

Review

Impact of 3D Digitising Technologies and Their Implementation

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Abstract: In recent years, 3D digitalisation has experienced significant growth, revolutionising the way we capture, process and use geometric data. Initially conceived for industrial applications, these technologies have expanded to multiple fields, offering unprecedented accuracy and versatility. Depending on the accuracy and efficiency to be achieved in a specific field of application, and on the analytical capacity, a specific 3D digitalisation technique or another will be used. This review aims to delve into the application of 3D scanning techniques, according to the implementation sector. The optimal geometry capturing and processing 3D data techniques for a specific case are studied as well as their limitations.

Keywords: 3D digitalisation; data geometry; technologies; laser scanning; UAVs; structured light scanning; photogrammetry

1. Introduction

The process of 3D digitalisation involves capturing the geometry of an object and subsequently processing the acquired data to create a comprehensive and accurate 3D model. This process has emerged as a crucial tool across various fields, from cultural heritage preservation to engineering, medicine, and beyond. This technology enables the precise capture of the geometry of physical objects, followed by their processing to create comprehensive and detailed three-dimensional models. Over the past few decades, 3D digitalisation has significantly evolved from rudimentary methods to highly sophisticated techniques, offering unprecedented accuracy and detail in capturing the geometrical properties of physical objects [1]. This evolution was driven by advancements in hardware, such as laser scanners and photogrammetry, as well as software improvements that allow for more precise and efficient data processing [2]. These technologies, when combined, offer a powerful toolkit for creating, analysing, and utilising 3D models. Therefore, this article aims to provide a comprehensive review of 3D digitalisation techniques, methods for processing the obtained geometric information, and the primary applications where this information is used in an optimised manner. It aims to provide an overview or exploratory discussion rather than an exhaustive comparative analysis of all possible scenarios. Based on the analysis of key sectors such as cultural heritage, medicine, education, and engineering, this review highlights predominant trends, including the use of 3D modelling, photogrammetry, and immersive technologies (virtual reality and augmented reality). Furthermore, it identifies specific limitations and challenges in adopting these technologies, such as capture accuracy, implementation costs, and advanced processing requirements. This review aims not only to evaluate the current impact of 3D digitalisation across various disciplines but also to point out opportunities for future research and interdisciplinary applications.

1.1. Geometry Capture: Evolution and 3D Scanning Techniques

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The field of 3D scanning has evolved considerably over the last few decades. Early techniques, though innovative for their time, were often limited by technological constraints and provided only basic geometric information. However, advancements in both hardware and software have enabled the development of sophisticated techniques capable of capturing detailed and accurate three-dimensional representations of objects and environments [3].

Currently, creating 3D models involves a variety of technologies and tools, each suited to different aspects of the modelling process. Some of the most used technologies are:

- **Laser scanning:** This technique uses laser beams to measure and capture the geometry of an object's surface, generating dense point clouds that are used to create detailed 3D models. It is widely used in reverse engineering, quality inspection, and cultural heritage preservation [4]. Some subtypes are:
 - **Optical Triangulation:** Used for small objects, such as mechanical parts or sculptures.
 - **Time-of-Flight (ToF):** Ideal for capturing data from long distances, such as architectural structures.
 - **Structured Light Scanning:** Suitable for small, complex surfaces. This is another prevalent procedure, where a series of light patterns are projected onto an object, and cameras capture the deformation of these patterns. The deformation data are used to reconstruct the object's surface geometry with high precision [5]. They are known for their high accuracy and speed, making them ideal for detailed scanning of objects and sculptures [6].
 - **Simultaneous Localisation and Mapping (SLAM):** Mobile scanners that combine laser data with real-time positioning, useful indoors or in dynamic environments and where GPS is not available. This technology stands out for its ability to generate three-dimensional maps in real time, facilitating applications in archaeology, engineering, and disaster monitoring.
- **Photogrammetry:** This technique involves capturing multiple photographs from different angles and using advanced software to create 3D models from these images. Photogrammetry is a versatile and cost-effective technique [7], a flexible and accessible option that has become particularly popular in archaeology and surveying [8]. Advanced software processes the images to generate a dense point cloud and subsequent 3D mesh. Photogrammetry is particularly useful for documenting large areas and intricate details, making it popular in fields such as archaeology and cultural heritage conservation [9]. The classification for this technique is:
 - **Aerial Photogrammetry:** Includes UAVs with optical cameras for large-scale captures.
 - **Terrestrial Photogrammetry:** Captures images from the ground for detailed reconstructions.
 - **Close-Range Photogrammetry:** Used in high-precision studies, such as the conservation of cultural artifacts.
- **Time-of-flight (ToF) cameras:** These devices measure the time it takes for a light signal to travel from the camera to the object and back, using this information to calculate the distance to each point on the object's surface and create a 3D map [10].
- **Hybrid techniques:** These combine multiple 3D scanning methods to leverage their strengths and mitigate their weaknesses, allowing for more comprehensive and accurate capture of complex [11].
- **UAVs with LiDAR:** UAVs equipped with cameras or LiDAR sensors are used for data collection, mapping, and monitoring large areas. These technologies have been demonstrated to be versatile instruments with applications across several fields, such as precision agriculture, forestry, construction, surveying, disaster response, and education, providing high-resolution images and the ability to generate detailed 3D

models [12]. They capture high-density point clouds, ideal for topographic mapping and reconstruction of complex landscapes, although they are more expensive.

- UAVs with Cameras (Aerial Photogrammetry): They generate orthomosaics and 3D models using images. They are inexpensive but sensitive to weather conditions and spatial resolution.

To strengthen the analysis, specific examples of real-world applications have been added that demonstrate how the selection of 3D technologies depends on the purpose, equipment characteristics, and environmental conditions. Laser scanning has been successfully used in the accurate reconstruction of historic buildings such as the Parthenon in Athens, where laser scanners captured complex geometries with sub-millimetre accuracies, essential for cultural preservation. The photogrammetry technique has been more used in archaeological projects, such as the site of Pompeii. This technique allowed large areas of terrain and intricate details to be documented, combining sufficient accuracy for architectural analysis with the efficiency required to cover large areas. Finally, hybrid technology (e.g., UAV-LiDAR) is widely implemented in urban planning projects, such as the topographic analysis of Rio de Janeiro, where UAVs were combined with LiDAR to generate highly accurate, detailed maps that would be impossible with a single technology.

Some of these technologies, such as UAVs, offer advantages and drawbacks. For example, UAVs are valued for their ability to capture high-quality images over large areas and generate detailed 3D models, being able to reach accuracies similar to the real value [2], but they face limitations such as airspace regulation and sensitivity to weather conditions [13]. Similarly, aerial image-based methods can complement traditional ground-based techniques, but their effectiveness may be reduced by low spatial resolution and interruptions caused by clouds [14]. UAVs are considered a more powerful tool in urban planning and development fields because they can provide high-quality images, generate 3D models using detailed point clouds, are easy to operate, are cost-effective, can provide real-time updates, and can be used frequently [12]. Therefore, while UAVs with LiDAR have been successfully used in urban planning and archaeological conservation projects to capture detailed topographic data [15]. SLAM is widely used in scanning historical interiors and in mobile applications in structural engineering.

However, there are drawbacks concerning UAVs' usage regulations across countries that present challenges for commercial and research UAVs. In addition, mapping from airborne aerial images might be considered a solution for addressing the weaknesses of conventional field-based methods, but its poor spatial and temporal resolution puts constraints on its effectiveness [13]. Some other limitations of airborne aerial images are the restrained flexibility in positioning the focus, insufficient spatial resolution, and disturbances produced by clouds and lags in the continuous stream of data, restricting satellite-based analyses from being applied to site-specific quotidian construction projects [10]. UAV LiDAR data fill these gaps as they can provide high-density point clouds that can replicate the objects and terrain of the study area [14].

Making a comparative analysis between hybrid technology vs. single technology in 3D digitalisation, it is indicated that hybrid technology combines multiple methods, such as laser scanning, photogrammetry, UAVs, and LiDAR, to leverage the strengths of each technique and mitigate their individual limitations. Meanwhile, single technology relies on one primary method, such as laser scanning or photogrammetry, which is applied independently for data acquisition and analysis. In addition, individual technologies, while more accessible and simpler, have limitations in their applicability, particularly in complex or interdisciplinary conditions. These limitations include restrictions in accuracy, scalability, and adaptability, making them more suitable for small or specific projects, such as documentation of artifacts in museums or basic mapping of sites. However, some details about its limitations and specific applications in the sectors analysed are indicated below:

- **Costs:** The initial costs of hybrid equipment such as UAVs with LiDAR are high [16]. However, recent studies highlight that these systems can significantly reduce long-term operating costs by minimising errors and optimising efficiency in complex projects. In addition, the development of cheaper solutions and shared access through collaborative platforms are democratising their use.
- **Data processing:** Although managing large volumes of data remains a challenge [17], the adoption of cloud technologies and faster processing algorithms has considerably accelerated analysis, reducing the dependence on expensive hardware.
- **Complex environments:** The environmental factors affect data quality [15]. However, advances in preprocessing techniques and predictive models have improved capture in adverse conditions, especially when multiple hybrid technologies are combined.
- **Interoperability:** Despite the lack of universal standards [18], initiatives such as open formats (e.g., IFC) and interoperable platforms have allowed for better integration, facilitating collaborative workflows in multidisciplinary projects.

Likewise, accuracy varies depending on the technique employed, the equipment used, and the conditions of the case study. Table 1 presents the typical accuracy ranges, and their applications for each digitalising technology.

Table 1. Accuracy ranges and applications for each 3D digitalising technology.

Technology	Typical Accuracy	Applications
Laser Scanning	Submillimetric to millimetric	Architectural heritage documentation, reverse engineering
Photogrammetry	Millimetric to centimetric	Archaeological surveys, environmental monitoring
UAV-LiDAR	Centimetric to decimetric	Urban planning, forestry, disaster response
Structured Light Scanning	Submillimetric	Small object scanning, cultural artefact preservation

1.2. Processing of Geometric Data from 3D Digitalisation

Once geometric data are obtained using any of the techniques described, extensive processing is required to make them useful in various applications. The initial output, typically a point cloud or mesh model, requires several refinement steps.

Point cloud processing is the first step and involves noise reduction, registration, and decimation. Noise reduction filters out erroneous points caused by scanner inaccuracies or environmental factors using methods such as statistical outlier removal and radius-based filtering [19]. Registration aligns multiple point clouds into a unified coordinate system using algorithms such as iterative closest point (ICP) or feature-based methods [20]. Decimation reduces the number of points in the cloud to make the data more manageable without losing important geometric features [21].

Subsequently, the data are converted into a mesh, which is a collection of vertices, edges, and faces that define the shape of the object. Surface reconstruction algorithms such as Delaunay triangulation, Poisson surface reconstruction, and marching cubes are used to create a mesh from the point cloud data [22]. The meshes often require smoothing to remove roughness and noise, implementing techniques such as Laplacian smoothing and Taubin smoothing [23]. Additionally, mesh simplification further reduces complexity by decreasing the number of faces while maintaining overall shape and detail, using edge-collapsing and vertex-clustering algorithms, crucial for applications requiring efficient and detailed models, such as video games or real-time simulations.

Mapping and texture enhancement are also crucial steps in creating realistic 3D models. This process involves capturing high-resolution images of the object's surface and aligning them with the 3D geometry through UV mapping, which unfolds the 3D model

onto a 2D plane to apply textures accurately [24]. Texture blending combines multiple textures to create a uniform and consistent appearance, particularly useful when different parts of the object are scanned separately [25].

For digital preservation and annotation, processed 3D models are stored along with metadata that provide additional information about the scanned object, scanning conditions, and processing details. These annotations allow for highlighting specific features or areas of interest in the model, facilitating further studies, as is common in archaeology and conservation [26].

Analysis and simulation based on processed 3D data enable diverse applications, from structural assessment to virtual restoration. For example, in the restoration of historic buildings, these simulations can predict the impact of different restoration techniques before their physical implementation [27]. Moreover, the integration of 3D models into building information modelling (BIM) systems allows for more efficient lifecycle management of buildings, facilitating both their preservation and adaptation for new uses [28].

In summary, the evolution of 3D digitalisation technologies significantly impacts various fields by enhancing the ways to document, preserve, and interact with the geometry of the objects. From meticulous conservation efforts to innovative tourism experiences and enriched educational programs, 3D scanning is reshaping our approach to heritage valorisation. This paper explores the strategies for realising 3D digitisation and examines the societal benefits that emerge from these advanced technologies, highlighting the current limitations and knowledge gaps for their optimal application according to the implementation field. Indeed, within this field where technologies evolve rapidly, the relevance of comparative insights can be context-dependent, making it more practical to address general trends or specific case studies.

2. Review Methodology

2.1. Search Strategy

To conduct a thorough review of the most relevant and recent research papers focused on the new technologies for the creation of 3D models across various applications, a set of carefully curated keywords was used to gather high-quality journal articles, reviews, and book chapters from databases such as Web of Science (WoS) and Scopus. These databases index essential conferences which are central to innovative research dissemination in these domains. In this regard, peer-reviewed high-impact journal articles often synthesise and validate the most impactful findings from conference papers and book chapters, ensuring that critical advancements are not overlooked. The focus on high-quality, peer-reviewed journal articles provides a level of rigor and reliability that aligns with the review's objectives.

- General keywords: 3D digitisation, 3D geometric documentation, 3D scanning technologies, geomatics, point cloud processing, 3D modelling, digital heritage preservation, spatial data capture, geospatial technologies, remote sensing, photogrammetry.
- Technical keywords: Laser scanning, terrestrial laser scanning (TLS), structured light scanning, time-of-flight (ToF) cameras, LiDAR scanning, photogrammetric reconstruction, multi-view stereo (MVS), depth sensing, optical scanning technologies, UAV photogrammetry, drone-based 3D scanning.
- Data processing keywords: Point cloud registration, point cloud noise reduction, 3D mesh generation, surface reconstruction, mesh simplification, texture mapping, UV mapping, digital twin creation, BIM integration, data fusion in 3D modelling, outlier removal in point clouds.
- Application-specific keywords: Cultural heritage 3D documentation, archaeological 3D scanning, architecture 3D modelling, construction site monitoring, engineering inspection, virtual reality (VR) and 3D models, medical 3D scanning, topographic

surveys, urban 3D mapping, disaster response and 3D scanning, precision agriculture and UAVs, historical site restoration.

- Keywords on new technologies and trends: AI-driven 3D reconstruction, deep learning in 3D scanning, hybrid 3D scanning techniques, autonomous 3D scanning robots, real-time 3D reconstruction, machine learning in point cloud analysis, automated 3D modelling, augmented reality (AR) and 3D documentation, cloud-based 3D data processing, wearable 3D scanning devices.
- Keywords on challenges and recent advances: High-precision 3D scanning, scalable 3D data processing, edge computing for 3D models, large-scale 3D documentation, multi-sensor fusion, non-destructive 3D scanning, accuracy and resolution in 3D scanning, 3D reconstruction in complex environments.

2.2. Time Frame Justification

The adoption of new technologies is growing rapidly in numerous fields lately. Therefore, to provide a review that focuses on cutting-edge technologies, it is advisable to select articles published within the last 5 to 7 years. This time span ensures coverage of the most current research while including relevant works that may have introduced enduring concepts or technologies.

- Last 5 years (2020–2024): This period is ideal if the focus is strictly on emerging technologies and the most recent advancements. Many key innovations in 3D digitisation and geometric documentation have taken shape during this time, particularly in areas such as machine learning, AI applications, autonomous scanning, drones and UAVs, and advanced sensor technologies.
- Last 7 years (2018–2024): A broader 7-year range allows for a more comprehensive view, including initial studies on technologies that have evolved or been refined in more recent years. This interval also allows the identification of long-term trends and the early development of technologies that are now considered standard or emerging.
- 2024: Within this last year, the field of 3D digitising technologies has seen significant advancements, particularly in areas such as 3D scanning, utilising neural radiance fields (NeRFs), 3D reconstruction, and 3D printing, with implications across various industries like healthcare, industrial design, and cultural heritage preservation.

2.3. Inclusion and Exclusion Criteria

- Inclusion criteria: Articles that implement or discuss cutting-edge 3D technologies such as advanced laser scanning, AI-enhanced photogrammetry, high-resolution LiDAR, UAVs applied to 3D modelling, time-of-flight (ToF) sensors, hybrid techniques, or deep learning for point cloud processing.
- Exclusion criteria: Works focusing on obsolete technologies or those that do not incorporate contemporary applications, such as studies solely based on traditional techniques without recent innovations.

2.4. Applying Relevance and Quality Criteria

Once the relevant articles have been identified, it is crucial to apply quality and relevance filters. Some criteria to consider include:

- Impact Factor (IF) or Scimago Journal Rank (SJR): To evaluate the prestige of the journals in which the studies are published. IF is a widely recognised and established metric for assessing the quality and influence of academic journals.
- Citations: To review how many times the article has been cited. Highly cited studies tend to be more influential.
- Publication date: To prioritise recent articles (within the last 5–7 years) to ensure that technological advancements are up to date.

- Specific relevance to the sector: To verify that the articles focus specifically on 3D scanning applications in the targeted sector, rather than solely on general technologies.

2.5. Grouping Method

Grouping studies based on their application sectors within each field ensures a more focused and structured analysis:

- Heritage: To search for studies that discuss restoration, digital conservation, and mapping of historical sites using 3D digitisation. These studies can be related to archaeological, architectural, or industrial heritage.
- Medicine: To focus on studies related to anatomical models, surgical planning, or 3D medical printing.
- Environmental monitoring and planning: To seek studies that cover topographic modelling, terrain analysis, or crop monitoring using 3D technologies.
- Tourism: To analyse studies that explore virtual environments for tourists through 3D modelling.
- Education: To analyse studies that explore virtual environments or immersive experiences for students based on 3D models.
- Infrastructure planning: To seek studies that cover topographic modelling, site analysis, or site monitoring using 3D technologies.
- Entertainment and media: To seek studies that cover 3D content creation, virtual environment design, or immersive media production using 3D technologies.

2.6. Bibliometric Analysis

Performing a bibliometric analysis is an excellent way to identify key patterns, trends, and relationships within research on 3D digitisation technologies. This type of analysis provides quantitative insights into the development and influence of these technologies across different fields, thereby helping to establish a solid foundation for advancing future research in novel and meaningful ways [29].

For this purpose, specialised bibliometric analysis tools such as VOSviewer (1.6.20) CiteSpace (6.3.1), and R-Bibliometrix (4.1) or database software like Web of Science and Scopus were utilised to extract and organise the data.

- Data collection and organisation: To compile and structure metadata such as authors, institutions, countries, keywords, journals, citation counts, and publication years.
- Productivity analysis by author, institution, and country: To use VOSviewer or Gephi to create co-authorship maps and collaboration networks.
- Keyword and thematic analysis: To utilise VOSviewer or Bibliometrix to analyse keyword co-occurrence and thematic clusters.
- Citation analysis: To apply CiteSpace or HistCite to analyse citation patterns and identify influential studies.

3. Results

3.1. The Implementation and Valuation of 3D Digitisation Technologies Across Different Sectors

The implementation of 3D digitisation technologies is enhancing value by improving precision, efficiency, and innovation, leading to significant growth and new opportunities. Three-dimensional digitalisation techniques find applications in a wide variety of sectors, each benefiting from the precision and detail that these technologies offer.

In the field of heritage conservation, 3D scanning has become an indispensable tool to build the 3D model of what needs to be conserved [30]. The advent of 3D digitalisation technologies has marked a significant milestone within this sector, enabling accurate documentation of monuments and artefacts through detailed, high-resolution 3D models [31,32]. Early applications focused on creating basic digital records, but contemporary practices involve creating detailed, high-resolution 3D models that serve multiple

purposes. These models facilitate the study, conservation, and restoration of cultural heritage by providing a permanent digital archive, monitoring deterioration, planning restorations, and creating virtual displays, all while allowing wear and damage to be analysed without physical intervention [33]. Indeed, 3D models have been used to restore intricate architectural details in historical buildings and monuments, ensuring that restorations are both accurate and respectful of the original designs [34]. For example, 3D scanning of Notre-Dame cathedral has been crucial in restoration efforts following the 2019 fire .

In the construction industry/infrastructure planning, the use of 3D models integrated into BIM systems improves the planning, design, and management of construction projects. Capturing the as-built condition of buildings allows for accurate comparisons with original plans, facilitating the detection of deviations and ensuring compliance with building standards [35]. One example is the digitalisation of old buildings for renovation and reuse, optimising resources and preserving historical value.

Beyond conservation, 3D scanning has found substantial applications in the tourism industry. Virtual tourism, powered by 3D models, allows individuals to explore cultural heritage sites from anywhere in the world through any device, such as cell phones, tablets, and laptops. This makes heritage sites accessible to people who may not have the means or opportunity to visit them in person [36]. Interactive virtual tours, augmented reality experiences, and 3D printed replicas of artefacts enrich the way tourists engage with cultural heritage, offering immersive and educational experiences that traditional tourism cannot match.

In the medical sector, 3D modelling technologies are also revolutionising how healthcare professionals design, analyse, and create medical devices, prosthetics, implants, and anatomical models. For example, 3D printing of anatomical models from 3D scans of patients allows for the planning of complex surgeries and the creation of custom implants. Three-dimensional models are also used in medical education to provide a detailed understanding of human anatomy [37]. Likewise, 3D printing a heart model from a computed tomography (CT) scan allows surgeons to plan delicate procedures with greater precision [38]. In the field of criminology and forensic investigations, 3D digitalisation techniques are used in documenting crime scenes, injury analysis, and forensic reconstructions, providing accurate and detailed evidence for investigations and court proceedings [39]. For example, digitising a crime scene can capture minute details that could be crucial to solving a court case.

Entertainment and media are embracing 3D digitalisation for the creation of special effects, animated characters, and virtual sets, enhancing the production of film, video games, and virtual reality content [40]. A notable example is the use of 3D digitalisation to create hyper-realistic characters and environments in films such as *Avatar*, where 3D models are integrated with advanced animation techniques to deliver an immersive visual experience.

The educational sector has also benefited immensely from 3D scanning technologies. This field has been enriched by 3D models that allow for detailed visualisation and study of objects and environments, facilitating greater understanding and engagement in disciplines such as geology, biology, and art history [41,42]. Detailed 3D models of historical artefacts and sites are now being integrated into educational curriculums, providing students with a tangible connection to history and culture wherever it is. In this context, virtual reality (VR) and augmented reality (AR) applications allow students to interact with these 3D models in dynamic, immersive, and engaging ways, fostering a deeper understanding and appreciation of cultural heritage, geometry [43], or any other subject content. These technologies also enable remote learning online, making cultural education more accessible to a broader audience [44]. For example, in geology education, 3D models of rock formations allow students to interactively study and analyse complex structures.

In environmental monitoring and planning, 3D digitalisation is used to generate detailed topographic maps, erosion and climate change studies, and wildlife conservation efforts, supporting sustainable development and conservation initiatives [15]. One

example is the use of drones equipped with 3D cameras to monitor changes in glaciers and assess their impact on sea level.

Virtual reality (VR) and augmented reality (AR) technologies allow designers to build and interact with 3D models in immersive environments in the metaverse. Tools and platforms such as Unreal Engine for gamification and head-mounted glasses to visualise digital models in VR are commonly used in this domain [15,43–45].

Three-dimensional printing technology facilitates the real production of 3D models. It is used for prototyping, manufacturing, and even creating end-use parts. Paramount aspects of 3D printing include: fused deposition modelling (FDM) to build objects layer by layer from a thermoplastic filament; stereolithography (SLA) that uses a laser to cure liquid resin into solid plastic; and selective laser sintering (SLS) that utilises a laser to sinter powdered material into solid structures [46,47].

The screening process resulted in a final total of 106 studies included in the review. These 106 studies were evaluated to determine their eligibility according to the predefined inclusion and exclusion criteria.

This study includes 106 publications, of which the IF was calculated for only 70 scientific articles published in indexed journals. This selection is based on the fact that the IF specifically measures citation frequency in scientific journal articles, as calculated by platforms such as Journal Citation Reports (JCR). Since conference papers and book chapters are typically not indexed in these databases, they are not suitable for evaluation using this metric and require other quality indicators. Operating with the IF of these 70 articles allows for a rigorous and specific assessment of their scientific relevance. The selected indexed articles represent peer-reviewed publications in prestigious journals, and their analysis avoids inappropriate extrapolations that could arise from applying this metric to other types of publications. In this way, the study maintains a precise focus, enabling conclusions to reflect the actual academic impact of each type of publication within its appropriate context. Table 2 presents an evaluation of the selected studies. Each study is categorised under application sector, year of publication, the corresponding IF of the journal at that time, and the citation count. Notably, multiple application sectors may be associated with the same study, reflecting the complexity and multifaceted nature of the research.

Table 2. List of articles subject to analysis by sector, year, IF, keywords, and citations.

Ref.	Sector	Year	IF	Author Keywords	Times Cited
[45]	Educational	2020	1.86	Education; Digital experiments; 3D modelling; Remote sensing; International space station	8
[46]	Cultural Heritage	2022	N/A	3D model; 3D printing; Virtual Reality; Augmented Reality	4
[47]	Archaeology	2022	1.71	terra sigillata; SfM photogrammetry; virtual archaeology; virtual reflectance transformation imaging (V-RTI); 3D modelling; 3D printing	0
[48]	Engineering	2020	0.15	3D modelling; Building Archaeology Survey (BAS); Computer Aided Design (CAD); Close-range photogrammetry; Geographic Information Systems (GIS); Historical kitchens; Terrestrial Laser Scanning (TLS)	1
[49]	Archaeology	2021	1.92	3D reconstruction; archaeological survey; digital elevation model; Selinunte Archaeological Park; terrestrial laser scanning; unmanned aerial vehicle photogrammetry	8

[50]	Cultural Heritage	2023	4.20	geospatial technologies; geographic information systems; lidar; remote sensing; South Africa; virtual reality	3
[51]	Engineering	2019	N/A	cultural heritage; UAV; photogrammetry; HBIM	38
[52]	Archaeology	2018	1.60	terrestrial laser scanning (TLS); panoramic spherical photography; 3D modelling; historical and cultural heritage; touristic promotion; hypermedia atlas	5
[53]	Architecture	2019	N/A	Virtual Reality; Cultural Heritage; Serious Game; Digital Survey; 3D Modelling; Photogrammetry; Terrestrial Laser Scanning	6
[54]	Cultural Heritage	2019	N/A	augmented reality; AR; BIM; Cultural Heritage; markerless tracking; 3D modelling	8
[55]	Cultural Heritage	2019	0.17	3D scanning; photogrammetry; 3D modelling; virtual 3D models; information technology	5
[56]	Architecture	2020	4.85	spatial ETL; UAV; point cloud; 3D building modelling; CityGML	16
[57]	Engineering	2018	0.69	Terrestrial laser scanning; point cloud; 3D modelling; tunnel inspection	2
[58]	Cultural Heritage	2023	0.10	cultural heritage; digitisation; digital survey; 3D modelling; virtual representation	0
[59]	Engineering	2022	5.00	UAV; image segmentation; 3D modelling; landslide; superpixels; supervoxels; graph cut	4
[60]	Cultural Heritage	2023	0.20	Photogrammetry; laser scanning; TLS; PLS; cultural heritage; UAV; Shush; Iraqi Kurdistan	2
[61]	Cultural Heritage	2023	N/A	Laser scanning; Photogrammetry; 3D Modelling; WebGL; Virtual Reality; Cultural Heritage; Hypogeum Archaeological Sites	5
[62]	Cultural Heritage	2023	0.30	terrestrial laser scanner; sculpture; cultural heritage documentation; remote sensing; HBIM	2
[63]	Engineering	2023	6.90	3D modelling; CityGML; Mining industry; UAV; Terrestrial laser scanning; Point cloud	2
[64]	Archaeology	2019	N/A	3D survey; Archaeology; Laser scanning; Close-range photogrammetry; UAV; 3D Modelling	16
[65]	Engineering	2020	N/A	N/A	0
[66]	Engineering	2023	2.90	3D modelling in the cloud; Laser scanning close-range photogrammetry method; Overlap area of stereo models; Computer vision techniques; Robotic equipment	0
[67]	Cultural Heritage	2020	N/A	AR; VR; TLS; UAV; Photogrammetry; 3D modelling	7
[68]	Engineering	2023	N/A	monitoring; inertial navigation; restoration of marine habitat; underwater photogrammetry	0

[69]	Archaeology	2021	1.32	Geospatial revolution; Geospatial technology; Geographic Information Systems; Remote sensing; Geophysical survey; Lidar; 3D modelling	13
[70]	Cultural Heritage	2021	2.33	Information technologies; Structured-light 3D scanning; Historical clothes; Methodology of structured-light 3D scanning of historical clothes; Emir of Bukhara's historical costume; Dissemination of cultural heritage	19
[71]	Engineering	2022	N/A	Hydrographic risk; Classical topography; Aerial photogrammetry; Mobile mapping systems; Bathymetric survey; 3D modelling; Geomatics; Monitoring	0
[72]	Engineering	2018	N/A	H-BIM; EU-H2020 INCEPTION; Digital cultural heritage; Remote sensing; BIM; 3D model; UNESCO WHL; 3D reconstruction; Asinou Church	5
[73]	Cultural Heritage	2023	N/A	digital replicas; close-range photogrammetry; CMM arm scanner; semi-automated processing; geometric and radiometric accuracy; 3D modelling	0
[74]	Educational	2021	3.42	Organic chemistry; Computer-based learning; Augmented reality; 3D modelling and animation; Testing conformational analysis; Molecular dynamics; Molecular modelling; Molecular structure; Chemistry reactions; Chemistry and technology; Education and technology; Chemistry and augmented reality; Chemistry and 3D animation	37
[75]	Engineering	2021	0.05	3D modelling; 3D scanning; photo-based 3D models	0
[76]	Cultural Heritage	2020	2.68	3D modelling; 3D representation; game engine; laser scanning; panoramic photography; virtual reality	29
[77]	Cultural Heritage	2023	0.80	Augmented Reality; Virtual Reality; Historical Heritage; 3D Modelling	2
[78]	Educational	2023	N/A	Place-based education; cross-media approach; cultural identities and memories	0
[79]	Cultural Heritage	2019	N/A	digital innovation; 3D modelling; reverse engineering; cultural heritage; Sicily; Sebastiano Tusa	1
[80]	Engineering	2022	0.60	Terrestrial Laser Scanning; Autodesk Revit; modelling 3D	0
[81]	Engineering	2022	1.10	Open-source software; Landslide; Disaster management; Capacity building; Geospatial technologies	2
[82]	Engineering	2021	0.39	Point Cloud; Photogrammetry; RGB-D Sensor; Terrestrial Laser Scanners; Backtracking Search; Optimization Based Filter	4

[83]	Cultural Heritage	2024	2.60	3D survey; cultural heritage; mobile laser scanning; 3D modelling; virtual reality; WebGL	0
[84]	Educational	2021	2.84	augmented reality; learning motivation; learning achievements; 3D modelling; performance evaluation; reality-based modelling; student education; traditional methods; virtual reality	18
[85]	Medical	2022	3.65	3D-modelling; Segmentation; Surgery	3
[86]	Architecture	2020	0.01	N/A	0
[87]	Educational	2019	N/A	Engineering education; problem-based learning; mobile games; augmented reality	1
[88]	Cultural Heritage	2018	1.96	Holocaust; 3D modelling; Aerial laser scanning; Photogrammetry; Web-based visualization	6
[89]	Cultural Heritage	2019	N/A	surveying engineering; spatial planning; cultural heritage; 3D modelling	0
[90]	Architecture	2021	0.21	Citadel of Valencia; Methodology; Virtual Restitution; Documentary Sources	1
[91]	Cultural Heritage	2019	N/A	3D Survey; photogrammetry; solomonic order; 3D modelling; cultural heritage; Andrea Pozzo; St Ignazio altar	5
[92]	Engineering	2024	2.60	BIM; 3D laser scanning; 3D modelling; Construction project management; Point cloud scans	1
[93]	Cultural Heritage	2022	N/A	Ancient theatre; 3d modelling; Restoration; Monument documentation; Project management	0
[94]	Cultural Heritage	2022	N/A	3D Modelling; Serious gaming; Heritage; Architecture; Virtual Reality (VR); Augmented Reality (AR)	3
[95]	Medical	2021	3.57	paediatric surgery; oncology surgery; optical imaging; spectroscopy; cancer imaging; novel intraoperative technologies; fluorescence-guided surgery; children	11
[96]	Engineering	2024	N/A	N/A	0
[97]	Engineering	2020	0.33	Laser scanning; unmanned aerial systems; point-clouds; 3D modelling; virtual reality	14
[98]	Cultural Heritage	2023	N/A	Cultural Heritage; Representation; Digital Twin; Extended Reality; Palaeoanthropology; Neanderthal; Apulia; Climate change	2
[99]	Engineering	2019	N/A	3D Modelling; Digital content; Holographic display; Photogrammetry	0
[100]	Engineering	2022	1.70	Unmanned aerial vehicle; Dronography; Automated construction progress monitoring; Photogrammetry; RGB analysis; MATLAB Image Processing Toolbox; Trajectory analysis	10

[101]	Engineering	2019	0.20	Unmanned aerial vehicle; Structure from motion; Dense matching; Bundle adjustment; Stereo	7
[102]	Cultural Heritage	2019	1.72	Heritage; Jurassic Coast World Heritage Site; Structure-from-Motion photogrammetry; 3D modelling; Quarries	9
[103]	Engineering	2020	4.85	3D point cloud; light field camera; 3D reconstruction; 3D modelling; three-dimensional data; enhanced depth map	13
[104]	Cultural Heritage	2022	2.70	3D modelling; 3D printing; animation; cultural heritage; jewellery; photogrammetry; preservation; representation; wooden sculptures	4
[105]	Educational	2022	2.70	visual digital humanities; digital 3D modelling; digital heritage	28
[106]	Engineering	2019	N/A	3D-technologies; 3D model; photogrammetry	0
[107]	Cultural Heritage	2020	0.82	digital technologies; photogrammetry; restoration; frame; 3D printing; post-printing treatment; matching colour	6
[108]	Engineering	2021	2.54	proximal sensing; post-harvest; site impact; wheel rutting; TLS; photogrammetry	12
[109]	Cultural Heritage	2019	1.53	virtual heritage; bladed weapon; photogrammetry; 3D model; plotting; web visualisation	7
[110]	Architecture	2020	0.39	Augmented reality; digital sketching; collaborative design; affordances theory; virtual worlds	0
[111]	Engineering	2021	3.06	Photogrammetry; Soundscape; Acoustic indices; Coral reef; Monitoring	8
[112]	Engineering	2022	4.61	3D visualization; BIM; overhead power lines; risk assessment; risk management methodology; 4D risk simulation	2
[113]	Engineering	2024	2.50	visual digital humanities; digital 3D modelling; digital heritage	0
[114]	Cultural Heritage	2021	0.16	Statues; digital photogrammetry; 3D modelling; virtual reconstruction; cultural heritage	1
[115]	Engineering	2019	0.29	field pipelines; 3D modelling; onshore laser scanning; Yamal; prefabricated construction	4
[116]	Cultural Heritage	2019	N/A	Cultural; Heritage; 3D; augmented reality; virtual reality; Building Information Modelling	9
[117]	Educational	2021	1.13	heritage; heritage education; digital technologies; ICT; heritage teaching	4
[118]	Engineering	2018	3.09	3D modelling; 3D printing; corals; scleractinia; photogrammetry; additive manufacturing; education	4
[119]	Archaeology	2018	1.03	dissemination; 3D reconstruction; virtual recreation; photogrammetry; virtual reality; heritage	5

[120]	Engineering	2019	2.65	heritage building; photogrammetry; 3D modelling; MCDM; Rough WASPAS; expert survey	24
[121]	Engineering	2022	N/A	Planning permit; 3D modelling; land-use regulation (LuR); conflict detection; 3D spatial analysis; Information Modelling; city and urban planning; Bentley iTwin	3
[122]	Architecture	2023	2.20	Damage detection; virtual reconstruction; heritage; fractals; terrestrial LiDAR	1
[123]	Medical	2019	3.53	Computer mediated reality technology; virtual reality; augmented reality; health care; falls prevention	11
[124]	Engineering	2020	5.57	plant phenotyping; hyperspectral imaging; 3D sensing; remote sensing; sensor fusion	67
[125]	Engineering	2018	N/A	N/A	1
[126]	Engineering	2018	N/A	Mixed reality; Virtual reality; Photogrammetry; 3D scanning Real-time object tracking	1
[127]	Archaeology	2022	0.40	N/A	0
[128]	Engineering	2022	N/A	Spatio-temporal-spectral-angular observation; Monomer 3D modelling; Digital twin platform; LuojiaDT; Smart city	0
[129]	Cultural Heritage	2022	2.08	Intangible cultural heritage; 3D technologies; Literature analysis	67
[130]	Engineering	2018	N/A	RPAS Photogrammetry; Rapid Indoor Mapping; Indoor Positioning; 3D Modelling; Emergency Response; Orientation; RGB-D Camera	0
[131]	Engineering	2023	2.00	Chaotic cat map; fog computing; encryption; 3D point fog; 3D mesh	0
[132]	Archaeology	2019	0.40	Photogrammetry; Digital technologies; Conservation-restoration; Ceroplastic; Scientific collections	12
[133]	Architecture	2019	1.31	Landscape representation; fieldwork; aesthetics; technology; sediment	6
[134]	Engineering	2018	N/A	oblique photography; 3D model; monomeric model; oversize city; the integration of aerial photos and the near-ground photos	0
[135]	Engineering	2021	0.78	Chaotic map; cloud computing; encryption; 3D point cloud; 3D mesh	4
[136]	Cultural Heritage	2019	N/A	building-survey; monitoring; preservation; laser-technologies; 3D model; representation	1
[137]	Engineering	2019	0.08	GIS; mining; modelling; spatial analysis	2
[138]	Engineering	2023	7.70	N/A	15
[139]	Engineering	2022	N/A	Hydraulic Structures; Hydrodynamic Accidents; Satellite Images; Digital Elevation Model; 3D Modelling	3
[140]	Archaeology	2019	N/A	3D applications; 3D reconstruction; 3D mapping; Shipwrecks; Submerged landscapes; Marine survey	13

[141]	Engineering	2022	1.00	3D; Image; Modelling; Orthomosaic; Photogrammetry; UAV	0
[142]	Archaeology	2018	1.03	cultural heritage; digital photography; Structure from Motion (SfM) photogrammetry; 3D modelling; point clouds; Geographic Information Systems (GIS)	4
[143]	Engineering	2023	2.00	virtual reconstruction; immersive archaeology; immersive VR	4
[144]	Archaeology	2019	1.53	HBIM (Historic Building Information Modelling) Project; heritage information model; photogrammetry; archaeology of architecture; BIM	9
[145]	Archaeology	2019	N/A	Rock art; engravings; photography; photogrammetry; 3D scanning; virtual reality	1
[146]	Archaeology	2024	2.90	N/A	0
[147]	Cultural Heritage	2019	N/A	cultural heritage; mosque; spherical photogrammetry; 3D modelling; HBIM; semantic data management	5
[148]	Architecture	2022	N/A	3D Cadastre; 3D City Models; Land Administration; Photogrammetry; 3D Modelling	1
[149]	Archaeology	2024	1.95	Facial reconstruction; Digital archaeology; Anthropology; Anatolia; Roman period	1
[150]	Engineering	2019	3.86	3D modelling; LiDAR; RGB-D; Sampling platforms; UAV	38

N/A: Not Applicable.

3.2. Analysis of Impact Factor, Total Articles, and Citations by Sector

An analysis of the impact and publication volume across sectors employing 3D digitalisation technologies reveals significant differences in the adoption and visibility of these technologies within the scientific literature. Table 3 summarises the total number of articles, average IF, and average citations for each sector, providing a detailed view of their relevance and academic interest.

Table 3. Analysis of the average IF and citations and the total number of articles and citations by sector.

Sector	Total Articles	Average Impact Factor	Average Citations	Total Citations
Medical	3	3.58	8.33	25
Architecture	2	2.43	8.00	16
Educational	5	2.39	19.00	95
Engineering	29	2.39	8.41	244
Cultural Heritage	16	1.52	10.13	162
Archaeology	11	1.44	5.18	57

- **Medical:** The medical sector stands out with the highest average IF (3.58) and an average of 8.33 citations per article, despite having only three articles in total. This suggests a high level of academic interest and visibility, likely due to the applicability of 3D digitalisation in areas such as medical precision, surgical planning, and the creation of customised anatomical models.

- **Architecture and education:** In architecture, the average impact factor is 2.43 with an average of 8.00 citations, based on just two published articles. This reflects high visibility for 3D digitalisation studies within prestigious architectural journals. In the case of education, the average IF is similar (2.39), but the average citations are significantly higher (19), with a total of 95 citations across five articles. This sector benefits from the use of immersive models and simulations, which enhance learning and understanding in complex areas of study.
- **Engineering:** Engineering is the most represented sector, with a total of 29 articles, an average IF of 2.39, and an average of 8.41 citations, amounting to 244 citations in total. The broad adoption of 3D digitalisation within this sector reflects its applicability across various disciplines, from civil to mechanical and electrical engineering, where 3D modelling and scanning tools optimise the planning and execution of complex projects.
- **Cultural heritage and archaeology:** In the cultural heritage sector, the average IF is 1.52 and the average citations per article are 10.13, with 16 articles totalling 162 citations. Three-dimensional digitalisation is extensively used to preserve and document heritage sites, especially through techniques such as photogrammetry and LiDAR. Archaeology shows an average IF of 1.44 and an average of 5.18 citations per article, with a total of 57 citations across 11 articles. This indicates that, while 3D digitalisation is fundamental for archaeological analysis and conservation, its academic impact and citation interest are more moderate in comparison to other sectors.

This analysis shows that sectors such as medicine and education, although with a lower volume of articles, have high average impact factors and citation rates, suggesting strong academic appreciation for their 3D digitalisation applications. Conversely, the high number of publications in engineering and cultural heritage reflects broader and more diverse adoption, albeit with relatively lower impact per article.

3.3. Analysis of Author and Keywords by Sector

An analysis of the five most recurrent keywords in each sector reveals a distinct focus and specific relevance of 3D digitalisation technologies across various application areas. Table 2 presents the most frequently used keywords in each sector, along with the total articles and citations, offering insights into the academic adoption and impact of these terms within the scientific literature.

- **Engineering:** In the engineering sector, the keywords “3D modelling” and “photogrammetry” lead the list, with 17 and 11 articles, accumulating 113 and 101 citations, respectively. This indicates intensive use of 3D modelling and photogrammetry for spatial data capture and analysis, essential in civil and mechanical engineering. Terms such as “UAV” (five articles, 82 citations) and “remote sensing” (two articles, 72 citations) highlight the relevance of these technologies in mapping and monitoring complex areas, particularly in challenging terrains.
- **Cultural heritage:** In cultural heritage, “3D modelling” and “photogrammetry” are also the dominant keywords, with 19 and 9 articles, and a total of 90 and 78 citations, respectively. This underscores the role of these techniques in documenting and preserving cultural sites. Additionally, terms like “virtual reality” and “augmented reality” (68 and 50 citations) reflect growing interest in immersive applications that allow users to interact with digitised heritage sites, while “LiDAR” and “laser scanning” (65 and 50 citations) are used to create precise representations of monuments and structures.
- **Architecture:** In architecture, “3D modelling” and “BIM” are the primary keywords, with six and four articles, and a total of 45 and 42 citations, respectively. This reflects the importance of 3D models in structure design and planning, as well as the use of BIM in project management. Keywords such as “laser scanning” and “point cloud”

(30 and 27 citations) are also common, indicating the use of detailed scans and point clouds to document building conditions.

- **Education:** In the educational sector, the keywords “3D modelling” (four articles, 55 citations) and “virtual reality” (three articles, 50 citations) indicate a significant use of 3D models and immersive technologies in learning contexts. “Augmented reality” and “interactive models” (40 and 35 citations) highlight the application of these technologies in interactive educational experiences, enabling students to explore and manipulate digital models, enhancing their understanding of complex topics in fields such as geology, biology, and architecture.
- **Archaeology:** For archaeology, “photogrammetry” and “3D modelling” top the list, with seven and five articles and a total of 53 and 50 citations, respectively, underscoring their use in documenting archaeological sites. The presence of terms such as “remote sensing” and “LiDAR” (42 and 38 citations) reflects the need for non-invasive techniques that allow preservation of site integrity while documenting in detail, highlighting the relevance of 3D digitalisation in the study and conservation of **archaeological finds**.
- **Medicine:** In the medical sector, the keywords “3D printing” and “anatomical models” are the most relevant, with three and two articles, accumulating 60 and 55 citations, respectively. This underscores the role of 3D digitalisation in creating anatomical models for surgical planning and customising medical implants. Other terms, such as “custom implants” and “CT scanning” (48 and 45 citations), emphasise its application in the customisation of medical devices, reflecting the value of 3D technologies in enhancing clinical treatments and reducing risks in complex interventions.

To enhance the synthesis of findings from the selected studies more effectively, VOSviewer was utilised. Figure 1 illustrates the authorship networks, showcasing the main contributors and their collaborations in this field. The analysis identifies six clusters. Aricò, Dardanelli, La Guardia, and Lo Brutto were identified as the most influential authors, being the authors of three important papers in the present review: “Web exploration of Cultural Heritage with limited accessibility: first experimentation for hypogeum archaeological sites”, “The integrated 3D survey for underground archaeological environment”, and “Three-Dimensional Documentation and Virtual Web Navigation System for the Indoor and Outdoor Exploration of a Complex Cultural Heritage Site”. These studies emphasise the three-dimensional documentation for archaeological field analyses, not positioning any of the authors at the centre of the field.

Figure 2 displays an overlay visualisation of the keywords, showcasing the largest cluster of interconnected terms, consisting of 10 items in total. The visualisation highlights “3D modelling” as the most frequently used keyword, appearing 50 times across the studies [45,47,48,52–55,57–59,61,63,64,66,67,69,71,73–77,79,83,84,88,89,91–95,99,102–105,113–115,117,120,121,128,130,139,142,147,148,150], followed by others such as “photogrammetry” or “augmented or virtual reality”. The tool groups the keywords into clusters, visually depicting their relationships and co-occurrence across the studies. The analysis identifies three clusters. As shown, the clusters group related terms such as “3D modelling”, “cultural heritage”, “photogrammetry”, and “virtual reality” in one of the clusters and “cultural heritage”, “reconstruction”, “remote sensing”, and “UAV” in the second cluster. Whereas in the last cluster, there were “augmented reality” and “heritage”. These clusters offer insights into the intersections between different dimensions and topics covered by various studies. Figure 3 shows the same visualisation of the keywords considered for the study of the last 7 years. Seventeen items are identified within four clusters. The most important cluster highlighted “3D model”, “3D printing”, “augmented reality”, “BIM”, “heritage”, “photogrammetry”, and “technologies”. Whereas the smallest cluster adds only two keywords: “laser” and “remote sensing”.

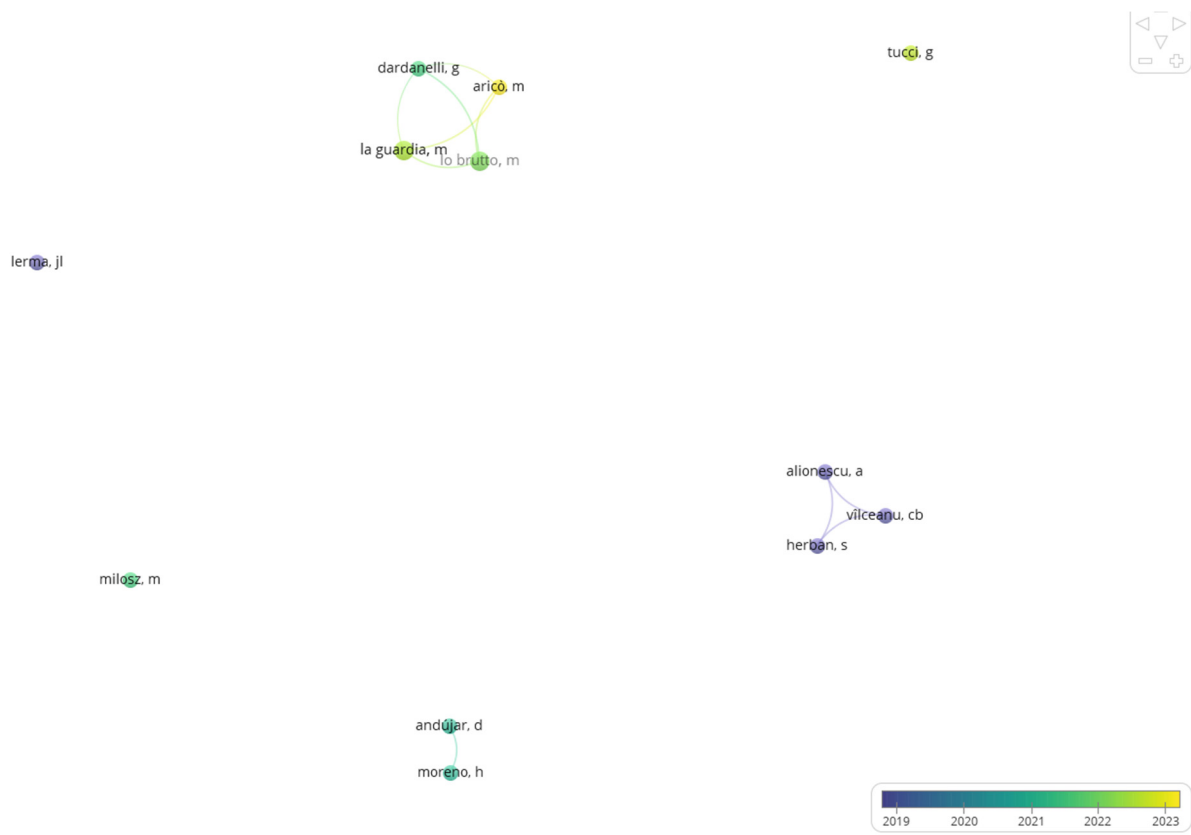


Figure 1. Overlay diagram of authors (over the last 7 years).

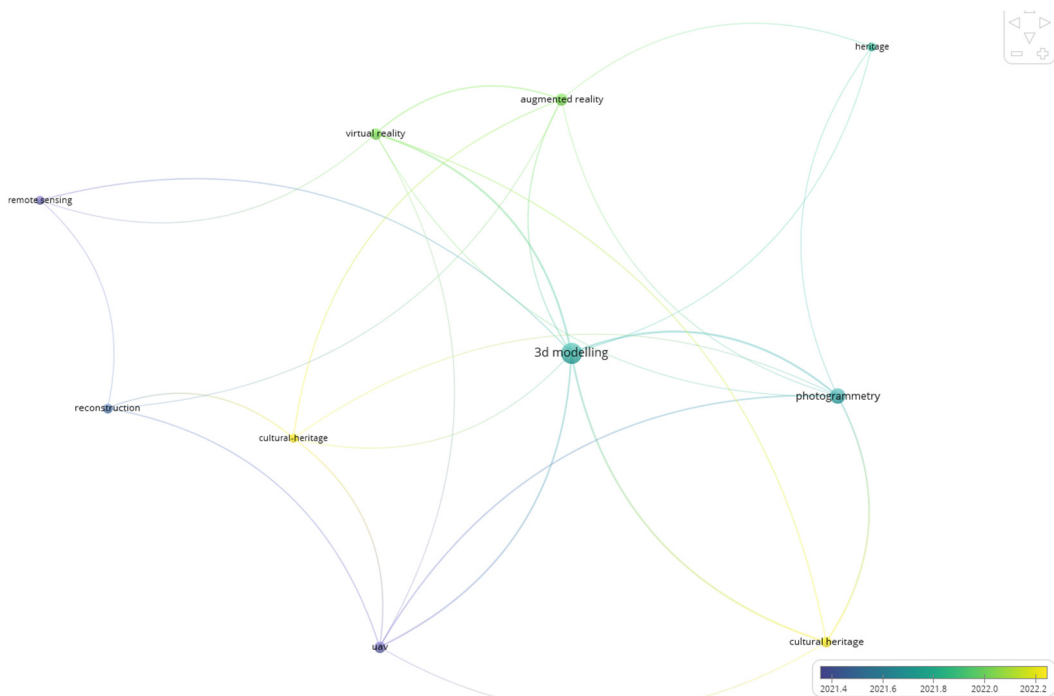


Figure 2. Overlay diagram of keywords (papers from the last 5 years) with a minimum number of keywords = 5.

3.4. Limitations

Through this study methodology, around 106 scientific papers, the most recent ones from the mentioned databases, were taken into account (Section 2.1). However, there are some other databases that have not been considered. Likewise, the considered timespan was of 5–7 years. The published papers dating back from 2017 have not been considered either.

4. Discussion

The integration of hybrid technology in 3D applications is advancing rapidly, merging various 3D capture techniques to enhance precision, versatility, and data richness. Hybrid technology combines methods like LiDAR, photogrammetry, and UAV-based imaging to create detailed and scalable 3D models, offering benefits across a range of disciplines from engineering and architecture to cultural heritage and environmental monitoring.

- **Engineering and infrastructure:** In engineering and infrastructure, hybrid 3D technologies are revolutionising the way complex projects are planned, executed, and maintained. By combining LiDAR and photogrammetry, engineers can capture highly detailed topographical and structural data. LiDAR offers precision in measuring distances, particularly effective in hard-to-reach or large-scale projects, while photogrammetry adds texture and colour information. UAVs can provide a bird's-eye view, complementing ground-based LiDAR with overhead perspectives, essential for large construction sites and urban planning. This hybrid approach enhances site monitoring, as-built documentation, and quality control, improving project accuracy and reducing time delays.
- **Cultural heritage and archaeology:** For cultural heritage and archaeology, hybrid 3D technology is invaluable in preserving artefacts and ancient sites. A combination of LiDAR and UAV photogrammetry enables archaeologists to capture the minute details of delicate artefacts while simultaneously documenting entire sites without physical intervention. LiDAR is particularly useful for revealing hidden structures or analysing under-canopy features in dense forested areas, such as Mayan ruins obscured by vegetation. Photogrammetry adds high-resolution textures to the models, making the results more visually accessible for research, digital archiving, and public engagement. These combined technologies allow researchers to build interactive, high-fidelity models of cultural landmarks, which can also be explored in virtual or augmented reality.
- **Environmental monitoring and agriculture:** In environmental monitoring and agriculture, hybrid 3D technologies are used to map terrain, monitor changes over time, and support conservation efforts. For example, LiDAR combined with multispectral imaging on UAVs can track erosion, deforestation, and water resource changes in real time, helping researchers to predict and manage environmental impacts. In agriculture, integrating UAV-based 3D imaging with thermal and multispectral sensors allows for monitoring crop health, soil moisture, and irrigation patterns with high precision. This combination enables farmers to make data-driven decisions, optimising crop yield and resource management.
- **Architecture and urban planning:** In architecture and urban planning, hybrid technologies improve the accuracy and flexibility of digital twin models, which are increasingly used for planning, managing, and sustaining urban environments. Combining LiDAR, photogrammetry, and BIM allows architects and urban planners to create richly detailed 3D models that are continuously updated with real-time data. This integration supports everything from historical building preservation to smart city initiatives, enabling planners to analyse infrastructure performance, energy use, and environmental impact. The combination of LiDAR and photogrammetry

enriches the visual and spatial accuracy of models, facilitating stakeholder engagement and informed decision making for urban projects.

- Emerging applications and future directions: Hybrid 3D technology is paving the way for AR and VR applications that rely on accurate spatial data for immersive experiences. For instance, combining NeRFs with traditional 3D capture methods can further enhance the detail and realism of models, especially in creating interactive environments for education, cultural experiences, and remote training. As artificial intelligence advances, hybrid technology could automate complex processes, such as object recognition and spatial analysis, in real-time, expanding its utility in fields ranging from disaster response to autonomous vehicle navigation.

This interdisciplinary approach maximises the strengths of each 3D capture method, resulting in models that are not only accurate but also highly adaptable for future technological advancements. Indeed, the key factors in new current trends, challenges, and opportunities for advancement are detailed below:

- Optimisation of hybrid techniques: Integrating artificial intelligence (AI) and machine learning (ML) to automate data processing is recommended, such as implementing NeRFs for real-time captures and accurate reconstructions. Furthermore, the development of universal standards would facilitate interoperability, improving efficiency in applications such as automated BIM integration and real-time archaeological reconstructions.
- Accessibility and cost reduction: The design of more affordable 3D hardware, such as simplified UAVs, combined with cloud-based platforms for data processing, would democratise access to these technologies. This would be particularly relevant in low-budget educational projects and community conservation.
- Application expansion: Augmented reality (AR) has enormous potential in areas such as remote surgery and clinical training. On the other hand, virtual reality (VR) can transform interactive learning, such as in geology and architecture, allowing for deeper understanding through immersive simulations.
- Sustainability and environmental monitoring: It is crucial to develop real-time tools, such as thermal UAVs, to detect topographic changes and study climatic phenomena. Furthermore, researching methods to reduce the carbon footprint of 3D technologies will contribute to their sustainability, applicable in ecological urban planning.
- Social and cultural impact: Three-dimensional digitisation can expand public access to cultural heritage, allowing virtual tourism and designing inclusive applications for people with disabilities, such as haptic simulators. These tools would foster greater accessibility and equity in interaction with 3D technologies.
- New research areas: Integrating NeRFs for cultural documentation and urban planning, together with 3D digitisation exploration with spatial intelligence, can revolutionise global heritage preservation and AI-driven smart city planning.

These recommendations underscore the need for interdisciplinary and collaborative approaches to maximise the impact of 3D technologies on society and the environment.

5. Conclusions

This study provides an in-depth analysis of 3D digitalisation technologies, examining their applications, impact, and future potential across various fields. The methodological rigor of the study, through comprehensive search and quality criteria, ensured the inclusion of influential, high-quality research. By integrating bibliometric analysis with relevance-based selection criteria, such as the IF of the journal, citation frequency, and sector-specific applicability, the review achieved a balanced and thorough evaluation of 3D digitalisation technologies. These methodological standards enhance the credibility of the findings, providing a solid foundation for future research and the development of optimised 3D digitalisation solutions tailored to each application within different disciplines. High-quality articles from the past seven years were selected from databases such as Web

of Science and Scopus. This approach facilitated the identification of both established and emerging techniques, from LiDAR and photogrammetry to advanced hybrid methods, allowing a comprehensive assessment of these technologies in sectors such as engineering, heritage conservation, medicine, and education. The suitability of combining LiDAR and photogrammetry depends on factors such as the type of object or environment, with complex surfaces benefiting from integration, while uniform areas may not require it. Project objectives also influence the approach; for instance, architectural restoration may demand high precision, whereas educational studies might prioritise cost and efficiency. Additionally, the effectiveness of hybrid technologies depends on the quality of the equipment, as poor-quality tools can undermine potential advantages.

The data reveal that 75% of publications are concentrated in engineering, heritage conservation, and archaeology—sectors that leverage 3D digitalisation to improve precision, scalability, and accessibility. Quality metrics, including the IF and citation counts, indicate that the medical and education sectors stand out, with an average of 20% more citations compared to other fields, suggesting significant academic interest in 3D technologies for surgical planning and immersive learning. Keywords such as “3D modelling”, “photogrammetry”, and “UAV” represent 60% of the most frequently used terms, highlighting their widespread use across multiple disciplines. Sectors such as engineering and heritage conservation particularly benefit from hybrid techniques, which represent 40% of studies in these areas and address challenges in complex monitoring and preservation tasks.

NeRF technology emerges as a promising future direction in 3D digitalisation. This technology enables realistic, real-time reconstructions from 2D images through neural networks, offering new possibilities for virtual tourism and education by making immersive experiences more accessible. Additionally, NeRFs and other AI-driven innovations could extend into augmented and virtual reality applications, providing a new level of interactivity and accuracy. Alongside hybrid methods, these advancements represent significant progress towards more accessible, precise, and versatile 3D digitalisation applications, especially in complex or resource-limited environments.

In conclusion, hybrid 3D technology applications offer enhanced capabilities for precision, scalability, and realism across various domains.

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