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REVIEW FUTURE TECHNOLOGIES IN UNDERWATER CULTURAL HERITAGE

Article 1

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Review Future Technologies in Underwater Cultural Heritage

Abstract

[Ar]

مراجعة التقنيات المستقبلية في التراث الثقافي المغمور بالمياه

يحمل التراث الثقافي المغمور بالمياه، الذي يشمل التحف الأثرية المغمورة بالمياه وحطام السفن والمواقع الأثرية، قيمة تاريخية وثقافية وعلمية هائلة. إن التقدم في تقنيات الذكاء الاصطناعي (AI) لديه القدرة على إحداث ثورة في استكشاف هذه الكنوز المغمورة والحفاظ عليها وفهمها. تتناول هذه المقالة المراجعة الوضع الحالي والآفاق المستقبلية لتقنيات الذكاء الاصطناعي في التراث الثقافي المغمور بالمياه. حيث نقوم بمسح كثير من التطبيقات المعتمدة على الذكاء الاصطناعي، بما في ذلك اكتشاف الأشياء وتصنيفها، والنمذجة التنبؤية، وتحليل البيانات، والمركبات المستقلة تحت الماء. كما نناقش تحديات وقيود الذكاء الاصطناعي في هذا المجال، مثل عدم وجود مجموعات بيانات مصنفة تحت الماء، ونسلط الضوء على تقنيات الذكاء الاصطناعي الناشئة، مثل التعلم العميق، والتعلم المعزز، والنماذج التوليدية، وإمكاناتها لتعزيز أبحاث التراث الثقافي المغمور بالمياه. بالإضافة إلى ذلك، نستكشف تكامل الذكاء الاصطناعي مع التقنيات المتطورة الأخرى مثل الروبوتات، ورؤية الحاسوب، وأنظمة الاستشعار تحت الماء، والتي يمكن أن تفتح إمكانيات جديدة للاستكشاف والتوثيق تحت الماء. أخيرًا، نسلط الضوء على الحاجة إلى تعاون متعدد التخصصات بين علماء الآثار والبحار والحاسوب وخبراء الذكاء الاصطناعي لمواجهة التحديات الفريدة وتسخير الإمكانات الكاملة لتقنيات الذكاء الاصطناعي في التراث الثقافي المغمور بالمياه. تهدف هذه المراجعة إلى إلهام الأبحاث المستقبلية، ودفع التقدم التكنولوجي، والمساهمة في الحفاظ على تراثنا الثقافي المغمور بالمياه وتقديره .

[EN] The exploration, preservation, and understanding of underwater cultural heritage, which includes submerged artifacts, shipwrecks, and archaeological sites, are greatly enhanced by the advancement of artificial intelligence (AI) technologies. This article overviews the current state and future potential of (AI) technologies in the field of underwater cultural heritage, examines various (AI)-driven applications, including object detection and classification, predictive modeling, data analysis, and autonomous underwater vehicles, and explores their implications for this domain. Several challenges and limitations are addressed to fully leverage (AI) in underwater cultural heritage. These challenges include the scarcity of labeled underwater datasets, the influence of environmental variability on data collection and analysis, and the complexities of deploying (AI) systems in underwater environments. Despite these obstacles, emerging (AI) techniques, such as deep learning, reinforcement learning, and generative models show promise in overcoming these challenges and advancing the capabilities of underwater cultural heritage research. Integrating (AI) with other cutting-edge technologies like robotics, computer vision, and underwater sensing systems presents exciting opportunities for underwater exploration and documentation. By combining (AI) algorithms with underwater robots and imaging systems, researchers can efficiently map, and document submerged archaeological sites, identify and classify artifacts, and predict the future condition of underwater cultural heritage. Interdisciplinary collaborations between archaeologists, marine scientists, computer scientists, and (AI) experts are crucial for driving progress in this field. By sharing expertise and knowledge, these collaborations address the unique challenges of underwater cultural heritage and unlock the full potential of (AI) technologies. This review aims to inspire future research, foster technological advancements, and contribute to preserving and appreciating our underwater cultural heritage. Through the integration of (AI) technologies, we uncover hidden historical monuments, deepen our understanding of the past, and ensure the preservation of these valuable underwater resources for future generations.

Keywords: Underwater cultural heritage (UCH), artificial intelligence (AI), augmented reality (AR), future technologies, preservation.

I. Introduction

Artificial Intelligence (AI) has revolutionized the field of underwater exploration by introducing new research methods and technologies. Traditional approaches, such as human divers and remotely operated vehicles (ROVs), have limitations in terms of the depth they can reach, how long they can operate without interruption, and their overall efficiency. AI-powered Robotics and Virtual Reality (VR) have emerged as game-changers in oceanography. Self-navigating robots are equipped with advanced sensors and machine-learning algorithms, allowing them to explore the depths autonomously[1].

Without human intervention, they collect valuable data about underwater ecosystems, geological formations, and sunken shipwrecks[2]. The advancement of digital technologies, including 3D, artificial intelligence (AI), machine learning, cloud computing, data technologies, virtual reality, and augmented reality, has opened unprecedented opportunities for digitization, online access, and digital preservation of cultural resources[3]. One of the most exciting applications of (AI) in underwater exploration is underwater imaging and object recognition[4]. In the past, capturing images in the deep ocean resulted in poor visibility and low-quality images; (AI) algorithms now process and enhance these images, uncovering hidden details[5].

(AI) systems accurately identify and classify marine life and underwater structures. They can distinguish different fish species, identify coral formations, and even detect man-made objects on the ocean floor; this capability contributes to scientific research and has implications for environmental conservation and archaeological discoveries[6]. (AI) has significantly impacted underwater exploration by leveraging technologies such as deep learning and neural networks. These advanced algorithms mimic the human brain's ability to process information and effectively analyze vast datasets[7]. Deep learning enables (AI) systems to recognize patterns, make predictions, and identify anomalies in ocean currents, changes in marine life populations, and even predict underwater geological events like earthquakes and volcanic eruptions[8]. Real-time data analysis is crucial in underwater exploration, and (AI) has made this task more efficient and accurate. (AI)-powered Autonomous Underwater Vehicles (AUVs) process data on the spot and transmit vital information to researchers in real-time[9].

This capability allows scientists to respond promptly to emerging situations like oil spills, tracking endangered species, and monitoring underwater research stations[10].

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[1] Pehlivanides et al. 2020: 8.
[2] Gambin et al. 2021: 12.
[3] Bräuer-Burchardt et al. 2023: 7.
[4] Bruno et al. 2019: 16.
[5] Mogstad et al. 2020: 10.
[6] Argyrou & Agapiou 2022: 5.
[7] Amin 2017: 6.
[8] Browne & Raff 2023: 3.
[9] Pehlivanides et al. 2020: 8.
[10] Argyrou & Agapiou 2022: 5.

(AI) also plays a vital role in environmental conservation. (AI)-powered monitoring systems help track the movements of endangered species, providing critical data for their protection. (AI) algorithms analyze the impact of human activities on marine ecosystems, enabling scientists to develop strategies to mitigate threats and preserve the oceans[11]. To make underwater cultural heritage accessible to the public, multimedia technologies are crucial. Digitizing and creating three-dimensional models of underwater sites allow people who cannot physically dive to experience virtual dives. Researchers use photogrammetry, capturing still shots with an affordable underwater camera, to generate detailed 3D models that provide an immersive and interactive experience[12].

Accessible tools and techniques allow underwater archaeologists to create these models without relying on computer engineers. This approach makes the process more inclusive and promotes eco-friendly tourism[13]. Visitor centers strategically place android robots, virtual reality headsets, and other interactive tools to spark tourists' interest in local marine biodiversity and ecotourism. By leveraging multimedia technologies and immersive experiences, the goal is to bring underwater heritage to wider audiences and encourage sustainable tourism practices[14].

The future of (AI) in underwater exploration holds promising prospects. AI-driven AUVs continuously evolve to reach greater depths, enabling the exploration of the ocean's deepest trenches. Improved communication systems will facilitate real-time data transmission from remote locations[15]. (AI) also contributes to sustainable resource management by monitoring fishing activities, mitigating overfishing, and supporting responsible aquaculture practices[16].

Efficiently applying (AI) in the public cultural domain requires investment in various areas, such as infrastructure, equipment, and highly skilled human labor. Human expertise is crucial as (AI) relies on high-quality data for training and performing its tasks effectively[17]. Interoperability and appropriate metadata are essential for valuable and easily shared data. Resolving copyright issues associated with the use of such data is necessary, and cultural heritage professionals need to acquire the skills required to navigate this complex landscape adeptly[18].

The paper aims to review and analyze future technologies in the context of underwater cultural heritage. It seeks to explore innovative technologies that have the potential to revolutionize the study, preservation, and accessibility of underwater cultural heritage sites. One significant research gap in this field is the limited exploration and

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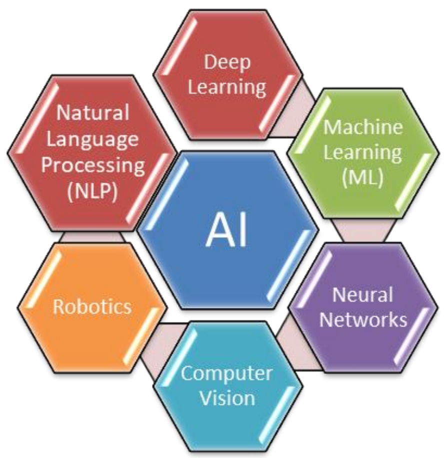
[11] BERGANZO-BESGA et al. 2021: 6.
[12] EL-TAWAB et al. 2020: 8.
[13] BREEN et al. 2021: 10.
[14] BRÄUER-BURCHARDT et al. 2023: 6.
[15] RICCA et al. 2020: 10.
[16] HENDERSON 2019: 2.
[17] ARGYROPOULOS & STRATIGEA 2019: 9.
[18] RICCA et al. 2020: 10.

utilization of emerging technologies for underwater cultural heritage[19]. While there have been advancements in technologies like virtual reality, augmented reality, and artificial intelligence, their specific applications and potential in the context of underwater cultural heritage are not fully explored[20].

Artificial Intelligence in Cultural Heritage

Various studies have highlighted the benefits of incorporating artificial intelligence into archaeological research and excavation; studies emphasize that (AI) significantly reduces the cost and time associated with these processes, particularly in limited archaeological areas. One approach that has shown promise is the use of deep learning (DL) algorithms in analyzing imagery captured by Unmanned Aerial Vehicles (UAVs)[21]. By applying computer vision techniques, (DL) algorithms identify and classify artifacts, structures, and other archaeological features in cost-effective and efficient manners[22]. This technology has the potential to revolutionize archaeological field research, providing support for future projects, especially those operating under tight schedules **[FIGURE 1]**.



[FIGURE 1]: Types of (AI) © Done by the researcher.

Recent advancements in (AI), particularly in computer vision and machine learning, hold promise of transforming the way archaeological research handles vast amounts of data covering large areas; this minimizes reliance on human resources and significantly enhances the speed and accuracy of analysis. Berganzo Besga et al[23] have improved an (AI) algorithm that uses LiDAR and multispectral satellite data for large-scale automatic detection of archaeological tombs, which are common structures of interest. Such automated detection methods offer viable alternatives to manual identification, enabling more efficient and accurate identification of archaeological remains.

[19] MENNA et al. 2018: 6.
[20] BROWNE & RAFF 2023: 3.
[21] ČEJKA et al. 2020: 11.
[22] HAIRY et al. 2020: 11.
[23] BERGANZO-BESGA et al. 2021: 8.

Case Study

Over 2,000 years ago, Baiae stood as a magnificent resort town on the Italian peninsula. Volcanic activity eventually caused half of the town to sink beneath the Mediterranean, transforming Baiae into an underwater archaeological park.

Wireless internet is ineffective in water due to the interaction between water and electromagnetic waves[24]. Researchers have developed a network of acoustic modems and underwater wireless sensors that gather environmental data, which is transmitted to land in real time. This innovative system utilizes (AI) algorithms that continuously adapt to network protocol based on changing sea conditions[25]. As a result, signals travel up to two kilometers, achieving data transmission speeds ranging from kilobits per second to tens of megabits per second, depending on the distance between transmitters **[FIGURE 2]**[16].

[FIGURE 2]: Aided by algorithms, researchers explore the underwater ruin at Baiae. HENDERSON 2019:2.

The underwater internet system at Baiae enables remote and continuous monitoring of environmental conditions, such as PH levels and carbon dioxide concentrations, which affect the preservation of artifacts[26]. It allows divers to communicate with each other, and with colleagues on the surface who use this technology to accurately locate the divers; this advancement in underwater communication technology has significantly enhanced the ability to safeguard the archaeological site and facilitate collaborative exploration and research in this unique underwater landscape[27].

[24] BERGANZO-BESGA et al. 2021: 10.

[25] CALLARIARCHIVE 2022: 1.

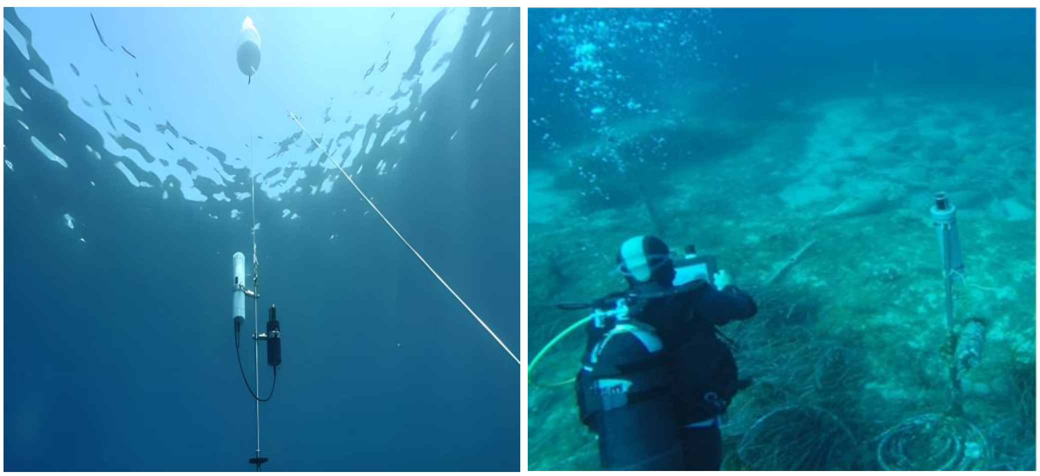
[26] FRIGERIO 2013: 3.

[27] BRUNO et al. 2019: 12.

II. UNDERWATER ACOUSTICS

In the context of underwater exploration, SONAR plays an important role in underwater acoustics systems. SONAR systems utilize the propagation of sound waves between transmitter and receiver to remotely sense the interior of bodies of water, including their floors and structures beneath them[28].

When sound waves encounter a surface interface between two media with different physical characteristics, such as seawater and sandy seabed, several phenomena occur[29]. Part of the sound energy is reflected, another part is refracted and continues to travel in the new medium but with a change in direction of propagation according to Snell's law, and the rest is scattered. By analyzing the energy returned to the sonar device, valuable information about the physical properties of underwater objects are obtained; the principles of modern SONAR have been known to humans for centuries **[FIGURE 3]**. SONAR plays a significant role in archaeological investigations of underwater environments.



[FIGURE 3]: SONAR applying underwater. MENNA et al. 2018: 8.

In archaeological studies, knowing the position and orientation of objects concerning a global reference system (geo-referencing) is often crucial. Airborne or ship-mounted systems achieve direct geo-referencing through a GNSS-INS (Global Navigation Satellite System-Inertial Navigation System) setup[30]. Mobile systems like remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) are fully submerged and cannot rely on satellite-positioning systems. Instead, they integrate other sensors and techniques such as simultaneous localization and mapping (SLAM) and acoustic positioning systems to determine their position accurately underwater[31]. High-resolution surveys conducted in the local reference systems were later geo-referenced using reference points with known coordinates[32].

[28] MENNA et al. 2018: 8.

[29] EID et al. 2018: 5.

[30] LUPIA et al. 2023: 8-9.

[31] KAPETANOVIC et al. 2020: 4.

[32] UNESCO 2023: 2.

2. Limitations and Challenges

While underwater acoustics has proven to be a valuable tool in Underwater Cultural Heritage (UCH), certain limitations and challenges are associated with its usage[33]. Two significant limitations are the propagation and attenuation of sound waves in water [TABLE 1]. In contrast, sound waves travel long distances underwater, and are subject to absorption, scattering, and reflection, which decreases signal strength and limits the range and resolution of acoustic systems, especially in deep-sea environments or areas with poor acoustic conditions[34].

Another challenge in underwater acoustics is interference and noise in aquatic environments. Natural factors like biological activity and anthropogenic sources like ship traffic and ocean currents contribute to high background noise[35]. This interference hinders the accuracy and reliability of underwater acoustic measurements, making it challenging to extract meaningful information from the data collected[36].

Limitations and Challenges	Description
Attenuation	Sound waves in water experience higher attenuation, limiting the range of effective signal transmission.
Ambient Noise	Underwater environments are filled with various sources of ambient noise, which interfere with acoustic signal detection and interpretation.
Multipath Propagation	Multiple reflections, refractions, and scattering of sound waves cause signal distortion and interference.
Limited Bandwidth	Underwater acoustic communication has limited bandwidth, restricting data rate and capacity.
Environmental Variability	Changing environmental factors, such as temperature, salinity, and pressure, affect sound propagation characteristics.
Limited Localization Precision	Achieving precise and accurate localization of sound sources underwater is challenging due to complex propagation and environmental factors.
Doppler Effect	The motion of the sound source or receiver introduces frequent shifts in received signals, leading to errors and distortions.
Sensitivity to Underwater Geometry	Acoustic signal propagation is influenced by underwater objects, seafloor topography, and water layers, making modelling and prediction difficult.
Communication Interference	Interference between multiple underwater acoustic systems degrades performance and limits network capacity.
Cost and Deployment Challenges	Building, deploying, maintaining, and repairing underwater acoustic systems are costly and logistically challenging.

[TABLE 1]: Limitations and challenges of underwater acoustics © Done by the researcher

33 SECCI 2017: 12.
34 KAPETANOVIC et al. 2020: 9.
35 MACLEOD et al. 2019: 6.
36 RICC et al. 2020: 2.

Achieving high-resolution imaging using underwater acoustics is difficult. Wavelengths of sound restrict resolution, transducers' capabilities, and environmental conditions. These limitations make it challenging to capture fine details and distinguish small underwater features accurately[37]. Underwater acoustics remains valuable in UCH research and exploration despite these challenges.

Ongoing advancements in technology and techniques aim to overcome these limitations and improve the capabilities of aquatic acoustic systems, enhancing our understanding and preservation of underwater cultural heritage.

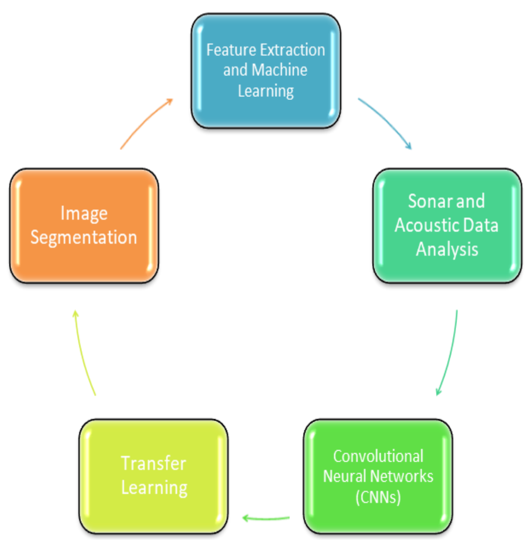
3. Transition to Future Technologies

Artificial Intelligence (AI) in Underwater Archaeological Research

Artificial Intelligence (AI) has emerged as a powerful tool in various fields, and its application in underwater archaeological research holds great promise for advancing exploration, analysis, and preservation of underwater cultural heritage. (AI) technologies assist researchers in object detection and classification, data analysis and interpretation, predictive modeling, and site mapping and reconstruction[38].

1. (AI)-assisted Object Detection and Classification

One of the critical challenges in underwater archaeological research is the identification and classification of submerged artifacts and structures **[FIGURE 4]**. (AI) algorithms are trained to recognize and differentiate objects and features from underwater imagery and sensor data[39].



[FIGURE 4]: Types of (AI) object detection and classification Techniques © Done by the researcher

[37] SECCI 2017: 16.

[38] AGARWALA 2020: 7.

[39] AGAPIOU & LYSANDROU 2023: 4.

Using deep learning techniques, (AI) algorithms analyze large volumes of underwater imagery, such as photographs and video footage, to automatically detect and classify artifacts, shipwrecks, or other submerged structures[40]. This (AI)-assisted object detection and classification enables researchers to efficiently identify and catalogue underwater cultural heritage, saving valuable time and resources[41].

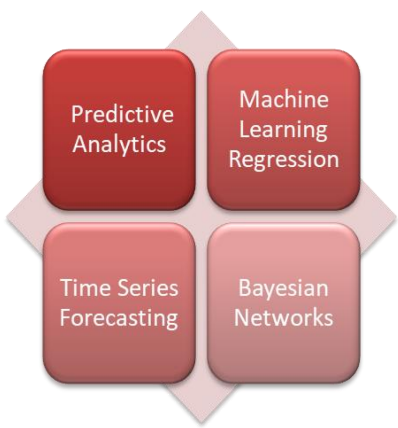
2. (AI)-based Data Analysis and Interpretation

Underwater archaeological research generates vast amounts of data, including sonar data, bathymetric data, and sensor readings. Underwater photogrammetry is the prevailing choice for documenting underwater cultural heritage (UCH)[42]. This method is characterized by its non-destructive nature and affordability, making it highly accessible. This method also generates detailed 3D models and 2D models of underwater archaeological sites and artifacts, boasting impressive levels of resolution and export to VR software[43]. (AI)-based data analysis techniques are employed to process and interpret this data, extracting meaningful patterns and insights.

(AI) algorithms identify data correlations, anomalies, and trends, helping researchers uncover hidden information and make informed interpretations. (AI) assists in identifying patterns in sediment layers, determining the age and origin of artifacts, or detecting environmental changes that impact the preservation of underwater cultural heritage sites.

3. AI-driven Predictive Modeling

(AI) plays a crucial role in predictive modeling, allowing researchers to simulate and forecast various scenarios related to underwater archaeological sites. By combining historical data, environmental factors, and (AI) algorithms, researchers develop predictive models that forecasts the degradation of artifacts, the impact of climate change, or the potential risks of human activities on underwater cultural heritage sites[44].



[FIGURE 5]: Types of (AI) modeling techniques in Underwater Cultural Heritage © Done by the researcher

40 GAMBIN et al. 2021: 11.
41 LUPIA et al. 2023: 8-9.
42 KAMEL & ELSHIWY 2022: 7.
43 CALANTROPIO et al. 2024: 2.
44 REIMANN et al. 2018: 3.

These (AI)-driven predictive models enable researchers to make informed decisions regarding conservation strategies, site management, and future research directions **[FIGURE 5].** They provide valuable insights into the long-term preservation of underwater cultural heritage and help prioritize conservation efforts[45].

4. AI-assisted Site Mapping and Reconstruction

Accurate site mapping and reconstruction are essential for understanding underwater archaeological sites' spatial layout and context. (AI) assists in processing and analyzing sensor data, such as multi-beam sonar data or LiDAR scans, to create detailed 3D models of submerged structures and landscapes[46].

[FIGURE 6]: Reconstruction of an underwater archaeological site with 3D points. BRUNO et al. 2020: 3.

(AI) algorithms automatically process and align multiple data sources, reconstructing the original appearance of the site. AI-assisted site mapping and reconstruction provide researchers with a comprehensive understanding of underwater cultural heritage sites, facilitating further analysis and interpretation [FIGURE 6][50]. These efforts require considerable sourcing, multi-specialists from different fields, and reference data, in order to teach (AI) cultural heritage[47].

Integrating (AI) technologies in underwater archaeological research brings numerous benefits. AI-assisted object detection and classification, data analysis and interpretation, predictive modeling, and site mapping and reconstruction enhance our understanding of underwater cultural heritage's efficiency, accuracy, and depth[48]. By leveraging the power of (AI), researchers unlock new insights, streamline processes, and contribute to preserving and exploring our rich underwater heritage.

[45] KOLIOLIOU et al. 2021: 9.
[46] KAPETANOVIC et al. 2020: 9.
[47] PETRIAGGI et al. 2019: 5.
[48] BROWNE et al. 2023: 8.

III. AUGMENTED REALITY (AR) IN UCH DOCUMENTATION AND PUBLIC ENGAGEMENT

Augmented Reality (AR) revolutionizes how we document, interpret, and engage with underwater cultural heritage (UCH). By blending digital information with the real world, (AR) technologies enhance site visualization, public outreach, education, and create immersive virtual museums and exhibitions[49].

1. AR-enhanced Site Visualization and Interpretation

(AR) provides archaeologists and researchers with enhanced tools for site visualization and interpretation. By overlaying digital reconstructions, historical images, or data onto real-world underwater environment, (AR) allows more comprehensive understanding of submerged sites.

Using (AR)-enabled devices, such as smartphones or headsets, researchers view real-time overlays of virtual elements on underwater sites, aiding in the identification and interpretation of submerged structures, artifacts, and geological features. This AR-enhanced site visualization enables researchers to explore different hypothetical scenarios, test theories, and gain deeper insights into the past. By doing so, it enhances the accuracy and depth of UCH research.

2. (AR)-based Public Outreach and Education

(AR) applications enable visitors to access additional information, multimedia content, and interactive features while exploring museum exhibits or archaeological sites. For example, visitors point their smartphones or tablets at artifacts or site markers, triggering (AR) overlays that provide historical context, 3D models, and virtual reconstructions. Economic barriers are also overcome by generating open-access software and projects in the App. This AR-based public outreach creates a more engaging and educational experience, allowing people to interact with UCH dynamically and interactively.

VR-based demonstrations have been repurposed for public use, although the primary focus of virtual exhibits is the presentation and visualization of archaeological data rather than entertainment[50]. In the realm of underwater environments, there is only a handful of examples where virtual heritage demonstrations incorporate the edutainment approach to engage users. Scholars have leveraged several games in the underwater environment to enhance cultural awareness of underwater archaeology[51]. On the other hand, immersive underwater VR environments have been specifically designed to enhance users' understanding of archaeology by enabling exploration of underwater archaeological sites.

3. (AR)-enabled Virtual Museums and Exhibitions

(AR) facilitates the creation of virtual museums and exhibitions, bringing UCH to broader audiences beyond physical locations. (AR)-enabled virtual museums allow users to

[49] KAMEL et al. 2022: 5.
[50] BRUNO et al. 2018: 3.
[51] BRUNO et al. 2020: 5.

explore and interact with digital replicas of artifacts, submerged sites, and historical contexts from the comfort of their own homes or any location with an AR-enabled device[52].

Remote access to museum resources can be achieved through a Virtual Private Network (VPN) provider that offers strong encryption, good connection speeds, and reliable server availability. By leveraging Content Delivery Networks (CDNs) or cloud-based storage, and the Internet of Underwater Things (IoUT)[53], museums can distribute (AR) content efficiently while reducing the load on their local network and underwater 5G-based networks[54].

Virtual exhibitions feature curated collections, immersive storytelling, and interactive experiences. Users navigate virtual environments, examine detailed 3D models of artifacts, and access multimedia content, allowing them to have a rich and engaging learning experience[55]. (AR)-enabled virtual museums expand access to UCH, making it more inclusive and allowing people from different locations to explore and appreciate our underwater cultural heritage[56].

Augmented Reality (AR) has significant potential in UCH documentation and public engagement. (AR)-enhanced site visualization and interpretation provide researchers with valuable tools for understanding and interpreting underwater archaeological sites. AR-based public outreach and education engage the public more effectively while fostering appreciation and understanding of UCH[57]. (AR)-enabled virtual museums and exhibitions expand access to UCH beyond physical constraints, creating opportunities for a broader audience to explore and learn about our rich underwater cultural heritage.

IV. Synergistic Potential of AI and (AR) in UCH

Integrating (AI) and (AR) has revolutionized how researchers explore and interpret underwater archaeological sites. (AI) algorithms efficiently analyze large volumes of sensor data, such as sonar scans and bathymetric maps, to identify and classify submerged structures and artifacts[58]. This (AI)-driven data analysis is then seamlessly integrated with (AR) technologies, enabling researchers to visualize and interact with the data in real-time. However, this integration requires substantial processing power, and economic and technical challenges associated with ship-based operations must be overcome[59]. The Oil and Gas sector may provide funding for these advancements due to their commercial interests in constructing oil and natural gas pipelines. Such funding would be used for underwater exploration research, particularly in surveying and mapping[60].

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[52] Bruno et al. 2019: 18.
[53] Nkenyereye et al. 2024: 1.
[54] Uga et al. 2021: 12.
[55] Calantropio et al. 2024: 2.
[56] Reimann & et Al. 2018: 10.
[57] Davidde petriaggi 2020: 4.
[58] Manglis et al. 2021: 12.
[59] Kolioliou 2021: 9.
[60] Lupia et al. 2023: 14.

1. Integration of (AI) and (AR) for Enhanced Site Exploration

Integrating Artificial Intelligence (AI) and Augmented Reality (AR) technologies in underwater archaeological sites presents promising avenue for enhancing research and exploration capabilities. (AI) can be utilized for tasks like biofouling detection, semantic segmentation for site detection, and geophysical surveys for mapping submerged cultural landscapes. (AR) provide divers with real-time visualization and interaction with underwater cultural heritage sites, improving the user experience and enabling the exploration of lost buildings and artifacts beneath the sea surface. By combining (AI) for data analysis and (AR) for immersive experiences, researchers and divers can collaborate effectively, leading to deeper understanding and appreciation of underwater archaeological sites[61].

2. (AI) and (AR)-enabled Conservation and Preservation Strategies

(AI) and (AR) play significant roles in developing conservation and preservation strategies for UCH. (AI) algorithms analyze environmental data, historical records, and site characteristics to simulate and predict the impact of various factors on underwater sites, such as climate change, sedimentation, or human activities. By integrating these (AI)-driven predictive models with (AR) technologies, researchers and conservationists can visualize and assess potential risks to UCH in real time.

(AR) overlays display information about the site's vulnerability, recommend conservation measures, or simulate long-term effects of different preservation strategies. This integrated approach of (AI) and (AR) enables more proactive and informed decision-making, ensuring the sustainable preservation of underwater cultural heritage.

3. Ethical Considerations and Challenges

The synergistic use of (AI) and (AR) in UCH research also presents ethical considerations and challenges that must be addressed. These include:

- **A.** Data Privacy: Integrating (AI) and (AR) involves collecting and analyzing large amounts of data, including sensitive information. It is crucial to ensure that appropriate data privacy and security measures are in place to protect the rights and privacy of the individuals and communities associated with UCH.
- **B.** Cultural Sensitivity: UCH is deeply tied to cultural heritage and indigenous knowledge. When applying (AI) and (AR) technologies, engaging with local communities, respecting cultural protocols, and involving stakeholders in decision-making are essential to ensure responsible and respectful use.
- **C.** Accessibility and Inclusivity: (AI) and (AR) should aim to be inclusive and accessible to diverse audiences. Consideration should be given to factors such as language barriers, technological access, and economic barriers. User-friendly interfaces should be designed to ensure that the benefits of these technologies are available to all.

[61] UGA et al. 2021: 5.

D. Accuracy and Interpretation: (AI) algorithms and (AR) visualizations are based on data interpretation and assumptions. Being transparent about these technologies' limitations, uncertainties, and biases is crucial. Researchers should strive for accuracy, validation, and peer review in their application of (AI) and (AR) in UCH3.

The synergistic potential of (AI) and (AR) in underwater cultural heritage research revolutionizes site exploration, conservation strategies, and preservation efforts. By integrating AI-driven data analysis with (AR) visualization, researchers enhance their understanding of underwater sites and make informed decisions. Ethical considerations and challenges, including data privacy, cultural sensitivity, accessibility, and accuracy, must be carefully addressed to ensure these technologies' responsible and inclusive use in UCH research.

V. Future Directions and Challenges in (AI) and (AR) at UCH

As fields of Artificial Intelligence (AI) and Augmented Reality (AR) continue to evolve, several future directions and challenges need to be considered in their application to underwater cultural heritage (UCH) research.

1. Advancements in (AI) and AR Technologies

The future of (AI) and (AR) in UCH research lies in technological advancements. AI algorithms have become more sophisticated, allowing for improved object recognition, data analysis, and predictive modeling. Enhanced machine learning techniques and deep neural networks enable more accurate and efficient processing of large volumes of underwater data.

Similarly, (AR) technologies have advanced in hardware capabilities, display resolution, and tracking accuracy. The development of wearable (AR) devices, such as smart glasses or contact lenses, provides researchers with more seamless and immersive experiences in underwater environments. Continued research and development in (AI) and (AR) drive innovation in UCH research, enabling researchers to explore new possibilities and push the boundaries of knowledge in underwater archaeology and cultural heritage preservation.

2. Technological Limitations and Solutions

Technological limitations still need to be addressed in applying (AI) and (AR) in UCH research despite advancements. These limitations include:

A. Underwater Environment Challenges: The underwater environment presents unique challenges, such as limited visibility, varying water conditions, and data acquisition difficulties. Overcoming these challenges requires the development of robust (AI) algorithms and (AR) systems that can handle and adapt to the complexities of underwater environments[62]. Overcoming challenges in the underwater environment requires robust (AI) algorithms and (AR) systems that adapt to limited visibility,

[62] Reimann et al. 2018: 20.

varying water conditions, and the need for considerable volumes of diverse source data. Gathering and processing such data is crucial for training (AI) models to effectively operate in underwater environments[63].

B. Data Quality and Availability: High-quality data is crucial for accurate analysis and visualization in (AI) and (AR) applications. Obtaining reliable and comprehensive data in underwater settings is challenging. Efforts are being made to improve data collection techniques, enhance sensor technologies, and establish data-sharing collaborations among researchers and institutions[64].

C. Power and Processing Constraints: (AI) and (AR) technologies often require significant computational power and processing capabilities. Overcoming power and processing constraints in underwater settings, where access to power sources is limited, is an essential area of research[65]. Developing energy-efficient algorithms and optimizing hardware solutions help address this challenge.

3. Collaborative Efforts and Interdisciplinary Approaches

The future of (AI) and (AR) in UCH research relies on collaborative efforts and interdisciplinary approaches. The complex nature of UCH requires collaboration among archaeologists, computer scientists, conservators, historians, and other experts to leverage the full potential of (AI) and (AR) technologies.

Collaborative efforts involve knowledge sharing, data exchange, and joint research projects. Interdisciplinary approaches promote the development of comprehensive solutions that integrate domain-specific knowledge with (AI) and (AR) capabilities. This collaboration creates more accurate and contextually rich (AI) algorithms and (AR) applications that address the needs and challenges of UCH research.

By fostering collaboration and interdisciplinary approaches, the future of (AI) and (AR) in UCH research is characterized by innovative solutions, comprehensive insights, and sustainable preservation practices.

The future of (AI) and (AR) in UCH research is promising because of technological advancements that overcome technological limitations, and collaborative efforts. Continued research and development in (AI) and (AR) open new avenues for exploring, interpreting, and preserving underwater cultural heritage. Overcoming challenges and embracing interdisciplinary approaches is crucial for harnessing the full potential of these technologies in UCH research and ensuring the responsible and inclusive use of (AI) and (AR) in the future.

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[63] CALANTROPIO & CHIABRANDO 2024: 6.

[64] PEHLIVANIDES et al. 2020: 12.

[65] MATTEI et al. 2019: 4.

VI. CONCLUSION

Integration of Artificial Intelligence (AI) and Augmented Reality (AR) technologies in underwater cultural heritage (UCH) research holds significant potential for documentation, public engagement, site exploration, conservation strategies, and preservation efforts. Synergistic use of (AI) and (AR) enhances site visualization and interpretation, facilitates public outreach and education, and enables the creation of virtual museums and exhibitions. (AI) and (AR) technologies enhance site exploration by providing researchers with tools for real-time data analysis, visualization, and interpretation of underwater archaeological sites. (AR)-based public outreach and education create immersive and interactive experiences, enabling the public to engage with UCH dynamically and educationally.

AR-enabled virtual museums and exhibitions expand access to UCH, allowing broader audiences to explore and appreciate underwater cultural heritage beyond physical constraints. Integrating (AI) and (AR) supports conservation and preservation efforts by analyzing environmental data, predicting risks, and simulating the impact of various factors on UCH sites. The future of (AI) and (AR) in UCH research lies in advancements in technology, such as (AI) algorithms, (AR) hardware, and data collection techniques. Overcoming technological limitations, including challenges in underwater environments, data quality, and power constraints, will be crucial to effectively applying (AI) and (AR) in UCH research. Collaborative efforts and interdisciplinary approaches are essential for harnessing the full potential of (AI) and (AR) in UCH. Comprehensive solutions that integrate domain-specific knowledge with (AI) and (AR) capabilities were developed by fostering collaboration among archaeologists, computer scientists, conservationists, historians, and other experts. Researchers and institutions collaborate with local communities and stakeholders to ensure responsible and inclusive use of (AI) and (AR) technologies in UCH research, By involving diverse perspectives and knowledge, the benefits of (AI) and (AR) are maximized while respecting the cultural heritage and values associated with UCH.

Integrating (AI) and (AR) in UCH research revolutionizes the field by enhancing site exploration, public engagement, conservation strategies, and preservation efforts. By embracing advancements in technology, addressing challenges, and adopting collaborative and interdisciplinary approaches, we unlock the full potential of (AI) and (AR) in underwater cultural heritage research and contribute to the sustainable preservation and appreciation of our rich underwater heritage. By focusing on application and the use of innovative technologies such as (AI) and (AR), education through 3D gaming harnesses the power of play to facilitate learning. Leveraging 3D assets can actively engage with immersive and interactive experiences, promoting more profound understanding and knowledge retention in various educational domains. This paper aimed to shed light on the transformative potential of these emerging tools in Underwater Cultural Heritage. The exploration of AI's capabilities in underwater archaeological research and the utilization of (AR) for documentation, public engagement, and conservation efforts pave the way for new possibilities in UCH; this enables us to uncover and preserve our submerged cultural heritage like never before. Further research and implementation are needed to address the ethical considerations and challenges of using (AI) and (AR) in UCH. This includes ensuring data privacy, respecting cultural sensitivities, promoting accessibility and inclusivity, and maintaining accuracy and transparency in data interpretation and visualization.

BIBLIOGRAPHY

AGAPIOU, A. & **LYSANDROU**, V.: «Interacting with the Artificial Intelligence (AI) Language Model ChatGPT: A Synopsis of Earth Observation and Remote Sensing in Archaeology», *Heritage* 6/5, 2023, 4072-4085.

AGARWALA, N.:. «Monitoring the Ocean Environment Using Robotic Systems: Advancements, Trends, and Challenges», *Marine Technology Society Journal* 54/5, 2020, 42-60.

AMIN, M.M.: «The Effect of Underground Water on Heritage Sites (a Case Study on Graeco-Roman Cemeteries in Alexandria)», *Journal of Association of Arab Universities for Tourism and Hospitality* 14/1, 2017, 65-78.

ARGYROPOULOS, V. **& STRATIGEA,** A.: «Sustainable Management of Underwater Cultural Heritage: The Route from Discovery to Engagement—Open issues in the Mediterranean», *Heritage* 2/2, 2019, 1588-1613.

ARGYROU, A. & **AGAPIOU**, A.: «A Review of Artificial Intelligence and Remote Sensing for Archaeological Research», *Remote Sensing*, 14/23, 2022, 6000.

BERGANZO-BESGA, I., **ORENGO**, H.A., **LUMBRERAS**, F., **CARRERO-PAZOS**, M., **FONTE**, J. & **VILAS-ESTÉVEZ**, B.: «Hybrid MSRM-Based Deep Learning and MultitemporalSentinel 2-Based Machine Learning Algorithm Detects Near 10k Archaeological Tumuli in North-Western Iberia», *Remote Sens* 13/20, 2021, 4181.

BRÄUER-BURCHARDT, C., **MUNKELT**, C., **BLEIER**, M., **HEINZE**, M., **GEBHART**, I., **KÜHMSTEDT**, P., & **NOTNI**, G.: «Underwater 3D Scanning System for Cultural Heritage Documentation», *Remote Sensing* 15/7, 2023, 1864.

BREEN, C., **EL SAFADI**, C., **HUIGENS**, H., **TEWS**, S., **WESTLEY**, K., **ANDREOU**, G., & **BLUE**, L.:«Integrating Cultural and Natural Heritage Approaches to Marine Protected Areas in the MENA Region», *Marine Policy* 132, 2021, 104676.

BROWNE, K., & **RAFF,** M.: *International Law of Underwater Cultural Heritage: Understanding the Challenges*, (Springer Nature Switzerland) 2023.

BRUNO, F., **BARBIERI,** L., **MUZZUPAPPA**, M., **TUSA**, S., **FRESINA**, A., **OLIVERI**, F., & **PELUSO**, R.: «Enhancing Learning and Access to Underwater Cultural Heritage through Digital Technologies: The Case Study of the "Cala Minnola" Shipwreck Site», *Digital Applications in Archaeology and Cultural Heritage* 13, 2019, e00103.

BRUNO, F., **RICCA**, M., **LAGUDI,** A., **KALAMARA**, P., **MANGLIS,** A., **FOURKIOTOU**, A., & **VENETI**, A.: «Digital Technologies for the Sustainable Development of Accessible Underwater Cultural Heritage Sites», *Journal of Marine Science and Engineering* 8/11, 2020, 955.

ČEJKA, J., **ZSÍROS**, A., & **LIAROKAPIS**, F.: «A Hybrid Augmented Reality Guide for Underwater Cultural Heritage Sites», *Personal and Ubiquitous Computing* 24, 2020, 815-828.

DAVIDDE P.B., **STEFANILE,** M., **D'AGOSTINO**, M., **RICCI**, S. & **SACCO PERASSO**, C.:«MUSAS: An Innovative Project for the Enhancement of the Underwater Cultural Heritage», in *International Conference in Management of Accessible Underwater, Cultural and Natural Heritage Sites: «Dive in Blue Growth»*, Athens, 2019, 169-179.

EID, E., **AL FAKHRI**, S. & **ISLAM**, S.: «Aqaba Marine Heritage Project», in *Archaeology in Jordan Newsletter: 2016 and 2017 Seasons*, edited by J.D.M. GREEN, B.A. PORTER & C.P. SHELTON, Amman (American Center of Oriental Research) 2018, 98–99.

EL-TAWAB, A., **MEHANNA**, W. & **ALASHWAH**, F.: «Sustainable Conservation of the Submerged Historic City of Heracleion, Alexandria», *Journal of Engineering Research* 4, 2020, 17-28.

FRIGERIO, A.: «The Underwater Cultural Heritage: A Comparative Analysis of International Perspectives, Laws, and Management Methods», *IMT Institute for Advanced Studies*, Lucca, 1-402, 2013.

GAMBIN, T., **HYTTINEN**, K., **SAUSMEKAT,** M. & **WOOD**, J.: «Making the Invisible Visible: Underwater Malta—A Virtual Museum for Submerged Cultural Heritage», *Remote Sensing* 13/8, 2021, 1558.

HAIRY, I.: «The Qaitbay Underwater Site at Alexandria, Egypt: The Evolution of Surveying Techniques», In *Under the Mediterranean: The Honor Frost Foundation Conference on Mediterranean Maritime Archaeology*, 2020.

Henderson, J.: «Oceans without History? Marine Cultural Heritage and the Sustainable Development Agenda », *Sustainability* 11, 2019, 5080.

Kamel, N.A. & **Elshiwy**, R.:«Virtual Reality and Virtual Diving Technologies: Innovative Tools to Promote Maritime and Underwater Cultural Heritage in the Red Sea, Egypt »*Journal of Tourism, Hotels and Heritage* 5/3, 2022, 18-46.

Kapetanović, N., **Vasilijević**, A., **Nađ**, Đ., **Zubčić**, K., & **Mišković**, N.:«Marine Robots Mapping the Present and the Past: Unraveling the Secrets of the Deep» *Remote Sensing* 12/23, 3902.

Kolioliou, D.: «The Development of a Video Game that Aims to Promote the Underwater Cultural Heritage and the Sustainability of the Underwater Archaeological Parks», MA Thesis, Sustainability and Quality in the Marine Industry/ University of Piraeus, 2021, 1-200.

Reimann, A.T., **Vafeidis**, S., **Brown**, J., **Hinkel** & **Tol**, R.: «Mediterranean UNESCO World Heritage at Risk from Coastal Flooding and Erosion due to Sea-Level Rise», *Nat.Commun* 9, 2018, 4161.

Lupia, M., **Gagliardi**, G., **Cario**, G., **Cicchello** G., F., **D'angelo**, V., & **Folino**, P.: «A Smart System for Environmental Parameter Monitoring in Underwater Archaeological Sites», *Electronics* 12/13, 2023, 2918.

Macleod, I.D.: «Corrosion and Conservation Management of the Submarine HMAS AE2 (1915) in the Sea of Marmara, Turkey», *Heritage* 2/1, 2019, 868-883.

Manglis, A., **Fourkiotou**, A., & **Papadopoulou**, D., «A Roadmap for the Sustainable Valorization of Accessible Underwater Cultural Heritage Sites», Heritage 4/4, 2021, 4700-4715.

Manuela Callari: «AI is Bringing the Internet to Submerged Roman Ruins» https://www.technologyreview.com/2022/12/29/1064745/underwater-internet-ai-roman-ruins/ (2022). Accessed on (16/01/ 2024).

Mattei, G., **Rizzo**, A., **Anfuso**, G., **Aucelli**, P.P.C. & **GRACIA**, F.J.: «A Tool for Evaluating the Archaeological Heritage Vulnerability to Coastal Processes: The Case Study of Naples Gulf (Southern Italy) », *Ocean & Coastal Management* 179, 2019, 104876.

Mogstad, A.A., **Ødegård**, Ø., **Nornes**, S.M., **Ludvigsen**, M., **Johnsen**, G., **Sørensen**, A. J., & **Berge**, J.: «Mapping the Historical Shipwreck Figaro in the High Arctic Using Underwater Sensor-Carrying Robots», *Remote Sensing* 12/6, 2020, 997.

Pehlivanides, G., **Monastiridis**, K., **Tourtas**, A., **Karyati**, E., **Ioannidis**, G., **Bejelou**, K., & **Nomikou**, P.: «The VIRTUALDiver Project. Making Greece's Underwater Cultural Heritage Accessible to the Public», *Applied Sciences* 10/22, 2020, 8172.

Reimann, L., **Vafeidis**, A.T., **Brown**, S., **Hinkel**, J., & TOL, R.S., «Mediterranean UNESCO World Heritage at Risk from Coastal Flooding and Erosion due to Sea-Level Rise», *Nature Communications* 9/1, 2018, 4161.

Ricca, M., **Alexandrakis**, G., **Bonazza**, A., **Bruno**, F., **Davidde Petriaggi**, B., **Elkin**, D., & **Francesco,** LA RUSSA.M.: «A Sustainable Approach for Managing and Valorizing Underwater Cultural Heritage: New Perspectives from the TECTONIC Project», *Sustainability* 12/12, 2020, 5000.

Secci, M.: «Survey and Recording Technologies in Italian Underwater Cultural Heritage: Research and Public Access within the Framework of the 2001 UNESCO Convention», *Journal of Maritime Archaeology* 12, 2017, 109-123.

UGA, M., **Bruno**, F., **Skarlatos**, D., & **Liarokapis,** F.: «Evaluating the Potential of Augmented Reality Interfaces for Exploring Underwater Historical Sites», *IEEE Access* 9, 2021, 45017-45031.

UNESCO: «Underwater Cultural Heritage», https://en.unesco.org/underwater-heritage, Accessed on (15/09/ 2023).

Calantropio, A., & **Chiabrando**, F.: «Underwater Cultural Heritage Documentation Using Photogrammetry», *Journal of Marine Science and Engineering* 12/3, 2024, 413.

Nkenyereye, L., **Nkenyereye**, L., & **Ndibanje,** B.: «Internet of Underwater Things: A Survey on Simulation Tools and 5G-Based Underwater Networks», *Electronics* 13/3, 2024, 474.