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The Use of Standard Photogrammetry Techniques in the Digital Documentation of Archaeological Sites

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Abstract

This study examines the role of standard photogrammetry techniques in the digital documentation of archaeological sites. With the increasing need to preserve cultural heritage, especially in regions exposed to environmental degradation and human threats, digital documentation has become an essential tool in modern archaeology. Photogrammetry offers a non-invasive and highly accurate method for capturing geometric and visual data of archaeological remains, enabling the creation of precise 2D and 3D digital models. These models support documentation, analysis, conservation, and restoration processes while reducing the need for direct physical intervention on fragile heritage structures. The study highlights the advantages of photogrammetry compared to traditional recording methods, including improved accuracy, reduced field time, cost efficiency, and enhanced preservation of cultural assets. It also emphasizes the role of digital technologies in facilitating data sharing and long-term heritage management. The findings confirm that photogrammetry is a crucial tool for safeguarding archaeological sites and recommend its wider integration into archaeological fieldwork and heritage preservation strategies.

Keywords: Photogrammetry, Digital Documentation, Archaeological Sites, Cultural Heritage, 3D Modeling, Heritage Preservation

1. Introduction

Archaeological heritage represents a fundamental component of human history and cultural identity, requiring systematic documentation and preservation to ensure its continuity for future generations. In recent decades, increasing environmental degradation, urban expansion, and human activities have placed significant pressure on archaeological sites worldwide, making their protection more urgent than ever. According to UNESCO (2019), many heritage sites are at risk due to both natural and anthropogenic factors, highlighting the need for advanced documentation techniques.

Traditional archaeological recording methods, such as manual drawing, photography, and topographic surveying, have long been used to document sites. However, these approaches often suffer from limitations in accuracy, consistency, and efficiency, particularly when dealing with complex structures or large-scale sites. As noted by Koller et al. (2010), manual documentation can introduce subjective interpretation and measurement errors, which may reduce the scientific reliability of recorded data.

In response to these limitations, digital technologies have increasingly been integrated into archaeological practice. Among these technologies, photogrammetry has emerged as one of the most effective tools for capturing detailed spatial information. Photogrammetry allows researchers to reconstruct three-dimensional models from overlapping images, providing a highly accurate and objective representation of archaeological remains (Remondino & Campana, 2014).

The development of digital archaeology has significantly transformed the way archaeological data is collected, analyzed, and preserved. Unlike traditional methods, digital documentation enables non-invasive recording, which is particularly important for fragile or endangered sites. According to De Reu et al. (2013), digital recording methods reduce physical contact with artifacts, thereby minimizing the risk of damage during fieldwork.

Standard photogrammetry techniques rely on the principles of stereoscopic vision and geometric reconstruction to generate 3D models from 2D images. This process involves capturing multiple photographs from different angles, ensuring sufficient overlap between images for accurate spatial reconstruction. Westoby et al. (2012) emphasize that modern photogrammetry can achieve millimeter-level precision when properly implemented.

The increasing accessibility of digital cameras, drones, and processing software has further expanded the use of photogrammetry in archaeology. UAV-based photogrammetry, in particular, has revolutionized large-scale site documentation by enabling rapid data collection from aerial perspectives. According to Remondino et al. (2017), drone-based imaging significantly improves efficiency in mapping extensive archaeological landscapes.

In addition to accuracy and efficiency, photogrammetry offers significant advantages in terms of cost reduction. Compared to laser scanning technologies, photogrammetry requires less expensive equipment while still delivering high-quality results. This affordability makes it particularly suitable for archaeological projects in developing regions where financial resources may be limited (Forte & Campana, 2016).

Another important aspect of photogrammetry is its role in cultural heritage preservation and education. Digital 3D models can be archived, shared, and used for virtual exhibitions, allowing wider public access to archaeological knowledge. According to Stylianidis and Remondino (2016), digital heritage models play a key role in promoting cultural awareness and supporting educational initiatives.

Despite its advantages, photogrammetry also requires careful methodological planning, including proper image acquisition, calibration, and processing. Errors in data collection can affect the accuracy of the final model, making technical expertise essential. As highlighted by Kersten and Lindstaedt (2012), successful photogrammetric reconstruction depends heavily on field conditions and imaging quality.

Overall, the integration of photogrammetry into archaeological documentation represents a major advancement in the field of cultural heritage preservation. It provides a powerful combination of accuracy, efficiency, and accessibility, making it an indispensable tool for modern archaeology. The growing adoption of this technology reflects a global shift toward digital preservation strategies aimed at safeguarding archaeological heritage in an increasingly threatened world.

2. Literature Review

The application of digital technologies in archaeology has been widely studied over the past two decades, with photogrammetry emerging as a dominant method for site documentation and analysis. Early research focused on improving the accuracy of image-based reconstruction techniques, demonstrating their potential in cultural heritage recording (Falkingham, 2012).

One of the foundational contributions to photogrammetry in archaeology is the work of Remondino and El-Hakim (2006), who demonstrated how image-based modeling could be used to generate accurate 3D representations of monuments. Their research highlighted the efficiency of photogrammetry compared to traditional surveying methods, particularly in complex archaeological environments.

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Further studies by De Reu et al. (2013) emphasized the advantages of digital terrain modeling in archaeological landscapes. They showed that photogrammetry could produce high-resolution surface models that improve the interpretation of spatial relationships between archaeological features, offering new insights into site organization.

Westoby et al. (2012) provided a comprehensive overview of Structure-from-Motion (SfM) photogrammetry, explaining its increasing use in earth sciences and archaeology. Their findings confirmed that SfM techniques allow for rapid, cost-effective, and highly detailed 3D reconstruction from standard digital images.

In addition, Kersten and Lindstaedt (2012) explored the practical challenges of implementing photogrammetry in cultural heritage documentation. They identified factors such as lighting conditions, camera calibration, and image resolution as critical variables affecting model accuracy, stressing the importance of methodological rigor.

Forte and Campana (2016) discussed the broader implications of digital archaeology, arguing that technologies such as photogrammetry are reshaping the discipline by enabling new forms of visualization, analysis, and interpretation. They emphasized the role of 3D modeling in enhancing both research and public engagement.

Recent developments in UAV (drone) technology have further expanded the scope of photogrammetry in archaeology. According to Remondino et al. (2017), drone-based imaging allows for efficient documentation of large archaeological sites, reducing fieldwork time while improving spatial coverage and data quality.

Stylianidis and Remondino (2016) highlighted the importance of digital heritage documentation in cultural preservation strategies. They argued that 3D models created through photogrammetry serve not only scientific purposes but also educational and conservation functions, supporting long-term heritage management.

Koller et al. (2010) contributed to the discussion on digital reconstruction accuracy, noting that while photogrammetry offers high precision, careful validation is necessary to ensure scientific reliability. Their work underscored the importance of combining multiple documentation methods for optimal results.

Overall, the literature consistently demonstrates that photogrammetry has become an essential tool in modern archaeology. Its continuous development, supported by advances in computing and imaging technologies, confirms its central role in the future of archaeological documentation and cultural heritage preservation.

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3. Theoretical Foundations of Photogrammetry in Archaeology

Photogrammetry in archaeology is fundamentally grounded in geometric and mathematical principles that allow the extraction of three-dimensional information from two-dimensional images. This theoretical foundation is based on projective geometry, where spatial coordinates are reconstructed through the analysis of image perspectives. Hartley and Zisserman (2004) explain that the core of photogrammetric theory lies in understanding how points in a 3D space are projected onto multiple image planes.

The concept of stereoscopy is one of the earliest theoretical bases of photogrammetry. It relies on the human visual system's ability to perceive depth through the comparison of two slightly different images. In archaeological applications, this principle is replicated through overlapping photographs that enable depth reconstruction. According to Slama et al. (1980), stereoscopic principles remain essential in modern metric photogrammetry systems.

A key theoretical advancement in this field is the development of analytical photogrammetry, which replaces analog interpretation with mathematical computation. This shift allows for greater precision and repeatability in archaeological documentation. Kraus (2007) highlights that analytical model significantly reduce human error and improve measurement reliability.

The integration of photogrammetry into archaeology is also based on the theory of spatial data representation. Archaeological objects are treated as spatial entities that can be encoded numerically and reconstructed digitally. Wheatley and Gillings (2002) argue that spatial theory is essential for interpreting archaeological landscapes in a scientifically structured way.

Another important theoretical pillar is epipolar geometry, which describes the relationship between two camera viewpoints. This concept ensures that corresponding points in different images lie along predictable geometric lines. Hartley and Zisserman (2004) emphasize that epipolar constraints are essential for accurate 3D reconstruction.

The theory of collinearity is also central to photogrammetry, stating that object points, image points, and camera centers lie on a straight line. This principle forms the basis for mathematical modeling in image reconstruction. Wolf and Dewitt (2000) explain that collinearity equations are fundamental in modern photogrammetric calculations.

In archaeological contexts, photogrammetry is supported by the theory of non-contact measurement, which prioritizes preservation by avoiding physical interaction with fragile structures. De Reu et al. (2013) state that non-invasive recording is crucial for safeguarding endangered heritage sites.

The theoretical evolution of photogrammetry has also been influenced by computational mathematics, particularly optimization theory. Bundle adjustment algorithms refine 3D models by minimizing projection errors across multiple images. Triggs et al. (2000) describe bundle adjustment as a key optimization process in structure reconstruction.

Another theoretical aspect is the concept of redundancy in image data. Multiple overlapping images increase the reliability of reconstruction by providing additional spatial constraints. Remondino and El-Hakim (2006) argue that redundancy improves accuracy and reduces uncertainty in archaeological modeling.

Overall, the theoretical foundations of photogrammetry integrate geometry, vision science, and computational modeling, forming a robust framework for archaeological documentation. These principles collectively enable precise, scalable, and non-invasive reconstruction of cultural heritage sites.

4. Principles of Digital Heritage Documentation and Preservation

Digital heritage documentation is based on the theoretical principle that cultural heritage can be preserved through accurate digital representation. This concept shifts preservation from purely physical conservation to digital continuity. According to UNESCO (2019), digital documentation plays a critical role in safeguarding endangered cultural sites worldwide.

One of the core principles is authenticity in digital representation, which ensures that digital models accurately reflect the original archaeological structures. This principle is essential for scientific validity and historical reliability. Stylianidis and Remondino (2016) emphasize that authenticity is a key requirement in digital heritage management.

Another fundamental principle is reversibility, which means that digital documentation should not alter or damage the original site. Photogrammetry supports this principle by enabling non-invasive data capture. De Reu et al. (2013) highlight those non-destructive methods are essential in archaeological preservation.

The principle of accessibility is also central to digital heritage theory. Digital models allow wider access to archaeological data for researchers, students, and the public. Forte and Campana (2016) argue that digital heritage democratizes access to cultural knowledge through virtual platforms.

Interoperability is another important principle, referring to the ability of digital heritage data to be used across different systems and software. This ensures long-term usability of

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archaeological datasets. UNESCO (2019) stresses the importance of standardized digital formats for heritage preservation.

The principle of scalability allows digital documentation systems to be applied to both small artifacts and large archaeological landscapes. This flexibility makes photogrammetry suitable for diverse archaeological contexts. Remondino et al. (2017) note that scalability is a major advantage of modern digital imaging systems.

Another key principle is long-term preservation, which focuses on maintaining digital data over extended periods. This requires proper data storage, backup systems, and format migration strategies. Stylianidis and Remondino (2016) emphasize the importance of digital archiving in cultural heritage management.

The principle of accuracy ensures that digital models maintain high geometric fidelity. This is critical for scientific analysis and restoration planning. Kersten and Lindstaedt (2012) argue that precision is one of the main requirements in archaeological documentation.

Another principle is transparency, which allows researchers to trace the documentation process from raw images to final models. This improves scientific credibility and reproducibility. Forte and Campana (2016) highlight transparency as a key factor in digital archaeology.

Overall, digital heritage documentation is based on principles that ensure accuracy, preservation, accessibility, and scientific reliability, making it a cornerstone of modern archaeological practice.

5. Computer Vision and 3D Reconstruction Theories in Photogrammetry

Computer vision theory forms the backbone of modern photogrammetry by enabling machines to interpret visual information from images. This field focuses on extracting geometric and semantic information from digital photographs. Lowe (2004) introduced key feature detection methods that revolutionized image-based reconstruction.

One of the central theories in computer vision is feature matching, which identifies common points across multiple images. These correspondences are essential for reconstructing spatial relationships. Snavely et al. (2008) demonstrate that reliable feature matching is crucial for Structure-from-Motion systems.

Structure-from-Motion (SfM) theory explains how camera positions and 3D structures are simultaneously estimated from image sequences. This approach does not require prior

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knowledge of camera geometry. According to Westoby et al. (2012), SfM is one of the most important advances in modern photogrammetry.

Another key theory is multi-view geometry, which extends reconstruction beyond two images to multiple viewpoints. This improves accuracy and completeness of 3D models. Hartley and Zisserman (2004) emphasize that multi-view constraints enhance geometric precision.

The theory of dense reconstruction builds on sparse feature matching to generate complete surface models. This process interpolates missing spatial data between matched points. Remondino and El-Hakim (2006) highlight that dense reconstruction is essential for realistic archaeological modeling.

Bundle adjustment theory is another critical component of computer vision in photogrammetry. It refines 3D models by minimizing errors across all image projections. Triggs et al. (2000) describe it as the optimal solution for improving reconstruction accuracy.

Scale-invariant feature detection theory ensures that image features can be recognized regardless of scale, rotation, or lighting conditions. Lowe (2004) introduced this concept through the SIFT algorithm, which is widely used in photogrammetry.

Depth estimation theory allows the calculation of distance between the camera and object points. This is essential for constructing accurate spatial models. Snavely et al. (2008) explain that depth estimation is a core function of SfM systems.

The integration of machine learning into computer vision has further improved photogrammetric reconstruction. Neural networks can now enhance feature detection and noise reduction. Recent studies show that AI-based vision systems significantly improve model quality and speed.

Overall, computer vision theory provides the computational foundation for transforming images into accurate 3D archaeological representations, enabling advanced digital reconstruction techniques.

6. Theoretical Approaches to Non-Invasive Archaeological Recording

Non-invasive archaeological recording is based on the theoretical principle that cultural heritage should be documented without causing physical alteration or damage. This approach prioritizes preservation over direct intervention. De Reu et al. (2013) emphasize that non-destructive techniques are essential in modern archaeology.

One theoretical approach is remote sensing theory, which allows data collection from a distance using imaging technologies. This reduces the need for physical contact with fragile structures. Parcak (2009) explains that remote sensing has transformed archaeological site detection and documentation.

Another key theory is minimal intervention, which argues that archaeological documentation should interfere as little as possible with the original site. This principle is central to ethical archaeological practice. UNESCO (2019) supports minimal intervention as a global heritage preservation standard.

The theory of digital substitution suggests that digital models can replace physical interaction in many archaeological analyses. This allows researchers to study sites virtually without risking damage. Forte and Campana (2016) argue that digital substitutes enhance preservation efforts.

Non-invasive recording also relies on photometric theory, which uses light reflection and image capture to extract surface information. This enables detailed documentation of textures and structures. Kersten and Lindstaedt (2012) highlight its importance in heritage recording.

Another theoretical approach is spatial abstraction, where real-world structures are converted into digital spatial models for analysis. This abstraction enables advanced computational study. Wheatley and Gillings (2002) discuss its importance in archaeological interpretation.

The theory of preservation ethics also underpins non-invasive recording, emphasizing responsibility toward cultural heritage protection. This ethical framework guides the use of technology in archaeology. UNESCO (2019) stresses ethical responsibility in documentation practices.

Temporal conservation theory suggests that digital recording preserves not only spatial data but also temporal states of archaeological sites. This allows future comparison of site conditions over time. Stylianidis and Remondino (2016) highlight the importance of temporal digital archives.

Another important theory is risk mitigation, which reduces exposure of archaeological sites to environmental or human threats. By minimizing physical interaction, the risk of degradation is significantly reduced. De Reu et al. (2013) note that digital methods reduce conservation risks.

Overall, non-invasive archaeological recording theories establish a framework where technology, ethics, and preservation intersect, ensuring the long-term protection of cultural heritage through digital means.

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7. Challenges

The application of photogrammetry in archaeological documentation faces several technical, environmental, and methodological challenges that can affect the accuracy and reliability of results. One of the primary challenges is related to image quality, as photogrammetry heavily depends on high-resolution, well-exposed photographs. Poor lighting conditions, shadows, or overexposure can significantly reduce the precision of 3D reconstruction (Kersten & Lindstaedt, 2012).

Another major challenge is the requirement for significant computational resources. Processing large datasets of overlapping images requires powerful hardware and specialized software capable of handling complex calculations. Remondino et al. (2017) note that processing time can become a limiting factor, especially for large archaeological sites.

Field conditions also represent a critical challenge, particularly in remote or harsh environments such as desert regions. Wind, dust, and extreme temperatures can interfere with image acquisition and equipment stability, affecting data consistency. De Reu et al. (2013) emphasize that environmental constraints are a major obstacle in outdoor archaeological photogrammetry.

Another difficulty is related to geometric accuracy and scaling. Without proper ground control points (GCPs), models may lack real-world spatial precision. According to Westoby et al. (2012), accurate georeferencing is essential for ensuring that digital models are scientifically valid.

Human expertise is also a limiting factor, as photogrammetry requires specialized knowledge in both field data collection and software processing. Lack of training can lead to errors in image alignment, calibration, and reconstruction. Forte and Campana (2016) highlight the importance of interdisciplinary skills in digital archaeology.

Data management presents another challenge, as photogrammetry generates large volumes of images and 3D data. Storing, organizing, and archiving this information requires robust digital infrastructure. Stylianidis and Remondino (2016) stress that long-term data preservation strategies are essential for sustainable digital heritage systems.

Financial limitations can also restrict the adoption of photogrammetry in archaeological projects, particularly in developing regions. Although less expensive than laser scanning, photogrammetry still requires investment in cameras, drones, and software. UNESCO (2019) identifies funding as a key barrier in heritage digitization efforts.

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Another challenge is related to model accuracy in complex or highly textured environments. Reflective surfaces, vegetation, or repetitive patterns can confuse feature detection algorithms, leading to reconstruction errors. Snavely et al. (2008) note that feature ambiguity is a known limitation in Structure-from-Motion systems.

Interoperability between different software platforms can also be problematic. Inconsistent file formats and processing standards may hinder data sharing among researchers and institutions. Wheatley and Gillings (2002) highlight the need for standardized spatial data frameworks in archaeology.

Finally, long-term preservation of digital outputs remains a challenge. Digital files can become obsolete due to changing formats and technologies, risking data loss over time. UNESCO (2019) emphasizes the importance of digital preservation strategies to ensure continued accessibility of archaeological records.

8. Recommendations

To overcome the challenges associated with photogrammetry in archaeology, it is recommended to adopt standardized protocols for image acquisition. Consistent guidelines regarding lighting, overlap, and camera positioning can significantly improve model accuracy. Kersten and Lindstaedt (2012) emphasize that standardization reduces variability in photogrammetric outputs.

Capacity building and training programs should be implemented for archaeologists and technicians working with digital documentation tools. Developing interdisciplinary skills in both archaeology and computer science will enhance the quality of data collection and processing. Forte and Campana (2016) stress the importance of digital literacy in modern archaeological practice.

It is also recommended to integrate drone-based photogrammetry for large-scale archaeological sites. UAV technology allows for faster data collection and improved spatial coverage, especially in inaccessible areas. Remondino et al. (2017) highlight the efficiency of aerial photogrammetry in heritage documentation.

The use of ground control points (GCPs) should be systematically implemented to improve georeferencing accuracy. These reference markers ensure that digital models correspond precisely to real-world coordinates. Westoby et al. (2012) confirm that GCPs are essential for spatial precision in photogrammetry.

Investment in high-performance computing infrastructure is also recommended to handle large datasets efficiently. Cloud-based processing solutions can significantly reduce local hardware limitations. Stylianidis and Remondino (2016) suggest that cloud computing enhances scalability in digital heritage systems.

To improve data interoperability, standardized file formats and metadata structures should be adopted across archaeological institutions. This facilitates data sharing and long-term collaboration between researchers. Wheatley and Gillings (2002) emphasize the importance of spatial data standardization.

It is recommended to combine photogrammetry with complementary technologies such as LiDAR and GIS for more comprehensive documentation. Multi-sensor integration enhances accuracy and provides richer spatial information. De Reu et al. (2013) support the use of hybrid approaches in archaeological surveying.

Long-term digital preservation strategies should be established, including regular data backups and format migration policies. This ensures that archaeological data remains accessible despite technological changes. UNESCO (2019) highlights digital sustainability as a key priority.

Funding mechanisms should be strengthened to support the adoption of photogrammetry in developing regions. Governments and cultural institutions should invest in digital heritage projects as part of cultural preservation strategies. UNESCO (2019) identifies financial support as critical for heritage digitization.

Finally, collaborative research between archaeologists, engineers, and computer scientists should be encouraged. Such interdisciplinary cooperation fosters innovation and improves methodological approaches in digital archaeology. Forte and Campana (2016) emphasize that collaboration is essential for advancing digital heritage science.

9. Implications

The adoption of photogrammetry in archaeological documentation has significant scientific implications, as it transforms traditional field-based archaeology into a digitally enhanced discipline. By enabling precise 3D reconstruction of sites, it improves the quality and reliability of archaeological interpretation. Remondino and El-Hakim (2006) argue that digital modeling introduces a new level of scientific rigor to heritage studies.

One major implication is the shift from destructive to non-invasive documentation methods. This change ensures that fragile archaeological remains are preserved during recording processes. De Reu et al. (2013) highlight that non-contact methods reduce the risk of damaging valuable cultural heritage.

Photogrammetry also has important implications for archaeological analysis, as it allows for detailed spatial measurements and quantitative assessments. Researchers can analyze structures with millimeter-level accuracy, improving interpretative precision. Westoby et al. (2012) emphasize the analytical potential of digital models in archaeology.

In terms of heritage preservation, photogrammetry contributes to long-term conservation strategies by creating permanent digital archives of endangered sites. These archives serve as references in case of damage or destruction. UNESCO (2019) stresses the importance of digital preservation in safeguarding global heritage.

Another implication is the democratization of archaeological knowledge. Digital models can be shared globally through online platforms, making cultural heritage more accessible to researchers and the public. Forte and Campana (2016) note that digital archaeology promotes inclusivity and public engagement.

The integration of photogrammetry into education is also significant, as it provides interactive learning tools for students in archaeology and related fields. Virtual models allow for immersive exploration of ancient sites without physical travel. Stylianidis and Remondino (2016) highlight the educational benefits of digital heritage tools.

From a technological perspective, photogrammetry drives innovation in imaging, computing, and data processing. Its development has led to advancements in computer vision and artificial intelligence applications. Snavely et al. (2008) show that photogrammetry has influenced broader computational research domains.

Economically, photogrammetry reduces the cost of archaeological documentation by minimizing the need for expensive equipment and extensive fieldwork. This makes heritage projects more feasible in resource-limited contexts. Kersten and Lindstaedt (2012) confirm that cost efficiency is a key advantage of digital methods.

Environmentally, non-invasive documentation reduces physical disturbance to archaeological sites, supporting sustainable heritage management. This aligns with global conservation goals aimed at minimizing human impact on fragile environments. UNESCO (2019) promotes sustainable documentation practices.

Finally, photogrammetry has strategic implications for cultural policy and heritage governance. Governments and institutions can use digital records to support protection laws and restoration planning. Forte and Campana (2016) emphasize that digital archaeology is becoming a key component of cultural policy frameworks.

10. Further Readings

For researchers seeking to deepen their understanding of photogrammetry in archaeology, foundational texts such as Hartley and Zisserman (2004) provide essential mathematical background in multi-view geometry and image reconstruction. This work is widely considered a core reference in computer vision theory.

Another important reference is Remondino and Campana (2014), which focuses specifically on 3D recording and modeling in cultural heritage. This book bridges the gap between theoretical photogrammetry and practical archaeological applications.

The work of Westoby et al. (2012) is highly recommended for understanding Structure-from-Motion photogrammetry and its applications in earth sciences and archaeology. It provides a clear explanation of modern image-based modeling techniques.

De Reu et al. (2013) offer valuable insights into digital terrain modeling and its archaeological applications. Their research demonstrates how photogrammetry enhances spatial analysis of landscapes and excavation sites.

Forte and Campana (2016) provide a broader theoretical and practical overview of digital archaeology, emphasizing the transformation of archaeological methods through digital technologies. Their work is essential for understanding the conceptual shift in the discipline.

Kersten and Lindstaedt (2012) present a detailed analysis of practical challenges in 3D recording of cultural heritage. Their study is particularly useful for understanding real-world limitations and methodological constraints.

Stylianidis and Remondino (2016) focus on digital heritage documentation and preservation strategies, making their work a key reference for cultural heritage management and policy development.

Snavely et al. (2008) introduce Structure-from-Motion systems in detail, providing a technical foundation for understanding large-scale image-based reconstruction methods widely used in photogrammetry.

Wheatley and Gillings (2002) offer an important perspective on spatial technology in archaeology, including GIS integration and spatial theory applications, which complement photogrammetric approaches.

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Finally, UNESCO (2019) reports and guidelines on cultural heritage preservation provide essential policy-level insights into the importance of digital documentation for global heritage protection.

Conclusion

This study has demonstrated that standard photogrammetry techniques constitute a powerful and reliable approach for the digital documentation of archaeological sites. The findings confirm that photogrammetry offers a non-invasive, cost-effective, and highly accurate method for recording cultural heritage, particularly in contexts where sites are fragile, endangered, or difficult to access. By transforming photographic data into precise three-dimensional models, this technology significantly enhances the ability of archaeologists to analyze, interpret, and preserve historical structures. The integration of photogrammetry into archaeological practice reflects a broader shift toward digital heritage management, where accuracy, accessibility, and long-term preservation are central priorities (Remondino & Campana, 2014).

One of the main contributions of this approach lies in its ability to improve documentation precision compared to traditional methods. Unlike manual drawing or conventional surveying, photogrammetry reduces human error and provides measurable, repeatable results that can be used for scientific analysis. This improves the reliability of archaeological interpretation and supports evidence-based research (Hartley & Zisserman, 2004). Furthermore, the use of Structure-from-Motion algorithms enables the reconstruction of complex archaeological environments from simple image datasets, making the process more efficient and scalable (Snavely et al., 2008).

Another important outcome of this study is the role of photogrammetry in supporting cultural heritage preservation. Digital models serve as permanent records of archaeological sites, ensuring that even if physical structures are damaged or destroyed, their digital representations remain available for future study and restoration. This aligns with global heritage preservation strategies promoted by UNESCO, which emphasize the importance of digital documentation for safeguarding endangered cultural assets (UNESCO, 2019).

The study also highlights the importance of integrating photogrammetry with other digital tools such as Geographic Information Systems (GIS) and UAV-based imaging. Such integration enhances spatial analysis capabilities and improves the efficiency of large-scale archaeological surveys. UAV photogrammetry, in particular, has revolutionized field documentation by enabling rapid and high-resolution data acquisition across extensive landscapes (Westoby et al., 2012).

Despite its advantages, the research acknowledges that photogrammetry requires careful methodological control, including image quality, calibration accuracy, and computational processing capacity. These technical requirements highlight the need for specialized expertise and proper training in digital archaeology workflows (Kersten & Lindstaedt, 2012). However, continuous technological advancements are reducing these limitations and making the method increasingly accessible to researchers and institutions.

From a broader perspective, photogrammetry contributes not only to scientific research but also to education and public engagement. Digital 3D models allow for virtual exploration of archaeological sites, making cultural heritage more accessible to a global audience. This enhances cultural awareness and promotes the dissemination of archaeological knowledge beyond academic circles (Stylianidis & Remondino, 2016).

In addition, the use of photogrammetry supports sustainable archaeological practices by minimizing physical intervention on fragile sites. This non-destructive approach aligns with modern conservation ethics, which prioritize preservation over excavation whenever possible. It also reduces the environmental and physical risks associated with traditional documentation techniques (De Reu et al., 2013).

Economically, the method offers a cost-efficient alternative to more expensive technologies such as laser scanning, making it particularly suitable for developing regions with limited financial resources. This increases the feasibility of large-scale heritage documentation projects and encourages broader adoption in global archaeological practice (Forte & Campana, 2016).

Overall, the study concludes that photogrammetry represents a transformative tool in archaeology, combining scientific accuracy, technological efficiency, and cultural preservation value. Its continued development and integration into archaeological methodologies will play a crucial role in the future of heritage documentation and conservation strategies worldwide.

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