique, is protected for intellectual property reasons. However, it can be said it was generated by AI itself, from multiple works subcategorized as being of potential authorship by a particular artist, based on intelligent piecemeal analysis (computerized) combined with a critical method at the preparatory stage.

#### 5. The importance of interdisciplinarity: art criticism - expertise - AI

To make this argument clearer, I will give a very current example: Ivan Gaskell, a teacher of Cultural History and Museum Studies at the Bard Graduate Centre, is a well-known expert on the Golden Age of Dutch Painting (Baroque) and, in particular, Vermeer. When dealing with the cataloguing of the artist, one of Gaskell's concerns already starts with the implications and inevitable clashes that would have been generated in the fields of History, Art, Semiotics, Philosophy, and even the Exact Sciences. Vermeer is the case of a painter with a very limited output, as explained above, and Gaskell's main concern in dealing with Vermeer's "authenticity" [9] is to address the relationship between visual material and art from the perspective of three fundamental institutions of Western culture: dealers, auction houses, and collectors; museum and public gallery management (based on bureaucracy); and art historians, academics, publishers, and critics. Note, for example, that the work of art, when in the hands of a dealer, acquires a different meaning, as it includes aspects of attribution from the perspective of *connoisseurship*. In a context of such complexity, it is necessary to analyze what distinguishes the category labeled "art" (itself subdivided into scholarly, decorative and

design) from its counterpart, defined by the term "other".

In this sense, *connoisseurship* is fiercely opposed by historians. "Radical theorists" define it as a limited and inherently right-wing activity that simply supports the art market and encourages the evasion of important issues by focusing on discrete and insignificant minutiae. Even photography - the boom that is taking artistic and philosophical events by storm at the end of the century - will be able to provide a personal reading of the material it produces<sup>5</sup> [10]. Thus, we use three theoretical aspects: authorship, canonicity, and interpretation. Trying to avoid any kind of preconceived notions, we take the example of Rembrandt (1606-1669) [11] and his study to suggest that, in terms of "authorship", *connoisseurship* can be seen as an ally in Art History studies. In fact, it provides information that contributes to the understanding of a particular author, their production and their era. It is advisable to see these phenomena in an anti-historical way, because each era perceives things according to the knowledge and manners of that time and social environment. Thus, one can better appreciate the information the image conveys, even if one feels a little uncertain. The willingness to understand the visual material is therefore entirely subjective and subject to changes in the involved judgments of value. In this regard, we have two "not uncommon" turning points in Art History: the "rebirth" of Botticelli's (1445-1510) name by the Pre-Raphaelites of the Belle Époque, and the "death" of Guido Reni's (1575-1642) name<sup>6</sup>.

That is why we must ask how far the legitimacy, competence and scientificity of criticism in general goes when it establishes levels of value - the most discrepant ones - to evaluate and classify an artist or a work of art, using an opinion that serves only at that precise moment. The way out is to avoid labels and the phrase "postmodern". Moreover, Gaskell extols the value of the works of iconoclasm, calling for interdisciplinarity on the issue of "nuances" that might go unnoticed by a historian steeped in traditional academicism: "While I sincerely hope that historians will increasingly turn their attention to visual material, I regret that few to date have shown awareness of the issues necessarily involved or the particular skills needed to cope with such material" [12]. According to the author, it is not even up to Image History to have the last word on visual material. It is on occasions like this that one is reminded of what Demosthenes said about the relativity - and fallibility - that happens in the human conception of things: "Nothing is easier than self-deceit. For what each man wishes he also believes to be true".

It is precisely because of the importance of this interdisciplinarity that it is necessary to cross-check tools in the service of Art History and its attributions: AI for *connoisseurship* and *connoisseurship* for AI. So much so that different AI models often produce different results when analyzing the same artwork<sup>7</sup> [13].

In the face of so many complex issues of a subjective nature, the Luminari method seeks to create a harmony between the necessary eye of the *connoisseur* and the convolutional coolness of algorithms. The method advocates the need for significant intervention by expertise and art criticism during test preparation, as it believes that a purely mathematical treatment - while also of the utmost importance - is not in itself definitive in the search for a result. In the end, the work of AI will present its final verdict in the attribution.

## 6. Technical report on model performance

To better exemplify this in a prototype test with trained systems, we will use a "confusion matrix" as a reference model, as can be seen in Figure 7. This matrix is a table used by some intelligent systems to evaluate the performance of a binary, but also

multiclass classification model.

For our example, the sum of the values in the horizontal (row) is equal to the number of test images that were taken for the artist in the respective row. For example: in the Modigliani row, we have:  $6 + 2 + 1 + 1 = 10$  test images of the artist Modigliani.

On the other hand, vertically (column), we have the distribution of model ratings (predictions) for each of the artists examined.

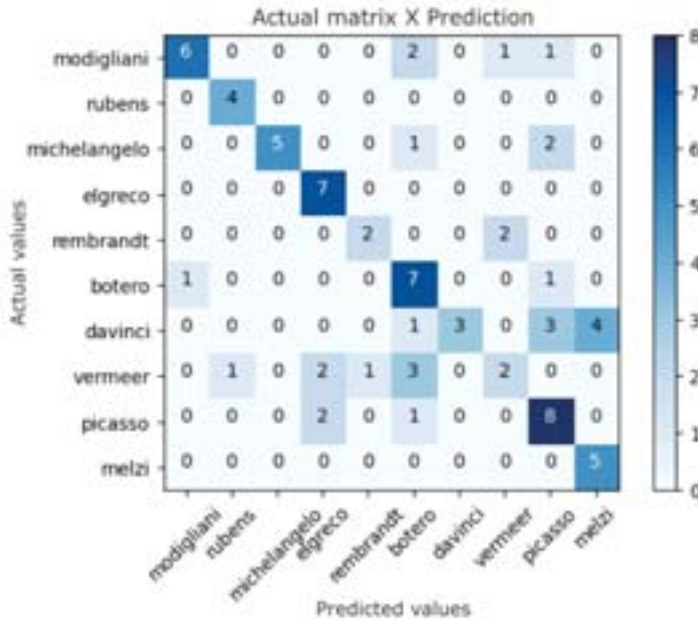


Figure 7. Generic example of a simplified "confusion matrix". (Source: Átila Soares da Costa Filho)

For example, in the Picasso column we have:

- 1 image recorded as Modigliani, but classified as Picasso (error);
- 2 images recorded as Michelangelo, but classified as Picasso (error);
- 1 image recorded as Botero, but classified as Picasso (error);
- 3 images recorded as Da Vinci, but classified as Picasso (error);
- 8 images recorded as Picasso and classified as Picasso (correct).

In other words, our main goal is to obtain as many values on the diagonal of the matrix (correct) as possible. Anything that does not fit on the diagonal is an error in the model. Thus, having correctly interpreted the "confusion matrix", we can conclude that:

- For Modigliani: the model correctly predicted Modigliani 6 times but erred by predicting him as Botero 2 times and as Picasso and Vermeer 1 time.
- For Rubens: the model correctly predicted Rubens for all 4 tested images.
- For Michelangelo: The model correctly predicted Michelangelo 5 times but erred by predicting him as Botero 1 time and as Picasso 2 times.
- For El Greco: the model correctly predicted El Greco 7 times.

- For Rembrandt: the model correctly predicted Rembrandt 2 times but erred by predicting him as Vermeer 2 times.
- For Botero: the model correctly predicted Botero 7 times but wrongly predicted him as Modigliani 1 time and as Picasso 1 time.
- For Leonardo da Vinci: the model correctly predicted Leonardo da Vinci 3 times, but erred by predicting him as Botero 1 time, as Picasso 3 times, and as Melzi 4 times.
- For Vermeer: the model correctly predicted Vermeer 2 times, but erred by predicting him as Rubens 1 time, El Greco 2 times, Rembrandt 1 time and Botero 3 times.
- For Picasso: the model correctly predicted Picasso 8 times but erred by predicting him as El Greco 2 times and as Botero 1 time.
- For Melzi: the model correctly predicted Melzi for all 5 tested images.

We will now examine the results of the model according to the criteria of "false positives" (FP) and "false negatives" (FN) - in this case, since it is a "multiclass" system, the calculations to be performed are different from those of binary classification problems.

- False positives (FP): cases where the model predicted one class, when in fact it was another.
- False negatives (FN): cases in which the model failed to predict a class that was actually present.

Usually, multiclass classification models are evaluated by the metrics of accuracy, precision, recall and score. In our case, the following metrics were used:

1. Accuracy: measures the overall correctness of the model and is calculated as the proportion of correctly predicted instances to the total number of instances. Thus:

*Accuracy = correct classifications / all classifications.*

The accuracy of our model, looking at the "confusion matrix", is the sum of the diagonal values (6 + 4 + 5 + 7 + 2 + 3 + 2 + 8 + 5 = 49) divided by the total number of test images (77). The result is  $49/77 = 0.64$  or 64% accuracy of the classification model. This accuracy considers the classes collectively, providing an overview of the model's performance over all series.

2. Precision: measures the ratio of correctly predicted positive observations to total positive predictions. It measures how many of the predicted positive images actually turn out to be positive. Precision can be calculated separately for each performer, providing insights into the quality of predictions on an individual basis. Thus:

*Precision artist X = correct classifications of artist X / (correct classifications of artist X + false positives of artist X).*

In this case, the precision of the artist Modigliani, observing the "confusion matrix", is the sum of the values correctly classified as Modigliani (6) divided by the values correctly classified as Modigliani (6), plus the difference between the

sum of the values in the Modigliani (7) column and the correct images of Modigliani (6). The result is  $6 / (6 + (7 - 6)) = 6 / (6 + 1) = 6 / 7 = 0.86$  or 86% accuracy to classify the artist's images as Modigliani.

3. **Recall:** measures the proportion of positive observations predicted correctly for all real positives. It measures how many real positive instances were captured by the model. Recall can be calculated separately for each artist, providing insights into the quality of predictions for individual artists. Thus:

*Artist recall  $X$  = correct classifications of artist  $X$  / (correct classifications of artist  $X$  + false negatives of artist  $X$ ).*

In this case, the recall of the artist Picasso, observing the "confusion matrix", is the sum of the values correctly classified as Picasso (8) divided by the values correctly classified as Picasso (8), plus the difference between the sum of the values in the Picasso row (11) and the correct images of Picasso (8). The result is  $8 / (8 + (11 - 8)) = 8 / (8 + 3) = 8 / 11 = 0.73$  or 73% recall for classification of the artist's images as Picasso.

In the specific case of this study, a total of 1022 images were used, attributed to 10 well-known artists in art history, including Vermeer, Da Vinci, Picasso, Rembrandt, Botero, Melzi, Modigliani, Rubens, Michelangelo and El Greco. The distribution of images considered for each artist is shown in the figure below: about 100 images for each. It should be noted that the choice (exclusive methodology), not to limit ourselves to perfect homology (the same number of works for each painter) is due to the very existence of greater or lesser stylistic variations between the individual productions of the painters analyzed. Throughout the centuries of art, just as there have been artists who have allowed themselves marked variation in the plastic direction of their creations, there have also been those who little dared to stray from their comfort zone. In some cases, they have not even lived long enough to do so.

This variety of works allows a more comprehensive and detailed analysis for the development of the model for identifying the authorship of paintings.

Out of the total number of images, 868 were used in the training of the machine learning models, while 154 were reserved for evaluating its performance, the total number of images and their subdivision between authors is showed in Figure 8.

This is equivalent to about 15% of the images allocated for testing. Note that, due to the fact that this technology is private in nature, certain graphical information regarding the validation phase had to be preserved. The following is a brief explanation of the machine learning models evaluated here.

- **Random Forest (RF):** RF is an ensemble learning method based on so-called "decision trees". It constructs a multiplicity of "decision trees" during training and then produces the mode classes of "individual trees" to determine an outcome.
- **Support Vector Machine (SVM):** the SVM is a supervised learning model used to analyze image classification. It works by finding the hyperplane that best separates classes in feature space.
- **Convolutional Neural Networks (CNNs) - ResNet:** this is a type of CNN that addresses the problem of missing gradients during training by introducing jump or residual connections. These connections allow the network to learn residual

mappings instead of learning the desired mappings directly. It should be noted that the ResNet model was pre-trained on ImageNet, a huge dataset that itself contains millions of images in thousands of categories.

- **Convolutional Neural Networks (CNNs) - ConvNet:** this CNN is a deep learning model designed specifically to process structured grids of data, such as images. It consists of several layers of convolution and pooling operations, followed by other fully connected layers.

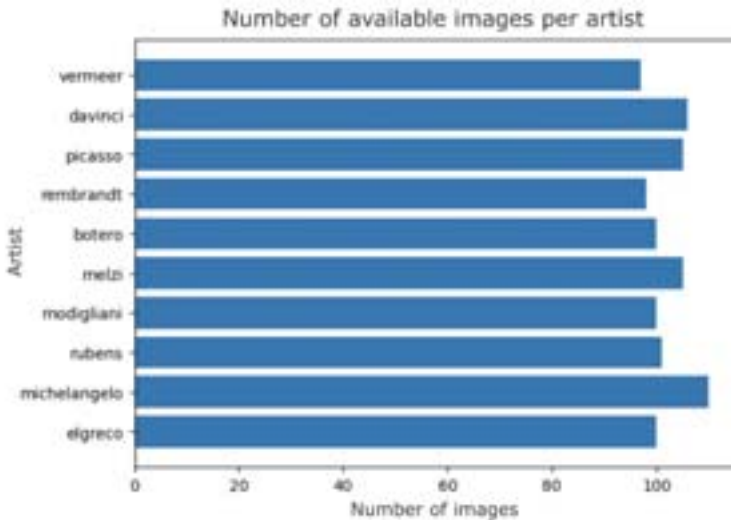


Figure 8. Balance between the number of works selected and the respective artists (Source: Átila Soares da Costa Filho).

SVM and Random Forest models can handle high-dimensional data, which makes them suitable for identifying patterns in paintings that can indicate authorship. ResNet and ConvNet models, on the other hand, are fully capable of training deep neural networks. They excel at learning intricate features and patterns on images, making them suitable for this type of task, where subtle details can be very important. In other words, each of the models presented brings unique strengths to the image classification task.

For this project, we were able to experiment with different configurations of the algorithms, such as the number of levels and the depth of the trees, with the goal of optimizing the performance of the models.

To determine which was best, we considered metrics such as accuracy and recall, as well as analyzing the confusion matrix, which shows where the model is right and where it errs. Importantly, factors such as the time required to train these models, the desired level of interpretability, and available computing resources were not part of the decision to choose models.

The model evaluation process involved 154 test images, ensuring a balanced data set. Figure 9 shows the best results obtained in terms of accuracy, recall, and precision for each of the models. It shows that the best result came from CNN - ResNet50 (RN50), with an accuracy of 75% - indicating that the model is correct in 75% of its global prediction - and an accuracy of 79% - indicating that when it makes a positive prediction, it is correct 79% of the time. Figure 10 shows the confusion matrix of the RN50 model,

which provides a more detailed view of its performance by showing how many images of each artist were correctly or incorrectly classified. Each row represents the true authors of the paintings, while each column represents the authors predicted by the model.

```

Model: CNN
Accuracy: 0.564935864935865
Precision: 0.5795424272887081
Recall: 0.564935864935865
F1 Score: 0.5583856364992984
Confusion matrix without normalization

Model: RF
Accuracy: 0.4825974825974826
Precision: 0.422372495830288
Recall: 0.4825974825974826
F1 Score: 0.4084126317991759
Confusion matrix without normalization

Model: SVM
Accuracy: 0.4155844155844156
Precision: 0.42699238939848445
Recall: 0.4155844155844156
F1 Score: 0.4824289886789133
Confusion matrix without normalization

Model: RNSD
Accuracy: 0.7532467532467533
Precision: 0.7895572348792811
Recall: 0.7532467532467533
F1 Score: 0.7586213612262889
Confusion matrix without normalization
    
```

Figure 9. Final results for each of the models. (Source: Átíla Soares da Costa Filho)

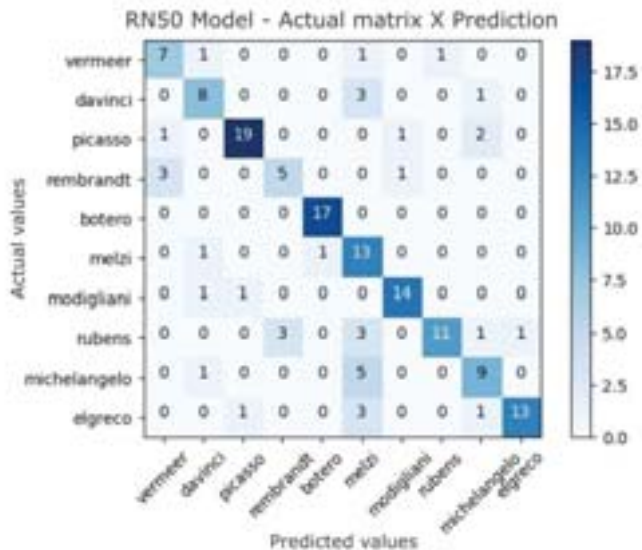


Figure 10. The current "confusion matrix" for measurements in complex architectures. (Source: Átíla Soares da Costa Filho)

In the first row of the confusion matrix, out of 10 Vermeer paintings (added



horizontally) used to evaluate the model, 7 were correctly classified as belonging to Vermeer himself. However, one painting was incorrectly attributed to Da Vinci, another to Melzi, and a third to Rubens.

In the second row of the confusion matrix, out of 12 Da Vinci paintings, 8 were correctly classified by the model as belonging to Da Vinci himself. However, three paintings were incorrectly attributed to Melzi and one to Michelangelo.

In the third row of the confusion matrix, out of 23 Picasso paintings, 19 were correctly classified by the model as belonging to Picasso himself. However, one painting was incorrectly attributed to Vermeer, one to Modigliani, and two to Michelangelo.

In the fourth row of the confusion matrix, out of 9 Rembrandt paintings, 5 were correctly classified by the model as belonging to Rembrandt himself. However, three were incorrectly attributed to Vermeer and one to Modigliani.

In the fifth row of the confusion matrix, all 17 paintings made by the artist Botero were correctly attributed to Botero himself.

In the sixth row of the confusion matrix, out of 15 Melzi paintings, 13 were correctly classified by the model as belonging to Melzi himself. However, one painting was incorrectly attributed to Botero and another to Da Vinci.

In the seventh row of the confusion matrix, out of 16 Modigliani paintings, 14 were correctly classified by the model as belonging to Modigliani himself. However, only two paintings were incorrectly attributed: one to Da Vinci and the other to Picasso.

In the eighth row of the confusion matrix, out of 19 Rubens paintings, 11 were correctly classified by the model as belonging to Rubens himself. However, three paintings were incorrectly attributed to Rembrandt, another three to Melzi, one to Michelangelo, and another to El Greco.

In the ninth row of the confusion matrix, out of 15 Michelangelo paintings, 9 were correctly classified by the model as belonging to Michelangelo himself. However, five paintings were incorrectly attributed to Melzi and one to Da Vinci.

In the last line of the confusion matrix, out of 18 El Greco paintings, 13 were correctly classified by the model as belonging to El Greco himself. However, three paintings were incorrectly attributed to Melzi, another to Picasso, and yet another to Michelangelo.

The superior performance of the ResNet model pre-trained with the ImageNet dataset can be attributed to several reasons.

- **Deep architecture:** ResNet is a neural network architecture with a depth of up to 152 layers. Its depth allows it to learn complex representations about the characteristics of paintings.
- **Pre-training on ImageNet:** the ResNet model, as mentioned above, has been pre-trained on a huge dataset (ImageNet) containing millions of images across thousands of categories [14]. This pre-training allows the model to capture general high-level features of paintings - such as shapes, textures, and parts of objects - that are transferable to specific classification tasks with a smaller data set.
- **Transfer learning:** using the pre-trained ResNet model as a base, we can apply transfer learning to adapt it to the specific task of classifying images of paintings. During training, the model can adapt the learned representations to focus on the patterns relevant to identifying the authorship of paintings, taking advantage of ImageNet's prior knowledge.
- **Improved generalization:** by pre-training on a diverse dataset such as ImageNet, the ResNet model tends to generalize better for new datasets. It develops a broader and more robust understanding of common visual features

in a variety of images, allowing it to better handle different artistic styles and variations in paintings.

- **Balanced overfitting:** pre-trained models such as ResNet are less prone to overfitting, especially when the training dataset is relatively small. This happens because pre-trained representations provide more stable initialization and implicit regularization, preventing the model from overfitting the training data. It improves its ability to generalize new examples.

Taking our New York painting again, at first the system established a standard value as a starting point to test of any works by or attributed to Michelangelo or his followers/imitators.

In other words, this number (standard value) refers to the "debugging" of mathematical probabilities according to typical criteria of the School of Michelangelo: it is a common value - across the entire artistic-historical spectrum - that makes a Michelangelo a true Michelangelo (including the mentor himself).

Next, the neural technology presented the values corresponding to the algorithmic identification of the unique peculiarities of the technique and style of each of the artists circumscribed to the selection.

At a further level, it also statistically displayed the least likely candidates (i.e. authors) in descending order - a purely speculative possibility (due to graphical matching points) - and based solely on pure arithmetical logic.



Figure 11. New York's "Pietà" based on Michelangelo's design for Vittoria Colonna. Right: (detail) "anatomical" Christ that led to favorable indices of authenticity via A.I. (Source: Fred R. Conrad/The New York Times).

Thus, by adding up the percentages in the two "debugging" stages, I have curiously verified that in such a painting, based on a drawing of the *Pietà* for Vittoria Colonna (Figure 11), the half-naked body of Christ would be by Michelangelo's hand with a 77% match percentage - since 75% is the minimum established for any authenticity test [15]. And the probable co-author would be Marco Pino (Marco di Giovan Battista), a disciple of Michelangelo, also known as "Marco da Siena" (1521-1583), with a significant 98% match rate on the rest of the work. Apparently, the multifaceted artist would have personally taken care of the "icing on the cake", which is the body of Christ.

## 7. The orant Christ

Striking is the uncanny similarity between the face of Christ in Michelangelo's drawing, "Christ at Prayer in the Garden of Olives" (which is now in a poor state of preservation in the Uffizi Gallery in Florence), and the later pictorial versions by his followers, such as Marcello Venusti, who, moreover, was a close friend of Michelangelo's. The painting "Oration in the Garden", showed in Figure 12, is a clear example of the inspiration that Marcello Venusti got from Michelangelo.



Figure 12. Marcello Venusti's "Oration in the Garden" (1570) (Palazzo Barberini, Rome). Frontal face and closed eyes of Christ in the left of the composition; in the centre Jesus scolds his lax disciples. (Source: Massimo Gaudio)

Enthusiastic about contortionist, dynamic and vibrant imagery, it was quite unusual for Michelangelo to choose to depict a static face in a solemn full-frontal view. I also call attention to how rare it was in Renaissance art to present Christ praying with his eyes closed - as in the Shroud - in the New Testament episode of the agony in Gethsemane. A design, then, consciously inspired by the Shroud face seems to make sense and would explain such a choice. Figures 13 and 14, as in Figure 1, show a clear correspondence (visible also at first glance) between them and the Holy Shroud, as evidenced by the overlapping with a portion of the shroud.

## 8. The *Last Judgment* as the face of the Holy Shroud

In 2012, a retired FBI special agent, Philip Dayvault, published a startling theory: the entire composition of the *Last Judgment* (Figures 15 and 16) in the Sistine Chapel is actually a representation of the face of the "Man of the Shroud" [16]. Although the idea of the fresco as a face had already been put forward by writer Sue Binkley Tatem,

it was Dayvault who gave an "identity" to the enigmatic face by drawing graphic analogies between some of the marks imprinted in the fabric and details in the *Judgment* - something highly unlikely to be produced by mere coincidence alone. For anyone with a modicum of reason, all the geometry and the body of evidence gathered by Dayvault seems worthy of certain attention.

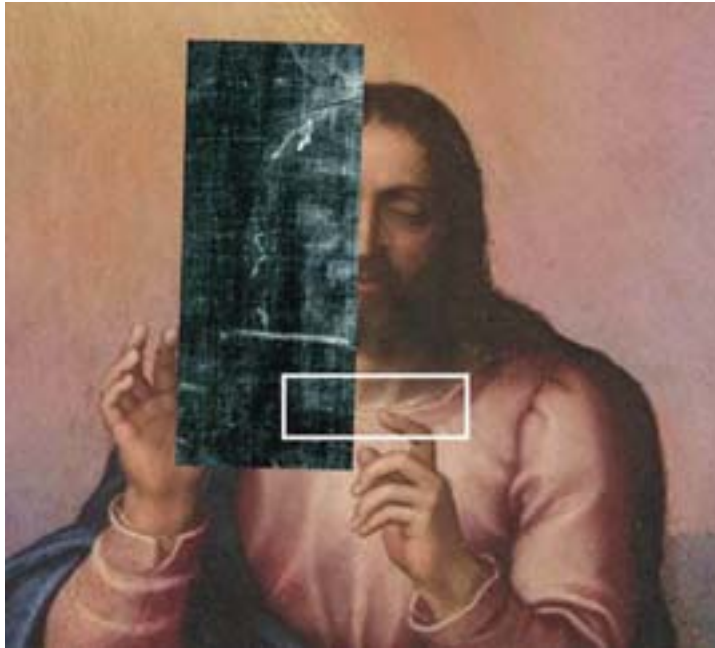


Figure 13. The left half (in relation to Figure 1): Interesting to note how the tip of Christ's left index finger "touches" exactly the cleavage line, as if to say, "look here"- in other words, this is "the limit". (Source: Massimo Gaudio)



Figure 14. The very high correspondence is also confirmed in other versions by Venusti (Source: Albertina).

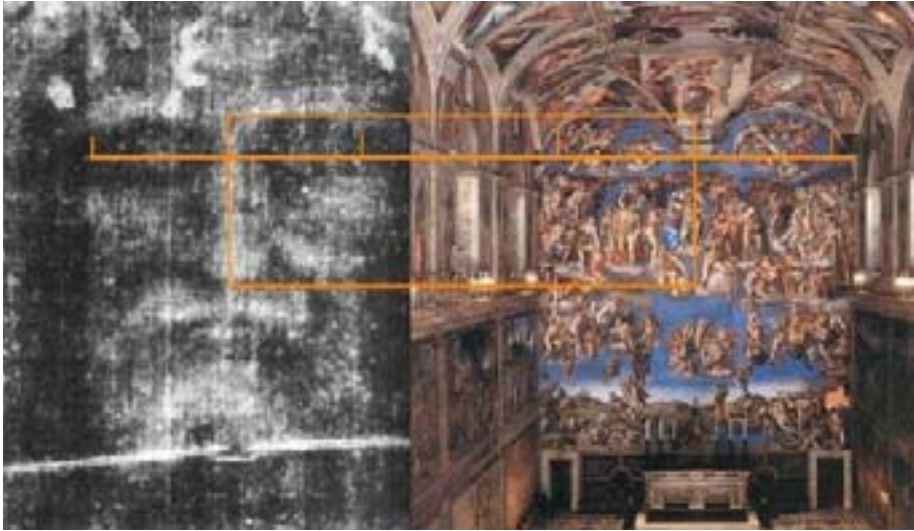


Figure 15. The "Last Judgment" is a face: geometries and other elements unite two large icons of the Resurrection as a "Metamorphosis" (Source: Wikimedia Commons / Jos Verhulst).

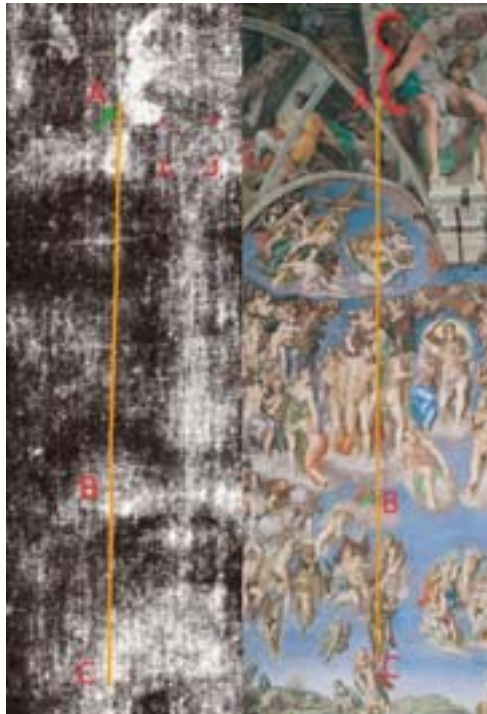


Figure 16. The "Last Judgment" is a face: landmarks in Michelangelo's colossal work anchor the signs of the Passion (Source: Wikimedia Commons / Jos Verhulst).

## 9. The remarkable “Michelangesque”

Interestingly, one of Michelangelo's most important followers was the Croatian, Giulio Clovio (1498-1578), whose name will be irreversibly associated with the Shroud for eternity. Indeed, he is responsible for a 1540 painting (Figure 17), preserved in the Galleria Sabauda in Turin) that is the most famous iconographic image of the Shroud, second only to the famous photograph taken by Secondo Pia in 1898, which revealed the image in negative with a wealth of detail worthy of a miracle.

As if that were not enough, probably towards the end of his life, Clovio was also responsible for the creation of a "new Shroud" or a "second generation" Shroud relic, that is: using pictorial techniques, he was able to reproduce the image of the Shroud on another cloth, previously "magnetized" (touched) onto the original relic, so as to obtain two relics - and no longer just one [17]. The whole process, or "ritualization", involving the production of copies, acquired an alchemical dimension - in fact, the real power and ultimate goal of the alchemist was "renewal" - in other words, a "resurrection". Clovio's "second relic" is considered one of the most perfect replicas of the Shroud<sup>8</sup> (today there are 135) [18].



Figure 17. The Holy Shroud, depicted by Giulio Clovio (Galleria Sabauda, Turin). The painting by a follower of Michelangelo has become an icon in the history of shroud devotion (Source: Wikimedia Commons).

## 10. Concealed elements

The rivalry between the genius of Michelangelo and that of Leonardo is well known by now, but because of this, the criticisms and disagreements between the two have given mankind masterpieces. In order to better understand one of the most revealing elements underlying my argument, I would like to elaborate on an issue concerning Leonardo's work.

We know that one of his most iconic projects, the *Last Supper*, holds a seemingly endless sea of religious and esoteric interpretations. And following this lead, I recently discovered what the true meaning of this mysterious painting might be. Objectively speaking, I was able to identify in the *Last Supper* that the group of Apostles with Jesus form the outline of Christ's dead body, identical to that of the Shroud. In other words, the Supper is, in fact, the Shroud itself. The visual effect is most obvious through the blurring of the whole, with Jesus and the Apostles united, where we can see the figure of a human body lying on the table - exactly like the image of the man imprinted on the Shroud.

The elements on which this new view of the *Last Supper* is based are not lacking: the face of the Shroud had already been identified in this painting, on the left wall, above and between the heads of St. Bartholomew and St. James the Less - perhaps to indicate on which side of the table the head of the "coded" body was located. Another factor is the hypothesis, supported by decades of study, that the tablecloth covering the table on the painting is, in fact, the Holy Shroud.

This is the thesis defended by archaeologist and art critic Yasmin von Hohenstaufen, as well as physician and writer Gabriele Montera. The latter has even presented a precise dimensional correspondence between the cloth of the Shroud and the tablecloth of the Da Vinci masterpiece [19].



Figure 18. a) Leonardo's "Last Supper" (top) and b) the "Dead Christ" (bottom) from the Museum of Sacred Art in Belém, Pará: a significant correspondence that may suggest Leonardo's greatest secret behind the most esoteric of his works (Source: WikiCommons - Átila Soares / Antônio Sales).

Later, finding it strange that the tablecloth did not have any of the Passion marks, I deduced that these should be somewhere else in the composition. And then I realized that the body could simply be depicted lying on the tablecloth/Shroud. If my assumption is correct, nothing could be more consistent than for the ghostly body of the Messiah to be part of it and discreetly and poetically presented in this way. The image speaks for itself: the conformation of the characters in the Upper Room has a very high level of correspondence with what the body imprinted on the Shroud must have been.



Figure 19. Michelangelo and the technique of concealing elements within a rich set of forms. The Sistine Chapel becomes an "Atlas of Anatomy". (Source: Frontal Magazine - 2015)

While we consider that the artistic-forensic reconstructions of the body imprinted on the relic vary slightly from each other (especially in the feet), the overall appearance indicates an immense resemblance to Leonardo's iconic painting - which strongly suggests that not only was the artist aware of the Shroud, but he had a great interest in it (Figures 18a and 18b).

Bearing in mind that both Leonardo and Michelangelo - precisely because of their competitive spirit - sought to learn about their opponent's designs and works, we can think that the latter, having come across this Shroud theme, used the former's inspiration to conceal elements in his works, in the Sistine Chapel, for example.

Thus, with the same formula, Michelangelo could have distributed, here and there, multiple volumes to insinuate various organs of the human anatomy (Figure 19). An amazing discovery to this effect was made in 1990, at different stages, by four physicians - two American and two Brazilian: neurologist Frank Lynn Meshberger, nephrologist Garabed Eknoyan, cancer surgeon Gilson Barreto and chemist Marcelo Ganzarolli de Oliveira, respectively [20].

If we interconnect all these factors, we come to the logical conclusion that Michelangelo may also have learned about the Shroud through Leonardo's box of surprises.

## 11. Conclusion

If it is something intentional on the part of Leonardo and Michelangelo, the practice of concealing elements and references in their creations is something already highly regarded in academia, a way of "arousing ingenuity", as Leonardo himself states in the *Treatise on Painting* [21]:



“Non isprezzare questo mio parere, nel quale ti si ricorda che non ti sia grave il fermarti alcuna volta a vedere nelle macchie de' muri, o nella cenere del fuoco, o nuvoli, o fanghi, od altri simili luoghi, ne' quali, se ben saranno da te considerati, tu troverai invenzioni mirabilissime, che destano l'ingegno del pittore a nuove invenzioni sì di componimenti di battaglie, d'animali e d'uomini, come di vari componimenti di paesi e di cose mostruose, come di diavoli e simili cose, perché saranno causa di farti onore; perché nelle cose confuse l'ingegno si desta a nuove invenzioni.”

“Don't underestimate this idea of mine, in which you are reminded that it is not grievous for you to stop sometimes to see in the stains of the walls, or in the ashes of the fire, or clouds or mud, or other such places, in which, if they are well considered by you thou wilt find most admirable inventions, which arouse the painter's ingenuity to new inventions as much of compositions of battles, of animals and men, as of various compositions of countries and monstrous things, as of devils and such like things, for they will be cause to do thee honor; for in confused things the mind is aroused to new inventions”<sup>9</sup>.

Michelangelo, too, could have made use of this as an exercise in perception or reasoning. A potential ploy to make a work richer and more interesting<sup>10</sup>. In the case of the Shroud, it would be a discourse of overcoming death, of alchemy, of resurrection, of the challenging metamorphosis in which passion becomes joy and the end is transformed into rebirth.

The evidence illustrated and analyzed here - with the help of a newly developed Artificial Intelligence model - reveals a new landscape based on the high probability, demonstrated here, that Michelangelo Buonarroti was not only aware of the existence of the Shroud, but was interested in including it in his work. These are traces of authorship and further symbolic indications that gain significance and emerge as silent witnesses to art, which have become a tool for meditation on the mysteries of the invisible wheel of life.

## Notes

<sup>1</sup> The replicas bore a seal, which was a sign of legitimacy, as these seals were issued by the church itself.

<sup>2</sup> However, Michelangelo projects the body of Christ from the very body of the Mother, as if the latter is desperately trying to revive him at the moment of his death. A perfect symbiosis between Mother and Son, united - the same flesh. Although it is considered unfinished, the resemblance of Jesus' face to that of the Shroud is evident.

<sup>3</sup> This was possible due to the use of a pre-trained model, which was adjusted specifically for our task through a process known as “fine tuning”. This pre-trained model had already been trained with thousands of images from different contexts, which probably influenced the relatively small number of images needed for that specific task.

<sup>4</sup> But there are other painters, such as Pablo Picasso (1881-1973), with 50,000 works, Katsushika Hokusai (1760-1849), with about 30,000, Pieter Paul Rubens (1577-1640), with 10,000, or Pierre-Auguste Renoir (1841-1919), with exactly 4,124 paintings executed.

<sup>5</sup> In fact, behind the lens is a manipulator who enables the picture to be taken. This manipulator - the photographer - captures his version of what he sees in front of him through the lens. He then chooses exactly how to make the scene appear to posterity, exploiting all the mechanical resources of the camera as a painter would when handling the brush and colors at his disposal.

<sup>6</sup> Reni was the leading exponent of the Carraccesque school in Bologna and the

first painter in Rome at the end of the Renaissance.

<sup>7</sup> One recent example was in 2023, when a painting attributed to Raphael Sanzio, the Tondo of the Madonna of Brécy, was authenticated by the University of Bradford in the United Kingdom, which showed a 95% match with the original Sistine Madonna, now housed in the Gemäldegalerie Alte Meister in Dresden. In contrast, Art Recognition, an authentication service using AI, based in Zurich, presents a robust 85% probability in the opposite direction.

<sup>8</sup> Preserved today in the Convent of Santo Domingo in Santiago del Estero, Argentina.

<sup>9</sup> Free translation by the author.

<sup>10</sup> Moreover, at a time when the dissection of human bodies was a very risky business and whose authorization, for scientific purposes, Michelangelo had managed to negotiate with the Church.

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### Biographical Notes

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### Summary

This study examines the implications of a discrete presence of the Shroud of Turin in the work of Michelangelo Buonarroti (1475-1564). With the use of a new artificial intelligence model, it was possible to construct evidence that points to a probable link between the greatest sacred artist in history and the greatest of sacred relics. One such piece of evidence reveals a striking similarity (and combination of details) between the face of Christ in a painting made to a design by Michelangelo and the face of the Shroud. The painting examined is by one of his illustrious disciples, Marcello Venusti, while the original drawing is the "Christ at Prayer in the Garden of Olives", preserved in the Uffizi in Florence. The very high correspondence is also confirmed by other versions by Venusti.

### Riassunto

Questo studio esamina le implicazioni di una discreta presenza della Sindone di Torino nell'opera di Michelangelo Buonarroti (1475-1564) e, con l'utilizzo di un nuovo

modello di intelligenza artificiale, è stato possibile costruire evidenze che indicano un probabile legame tra il più grande artista sacro della storia e la più grande delle reliquie sacre. Una di queste evidenze rivela una sorprendente somiglianza (e combinazione di dettagli) tra il volto di Cristo in un dipinto realizzato su disegno di Michelangelo e il volto della Sindone. Il dipinto preso in esame è di un suo illustre discepolo, Marcello Venusti; mentre il disegno originale è il "Cristo in preghiera nell'Orto degli Ulivi", conservato agli Uffizi di Firenze. L'altissima corrispondenza è confermata anche da altre versioni del Venusti.

# HISTORICAL AND CULTURAL FACTS FOR THE STUDY OF THE ARMENIAN-QYPCHAK HERITAGE

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## 1. Introduction

The study of data on the history of Kazakhstan is based on the national idea of the Eternal Country, aimed at collecting, studying, preserving, as well as reproducing and effectively using historical and cultural artifacts. The state program of the Republic of Kazakhstan entitled *Cultural Heritage* provided access to thousands of historical and cultural documents related to the history of the country from foreign archives and scientific institutions. Today, 112 inscriptions in the Armenian-Qypchak language dating from 1521 to 1669 represent a large collection of inscriptions testifying to the high cultural significance of the Armenian-Qypchak written heritage.

The discovery, collection, transcription, publication, translation and definition of Armenian-Qypchak written heritage has been studied by foreign scientists, such as J. Deni, E. Schutz, G. Derfer, J. Klosson, A. E. Krymsky, F. E. Korsh, E. Triyarsky, Ya. Dashkevich, I. Vashari, O. Pritsak, E. Slushkevich, G. Alishan, M. Levitsky, R. Kokhnova, I. A. Abdullin, A. V. Safaryan, as well as by national scientists, such as G. Aidarov, A. N. Garkavets, G. Sapargaliev, S. Kudasov, etc. To study the peculiarities of the heritage languages, systematic statements and so on, scientific research has been carried out by S. Zh. Kudasov, T. I. Grunin, E. V. Sevortyan, J. Clauson, J. Deni, A. N. Garkavets and other scientists. However, it is difficult to say that the Armenian-Qypchak heritage has been fully studied in historical and linguistic terms. Currently, the research requires manuscripts written in Armenian-Qypchak language stored in archives around the world, but mainly in Armenia and Ukraine.

In the Middle Ages, one of the largest Turkic-speaking tribes that owned the vast territory from Central Europe to northern China was the Qypchaks; the territory they occupied is well known in eastern sources as *Desht-i-Qypchak*.

In his work, M. Kashgari states that the Qypchak unity of the 9<sup>th</sup> century included a number of tribes, such as the *Kimek*, *Subar*, *Kangly*, *Karaborykty*, *Toksoba*, *Zhete*, *Borly*. After the collapse of the Turkic Khaganate, the Qypchaks were originally part of the Kimak Khaganate, but separated from it in the 11<sup>th</sup> century. From the 11<sup>th</sup> century, the political union of the Qypchak tribes became a powerful state under the name of *Desht-i-Qypchak*, and the Qypchak language served as the state language. Thus, the

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written heritage of the Qypchak language made a significant contribution to world civilization, culture, and history.

Due to the lack of geographical unity in terms of settlement, the Qypchaks were called differently in different regions (e.g. Golden Horde Qypchaks, Central Asian Qypchaks, Crimean Qypchaks, Cumans, Mamluk Qypchaks, Armenian Qypchaks). Written artifacts of the Qypchak language are classified by domestic scientists into several groups according to content, structure and pictorial character.

## 2. Methods

The main principles and scientific methods developed in modern language education were used for this study. Specifically, the main linguistic methods employed were: semantic analysis, diachronic and synchronic comparative studies, description, systematization, grouping, data processing, differentiation, and concepts collection methods were also used.

## 3. Experiment

G. Aidarov, A. Kuryshzhanov and M. Tomanov recognize Qypchak inscriptions as a heritage of the 11<sup>th</sup>-17<sup>th</sup> centuries and group them into five categories.

- 1) written heritage in the ancient Gothic font (13<sup>th</sup>-14<sup>th</sup>);
- 2) written heritage in Arabic letters (11<sup>th</sup>-14<sup>th</sup>);
- 3) materials in Armenian script (15<sup>th</sup>-16<sup>th</sup>);
- 4) data written in the Russian alphabet (11<sup>th</sup>-13<sup>th</sup>);
- 5) Words preserved in the language of some peoples inhabiting the territory of Eastern Europe and given by their own writing patterns (personal names, place-names, etc.) [1].

In addition, A. Kuryshzhanov classifies Qypchak inscriptions as follows:

- 1) written heritage in the language of the Karakhanid Turks;
- 2) written heritage in the language of the Turks of Central Asia;
- 3) written heritage in the ancient Qypchak language;
- 4) written heritage in the Chagatai language.

Since written documents appeared in certain political and administrative centers and were written in accordance with their requirements, the artifacts can be differentiated by the written language that was used, into the following groups: Kuman Qypchak, Polovtsian Qypchak, Central Asian Qypchak, Golden Horde Qypchak, Mamluk Qypchak, and Armenian colony [2].

Guided by the research of scientists who studied the heritage of the Middle Ages and made valuable remarks, the scholar M. Sabyr divided the heritage into two major groups:

- a) oral artifacts in the Qypchak language;
- b) written artifacts in the Qypchak language [3].

The term «Armenian-Qypchaks», which is frequently exploited by both historians

#### 4. Results and discussion

Armenian-Qypchak issues have been studied by scientists in Kazakhstan over the years, based on the scientific works of A. Garkavets, S. Kudasov, N. Shaimerdinova. Figure 2 showcases a collection of book covers related to Armenian-Qypchak heritage, highlighting texts and research documents that explore this linguistic and historical phenomenon. As a result, Armenian graphic Qypchak texts that are kept in foreign archives have been deciphered and linguistic peculiarities have been revealed. For the Kazakh people, who are considered the direct heirs of the Qypchaks, and for global science, Armenian-Qypchak scripts have yet to be fully explored, because although manuscripts written in Armenian script, have been transcribed, transliterated and translated, they have not been historically and linguistically fully investigated.



Figure 2. Armenian-Qypchak research publications collection.

The main peculiarity of the Armenian-Qypchak written heritage is the use of Armenian script in terms of appearance, while the internal meaning is given by the presence of the Qypchak language. As A. N. Garkavets points out, these inscriptions differ in the designation of consonants from the Western (Old Armenian script) and the Eastern (the current Armenian script) version of the Armenian script. That is, by origin the Armenian-Qypchak language belongs to one of the Qypchak-Polovtsian languages of the Crimean area, and by structural specificity it is closer to the Trakai dialect of the Karaime language, the Quman language, and the Urum dialect of the Qypchak language, on the territory of the Donetsk region of Ukraine, and the mountain dialect of the Crimean Tatar language. For this reason, the language is scientifically labeled as Qypchak. T. I. Grunin comprehensively analyzes the similarity of the Armenian-Qypchak language and the Old Qypchak language. Taking into account that the basis of the modern Armenian literary language was formed on the basis of the eastern version of the Armenian script, it is understandable today that the reading and deciphering of these written worlds has

been delayed and also influenced by this complexity. Determination of the linguistic peculiarities of Armenian-Qypchak script in the Middle Ages allows us to form a model specificity of the Qypchak language.

Medieval written texts in the Armenian-Qypchak language are large in size, diverse in genre, and can be divided into 6 groups based on a thematic system: 1) historical chronicle; 2) legal codes and acts documents; 3) philological works; 4) religious works; 5) artistic works; 6) scientific works of natural sciences.

#### **4.1. Historical chronicles**

Among the important works for Armenian-Qypchak written heritage are the historical chronicles: «Kamenets Chronicle», «Venetian Chronicle» and «Polish Chronicle».

The Kamenets Chronicle was originally compiled by Agop Piradir (1582-April 16/26, 1621), a representative of the clergy, who was a descendent of the Armenian aristocracy of Kamenets and was later edited and supplemented by his brother Aksent der Krikor during 1650-1652. The chronicle describes the events (wars) that took place on the Right Bank and in the west of Ukraine, in Moldavia and Wallachia, the most important of them in Kamenets-Podolsk during the period from 1430 to 1652. The Qypchak section depicts the aggravation of Polish-Turkish relations during the Battle of Caesarea and the Khotyn War. The first Qypchak chronicle is dedicated to the election of the Armenian community in Kamenets in January 1611, and the last chronicle is about the death of Mesrop, Kafka's commander, who died on May 12, 1622, in Zamosc.

The Kamenets chronicle is written in short and extended versions. Currently, the manuscripts are stored in the National Library of Paris in the form of manuscripts No. 194 (short version), which is approximately 80 pages and in the library of the Library of St. Lazarus in Venice in Manuscript No.1700 (extended version), compiled of 169 pages.

Jan Deni published a Latin transcription of the Paris version of the chronicle, translated it into French under the title «L'arméno-coman et les Ephémérides de Kamieniec» and supplemented the edition with a dictionary. In the text of the Chronicle there are records from January 1060 (1611 according to the Gregorian calendar) to November 3 (13) of 1062 (1613) [4]. The version of the Annals of Venice preserved in Venice; Alishan published the full text with Armenian script in 1896 [5]. The Qypchak texts in this manuscript, in particular the part describing the Battle of Tsetsor and the Khotin War were published in 1968 by E. Schutz. He translated them into English and provided a translation with a dictionary, a voluminous foreword and explanations [6].

In 1969, I. Vashari published his work "Armenian-Qypchak Parts" from the Kamenets Chronicle, where he provided an English translation and transliteration for manuscripts by E. Schutz and J. Deni and added indexes and glossaries for proper names and geographical locations [7].

«The Chronicle of Venice» and «Chronicle of the Polish nation» (Chronicle of Poland) are kept in their original handwritten form in the collections of the National Library in Paris, both published by G. Alishan [8].

Fragments from «The Venice Chronicle» were quoted by J. Deni in his work published in 1957. The Chronicle of Poland was carefully studied and reprinted in 1981 by Ya. Dashkevich and E. Triyarsky, based on the publications by G. Alishan [9].

Both chronicles, written in the Armenian alphabet in the Qypchak language, are brief and tell the story from the birth of Jesus to 1537. These two manuscripts have not yet been subjected to a deliberate study. The Qypchak version of the «Kamenets Chronicle» preserved in Venice has been studied by the scientist A. Garkavets on the basis



of the publications by Schutz and J. Vashari. The scholar also provided a Russian translation of the chronicle [10]. Still, the incompleteness of the passages or the lack of a close connection between the events described does not diminish the value of the manuscript. The presented data reveal information about the activities of the Armenian-Qypchak colonies in Kamenets and Lvov and the Armenian-Gregorian Church in Ukraine.

#### **4.2. Legal codes and acts documents**

Most of the Armenian-Qypchak written heritage is represented by documents for conducting judicial and administrative affairs, charters of professional and public organizations, codes of law and acts of religious and civil self-government. Among them, a unique document and an additional source for studying the legal history of the Kazakh people, is the collection of secular laws «Tore Bitigi», which was translated from the Armenian language into Latin in 1519 and approved by the Polish king; it was later translated into the language of the Armenian-Qypchaks of Lviv. This set of laws consists of three parts, including an introduction, secular laws, and an additional article, comprising three chapters. There is a set of rules, including the «Book of the Armenian judge», which contains 124 articles regulating various legal relations related to state power, other rights and legal proceedings, and 99 additional articles to the «Procedural Code» [11].

Currently, 3 versions of «Tore Bitigi» are stored in the archives of different nations, they are the:

- 1) Wroclaw version (1523) - registered in the National Library and named after Ossolinsky in Wroclaw (Poland) under number 1916 / II. The Wroclaw version was first published in 1957 by M. Levitsky and R. Kokhnova published it as «La version turqueiptchak du Code des lois des Arméniens polonais» in the journal «Rocznik Orientalistyczny» [12].
- 2) Lviv version (1568) - registered in the National Library of Paris (France) under number 176 [13].
- 3) Kamenets version (1575) - registered in the Vienna Library of Mkhitarists (Austria) under number 468 [14].

The Qypchak-Polish version of the Armenian Tore Bitigi and the Armenian-Qypchak Judicial Procedure Code were written in Kazakh and Russian in 2003 by the well-known linguist A. N. Garkavets and G. Sapargaliev, a historian, scientist, and academician of the National Academy of Sciences of the Republic of Kazakhstan. The first part of the book presents a translation of the text of the Wroclaw version and its translation into Russian, and the second part displays a comparative analysis of the Paris and Vienna versions of the manuscripts.

Also in Lviv, records in assembly documents, such as birth certificates, religious and court cases, in addition to Armenian-Qypchak, were conducted in Polish, Latin, Italian, and Ukrainian. In Kamenets-Podolsk, court cases were mostly conducted in the Qypchak language, so the last document registered on March 20, 1663 (the Central State Historical Archive of Ukraine in Kiev, f.39, op. 1, unit. 42, l. 266) was known as the will of Simon Harakhash's wife Zosi. The letter is dated approximately December 8/18, 1118/1669 (Bibliography of the Academy of Sciences in Lviv, F. Bavorovskikh, manuscript 1660 III, ll. 6-9). The manuscripts written earlier include documents written in the Lviv Church and are registered in the Mkhitaryan Library in Vienna as a manuscript, under the number 440.

Among the unique documents stored in the collections of libraries and Archives in Lviv (Lviv city, state archive of Ukraine), are the letter of Catholicos (ecclesiastic title) Melkhisedek, written in Yazlovets on February 15, 1627, and the letter of the vardapet (archimandrite) Jovganes, governor of the Catholicos Filippos, in Tokhat on August 6, 1957. They are important because these documents reveal the specificity of the Qypchak language. The two manuscripts were translated and published by Ya. Dashkevich and E. Slushkevich in Latin and Polish [15].

In the Lviv State Library of Ukraine, two debt obligation documents written in the Armenian-Qypchak language from Edirne (1609) and Lviv (1615) were also found, one of which turned out to be a debt obligation from the Lviv Armenian merchant Stetska Oganovich. This debt obligation was translated into the Armenian-Qypchak language in Edirne in 1609 for Joseph, the son of Abraham from Constantinople. It was translated into Polish in 1620, and on September 15 of the same year, along with the original text, it was transferred to the Lviv Armenian-Polish judicial institution. The second is a debt obligation in the Armenian-Qypchak language made in Lviv on April 24, 1615, for the Armenian merchant Shimka Kevorovich, as well as for the Armenian merchant Andrey Torosovich. In 1618, the script and debt obligation were translated into Polish, and on May 28, 1618, along with the original document it was delivered to the Lviv Armenian-Polish judicial institution. Both of these manuscripts, together with translations into Polish and Russian, were published by Ya. Dashkevich and E. Triyarsky [16].

Currently, 40 books of acts published in the Armenian-Qypchak language have been identified by scientists, and the total volume of these legal documents with Armenian-Qypchak records exceeds eighteen thousand (18,000) pages. The three manuscripts which have been lost, and can only be determined by the fragments published by scientists are as follows:

- T. I. Grunin in 1967 published 298 entries of the oldest book of acts of the Armenian judicial institution in Kamenets-Podolsk (1559-1567) No. 4386, stored in the central archive of Kiev ancient manuscripts. The four texts of the same manuscript were published by I. Abdullin in 1976 on the basis of a handwritten copy by H. I. Kuchuk-loannesova and F. E. Korsh [17].
- Two entries of the book of acts dated 1585 were published by M. Brzhshkyants in 1830 on the basis of a document stored in the archive in the form of a manuscript, No. 4395. He also published an excerpt from The Book of the Lviv Armenian religious court in the Armenian-Qypchak language, which dates back to 1521.

The remaining 37 books of acts written in the Armenian-Qypchak language are kept in the archives of Kiev, Vienna, Venice, and Poland, and are namely:

- In inventory 1 of the 39 funds of the Central State Historical Archive of Ukraine, 28 books of the Armenian-Qypchak court of Kamenets-Podolsk for 1572-1663 (consisting of more than eight thousand pages).
- In the Vienna Armenian Library of the Mkhitaryan Congregation, the metrical records of the Lviv Church No. 440 for the period from 1636 to 1736 (120 pages), two books of the Lviv Armenian-Qypchak legal Proceedings No. 444, the Second Epistle of the Apostle Paul No. 446, the Cash Book of the Lviv Armenian-Qypchak Legal Proceedings No. 452, the cash book of the Lviv Armenian-Qypchak judicial proceedings under No. 441, No. 447 Lviv registers of the Armenian religious Court, written in 1572-1630, 1643-1667. E. Tryarsky published the manuscript under the number No. 446, the Second Epistle of the

Apostle Paul in 1976 [18]. And in 1971, E. Schutz published the registers of the Armenian religious court of Lviv, preserved as a manuscript under the numbers 441, 447 [19].

- In the library of the Armenian Mkhitarist Congress in Venice, The Book of acts of the Armenian religious court of Lviv (179 pages), which covers the period from 1630 to 1642, is kept as a manuscript under No. 1788.

There are also two works kept in the personal collection of the descendants of M. Levitsky (1906-1992); Levitsky had been engaged in the study and collection of Oriental, Armenian-Qypchak written heritage, microfilms and photocopies for many years: 1) The Book of acts of the Lviv Armenian judicial institution, covering the years 1625-1630, consisting of 48 pages (the series of manuscripts is in the library archive in the Armenian Mkhitarists Congress in Vienna); 2) the Archbishop's book of Birth Records.

### **4.3. Philological works**

Among the philological studies of Armenian-Qypchak written heritage there are two auxiliary textbooks (grammar textbooks) in the Qypchak language with Armenian graphics, five Qypchak translation dictionaries and one Psalter. The grammar textbooks were written in Lviv within the period 1581-1613 and are currently available at the Matenadaran Institute of manuscripts (Yerevan/Armenia) and in the libraries of Vienna and St. Petersburg, namely: a manuscript of 366 pages, numbered 51 in the Manuscripts Department of the Lviv University library; a 280-page manuscript, numbered 8 in the M. E. Saltykov-Shchedrin State Library in St. Petersburg; and a 106 page manuscript in the Vienna National Library, numbered 3. Also, two manuscripts of 178 and 301 pages, correspondingly numbered 84 and 311 are kept in the library of the Armenian Mkhitarists of Vienna.

In 1968-1972 in Warsaw E. Triyarsky developed the Qypchak-Polish-French dictionary, based on three versions of the Armenian-Qypchak translation dictionary in Vienna, by listing words in the Qypchak language and comparatively providing their meanings in Polish and French. The dictionary was distinguished by an extensive introduction and included a facsimile of some pages of the five manuscripts at the end of the dictionary [20]. Later, the lexicographical work of E. Tryarsky became the basis for G. Derfer, K. Menges, and J. Clauson's etymological research.

Nowadays, eight manuscripts are kept at the Matenadaran Institute of Manuscripts in Yerevan, Republic of Armenia [21]. None of these works have been the subject of comprehensive study to date.

Knowledge of ancient Armenian scripts, Western versions of Armenian graphics, Armenian dialects, as well as knowledge of Turkic languages, including Qypchak-Oguz is required to read these manuscripts.

Among the manuscripts, one sample under No. 3522 (354 pages), entitled "The Grammar of the Qypchak Language" is of particular value, and covers 226-353 pages; the author is listed as Avetik. The manuscript is mainly religious, but much attention is paid to everyday topics, such as nature, animal husbandry, agriculture, astronomy and geometric dimensions, with terms related to these topics. Classification of the parts of speech is presented in Armenian and Qypchak, i.e. the manuscript is bilingual, sometimes with text insertions given in three languages (Armenian, Qypchak and Polish).

«The Grammar of the Qypchak Language» provides the description for case forms of nouns (singular, plural), word-formation (presented in appendices), and synonyms and homonyms. To reveal the internal grammatical patterns in the Qypchak language,

a clear description of the surroundings is delivered with the help of nouns, adjectives and numerals, pronouns and verbs [22]. These manuscripts allow us to reconstruct the features, as well phonetic, grammatical, and morphological models of the Qypchak language. It is an extremely valuable document which provides information about the vocabulary of the Qypchak language at that time.

#### **4.4. Religious Works**

A number of religious works written in the Qypchak language with Armenian graphics are now stored in the libraries and archives of Europe. They include the Psalter, the collection of the Apostle Paul, prayer books, and the collections of the sermons of the theologian Anton, which are all worth considering. In addition, there is one Easter calendar and an 18-year calendar, as well as a list of 12-year animal calendars in Armenian and ancient Turkic languages found among the works in this category. The first translation of the Psalter was done in Lviv in 1575. According to A. N. Garkavets the issue was translated by the Lviv Deacon Lustig [10]. The versions of the Psalter work written in Qypchak are registered and stored in the following locations:

1. The Czartoryski Museum in Krakow (Poland) with number 3646 (Cracow version).
2. The Vienna National Library (Austria) under number 13 (Vienna version).

The Armenian-Qypchak dictionary developed for Lusig's Psalter book is kept at the Matenedaran Institute of manuscripts in Yerevan under No. 2267. In addition, there are three existing records of the Psalter preserved in Paris, Venice, and St. Petersburg. Two versions of this work (Krakow and Vienna) and the Armenian-Qypchak dictionary for it were published by A. N. Garkavets and E. Khurshudyan [23]. One of the religious manuscripts written in Armenian script in the Qypchak language is the prayer book «Algysh Bitigi» written in 1618 in Lviv. This work is recognized as the first published manuscript in Turkish in the world, the only version of the manuscript is stored in the library of the University of Leiden in the Netherlands. The work was first published by E. Schutz in 1961 [24]. Among the religious manuscripts in St. Petersburg are the Manuscripts, «Zhitii svyatyh» and «Haismavurke», written in Qypchak in ancient Armenian script. They are stored in the State Library named after M. E. Saltykov-Shchedrin. These manuscripts were published by I. A. Abdullin in 1971 [25].

#### **4.5. Artistic works**

Among the artistic works discovered so far, written in Armenian script in the Qypchak language and which have become the subject of study, is the work «The Word of Dana Hikar», written in the artistic and didactic genre. The manuscript is currently kept in the library of the Armenian Congress of Mkhitarists in Vienna under No. 468. For the first time a publication related to this manuscript was released by J. Deni and E. Triyarsky [26]. It is assumed that the work originally appeared in Assyria, Babylonia, as the manuscript mentions the land of Assyria, the city of Nineveh, as well as the names of the kings, Sinaherib and Assarhadon. There is also additional evidence given by the papyrus fragment in Aramaic from the fifth century, which was discovered and is now kept in Berlin. The description of the life of Ahikar, the wise and resourceful adviser of the king, Sinaherib and his commandments to his adopted son was collected, although incomplete, and then disseminated in Arabic, Armenian, Greek, Russian, Persian,

Romanian and many other languages. One of them reached the Qypchaks who lived near Lviv, and it was translated into the Qypchak language in Armenian script.

The Kazakh scientist S. Kudasov published the work «Qypchak heritage with Armenian inscriptions» «The language of the words of Wise Hikar» in 1990. Moreover, he transcribed and translated the manuscript into modern Kazakh for the first time and analyzed the phonetic, lexical and morphological system of the text. The variant written in the Qypchak language with the Armenian script was slightly shortened, and only the commandments have survived till nowadays. They contain miscellaneous issues related to world existence, human qualities, and justice, and good and evil are skillfully depicted by literary and expressive means as brief descriptions, reflections, comparisons, epithets, exaggerations, proverbs and sayings. In «The language of the words of Wise Hikar» for example, there are many instructive or propaganda commandments: e.g. «*What is sweet in the world? Hikar answered: Shame on the face. Whoever has shame on his or her face is charming, because every evil act is born of dishonesty*»; «*Be afraid of shame as you afraid of the Lord*»; «*Keep your tongue away from bad words*», «*If you see your fallen enemy, do not laugh and humiliate him, as soon as he recovers, he will take revenge on you*»; «*When you give alms, do not humiliate a beggar, as the Lord will not reward you*» [27].

#### 4.6. Natural Science works

One of the most valuable manuscripts of Armenian-Qypchak origin, which belongs to the category of natural sciences, is the work by Andrey Torosovich of Lviv entitled *Secrets of the Stone of Philosophy*, written in 1626-1631. The work is considered valuable, as Andrey Torosovich wrote a number of comments on the work in the Armenian-Qypchak language. This manuscript is currently stored in the State Archives of Ukraine in Kyiv under the number No. 250. Some excerpts from the works of Socrates, Aristotle, Avicenna, Democritus, Plato and other philosophers are given in the Polish version of the work and the experience of scientists in alchemy, such as Hermes Trismegist, Skyd Geber, Arnaldo de Villanov, and Albert is described extensively. Andrei Torosovich wrote a number of explanations to the work in the Armenian-Qypchak language, and for this reason it is considered valuable. In the Qypchak version of the manuscript, individual analysis and experiments on gardening are widely discussed, as well as an irreplaceable scheme of herbal medicines; for example, the recipe for ointments for headaches is presented as follows: «*Baş ahriḫina hakimlik: al 2 lot temyan, 2 lot mira, 2 lot burč, 2 lot šalviya, 4 lot sīrkā, 4 lot oliva. Bu barčanī ezip igi sīrkā bilā olivaga qatīštirma da biširmā igi, ki mast kibik bolgay. Soḡra čöprāk üsnā kendin silama da anīḡ bilā basin čürgāmā kečār ahrīma baš*». In the Qypchak version of the manuscript, there is a wide range of personal analyses and experimental descriptions on gardening, and unique formulae of herbal medicines, such as a prescription for ointment compresses for headaches. The manuscript is considered to be priceless as it contains many scientists' experiments on chemistry, fruit cultivation, hybridization (selection), as well as excerpts and notes from works by outstanding scholars of the fifth to tenth centuries and the Middle Ages (10<sup>th</sup>-16<sup>th</sup> centuries) [10].

#### 5. Conclusions

This article was prepared within the framework of the project AP13068438 «The universal and the special in the language of the Armenian-Qypchak monuments», and paves the way for further historical and comparative research in the field of Qypchak

studies. Armenian-Qypchak issues are studied by scientists of the L. N. Gumilyov Eurasian National University.



Figure 3. L.N. Gumilyov Eurasian National University.

As can be seen, the genre diversity of the Armenian-Qypchak written heritage is to be considered as a masterpiece of the Middle Ages. Today, Armenian-Qypchak manuscripts, stored in archives around the world, are of great cultural value, since they are written in various genres, and cover extremely diverse topics, such as history, jurisdiction, religion, as well as philology and fiction, and natural sciences [28].

Kazakh scientists also make a great contribution to the collection and publication of the Qypchak written heritage with Armenian graphics, as well as to the translation and study of the peculiarities of the language of this particular heritage. The work of G. Aydarov «The language of the Qypchak heritage with Armenian writing» contains information about the Armenian alphabet and phonetics, vocabulary, grammar, and syntax.

A. N. Garkavets collected, transcribed and published the written heritage in the Armenian-Qypchak language, which is scattered in libraries and various archives of the world. Also, in the work «Qypchak languages: Cuman and Armenian-Qypchak» on the basis of the «Codex Cumanicus» A. N. Garkavets tried to identify the linguistic features of the Qypchak language and the phonetic features of the Armenian-Qypchak language, as well as the use of nouns and verbs; and in his second work «Convergence of the Armenian-Qypchak language to Slavic in the 16<sup>th</sup>-17<sup>th</sup> centuries», he devoted the first chapter to morphology, and the second chapter to syntax, comparing them with Slavic languages [29].

Taking into account the relevance of the Armenian-Qypchak written heritage, Kazakh scientists are pleased that scientists from both countries are making efforts to jointly study the historical heritage stored at the Institute of Manuscripts Matenadaran in Yerevan, Republic of Armenia. A. V. Safaryan and A. Sargsyan were the first to study in detail the Qypchak written heritage in Armenian graphics from a philological point of view [21]. This, in turn, will serve to strengthen Kazakh-Armenian cultural ties and expand cooperation.

The historian, and scholar G. Sapargaliev, translated «The Qypchak-Polish version of the Armenian judicial act and the Armenian-Qypchak procedural code». S. Kudasov

through his work «The language of the words of Wise Hikar» examined the specifics of the Qypchak language. N. G. Shaimerdinova conducted a lexical and semantic analysis of the Armenian-Qypchak manuscript «Tore Bitigi» through the scientific monograph "Qypchaks: history and language" (based on Armenian-Qypchak monuments) [30].

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## Summary

At the current time, turning to historical facts is a matter of great significance for the public life of Kazakhstan. It is known that in the Middle Ages the rich heritage of the Qypchaks, who had founded the Desht-i-Qypchak state in Eurasia and contributed to world civilization and culture, was written in different alphabets at certain periods of history. Historical documents, written in Armenian graphics in Qypchak, are based on knowledge of religion, literature, history, law, philosophy, natural sciences and talk about the political, economic, historical and cultural spheres of the life of the ancient state. Since the 20th century, the Armenian-Qypchak heritage, has been the subject of in-depth study by scientists, and, published in foreign academic editions, transcribed, supplemented by dictionaries and translations, its secrets are being revealed day by day. The term «Armenian-Qypchak» was introduced by scientists, and the life and cultural ties of the medieval Qypchaks and Armenians became the basis for their research. Today there is a need for more detailed study of the linguistic features through comparative analysis of the Armenian-Qypchak heritage set out in different genre texts.

## Riassunto

Al momento, il riferimento ai fatti storici è una questione di grande importanza per la vita pubblica del Kazakistan. È noto che nel Medioevo la ricca eredità dei Qypchak, che avevano fondato lo stato Desht-i-Qypchak in Eurasia e contribuito alla civiltà e alla cultura mondiale, era scritta in diversi alfabeti in determinati periodi storici. I documenti storici, scritti in grafica armena in Qypchak, si basano sulla conoscenza di religione, letteratura, storia, diritto, filosofia, scienze naturali e raccontano le sfere politiche, economiche, storiche e culturali della vita dell'antico stato. L'eredità armeno-Qypchak, dal XX secolo, è stata oggetto di studio approfondito da parte di scienziati, pubblicata in edizioni accademiche straniere, trascritta, integrata da dizionari e traduzioni, i suoi segreti vengono svelati giorno dopo giorno. Il termine «Qypchak armeno» è stato introdotto dagli scienziati e la vita e i legami culturali dei Qypchak medievali e degli armeni sono diventati la base per la loro ricerca. Oggi è necessario uno studio più dettagliato delle caratteristiche linguistiche attraverso l'analisi comparativa del patrimonio armeno-Qypchak, esposto in testi di genere diverso.



# PROTECTING AND REDEVELOPING INDUSTRIAL ARCHAEOLOGICAL HERITAGE THROUGH DESIGN STRATEGIES DRIVEN BY DIGITAL MODELLING

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*Keywords:* regeneration, heritage, landscape, BIM, retrofit

## **1. Introduction: contextualizing territorial constraints and industrial archaeology**

The Municipality of Tivoli, owner of the building, has promoted a design competition with the idea of turning what is now an industrial ruin of considerable negative perceptual-functional impact for the city into an important and strategic opportunity for urban transformation. The former Amicucci-Parmegiani paper mill represents a dross space, an urban void, so defined not just because of its dilapidated, neglected and deteriorated condition, but because it has lost its original functional vitality within the context, its meaning within the city fabric, consequently becoming a typical greyfield.

The objective of renewing the area occupied by the building is to revamp a process of urban regeneration through the improvement of aspects such as the architectural perception of the context, especially through the redesigning of the downstream elevation, increasing its attractiveness for the city centre, its mobility, the environment and integration with the surrounding landscape, improving social and economic relations, infrastructures and interaction by creating new common spaces that connect with the urban fabric. The area is characterised by a notable landscape, given its location close to the historical centre (Figure 1) and important landmarks such as the Duomo to the south and the valley formed by the course of the Aniene river, the waterfalls, the church of S.M. di Quintiliolo on the opposite slope to the north, and the Sanctuary of Hercules Vincitor. Historically, before the settlement of industrial activities, the area was characterised by a visual and direct connection between the building fabric and relevant naturalistic landscape with the presence of cultivated terraces, in particular, used for the production of the typical Pizzutello Tiburtino<sup>1</sup>. In our collective imagination, the city of Tivoli is strongly linked to the presence of important historical sites, such as Villa Adriana and Villa D'Este. Tivoli, however, has an industrial soul. From the beginning of the 20th century, thanks to the special exploitation of the waters of the Aniene and through a system of underground canals, numerous mills of different kinds, including paper, of course and other factories, flourished. Thanks to this natural local feature and industrial development, it was here that the development and use of hydroelectric energy was

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born and it was Tivoli itself that was the first town to benefit from electric light produced by hydraulic motors in 1886 [1].



Figure 1. a) City plan of Tivoli showing position of the paper mill (highlighted in red); b) the building in its urban context (perimeter highlighted in red).

The area on which the industrial plants and artisan workshops were located was close to the medieval part of the town, in the area known as 'del Colle' (Figure 2), adjacent to and, on some occasions, integrated into the fabric of the historic centre.



Figure 2. Panorama of Tivoli on the outskirts of Rome with the Roman countryside. On the right, the area known as 'del Colle', Brogi 1900-1910 ca (Source: Archivi Alinari, Florence).

The relationship between the buildings used for production activities, the city and the residences of the occupants in the sector, was quite peculiar in Tivoli: alongside the

industrial development there were no workers' districts, despite the fact that in 1941 there were more than 7,000 workers<sup>2</sup>. This immediately highlights how the phenomenon of urbanisation, typical of the Industrial Revolution period, which caused 'the evils' of many cities, did not occur here.

The reasons for this positive development are linked, on the one hand, to a gradual process of growth over time, in which the search for spaces and functions took place within old buildings and, in some cases, also through the reuse of pre-existing archaeological sites; secondly, it was the historic centre itself that represented the residential district of reference, thus generating a balance between home and workplace, between living and working. However, since the paper mills and other industrial plants have closed, there has been a slow emigration of inhabitants from the medieval district.

In the old industrial area of Tivoli, therefore, important remains of the classical age coexist with paper mills, factories and related infrastructure such as, in particular, the canals. These heterogeneous elements, layering one on top of the other, make it difficult to recognise the historical character of each individual part. The case of the former area of the Segrè paper mill is exemplary [2], embracing a time span of more than 2000 years: from the Sanctuary of Hercules the Victor to the 15th-century convent, the powder warehouse and the 18th-19<sup>th</sup>-century ironworks, up to the transformation realized until the mid-20th century.

## **2. Origins, development, and abandonment: The industrial system along the Aniene Valley**

Generally speaking, during the process of industrialization that characterised the economic and productive evolution of the pre-unification of Italy, paper production played a leading role [3]. Between the 15th and 16th centuries, there was already evidence of ancient paper mills throughout the region, such as those in Grottaferrata, Sant'Elia Fiumerapido, Carnello, Tivoli and Subiaco, the first three of which were, not surprisingly, abbey paper mills. In the same places, factories were set up which, in some cases, would see production activities consolidate and expand over time until the establishment of flourishing industrial basins.

Finally, the 1820s saw the industrialisation of production in the Terra di Lavoro in the Kingdom of Naples, today's Lower Lazio region, based on a long artisan and proto-industrial tradition and in exceptional synchrony with similar experiences in France and England, which in a short time transformed production into a continuous mechanical process [4]. However, the paper mills mentioned above, although in very close proximity to each other, do not belong to historically homogeneous areas. We will focus, for the purposes of this project, on those of Tivoli. Presenting an overall picture of the Tiburtine paper mills is not easy, as they are numerous and mentioned in various sources with references that are not always in agreement.

The paper mills initially drew impetus and benefited from the network of pipelines that had already been dug under the city in Roman times, as well as from the waterfall of the Aniene, also known in the past as the Teverone. From the 16th century onwards, this network became more complex and vast, heralding the remarkable hydraulic constructions of the 19th century and the exploitation of energy production of the 20<sup>th</sup> century. This was the era of mechanized paper making: the hydraulically operated pestle mallet was introduced by the masters of Fabriano and was associated with the pulp pile [5]. There are many testimonies attesting to the production of paper in Tivoli as early as the 15th century, and which also report some proprietary events linked to the presence of many piles. It is still possible, on the side of Tivoli that looks towards Via del Colle, to

recognise environments and signs of this proliferation of activity. This settlement, located within the urban fabric of the city, was a crucial place of craft activities that characterised one of the most flourishing productions of the time. The description by Tommaso Neri (*De Tyburtini aeris Salubritate Commentarius* of 1622) with the accompanying plan, later taken up by Stoopendaal many decades later, emphasizes precisely this aspect of the city. We would say today a 'city of water' in which a dense web of canals is interwoven with the bends and twists in the road network and the fabric of the residential and artisan buildings (Figure 3).



Figure 3. Peter Vander Aa (dis.) D. Stoopendaal (Inc.) *Civitatis Tyburis Delineatio*, 1721-1750, from the plan by Tommaso Neri, 1622.

The second most widespread innovation in pre-industrial production is the 'stack' or Hollander beater (1670), or 'stack with cylinder'. It replaced the use of pestles to prepare the paper pulp. Although it was invented in the 17th century, it only became more widespread, in Italy in general and in Tivoli in particular, in the 19th century. The 'Dutchman' consists of an oval stone or masonry basin divided into two parts by a median septum, so as to form two communicating channels. One of the two channels is wider and is called a working channel. There was a wooden cylinder, later made of metal, fitted with blades. The bottom of the sloping channel was also equipped with blades held together by screws and separated by wooden rods and was called 'platten'. The Hollander beater became a success also because of its versatility because with the appropriate modifications it could be used for various purposes. However, it is undeniable that Roman and Tiburtine paper mills at the beginning of the 19th century were technologically behind and mainly specialised in cardboard, wrapping paper and other types of paper rather than in the production of printing paper. Later, in paper mills with long histories,

such as Ranzi<sup>3</sup>, there are special areas defined over a long period of time for grinding wheels, kettles and Dutch stacks. In 1883, the Ranzi paper mill had 10 Dutch cylinders and the production system was organised for the manufacture of different types of paper, cardboard and wrapping paper. Rolls were used to defibrate and pound straw. From the end of the 19th century, and with the impetus of hydroelectric power generation, industrial production took off.

### 3. The collapse: implications and consequences

The area of study is located<sup>4</sup> on the edge of a subsiding basin at the foot of the first Apennine reliefs of Latium, in a zone where the proximity of the volcanic complex of the Alban Hills (Colli Albani in Italian) has favoured the development of hydrothermal upwelling events which have contributed to the formation of travertine deposits. The historic centre of Tivoli stands on a travertinoid formation resting on fluvio-lacustrine sequences, volcanic products and Pleistocene Pliocene marine soils, in turn resting on Meso-Cenozoic terms that form outcrops on the outline of the area. Sheet 375 [6] of Tivoli of the New Geological Map of Italy (CARG project, scale 1:50,000) indicates the travertine deposits (TBT<sub>b</sub><sup>5</sup>), outcroppings in the area of the former paper mill, whose structures rest on very porous, stratified and fractured travertine deposits, generally cemented and only locally altered in the form of travertinoid sandstone. Morphologically, the former paper mill is located on a sub-flat area on the edge of a slope that connects the summit elevations of approximately 200 m a.s.l. with the valley floor elevations of approximately 70 m a.s.l. The slope has a very high gradient, generally between 80° and 90°, and consists of two sub-vertical slopes interrupted in the middle by a terrace of a few metres wide, on which the roadway of 'Via degli Stabilimenti', currently partly in disuse, is located. On 9 April 2009, a portion of the former paper mill was involved in a massive collapse, immediately falling down onto 'Via degli Stabilimenti' that runs through a tunnel (Figure 4).



Figure 4. Present day situation (2020): result of the massive collapse of 2009 on a section of road, "Via degli Stabilimenti", that runs through a tunnel (Source: Municipality of Tivoli).

The collapse was probably induced by the sequence of aftershocks of the L'Aquila earthquake. In particular, one event occurred at 00:52:59 with a peak acceleration registered at Poggio Cancelli of approximately 0.3g [7]. It is not easy to determine the sequence of the collapse precisely, consequently what is visible in Figure 4 could have been induced either by a first collapse of the structural element which successively involved the soil foundation or viceversa. At present, the slope is affected by at least two escarpments listed among the active landslide escarpments by the hydrogeological management plan chart of the Central Apennine basins (formerly the Tiber basin).

Examination of the available data reveals a generally critical situation with regard to the stability of the slopes on the edge of the former paper mill structures. The proposed project was set up with a view to mitigating and alleviating the unstable conditions of the slopes as much as possible by providing escarpments for:

- The removal of some sections of the former paper mill structures which will lead to a reduction in the weight bearing on the top of the wall;
- Sub-founding and consolidation work at the portion of the car park that is to be built in correspondence with the sector of the slope affected by the 2009 collapse;
- Slope cleaning operations with the removal of any unstable blocks so as to guarantee the possibility of carrying out the geostructural surveys that are indispensable for the definition of the slope safety project.

With regard to the demolition of part of the structures of the former paper mill and given the considerations on the static condition of the building (Figure 5) the following aspects were assessed in order to optimise demolition.



Figure 5. Image from the outer courtyard of the paper mill, taken at elevation relative to the direct connection with the city of Tivoli (208 meters a.s.l.), towards the opposite slope, where the complex of the Sanctuary of Maria SS. del Quintiliolo stands (Source: Carlo Vannini).



- Reconnect with the historic centre, obtain an extension of Piazza Tani and recover full enjoyment of the admirable and evocative sights (Figure 6);
- Highlight historical and cultural aspects of relevance related to industrial archaeology (Figure7), such as the processing chain of the former paper mill;
- Enhance the relationship with the landscape, which is of great scenic value due to the view of the valley below and the opening to the countryside (Figure 8).



Figure 6. Image from the outer courtyard of the paper mill, taken at elevation relative to the direct connection with the city of Tivoli (208 meters a.s.l.), towards the bell tower on Domenico Tani square (Source: Carlo Vannini).



Figure 7. Image taken at elevation of the boilers area (204 meters a.s.l.) (Source: Carlo Vannini).



Figure 8. Image taken on the floor at 199 meters asl: that is the view from the facade facing the Aniene valley, towards the complex of the Sanctuary of Maria SS. Del Quintiliolo, on the right (Source: Carlo Vannini).

#### 4. Tools for understanding and valorizing industrial heritage

Technical advances in architectural and structural surveying provide valuable tools to optimise time and reduce errors and approximations, typical of traditional methods. These tools allow professionals to achieve a high degree of knowledge of the object that is to be studied and represented and on which they will subsequently have to intervene [8].

Today, technology has gone beyond the typical aerophotogrammetric survey from which modern cartography was born by polishing orthophotos. Systems have advanced from a two-dimensional to a three-dimensional reading. First, through the superposition of orthophotos with DTMs (Digital Terrain Models) and later, at the beginning of this century, laser survey systems were introduced, LIDAR (Laser Imaging Detection and Ranging), positioned on planes and helicopters and nowadays positioned also on drones.

The most significant development concerns software that uses photogrammetry to reconstruct three-dimensional meshes. Laser-scanning equipment, which was previously very large and expensive, has become increasingly compact and accessible over time and, as a result, its use is widespread.

At the same time, there is a tendency to limit new construction and enhance the existing heritage. With this in mind, technological advances in automatic surveying and diagnostic instrumentation make it possible to operate with greater knowledge and thus to produce higher quality interventions on the built environment. The data collected by laser and photographic equipment is transformed into a point cloud (Figure 9): that is,

a set of data points in a three-dimensional space, each characterised by spatial coordinates (x, y, z) indicating its position in space and any relevant values, such as colour intensity or depth [9]. These new points are models made up of images, which, once imported into three-dimensional modelling or BIM programmes, can be polished in a more or less automated manner depending on the type of software being used. Designers thus find themselves being able to work on high-definition models that, together with a direct knowledge of the building object, allow them to be aware of all the geometric, qualitative and material information that form the basis of a recovery operation. From this photogrammetric model, by means of parametric modelling in the BIM sphere, it is possible to create a digital reproduction which is completely superimposable on reality. The parametric model developed in BIM starting from the polishing of the new point cloud, is a complex process that consists of sectioning the point cloud at different heights, which is indispensable for organising the digital work environment, setting the reference planes and then polishing the building texture in plan and elevation. The digital model was elaborated from the point cloud obtained in the survey campaign carried out by laser scanner, which provided dimensional and qualitative information that also helped describe the state of material degradation.



Figure 9. Final point cloud of the paper mill (Source: Antonio Landa).

Other equipment such as thermal imaging cameras and carpenter's hammers allow us to learn about the type of masonry, the crack pattern, the presence of hidden structures; they can also aid in identifying thermal anomalies and moisture content in the masonry which can be related to variations in mass [10,11]. Structural testing campaigns carried out by means of common techniques such as cores, jacks and extractions are still indispensable for working on load-bearing structures and they can be eventually enriched by other non-invasive technologies such as gamma tomography, x-rays and neutronic analysis. Taken together, these operations make it possible to obtain, by combining all the data collected, bimodal, parameterised digital models containing all the information, from geographical to spatial, structural, plant, material and qualitative. The complexity of the models thus created condenses all the information within a single digital object that becomes a twin of the real one [12]. Thus, the integral approach to design has consisted in the continuous interchange of data between architects, structural engineers and plant engineers. From these models developed in BIM with different software it is possible to extrapolate interchangeable copies in different

formats, which can be read by different specialised programmes to make calculations on structures, plants and, clearly, for architectural design. Thus, the work is organised through a continuous flow of interchange. This is segmented into the different specialised areas and then reconnected within a 'mother' file that encapsulates all the information. The interoperability between BIM models and FEM models (Figure 10a) have permitted the structural design project to be developed step-by-step with the evolution of architectural projects and optimizing economic resources to obtain better safety enhancement for both static and dynamic loads provoked by the expected earthquake for the area. Comparing the structural models, it appears clear that in the post-operam configuration the main building loses the top floor (Figure 10b).

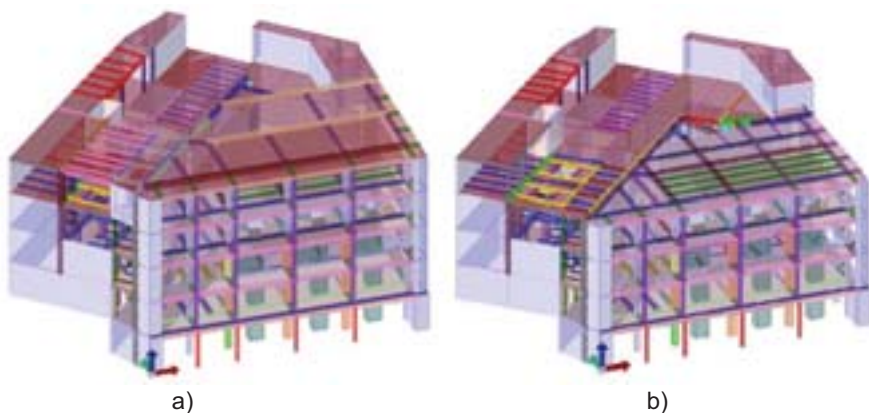


Figure 10. Structural Finite Element Model: a) ante-operam; b) post-operam (Source: Vincenzo Gattulli).

Systems are being developed, also through the use of artificial intelligence, that allow parametric modelling to be automated from new point clouds, but there is still a long way to go. The data must still undergo a critical reading and have direct knowledge of the objects to be digitally reproduced. Perhaps over time the work will be greatly simplified, but eliminating human contribution won't happen soon, as it is an essential part in the interpretation of the data and the coordination of the interferences generated in such complex and heterogeneous workflows.

The experience of the redevelopment project and adaptive reuse of the former Amicucci Parmegiani paper mill in Tivoli as a museum, is an example of this process.

Specifically, the laser scanner survey campaign, conducted on 20 March 2023, was carried out with Leica's 'Cyclone REGISTER 360 (BLK Edition)' equipment.

The quality of the recording can be summarized through the following parameters:

- Set Up count: 103;
- Link count :140;
- Robustness 74%;
- Overlap 43%.

The polishing of the point cloud and the creation of the Bim model was mainly developed through Autodesk's Revit platform.

## 5. Collaboration with the supervisory authority: Towards transformation

The building in question is a portion of the former paper mill complex, overlooking the valley through which the Aniene River flows. It has been decommissioned and is in a completely empty and dilapidated state. It has a main entrance on the north side of Piazza Tani and one from 'Via degli Stabilimenti'. The factory, consisting of five levels, has a maximum height of 30 meters on the north elevation and a linear development of about 160 meters. The surface area of the interior spaces of the current building is approximately 20,000 square meters, giving a total volume of approximately 92,000 cubic meters; there are also a series of external spaces, adjacent and functionally connected to the Paper Mill: the total area of the latter, included within the perimeter of the Amicucci-Parmegiani complex, is approximately 2,400 square meters. The calculated surface area includes the central portion of the building that has been in a state of collapse since 2009. As a result of the collapse, which also involved the underlying gallery and 'Via degli Stabilimenti', the area was at risk, thus interventions were required to secure the slope affected by the collapse.

The choices made in the final design confirm and deepen the criteria and strategies made during the preliminary elaboration phase by the Municipality of Tivoli. Given that the building is a listed one, during meetings with the municipal administration's technicians and at the meeting with the 'Soprintendenza Archeologia, Belle Arti e Paesaggio per l'area metropolitana di Roma, la Provincia di Viterbo e l'Etruria meridionale', the general objectives of the project proposal were illustrated for the redevelopment and valorisation of the building block of the former Amicucci Parmegiani Paper Mill. Through the meetings with the technicians of the office deputed to the protection and valorization of the listed building complex, the main design concept was defined and shared, adopting the following guidelines.

- The mandatory guidelines of transformation and protection indicated in the historical-artistic report attached to the Decree<sup>6</sup> of constraint of historical-artistic interest pursuant to Article 12 paragraph 2 of Legislative Decree 42/2004 applied to the building complex (Figure 11);

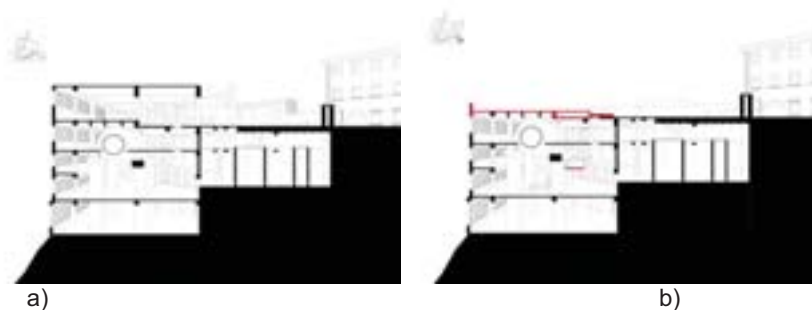


Figure 11. Perspective sections from the BIM software: a) ante-operam, b) post-operam. (Source: Antonio Landa and Carlo Vannini).

- The general criteria set forth in the design guidelines document<sup>7</sup> of the Design Competition for the construction of the auditorium and car park in the area of

the former Amicucci Parmegiani paper mill and the principles of the general proposal of the winning project.

The general objectives of the design competition, beyond the programme of uses and the definition of the perimeter of the areas to be demolished with respect to the portions to be conserved, paid particular attention to the relationship (Figure 12) of the complex with the landscape, in relation to the view from and towards the valley, with the complex of the Sanctuary of Hercules the Victor, and in relation to the opposite slope, where the complex of the Sanctuary of Maria SS. Del Quintiliolo stands.



Figure 12. Perspective view on the new square (199 meters a.s.l. elevation) from the paper mill towards the complex of the Sanctuary of Maria SS. Del Quintiliolo (Source: Antonio Landa).

## 6. Future perspectives: Leveraging digital technologies for sustainable development

In envisioning the future of industrial heritage sites, it is imperative to adopt a comprehensive and forward-thinking approach. This chapter explores the multifaceted strategies and considerations involved in revitalizing these sites, drawing upon insights from stakeholder consultations, expert interviews, and scenario planning exercises. The future of industrial heritage sites is not predetermined but can be shaped through careful planning and foresight. Scenario planning exercises allow us to explore a range of possibilities, from adaptive reuse to innovative redevelopment schemes [13]. By anticipating various trajectories, we can develop resilient strategies that adapt to changing societal needs and economic trends. Digital technologies offer unprecedented opportunities for preserving and presenting industrial heritage in engaging and immersive ways. Through the creation of digital archives, virtual reality experiences, and interactive exhibits, we can bring the stories of these sites to life for present and future generations. Augmented reality apps can overlay historical information onto physical spaces, creating dynamic educational experiences for visitors. For example, virtual tours related to

the history of the building can show the changes in papermaking techniques through the centuries. The virtual tour could indeed incorporate some traditional elements of tours and lectures, such as images of artefacts and photographs, but also include videos illustrating different papermaking methods. Papermaking, for example, becomes much more understandable when the exhibited artefacts can be seen in action. A virtual tour encourages the public to spend more time examining the artefacts of industrial archaeology and learning about their history.

Central to the revitalization process is the active involvement of local communities. Community engagement strategies go beyond mere consultation, seeking to empower residents as active participants in decision-making processes. Advisory committees, public workshops, and community events foster a sense of ownership and stewardship, ensuring that revitalization efforts reflect the diverse needs and aspirations of the community. Sustainability lies at the heart of our approach to revitalizing industrial heritage sites. By integrating sustainable development principles into our plans, we can minimize environmental impact and maximize social and economic benefits. This includes the adoption of green building practices, the promotion of renewable energy sources, and the prioritization of local sourcing to support the circular economy. Revitalizing industrial heritage sites presents an opportunity to drive inclusive economic growth that benefits all members of the community [14]. Job training programs, support for local businesses, and equitable development incentives ensure that the benefits of revitalization are widely shared. Revenue-sharing agreements and community benefit agreements can further promote economic equity and social cohesion. A successful revitalization effort requires collaboration across disciplines and active participation from stakeholders at every stage. By harnessing the expertise of urban planners, architects, historians, economists, and community organizers, we can develop holistic and sustainable solutions. A participatory approach ensures that diverse perspectives are heard and valued, leading to more informed decision-making and greater community buy-in. In conclusion, revitalizing industrial heritage sites demands a holistic approach that integrates digital innovation, community engagement, sustainability, and economic inclusivity. By embracing this approach, we can breathe new life into these sites while preserving their cultural significance and promoting inclusive and sustainable development for the benefit of present and future generations.

## 7. Conclusion: Charting a path forward

In conclusion, this article underscores the profound impact of digital models in the preservation, comprehension, and reimagining of industrial archaeology heritage. Through a comprehensive synthesis of the insights gleaned from the preceding sections, we reaffirm the paramount significance of collaborative partnerships, technological advancements, and sustainable development principles in the protection and promotion of our collective cultural legacy for generations to come.

By amalgamating the knowledge distilled from our exploration, we emphasize the critical role of collaborative efforts between stakeholders, including academic institutions, governmental bodies, private enterprises, and local communities. These partnerships serve as the bedrock for the successful implementation of innovative solutions aimed at safeguarding industrial heritage sites. Moreover, we highlight the indispensable contribution of technological innovation in the documentation, interpretation, and dissemination of industrial archaeology. Digital models serve as dynamic repositories of historical information, offering unprecedented opportunities for immersive exploration and interactive learning experiences. By harnessing emerging technologies such as

virtual reality, augmented reality, and 3D scanning, we unlock new dimensions of understanding and appreciation for our industrial past. In tandem with technological innovation, we advocate the integration of sustainable development principles into heritage conservation practices. Embracing principles of environmental stewardship, economic viability, and social inclusivity, we strive to ensure the longevity and relevance of industrial heritage sites in a rapidly changing world. As we chart a course forward, we envision a future that embraces adaptive reuse, cultural tourism initiatives, and community-driven empowerment strategies. By leveraging the inherent resilience and cultural capital of sites like the former Cartiera Amicucci Parmegiani, we aspire to foster vibrant ecosystems where heritage preservation coexists harmoniously with economic revitalization and social cohesion. In essence, our collective endeavor is not merely to preserve relics of the past but to breathe new life into them, transforming industrial heritage sites into catalysts for sustainable development and cultural enrichment. Through unwavering dedication, ingenuity, and a shared commitment to our cultural heritage, we pave the way for a more resilient and inclusive future, one where the echoes of the past resonate vibrantly in the tapestry of our collective identity.

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### Notes

<sup>1</sup> The Pizzutello Tiburtino is an ancient variety of table grape cultivated mainly in the area of Tivoli, where it has been grown for centuries. This variety is prized for its characteristic, elongated fruits, hence the name 'pizzutello', which in Italian means 'little peak' or 'little point'. It is considered a high-quality product and is often found in local markets and food fairs in the region. This variety is particularly renowned for its quality and for the role it plays in the agricultural culture and tradition of the Tivoli area.

<sup>2</sup> From the "Design Competition rules and regulations" of the "Open design competition for the construction of the auditorium and parking lot in the area of the former Amicucci Parmegiani paper mill.

<sup>3</sup> Ranzi-Sibilla was one of the first three paper mills to produce ordinary paper called waste paper. It was built in 1847 near the San Martino steps in Tivoli. It is currently in disuse but is in a fairly good state of preservation. It too is part of the industrial archaeological heritage of the city of Tivoli, and like the Amicucci-Parmegiani paper mill, is located near the historic centre and not far from the factory that is the subject of this article.

<sup>4</sup> From the chapter "Geological framework", of the General Project Report (BEST Design, Sapienza startup) for the recovery, refunctionalisation and musealisation of the



building block of the former Amicucci-Parmegiani Paper Mill in the Municipality of Tivoli.

<sup>5</sup> Vacuolar travertine, Travertine deposits from thermal waters, porous and more or less friable, whitish, yellowish or reddish in colour, with horizontal, often indistinct stratification. Outcrops of lithoid travertine deposits in the Bagni di Tivoli area. Shallow lacustrine environment. Variable thickness, between 5 and 10m.

<sup>6</sup> Extract of the constraint of historical-artistic interest placed on the building complex by Ministerial Decree no. 104 of 30/07/2020:

*“As can be read in the excerpt, the part of the complex located above a height significant for landscape perception and the most recent portion of the building, built in front of the ancient complex of the Convent of St. Catherine, are excluded from the constraint.”*

*“[...]In the part of the complex to the west, accessible from the square facing Piazza Tani:*

- *The part identified by red shading in the drawings on the various levels, which preserves legibly the chain of workings in its vertical development, is subject to protection:*
- *The part of the building set at the height of Piazza Domenico Tani (elevation +208) is not subject to protection - due to the poor architectural quality, the degraded state of the structures (mostly cement), and not preserving significant elements of the chain of workings - in order to restore the view towards the picturesque river valley below; and the Quintiliolo hill, which has always constituted, until before the raising of the paper mill, the main attraction of the square itself.”*
- *“[...] Of the remaining part of the industrial complex, located to the east and of the forecourt towards Piazza Tani:*
- *The buildings are not subject to protection, as they are post-1950 and of no historical, architectural or cultural interest.*

*All demolitions shall be carried out with due caution so as not to cause damage to adjacent parts and with the involvement of an archaeologist for the part at the lower level.”*

<sup>7</sup> Extract from the 'Design Competition for the construction of the auditorium and car park in the area of the former Amicucci Parmegiani paper mill', Municipality of Tivoli, 2020: *“[...] The current building, with its massive out-of-scale volume of the former paper mill, obscures the Tower of Santa Caterina located in the western area of the complex, which represents a distinctive architectural and geometric sign, not only of the immediate context, but of the entire skyline of Tivoli's historic centre. The tower, in addition to requiring urgent consolidation works, constitutes an element with which every design intervention will have to integrate and relate.”*

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### Summary

The former Amicucci-Parmegiani paper mill is a publicly owned building in the historic center of Tivoli: long abandoned and dilapidated, it has recently been the subject of a design competition for its recovery. It is part of a wide system of old industrial paper mill settlements located along the Aniene river, due to the availability of water; nowadays, they are abandoned and testify to the stratification of a productive activity in a place that has been inhabited since Roman antiquity. The strategy regarding the aim to create a new approach to the old - the case study was developed through the activity of a Sapienza Startup - is a notable example of a new approach to renewing, repairing and rebuilding the built modern heritage. With dwindling resources, it has become necessary to listen to and work with the history of the buildings rather than demolish them. Guided by these principles, an integrated strategy of conservative intervention has been studied to preserve the industrial identity of the building, enhancing its productive characteristics with a functional programme that involves the citizenship and tells the story of the Paper Mill and its industrial processes through a museum, triggering a virtuous cycle of growth, development and landscape restoration. A landscape belonging to a current drosscape has the opportunity to push the renovation of a piece of city. Demolition of the existing heritage is triggered by the opportunity to initiate processes of economic valorisation: the case of the former paper mill is a unique one since the right to demolish - sanctioned by the constraint placed on the area and the building - aims at constructing, through complex demolition work and a little reconstruction work, the common value of a "new urban landscape", in an area of extraordinary quality. Within a framework of shrinking public resources, the value of recovering the existing heritage - specifically a fragment of industrial archaeology - represents an opportunity to validate choosing conservation over the hypothesis of building replacement, with respect to social, environmental and economic variables.

### Riassunto

L'ex cartiera Amicucci-Parmegiani è un edificio di proprietà pubblica nel centro storico di Tivoli: da tempo abbandonato e fatiscente, è stato recentemente oggetto di un concorso di progettazione per il suo recupero. Appartiene a un ampio sistema di precedenti insediamenti industriali di cartiere situati lungo il fiume Aniene, per la disponibilità di acqua; oggi sono abbandonati e testimoniano la stratificazione di un'attività produttiva in un luogo abitato fin dall'antichità romana. La strategia relativa all'obiettivo di

sviluppare un nuovo approccio all'antico – il caso di studio, sviluppato attraverso un'attività di una startup della Sapienza – è un esempio notevole di un nuovo approccio al rinnovamento, alla riparazione e alla ricostruzione del patrimonio costruito moderno. Con la diminuzione delle risorse, è diventato necessario ascoltare e lavorare con la storia degli edifici piuttosto che demolirli. Sulla base di questi principi, è stata studiata una strategia integrata di intervento conservativo per preservare l'identità industriale dell'edificio, valorizzando le caratteristiche produttive con un programma funzionale che coinvolge la cittadinanza e racconta la storia della Cartiera e dei suoi processi industriali attraverso un museo, innescando un ciclo virtuoso di crescita, sviluppo e restauro del paesaggio. Un paesaggio appartenente a un attuale 'drosscape' ha l'opportunità di spingere un rinnovamento di un pezzo di città. Le azioni di demolizione del patrimonio esistente sono innescate dall'opportunità di avviare processi di valorizzazione economica: il caso dell'ex cartiera rappresenta un unicum, poiché la facoltà di demolizione - sancita dal vincolo posto sull'area e sull'edificio - ha l'obiettivo di costruire, attraverso un'azione complessa di demolizione e una ridotta attività di ricostruzione, il valore comune di un "nuovo paesaggio urbano", in un'area di straordinaria qualità. In un quadro di contrazione delle risorse pubbliche, il valore del recupero del patrimonio esistente - nello specifico un frammento di archeologia industriale - rappresenta un'opportunità per validare la scelta conservativa rispetto all'ipotesi di sostituzione edilizia, rispetto alle variabili sociali ambientali ed economiche.

# EQUESTRIAN GAMES AND COMPETITIONS IN THE ETHNO-CULTURE OF TURKIC PEOPLES

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## 1. Introduction

Despite the fact that the article is devoted to the equestrian games and competitions of Turkic peoples in their historical past, we considered it necessary to define the essential understanding of the term *game* to try to reveal its ontology. The definition of *game* in the dictionary has many meanings, but invariant in it is the designation of “activity, spending time in any occupation, serving to fill leisure, entertainment” [1]. A game is a life-affirming form of activity of the whole being – nature and man. As researchers note, games are older than culture, animals did not wait for the appearance of man to teach them to play. Moreover, according to Heisinga [2], “*human civilisation has not added any significant feature to the concept of play in general. Animals play - just as humans do. All the basic features of play are already embodied in animal games. One need only watch puppies frolicking to recognise all these features in their merry fiddling. They induce each other to play through a special kind of ceremonial posture and movements. They observe the rule of not biting each other's ear. They pretend to be extremely angry. And most importantly: all of this they clearly perceive as a highly humorous activity and experience great pleasure in it*”. In this context, the games of other domestic and wild animals, the mating games of birds and insects are also manifested, and the signs/properties of these games are relevant to the present day.

For man, play is first of all the embodiment of his intellectual and spiritual activity, the expression of his physical and biological capabilities, and the disclosure of his emotional and psychological state. A man plays when he is freed from satisfying his needs for food, clothing, housing, i.e. by interrupting the process of providing for his vital needs, a man transgresses the sphere of holiday, cultural leisure, satisfying “the ideals of individual self-expression and social life”. It is known that any game is *played out* in time and space, representing a certain process, the game has its beginning, climax, denouement, participants in the action. Therefore, “*once played, a game remains in the memory as a kind of spiritual creation or spiritual value and is passed from one to another and can be repeated at any time: immediately - as children's games, a game of trictrak, running against the clock - or after a long break*” [2]. Hence the most important property of a game, is its repeatability, fixed in human consciousness through the prism

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of spiritual activity, and transmitted from generation to generation in the historical development of the culture of many peoples of the East and West, including the ethnic culture of Turkic peoples.

In the history of the development of human culture since ancient times, games are associated with the highest piloting of human physical capabilities (*ancient games and competitions, Olympic games, the games of nomads*), rhythm and harmony of movement, the embodiment of the beautiful, therefore, the ontology of the game is also in its aesthetic perception of the physical body, in the implementation of the physical and biological data of man.

A game is an expression of the emotional-psychic state of a person, as they compete; struggle is manifested in the emotional heat that results from the competition, the need to achieve victory, or diversely, tension when there is a negative result - defeat - when the emotional state of the player is off the scale, being in the highest degree of emotional state.

These characteristics are clearly manifested in the equestrian games and competitions of the Turkic peoples, formed historically over centuries and millennia. It is known that in the ethnic culture of Turkic peoples, games were very diverse: intellectual, gambling, children's, youth, sports, but it is the equestrian games and competitions that were deeply symbolic for the nomadic culture of many Turkic peoples. Within this context, the aim of this article is to consider several horse games and competitions, seen as a manifestation of the spiritual culture of Turkic peoples on the basis of written Turkic manuscripts, oral art and the traditions and customs of Turkic peoples. Such games include, first of all, *kokpar* ("goat-dressing"), *shogen* (polo), *zhamby atu* (archery), *baige* (horse racing).

Several studies have been devoted to the study of the game as a spiritual activity, a factor in the cultural life of peoples, including Turkic peoples. Heisinga's concept of treating games as a spiritual activity of man, sees it as independent of morality, and beyond the plane of good and evil, truth and untruth, wisdom and stupidity, in determining the various properties and characteristics of games and that most importantly, a game is a comprehensive expression of human activity, a universal category of human existence, it permeates all forms of Western culture from antiquity to modernity. The author reveals philosophy and poetry, music and jurisprudence, fashion and clothing, modern Western art through the prism of the game [2]. Research by Lipets [3] is devoted to the hero-warriors of the Turkic-Mongolian peoples, and in the context of horsemanship culture the author considers the image of a war horse participating in races and competitions. Omirzakov and Musin [4] study the features of numerous Kyrgyz folk games such as "*at-chabysh*", "*jamba atmay*", "*kuresh*", "*ordo*", "*kyz kuumaï*", etc. Tani-keev [5] reveals the continuity of Kazakh folk games with modern sports competitions. In contrast to the above-mentioned works, the article looks at the historical context of the equestrian games of Turkic peoples, including the Kazakh people (revealed in the material of written texts, as mentioned above) and determines their continuity in the modern ethno-culture of Kazakhs.

## 2. Literature Review

In the culture of Turkic peoples the traditions connected with the equestrian culture of the Turks occupy an important place; it is not by chance that researchers note that the Great Steppe gave the world horse breeding and horsemanship culture. In the Late Bronze Age, the Steppe people's stable and herding economy, characteristic of the Andronovo culture, gradually began to change into a nomadic one. Klyashtorny and

Sultanov [6] note that the main breakthrough from the Bronze Age, from the world of the Avestan Aryans, to the Iron Age, the age of the Scytho-Saxon tribes, was a breakthrough in the way of conducting economic activity and, accordingly, the way of life. The sign of the breakthrough was the formation of the nomadic cattle-breeding economy. The transition to nomadism involved the economic turnover of huge interfluvial steppe spaces which had earlier been uninhabited and unused. The change in the type of herd happened in the late Andronovo era, during which cattle were increasingly replaced by *horses*, which did not require daily care and were capable of calving; it also made it possible, in the early 1st millennium B.C. to sharply lengthen the routes of migrations and make them seasonal [6].

The main “figure” in nomadic economic activity was the horse, because in the harsh climate of Steppe Eurasia it could provide its own fodder, known as *tebenovat*, which means to pull out fodder from under the snow with the hoof, and is still done by horses in the steppes of modern Kazakhstan. As researchers note, the Cimmerian and Scythian invasions of the 8th-7th centuries in West Asia and the Black Sea region, the struggle of the Akhmenid kings Cyrus and Darius against the Saks on the territory of the modern Amu-Darya and Syr-Darya became the beginning of the Sak epic. Akishev investigated numerous large and small Saka burial mounds. He discovered and reconstructed the costume of the Issyk golden warrior and believed that the heyday of the Saka culture in Semirechye, South Kazakhstan was observed in the fifth to fourth centuries. [7].

According to ancient scriptures (Herodotus, Strabo, Lucian) and Persian sources and archaeological excavations, the numerous Sako-Scythian tribes of Massagetes, Saki-Tigrahauda, Saki-Khaumavarga, Dakhi, Iscedonians, and Sarmatians were a formidable force for the Achaemenid kings, Sogdiana, the Chinese Empire, and later Alexander the Great, primarily because they were warriors. The Greek poet Lucian transmits Scythian’s words: “*We have constant warriors, we either attack others ourselves, or withstand attacks, or engage in skirmishes over pastures and booty*” [8]. It was in the Saka era that the culture of horsemanship was born, and troops of “horse archers” appeared, who were mobile, agile, travelled quickly over long distances and shot accurately. Herodotus writes of the Massagetae: “*the horses wore copper armour on their chests*” [9].

The Sak culture combines military art with equestrian games and competitions. An ancient source says: “*The Persian king organised equestrian rallies for riders representing different nations. The length of the running track was determined in five stadia. When the race began, a young Sak took the lead and reached the finish line, leaving all the other riders almost halfway down the track. The Persian king offered Sak the kingdom in exchange for a horse, but he refused, saying that he would give the horse only in exchange for the gratitude of a brave man*” [10]. This fragment of the text, on the one hand, testifies to the high ethical standards of the Saku, on the other hand, it emphasizes the origins of Turkic horse racing, dating back to ancient times. Following the Sakas, for the early nomads of Central Asia, for the Jung, Huns, Yuezhi, Usuns, the horse is the main domestic animal in military life and peacetime. Researchers note that at the beginning of the 1st millennium B.C. the tribes inhabiting Central Asia created a nomadic culture of the Scythian type. They mastered bronze and iron metallurgy, metalworking, wheeled carts and horsemanship. Among these tribes, Chinese dynastic sources note their northeastern neighbours, calling them “*horse qiang*”, i.e. “*horse-breeding qiang*” or *zhong*, in multitudes. “*In the course of military encounters the Chinese were more than once convinced of the merits of the barbarian cavalry, and sometimes adopted the dress and arms of their opponents. The ruler of the kingdom of Zhao, Ulin-wan, changing the existing customs, began to wear barbarian clothes, learn riding*

and archery". However, the real opponents of the Chinese Empire, according to Sima Qian, were the strong nomadic tribes of the Huns (Hunnu) and Yuezhi, who had a single ruler, and the fierce struggle with the nomads for Ordos had varying success. Klyash-torny and Sultanov wrote: *"the main type of economic activity of the Huns has always been nomadic cattle breeding, which confirms both the messages of written sources and the results of archaeological excavations. The primary role of the Huns was played by the horse. In extensive cattle breeding, when fodder for cattle was not prepared for the winter, the horse had the advantage of being able to tebeneval, i.e. to be on fodder all the year round, extracting grass from under the shallow snow. Judging by the bones found in the Hun burials, horses were typical Mongolian - small in stature, rough but of muscular build, with a short broad muzzle"* [6].

On their Mongolian-type horses, the Huns conquered and subdued vast territories and states, reaching the borders of the Roman Empire. The mythical unity of the warrior with the horse, the phenomenal importance of the horse for the Huns was described by a Roman historian: *"... they, i.e. Huns (eponym inserted by the authors), do not act well in foot races, but as if attached to their hardy, but ugly looking horses, sitting on them in a feminine way, they perform on them all their usual activities; on them, each of this tribe sleeps and in daytime, buys and sells, eats and drinks and, ducking to the narrow neck of his horse, falls into a deep sleep"* (the authors have added emphasis) [6]. Later in the epochs of the early and late Middle Ages as well as modern times, in the culture of the Turks, the horse continues to be a symbol of nomadic culture, seen in the art of riding and military power, as evidenced by various Turkic texts written in different scripts: runic, Uigur, Brahmi, Arabic, Latin.

Runic manuscripts depict the picture of the world of the ancient Turks, the epoch of the first (545-630) and second (682-744) Turkic Khaganates, the activity of the ancient Turkic Kagans Bumyn, Istemi, Mukan, Kutluk, Kapagan, Bilge, etc. Orkhon runic texts with historical authenticity present the history of campaigns and battles on the conquest and preservation of the huge territory from the rocky ridges of Khingan in the east to the interfluvium of Volga and Ural in the west, from the Chinese wall in the south to the Sayan ridges in the north; as the chronicler describes *"...the peoples living in all four countries of the world were all their enemies, coming out with an army, they subdued all the peoples living in the four corners and forced them all to peace. Those who had heads, they made bow their heads, those who had knees they made kneel"* [11]. The symbol of the martial art of the ancient Turks is an armed warrior on a war horse such as Kültegin, and all his battles in the text are connected with the description of his horses, *"grey horse Tadykyn - Chor, white stallion from Bayyrku, grey horse Bashgu, Alyp-Shalchy, Azman, brown horse, horse Azov"*: *Kültegin, mounting the white horse Azman, rushed to the attack. Six warriors he stabbed with his spear. In the battle he killed the seventh* [12].

Also, Turkic folk epic tales (*zhyrau*) for centuries, have depicted legendary heroes (*batyrs*) with their famous horses *Taiburyl* - Koblandy batyr, *Bayshubar* - Alpamys batyr, *Ak-Kula* - Manas, *Tarlan* - Er-targyn, *Kulager* - Akhan seri.

In the Kyrgyz epic "Manas", his future faithful companion, the horse Ak-Kula, is born at the same time as the hero. *"Ak-Kula, Manas's horse, has died, and his master believes that everything is over for him - he has lost 'his wings'."* Here the connection between the horse and the rider was so close and inseparable that often the loss of the horse deprived the hero of the power of internal resistance, although initially the life span of a horse is biologically three times shorter than that of a man [3]. All the above is a reason to understand the special status of the horse in nomadic culture and its active use in peacetime, not only for economic needs, but also in traditions and rituals and are either memorial cases in honour of famous personalities (khans biys), or



playthings or toys in family and domestic rituals. On such occasions, as a rule, equestrian games and competitions such as *kokpar* (“goat-dressing”), *shogen* (polo), *zhamby atu* (archery), *baige* (horse racing) were organized. These equestrian games, once played in the distant past, were deposited in the collective consciousness of Turkic peoples and passed from generation to generation as a special cultural artefact.

### 3. Materials and Methods

Current research has been based on the analysis of texts that are based on the cultural heritage of “Divani lugat-it Turk” by M. Kashgari, “Blessed Knowledge” by J. Balasuguni, the epics “Manas”, “Alpamys”, and ethnic culture materials. Authors analyze the most common horse games recorded in the historical memory of the Turkic peoples: *kokpar* (“goat tearing”), *shogen* (polo), *zhamby atu* (archery), *bayge* (horse races), the origins of which go back to ancient times and are recorded in written Turkic texts and the ethnic culture of the Turkic peoples.

The authors have made an attempt to determine the origins of horse games by considering their main content, the behavioral roles of game participants, revealing the semantic meanings of game lexemes.

### 4. Results and discussion

#### 4.1. *Kokpar*

Such spectacular equestrian competitions include *kokpar*, a game dating back to antiquity and widespread among the peoples of Central Asia (Figure 1).



Figure 1. Horse riders playing “*kokpar*”.

There are different versions about its origin. A. Kaliuly notes that the origin of *kokpar*

is connected with the military training of nomads. In the era of the ancient Turkic Khaganates, valiant ancient Turkic warriors and batyrs were formed from such military training. Skills acquired in campaigns and battles were continued in equestrian competitions of kokpar [13].

Other researchers associate the origin of kokpar with the cult of the wolf in Central Asia, which is confirmed by some facts. In our opinion, this connection is manifested in the very name of the game kokpar, because the word is certainly a derivative complex formed from the merger of two lexemes *kok* + *par*, and more precisely *kok* + *beri*. The word “*beri*” in Kazakh means “wolf”, and this meaning is preserved in other Turkic languages in various phonetic variants: *böru* Alt.; *bëru* Tuvin; *biori*, *byre*, *bëre* Nogai, Tatar, Bashkir, Uigur languages. As noted by Kazakhologists, the word *buruu* is found in Buryat and Mongolian languages in either the meaning of calf, or in the designation of cubs of wild animals bears, leopards, wolves [14]. Thus, the genesis of *bori* goes back to the Altaic family of languages, expressing various semantic variants.

The phonetic laws of Turkic languages played their role in the change of the name of the game in the culture of modern Turkic peoples: *këk beri* to *kokpar*. Firstly, the law of progressive assimilation, characteristic of Turkic languages, when in the word-forming act under the influence of the deaf phoneme [k] there is a deafening of the phoneme *b* > *p*. Secondly, the law of syngarmonism of labialised and palatalised vowels in the root morpheme is also historically characteristic of Turkic languages. Thus, Baskakov [15] notes: “*The presence of only two basic phonemes - [u] and [a] is preserved in modern Turkic languages with eight phonemes for the root morpheme, as allophones for [u] - i, u, ü and for [a] - e, o, ö were regulated by the laws of palatalisation and labialisation for the whole word, are characteristic, in fact, of most Turkic languages*” [15]. Thus, in the change of *beri* into *pairs*, the allophone *ö* changes to the allophone *a*, combined with the loss of the palatalised vowel *i* at the end of the word.

The word “*këk*”, in the mentality of Kazakh, Kyrgyz, Nogai and other Turkic nations is multispectral and combines blue and green colours as well as all their shades (despite the fact that there is a separate lexeme for green - *jasyll/jashyl*). “*Këk* means not only blue, the colour of the sky, but also everything that is associated with renewal, freshness, greenery, hence *koktem* “spring”, *këk shykty* “first spring grass”, *këk shai* “green tea”, *këkenis* “fresh vegetables, fruits”.

The next meaning of the word is connected with the image of the wolf *këk beri*, the totem animal of the ancient Turks, the legend (known from Chinese sources) says: the ancestors of the Turks were exterminated by their neighbours and only a nine-year-old survived; the enemies cut off his hands and legs, and threw him into the swamp. There a she-wolf became pregnant. The enemies still killed the boy, and the she-wolf ran away to Altai and there gave birth to ten sons. The clan multiplied, and one of them, named Ashina, became the leader of the confederation “Kok Turk” (blue Turks). The word Ashina means “noble wolf”, “Turk” - “strong, sturdy” [16]. Thus, the meaning of the lexeme “*kok*” is metaphorically comprehended through the meanings of the words “wolf, genetic, Ashina, noble”, and the very combination “*kok Turk*”/“*kok Turki*” means “strong, powerful like wolves, noble” Turks. The image of the wolf is the patron spirit for ancient Turks. On their blue battle banners they had a wolf’s head embroidered with gold threads as a sign of their strength and majesty. Perhaps, the ancient Turks in campaigns and battles, and in equestrian games in peacetime, represented themselves in the image of a wolf. Researchers note that the image of this formidable beast with other predators was found in the ancient barrows of the Altai Mountains on everyday objects, ritual items, jewellery, combat weapons [17]. The beliefs of many Turkic peoples still retain echoes of the cult of the wolf: Kazakhs protect herds by displaying a wolf skull;

Turks have a wolf tooth as an amulet against the evil eye; Uzbeks have a wolf skin as an amulet for a newborn baby [18,19].

Thus, the semantic analysis of the word *kokpar* and the analysis of sources show that the origin of the game is substantiated with the totem of the wolf and its cult, widespread in the culture of Turkic peoples in antiquity. Some researchers also share this position. Karmysheva and Tolstov studied the archaeology and ethnography of Central Asia. They note that in the equestrian competition of nomads “*originally there was no goat-killing, but on the contrary, the wolf was thrown*” [20]. A similar idea is expressed by ethnographer Simakov [21], noting that the Kazakhs in the distant past, in hunting drove the wolf all the way to the village. The original status of the wolf in the game *kokpar* is also based on the realities of the ethnic culture of Turkic peoples. In the deserted steppes and mountains animals grazed in the open air, so very often herds were attacked by wolves. Shepherds armed with *kamcha* and sticks had a hard time fighting them. Courageous *dzhigits* on fast and hardy horses pursued the predators until they drove them half to death. Having killed the wolf with sticks or *kamcha*, they picked up the animal from the ground and rushed back, beating the carcass to and from each other. Thus, the game of *kokpar* was born. Later, with a more settled way of life, the wolf carcass was replaced by a goat carcass. The latter was cut before the game, the entrails taken out and the belly sewn up; the head and hooves were removed, and the winner received it at the end [22].

Much later, the carcass of the wolf was replaced by the carcass of a goat, lamb, calf, etc., but the name of the game itself remained *kokpar* (as we justified above, derived from *kok bori*). In this context, the notes of the American anthropologist Huntington [23] on the life and social structure of the Kyrgyz, published in the journal “Turkestan Mountains” (1907) are quite remarkable. The researcher notes, “...As we drew nearer, we saw two galloping horsemen who, rushing past us fought over a large black object. It was the carcass of a black calf (added by Authors for emphasis). Three or four men riding behind the leader were trying to lift it. Two grabbed the carcass, twenty or thirty others surrounded them, and all tried to grab the calf and run away with it ... The occasion for such contests could be a wedding, the birth of a son, the installation of a new *kibitka* and a wake. Whatever the origin of the game, it is a wonderful exercise in riding. The Kyrgyz are true nomads and skillfully skilled in horse-riding” [23].

In general, for nomads, *kokpar* was not just a game or a competition, on the contrary, it meant a way to learn the art of war, to educate warriors in courage, agility, perseverance and collective cohesion. *Kokpar*, which has its centuries-old history of playing out, today is one of the favorite national games of modern Turkic peoples - Kazakhs, Kyrgyz, Karakalpaks, Nogai, etc., held during holidays and various traditions, rituals, customs [24].

As for any game, the rules and participants, the tension shown in the competition, the place and time, which have come down from ancient times and have been strictly observed for centuries, are important for *kokpar*. The most important rule is throwing a goat into the centre at a distance of 50-60 paces, when on command the participants of the game, usually dozens of strong young riders on horseback, rush to the carcass of the goat. The tension of the game intensifies when the first rider who has lifted the carcass from the ground is attacked by rivals trying to catch up with him to take the carcass away. Sports competitiveness and the riders' emotional tension reaches the highest peak in the struggle for the prey and the fight can last for several hours. It is about such situations that Hoizinga wrote, noting that the tension of the game puts the players' forces to the test: not only their physical strength, perseverance, ingenuity, courage and endurance, but their *spiritual forces* too because driven by the desire to win they are forced to keep within the prescribed limits of the permissible [2]. That is

why the game is not only a manifestation of the physical and emotional-psychic capabilities of a person, but also, above all, of spiritual principles, and the observance of ethical rules and principles. And in *kokpar*, it is the one who, either by force or dexterity and without breaking the rules, is the last to seize the carcass of the animal that wins. Thus the culmination of the game is reached. A man and a horse, participating in the competition *kokpar*, must be - a single whole. The rider must be physically strong, agile, enduring, with excellent riding techniques, and his horse must match him. The player must feel his horse. The unity of the *tulpar* (mythical Turkic horse) and rider is one of the conditions of victory. *Kokpar* requires the subtle, well thought-out tactics and strategy of the players.

#### 4.2. *Shogen*

Another popular type of equestrian sports game among Turkic peoples, including Kazakh people, is "*shogen*" or *polo* as it is named in Europe (Figure 2). Despite the fact that there are many versions about the origins of polo in Europe, one of the main hypotheses is that the game originated in Central Asia, in the culture of nomads, although polo was played by the English aristocracy, nobility and members of the royal family, and was popular in other European countries.



Figure 2. Horse riders playing "*shogen*".

In Attila's time, the game of "*shogen*" was played after a successful military campaign, riders took in their hands not draughts, but long crooked sticks and drove across the field with the head of the enemy wrapped in a leather bag. Today, they do not race after a severed enemy's head, as they used to do, but a wooden ball, according to the same ancient rules [25].

If we are looking at the etymology, the word "*shogen*" goes back to the Old Turkic

lexeme “sök”, which means to break the army [26]. In our opinion, derivatives of “shögen” are derivatives of “shogan”, “shogban”, “chavgon”. Akhmetzhan [27], who researched Kazakh weapons, reveals there are close semantic links between “shogen” and “shokpar”: *Shegen sezi shokparmen tybirlis. If you do not want to use it, you must use it.* The words “shogen” and “shokpar” are homonyms, the single root morpheme expresses the meaning “to beat” (the translation of the sentence from the Kazakh language is by the authors) [27].

Hence the dominant meaning of *shögen* and its derivatives is revealed in the designation to strike, to beat, which is manifested in the ontology of this game. *Shegen* is a popular equestrian game of nomads, played on horseback in a flat open space, in which the ball is moved across the field with the help of a special curved stick. The rider on horseback needs skill, dexterity and ingenuity to take the ball from the opponent and score.

The game seems to have been popular in the culture of Turkic peoples and was reflected in Turkic written documents of the Karakhanid era. Thus, in “*kutadgu bilig*” (“gracious knowledge”) Balasaguni [28] believes that good ambassadors, military leaders and *beks* should play polo well, and also engage in other sports: *Chovgan should know arrow throwing; and know the art of hunting* [28]. Moreover, in the section about ambassadors, the text also describes how the game was popular among the Turkic nobility of that epoch: *Ambassadors, military leaders and beks played chovgan, the game well develops agility, intelligence, wisdom, skill and courage* [29]. Thus Balasaguni appeals to the idea that the game *chovgan / shogen*, not only strengthens a person physically, but also develops his intellectual potential, the world of his spiritual beginnings.

We find important information about the game of *shögen* in Kashkari's “Divani lugat-it Turk”, captured in some words and forms of the Dictionary. For example:

- 1) Aktur “to bend” (forms *akturdi, akturur, akturmak*). *Ul zhukan akturdi - He ordered the stick to be bent (for playing horse polo).*
- 2) Atgar “to help a man to get on a horse” (*atgarur, atgarmak*). *Ul mani atgardi - He helped me get on a horse.*
- 3) Argur “to ride”, “to bring to exhaustion” (*argurur, argurmak*). *Ul atin argurdi - He rode his horse.*
- 4) Tasal “a field, a boundary set up for the game of polo”. It is the same as talas: “there is no spread on this land”.
- 5) Zhukan “polo stick” [8].

Thus, these and other words in the document fully disclose the features and rules of the game of *shögen*: the instrument “crooked stick”; the participants, who could be people of different ages; the place “field with delineated boundaries”; the excitement and heat of the game in the highest degree, when the horse under the rider was brought to exhaustion. The rules of *shogen* (polo) have not actually changed until now. According to sources, the game was widespread not only among Turkic peoples, but throughout Central Asia. In the era of Sultan Babur, the Semirechen Mughals captured part of India, and thus the game became popular there and attracted the attention of the British conquerors. Thus, *shogen* (polo) spread to England, Europe, North and South America.

Nowadays the game of polo is widely spread in such countries as Great Britain, Spain, France, Germany, Pakistan, India, United Arab Emirates, Argentina, Mexico, Brazil, USA, Australia. In general, the game of polo is a game of privileged people, aristocratic nobility. Among these countries only in Argentina is polo a national sport in

general. In addition, Argentina has turned polo into a sustainable financial source. It is involved in training horses, making the balls and sticks used during the game, and educating those interested in the game [30].

### 4.3. *Zhamby atu*

For Turkic peoples the equestrian game of *zhamby atu* (archery) is a traditional one (Figure 3). According to researchers, the origins of the game date back to the fourth and third centuries BC, when the bow was one of the main weapons used in everyday life for hunting, in campaigns and battles for war. A skilful archer was a respected person with a status for tribesmen of the ancient society. It is known that it was in the era of the Huns that warriors-shooters and archers-hunters appeared. In Chinese sources there is information that the ruler of Moda had three thousand military archers.



Figure 3. Horse riders playing “*zhamby atu*”.

Our study of the etymology of the game of *zhamba/yamba* suggests that the word itself was borrowed by the Turks and Mongols from the Chinese language. As the authors of the etymological Kazakh dictionary write, the Chinese word *yuyaan* meant “coin”, “money”; *bao* meant “valuable”, “expensive”; in Mongolian borrowing these Chineseisms in the forms *yumby (yuamby)* it came to mean “silver equal to 50 lan”, and with a figurative meaning, “degree”, “the art of owning something”. The meaning of the valuable metal, silver, has been preserved in Turkic languages: in Uigur. *yamb, yambu/yamby* is equal to the Chinese 35 grams of silver; in Kyrgyz, *zhamby* means “a piece of silver”, differing in weight and shape and used instead of money [14]. In our opinion, for the name of the game in the Turkic languages the figurative meaning of the word from the Mongolian language was dominant, due to which *yambgu/jamby* came to mean the art of wielding an arrow from a bow.

The art of archery in the culture of Turkic peoples was popular in the early, late

medieval and also later times, which is undoubtedly recorded in documents and in the oral folk art of Turkic peoples. For example, Mahmud Kashkari's "*Divani lugat-at Turk*", as an encyclopaedia of Turkic culture, contains words and forms of words related to the game of *jamba*: *atish* "to compete in shooting, throwing" (forms *atishur*, *atishmak*). *Ul mannik uk atishdi* - *He competed with me in shooting (or in throwing)*; *atum ar* "a person, skilful in shooting, a good marksman"; *atum ar* "a person, skilful in shooting, an apt marksman"; *atishgan* "a man who competes with me in shooting". *Ul mannik birla uk atishgan ul* [8].

In the epic "Alpamys", the contest is interrupted by a competition in *jambas*: ...*Suddenly Ultan's loud voice rang out: "Let all shooters move to the right, now on that distant high tree hang jambas, whoever hits it, I will give Baibori Karlygash's daughter to him in marriage! The crowd of dzhigits rushed for the jambas. And again Ultan's voice rang out: "Give, give a turn to the dervish". Alpamys, not hesitating, pushed the crowd, shot and hit the target* [31]. As can be seen from the text, not only the game itself, but also its instruments could be called *jamba*, i.e. metonymic transfer of the name of the game and its components.

The game of *jamba* was also widespread in the Mongol era. Thus, in the "Secret Annals" of the Mongols it is written that in 1225 Genghis Khan completely conquered Khorezm and arranged a large toga in "*bugyly-shashak*", where he summoned mounted archers and held a competition. In this competition, the shooter Esei reached the *zhamba* target at a distance of 502 metres [32].

In the ethnoculture of the Turkic peoples, the game was most often played at large feasts, festivals, memorial asahs, in honour of kagans, khans and other famous personalities of Steppe Eurasia. The rules of the game were preserved in the memory of the people and passed on to subsequent generations. The place where the game took place, the participants, the horse, the equipment, as well as the equal, the final prize - everything was regulated by these rules. Describing the process of the game in Kazakh culture, Dzhelbudin notes: "*The number of participants was not limited. In the past, girls also took part in it. Each participant took part with his horse and bow. A target sewn from cloth, covered with gold or silver was hung to a tree branch at a height of 4-5 metres with a thin hair rope so that the target dangled. Participants shot at the target with a bow three times in a row from a distance of 50-60 paces, and shot not at the target itself, but at the rope to which it was tied. The competitor who managed to shoot down the target, took it with its contents. The game required special marksmanship, and only excellent shooters could knock the target off the tree*" [32]. As recorded in cultural texts the information is confirmed by the ethnic constants of the Turkic people.

#### 4.4. Horse racing - *baige*

Rather interesting, spectacular and emotionally colourful are horse *baige* (horse races), the origins of which go back to ancient times, as noted above, in the era of the Saks and Scythians. The main element in the *baige* is the horse, which is intended only for races, because the time, distance and type of race depends on the parameters of the racehorses, their age and breed (Figure 4). Thus, foals were chosen for *tai baigue*, and 3 to 4-year-old horses for *alaman baigue*. The name of the race is also associated with the horse: "*tai-baige* (for 6-8 km), *kunan-baige* (for 10-15 km), *donen-baige* (for 15-20 km), *at-baige* (for 25-30 km), *alaman baige* (for 40-100 km)" [5].

For thousands of years, a competition was a significant event for nomadic culture, because inter-tribal agreements, successful campaigns and battles, asces and toi, a clan's important exploits, ethnos, state, did not happen without *baige* races. *Alaman baige*, historically popular in the culture of Kazakhs and other Turkic peoples, are

indicative in this context. Roslyakov [34] notes: “*The epoch of military democracy, which emerged at the stage of decomposition of the primitive communal system, is associated with the emergence in the Kazakh steppes of alaman baige, a type of competition used to train a warrior. Alaman is one of the types of warfare, specifically a raid made by a mounted armed detachment. Alaman was also called a warrior as a participant of a raid*” [34]. The origins of *alaman-baige* lie in Alamanism, when horse racing not only served for military purposes, but also the special physical training of both man and horse. *Alaman baige*, as noted above, was a race for extremely long distances. We agree with Tanikeev's statement that nomadic culture required people to be ready for long distant journeys, hence, it was necessary to breed strong hardy horses. This was a test not for the rider, but for the horse and according to the rules, only local breeds of horses could be used. Sometimes the horses were killed by overloading or even collapsed. Riders often braided the tail and mane into plaits and attached bird feathers and various amulets to them to protect the horse from misfortune [5].



Figure 4. Horse riders participating in “baige”.

In Kashkari's “*Divani lugat-at-turk*” [8] the key meanings of *baiga* as an equestrian competition are given. The organisers and participants of the games are revealed: *Ul at yarishti* - *He sent a horse to the competition*, as well as the conditions for the competition: “*uzush* - *assistance in riding, in races*”. The Kipchak, Oghuz, and Karakhanid Türks chose the fastest horses for races, such as Arkun, a *horse born from a wild stallion and a tame mare. The fastest horse in races*. At the same time, attention was paid not only to the horse, but also to the rider, attention is paid to his strength, perseverance, riding technique: *Uzitgan bu ar ul atin uzitgan* - *a man on a horse, ahead of all*. The text also reveals the rivals: *Ul mannik birla at uzushdiy (uzushur, uzushmak)*. - *He competed with me in horse races* [8]. *Baige* (horse racing) represents the rich traditions and culture of the Turkic peoples, the tradition of equestrian competitions, when the strongest and toughest horses were chosen for races. The riders also had to be strong, agile, persistent, fast and organised.



## 5. Conclusions

A game is an activity inherent in the natural world and the human world. For man, a game is an act of spiritual activity, manifested in centuries-old culture and revealing his intellectual potential, physical and biological capabilities and emotional and psychological state. The ontology of the game is fixed in human consciousness as an artefact of culture and once played is passed on to subsequent generations with all its rules, properties, participants and attributes.

In the culture of Turkic peoples, the most relevant equestrian games come from their nomadic culture, the way of life of the peoples, originating from the Saks, Scythians, Huns, ancient Turks, Kypchak and Mongolian epochs; in later times too, the horse and the horse rider as a whole, embodied not only the idea of horsemanship, but also the millennial history of the development of Turkic culture. The nomadic culture of the Turks demanded readiness for long-distance journeys, so breeding strong horses with strong resistance and stamina was essential, and included the training and physical preparation which was carried out in races and other equestrian competitions.

The equestrian games, *kokpar* ("goat-dressing"), *shogen* (polo), *zhambi atu* (archery), *baige* (horse racing) have revealed themselves to be the most popular, fixed in the genetic memory of the Turkic peoples, and therefore their origins are deeply rooted in antiquity and are recorded in the Turkic written documents and ethnic culture of the Turkic peoples. Each of the mentioned games reveals their origins, reflected in the written texts, rules and properties of the games.

The equestrian games of Turkic peoples, including the Kazakh people, found continuity in the ethnic culture of modern Turkic peoples, preserving the basic rules used by the Kazakhs, Kyrgyz, Nogai and others. At festivals, different types of *kokpar* are played; *shogen* became popular especially after the celebration of the 550th anniversary of the Kazakh Khanate, and in Kazakhstan they created the Federation of polo ("shogen"); *jamba* was revived as a historical artefact of ethnic culture; *baige* is still an emotionally spectacular game during weddings, sundet-toys, and anniversary events.

The "World Nomad Games" an international sports competition held in Turkic-speaking countries are also relevant today and considered an analogue of the Olympic Games for Turkic-speaking peoples, where the palette of national sports is revealed, and in which the true spiritual values of the nomadic peoples are preserved, and genetic memory and common historical consciousness are revived, bringing the peoples of the Turkic world closer together.

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### Summary

The article is devoted to the games and competitions of Turkic peoples, which have developed historically over many centuries. Games are activities inherent in the world of nature and man. For man, a game is an expression of his spiritual activity, his intellectual potential, emotional and psychological state and physical and biological capabilities. Human freedom and its ethnic-cultural features are revealed in the equestrian games and competitions of Turkic peoples, considered through the prism of horsemanship culture, when, starting from the Saks, Scythians, Huns, ancient Turks and subsequent eras, a warrior on a warhorse was a symbol of mobility, masculinity, military might, freedom of spirit of the peoples of the Eurasian Steppe. The article analyses equestrian games such as *kokpar* ("goat-dressing"), *shogen* (polo), *zhamby atu* (archery), and *bayge* (horse racing), the latter found to be the most widespread and fixed in the genetic memory of Turkic peoples, the origins of which go back to deep antiquity

and are recorded in Turkic written documents and in the ethnic culture of Turkic peoples. Using the texts "Divani Lugat-it Turk" by M. Kashgari, "Graceful Knowledge" by J. Balasuguni, the epics "Manas", "Alpamys" and other materials from ethnic culture, the authors have tried to determine the origins of horse games, and consider their main content, the behavioural roles of game participants, and reveal the semantic meanings of game lexemes. Equestrian games have a continuity in the culture of modern Turkic peoples and have preserved the basic historical rules through the years. Today they are still played and are spectacular events performed during the ethnic festivals of the Turkic world.

### Riassunto

L'articolo è dedicato ai giochi e alle competizioni dei popoli turchi, che si sono sviluppati storicamente nel corso di molti secoli. I giochi sono attività inerenti al mondo della natura e dell'uomo. Per l'uomo, un gioco è un'espressione della sua attività spirituale, del suo potenziale intellettuale, del suo stato emotivo e psicologico e delle sue capacità fisiche e biologiche. La libertà umana e le sue caratteristiche etnico-culturali si rivelano nei giochi e nelle competizioni equestri turche, considerati attraverso il prisma della cultura dell'equitazione, quando, a partire dai Saks, dagli Sciti, dagli Unni, dagli antichi Turchi e dalle epoche successive, un guerriero su un cavallo da guerra era simbolo di mobilità, mascolinità, potenza militare, e libertà di spirito per i popoli della steppa eurasiatica. L'articolo analizza i giochi equestri come *kokpar* ("acchiappa la capra"), *shogen* (polo), *zhamby atu* (tiro con l'arco) e *bayge* (corse di cavalli), questi ultimi risultati essere i più diffusi e fissati nella memoria genetica dei popoli turchi, le cui origini risalgono a una profonda antichità e sono registrate nei documenti scritti turchi e nella loro cultura etnica. Utilizzando i testi "Divani Lugat-it Turk" di M. Kashgari, "Graceful Knowledge" di J. Balasuguni, i poemi epici "Manas", "Alpamys" e altri materiali della cultura etnica, gli autori hanno cercato di determinare le origini dei giochi ippici, e considerare il loro contenuto principale, i ruoli comportamentali dei partecipanti al gioco, e rivelare i significati semantici dei lessemi di gioco. I giochi equestri hanno una continuità nella cultura dei turchi moderni e hanno conservato le regole storiche di base nel corso degli anni. Oggi vengono ancora eseguiti e sono eventi spettacolari che si svolgono durante le feste etniche.

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- [7] Author surname, initial. (Year) *Book title*. Edition. City: Publisher. DOI: (if available)
- [8] Danielson, D. (ed.) (1999) *The Cambridge companion to Milton*. 2nd edn. Cambridge: Cambridge University Press.

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