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Kültürel mirasta yapay zeka algoritmaları uygulayarak 3B nokta bulutlarından HBIM modelleme süreci üzerine bir inceleme

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A Review on HBIM Modelling Process From 3D Point Clouds By Applying Artificial Intelligence Algorithms in Cultural Heritage

Kültürel Mirasta Yapay Zeka Algoritmaları Uygulayarak 3B Nokta Bulutlarından HBIM Modelleme Süreci Üzerine Bir İnceleme

Highlights

- *From 3D Point Clouds to HBIM Modelling Process*
- *3D Point Clouds Segmentation and Classification*
- *Artificial intelligence algorithms (ML and DL*
- *Cultural Heritage Documentation and Digitation*

Graphical Abstract

Abstract representation of the stages of the workflow from cultural heritage data capture to the HBIM parametric object steps.

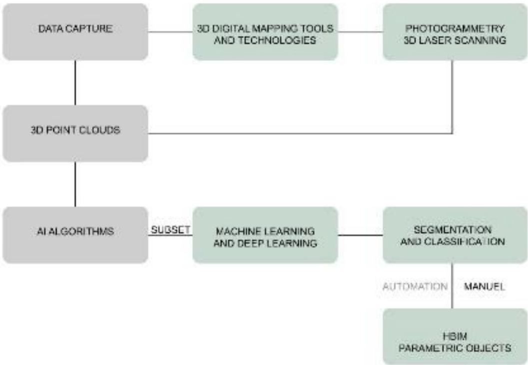

Figure. The HBIM workflow from the Data Capture examined in the literature review

Aim

The objective of this study is to comprehensively evaluate the implementation of the HBIM (Historic Building Information Modeling) process through the utilization of AI algorithms, such as Machine Learning and Deep Learning, to automate the segmentation, classification, and BIM geometry of point clouds in the context of cultural heritage case studies.

Design & Methodology

Upon reviewing around 50 papers, we have identified 15 articles about point clouds in HBIM. But, 11 main papers using AI applications on point clouds were selected and analyzed.

Originality

The study examines studies on semantically parsing and classifying 3D point clouds using AI algorithms, particularly within complex cultural heritage geometries, shedding light on potential benefits and barriers.

Findings

Segmentation of point clouds in Cultural Heritage is still an emerging field. Promising developments have been studied in the literature regarding the application of ML & DL methods on point clouds. However, current best practices continue to face significant challenges and the variety of building assets in Cultural Heritage makes these stages somewhat more difficult.

Conclusion

The study reveals constructing digital cultural models and establishing the foundation for upcoming studies on automated HBIM modeling.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

A Review on HBIM Modelling Process From 3D Point Clouds By Applying Artificial Intelligence Algorithms in Cultural Heritage

Araştırma Makalesi / Research Article

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ABSTRACT

In the context of Cultural Heritage (CH), the widespread adoption of 3D point cloud technology, coupled with Artificial Intelligence (AI) algorithms, plays a pivotal role. These technologies facilitate the creation of as-built models by integrating Building Information Modelling (BIM) strategies, enhancing collaboration within the Architecture, Engineering, and Construction (AEC) sector. Leveraging computer vision, robotics, and remote sensing, 3D point clouds provide rich data. However, manual segmentation and classification are labor-intensive and error prone. Consequently, researchers increasingly turn to machine learning (ML) and deep learning (DL) techniques for automating these tasks. The transition from manual reconstruction to automated procedures is crucial. Despite progress, gaps remain, particularly in incorporating 3D point cloud segmentation into Historical Building Information Modelling (HBIM). The lack of conclusive evidence regarding automated derivation of parametric attributes from segmentation outcomes underscores the need for further exploration. Addressing this gap is essential for cultural asset documentation, conservation, and upkeep. By automating the segmentation and classification of 3D point clouds, efficient communication via a shared database becomes feasible. The article aims to review studies on semantically parsing and classifying 3D point clouds using AI algorithms, particularly within complex cultural heritage geometries, shedding light on potential benefits and barriers.

Keywords: Cultural Heritage and Documentation, Laser Scanning and 3D Point Cloud, Digitation and Automation, Artificial Intelligence, BIM (HBIM)

Kültürel Mirasta Yapay Zeka Algoritmaları Uygulayarak 3B Nokta Bulutlarından HBIM Modelleme Süreci Üzerine Bir İnceleme

ÖZ

Kültürel Miras (KM) alanında, 3D nokta bulutu teknolojisinin ve Yapay Zeka (YZ) algoritmalarının geniş çapta kabul görmesi, bu alanda dönüştürücü bir etkiye sahiptir. Bu teknolojiler, Yapı Bilgi Modellemesi (YBM) stratejileriyle bütünleşerek, Mimarlık, Mühendislik ve İnşaat (AEC) sektöründe iş birliğini artırır ve inşa edilmiş modellerin oluşturulmasını kolaylaştırır. Bilgisayarla görme, robotik ve uzaktan algılama gibi alanlardan yararlanan 3D nokta bulutları, zengin veri setleri sunar. Ancak, manuel segmentasyon ve sınıflandırma süreçleri, yoğun emek gerektirir ve hata yapmaya müsaittir. Bu nedenle, araştırmacılar bu süreçleri otomatize etmek için giderek artan bir şekilde makine öğrenimi (MÖ) ve derin öğrenme (DÖ) tekniklerine başvurmaktadır. Manuel yöntemlerden otomatik süreçlere geçiş, bu alandaki ilerlemenin kritik bir parçasıdır. Bununla birlikte, özellikle 3D nokta bulutu segmentasyonunun Tarihi Yapı Bilgi Modellemesi'ne (HBIM) entegrasyonu konusunda mevcut boşluklar sürmektedir. Segmentasyon sonuçlarından parametrik özelliklerin otomatik olarak çıkarılması konusunda net kanıtların eksikliği, bu alanda daha fazla araştırma yapılması gerektiğini göstermektedir. Bu boşluğun kapatılması, kültürel varlıkların belgelenmesi, korunması ve bakımı açısından hayati öneme sahiptir. 3D nokta bulutlarının segmentasyon ve sınıflandırılmasının otomatize edilmesi, paylaşılan bir veri tabanı üzerinden etkin iletişim kurulmasını sağlar. Bu makale, karmaşık kültürel miras geometrilerinde YZ algoritmaları kullanılarak 3D nokta bulutlarının semantik olarak ayrıştırılması ve sınıflandırılmasına yönelik çalışmaları inceleyerek, bu yaklaşımın potansiyel avantajlarına ve karşılaşılan zorluklara dair bir bakış sunmayı hedeflemektedir.

Anahtar Kelimeler: Kültürel Miras ve Dökümantasyon, Lazer Tarama ve 3B Nokta Bulutu, Dijitalleşme ve Otomasyon, Yapay Zeka, YBM (HBIM)

1. INTRODUCTION

The utilization of leading-edge technologies in cultural heritage (CH) has witnessed a significant surge in recent times. Data acquired through these technologies has garnered more attention in contrast to conventional methods, owing to its capacity to facilitate the

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development of precise and swift information models for documenting, analyzing, and interpreting cultural heritage - encompassing architectural and historical features. Moreover, it enables seamless communication among stakeholders [1]. Nevertheless, managing heritage data poses greater challenges for the Architecture, Engineering, and Construction (AEC) sector due to the intricacy of cultural heritage compared to new building data, and the immediate recourse to this challenge is digitization [2]. The timely and accurate preservation of cultural assets, including UNESCO World Heritage Sites, necessitates interdisciplinary collaboration and the adoption of pragmatic methodologies to comprehend the evolutionary trajectories of heritage areas [3]. Maintenance, conservation efforts, and documentation play pivotal roles in safeguarding cultural assets, demanding collaborative efforts among architects, engineers, archaeologists, and other domain experts. These professionals often generate diverse data streams necessitating parallel and multifaceted analyses [2]. Hence, employing sustainable approaches to convey the transformations of historical artifacts, cultural heritage, and natural sites throughout different eras and civilizations from the past to posterity holds paramount significance [4]. Consequently, it's crucial to focus on incorporating digital technologies into the conservation of cultural heritage (CH), particularly within historic structures. This approach will encourage greater collaboration between these two fields and ultimately unleash the full potential of digital tools to support preservation endeavors and ensure their endurance.

Building Information Modeling, often known as BIM, has emerged as a comprehensive documentation tool for sustainable practices, documenting and creating parametric features for Cultural Heritage BIM (HBIM) poses heightened challenges compared to new constructions. This is because each cultural asset has unique historical and architectural features and requires different solutions for each unit. Hence, given the absence of 3D modeling prerequisites and integrated frameworks for semantic data comparisons, the cultural heritage sector's reluctance towards this issue is comprehensible [5]. Initiatives have been launched within the realm of Computer Science to address the present challenges. Computer vision aims to mimic human sight in machines, helping humans understand and analyze visual information like digital images and videos. It's an interdisciplinary field that overlaps with signal and image processing and classification [6], mathematics, and increasingly, machine learning and artificial intelligence. Initially, computer vision research was centered on understanding shapes, detecting edges, classifying patterns, and recognizing faces. However, recent progress has been significant, especially in combining vision with natural language processing and developing new uses such as processing 3D point clouds. In contrast to traditional 2D vision that only deals with images and flattens the 3D world into a 2D view, 3D vision techniques work with different data types including depth maps, multi-view images, voxel grids, networks, and point clouds [7]. Based on this information, this research focuses on the automation of parametric historical features in BIM modeling using artificial intelligence algorithms. Despite numerous experimental efforts in cultural heritage, complete automation has yet to be realized in the workflow from point cloud segmentation to subsequent BIM modeling [2]. To address this gap, this study examines digital technology studies in cultural heritage and conducts a literature review on automation in BIM modeling and elucidates the primary research objectives, culminating in a discussion on anticipated outcomes.

This research endeavors to enrich the cultural heritage field (HBIM) by integrating 3D point cloud into the BIM modeling workflow employing artificial intelligence algorithms, facilitating the creation of intricate and informative digital representations of historical artifacts and spaces, thereby augmenting their long-term preservation and knowledge dissemination. The following sections will introduce key concepts and terms necessary to understand the paper, then outline the methodology of the literature review and the subject of research. Next, there will be an in-depth examination of semantic 2D studies and 3D point cloud segmentation, including a critical evaluation of studies on automation in BIM modeling. The analysis and the results sections of this research end with articles applying semantic classification through machine and deep learning to the obtained point cloud were reviewed, and their success rates were examined. After these stages, the challenges in HBIM modeling applications and the opportunities that can serve as a guide in these stages were discussed.

2. TERMINOLOGY

Prior to the elucidation of essential terminology underpinning this research, it is critical to delineate the core objective of this study. The study seeks to examine a comprehensive review of literature pertaining to the automation of HBIM (Heritage Building Information Modelling) modeling via the application of artificial intelligence algorithms to 3D point clouds, which are procured through laser scanning of cultural heritage artifacts. Nevertheless, there exists a research gap concerning the transition from point cloud data acquired from Cultural Heritage buildings to the HBIM (Heritage Building Information Modeling) workflow. Despite efforts to segment and classify the point cloud using image processing techniques and to minimize errors arising from the raw state of the data, there remains a lack of consistent studies enabling automatic parametric modeling of cultural heritage. This highlights the need for further research in this area. However, this paper endeavors to explore potential works for future research within this identified gap. To facilitate the comprehension of this objective, the lexical definitions of the pertinent terms have been examined in advance. Therefore, our study's primary focus is HBIM (Historic Building Information Modeling), and in alignment with this objective, we will elucidate the terms associated with Cultural Heritage. These terms take precedence in our investigation. "Cultural heritage" encompasses elements of a society's culture, including traditions, languages, and structures, that originated historically and continue to have significant value [8]. The concept of heritage comprises both tangible and intangible components, including objects, buildings, customs, and natural resources. These elements embody our shared history and are vital in nurturing and shaping cultures worldwide. The concept of World Heritage sites emanates from the UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage, adopted in 1972 and entered into force in 1975 subsequent to ratification by 22 nations. This treaty instituted a global mechanism for the preservation and management of significant cultural heritage sites, providing a structure to understand the value of cultural heritage. The convention classifies monuments, historic urban areas, archaeological sites, and artistic works as "cultural heritage sites" within the three designated site properties (natural, cultural and mixed heritage sites) delineated in the UNESCO convention [9]. Preserving heritage necessitates meticulous documentation and safeguarding of cultural and historical sites, structures, and landscapes. This involves creating comprehensive records such as photographs, architectural drawings, and written descriptions to capture their historical context and significance. The documentation is vital for ensuring the conservation of heritage for future generations and guiding preservation efforts. Laser scanning technology is a pivotal tool in this endeavor, as it aids in recording and safeguarding cultural heritage. This technology is employed to create digital records of heritage items, such as ancient structures, objects, and natural sites, aiding in the safeguarding of our cultural and natural legacy for succeeding generations. Laser scanning's rapid and efficient data capture capability allows for the generation of highly accurate virtual replicas of structures or objects by recording millions of 3D coordinates within minutes. This technology effectively addresses challenges related to site size, accessibility, and working conditions, making it particularly beneficial for hard-to-reach areas. Beyond heritage preservation, the data obtained from laser scanning serves purposes such as expanding project scopes, attracting sponsorship, and promoting both physical and virtual tourism. In summary, laser scanning contributes to advancing research, understanding, and monitoring of cultural heritage, thereby ensuring its longevity and accessibility. A point cloud is a collection of data points within a three-dimensional coordinate system that precisely captures the surfaces of objects or environments. Each point is characterized by its x, y, and z coordinates, offering an exact digital representation of an object or area. Typically acquired using techniques such as laser scanning, LiDAR, or photogrammetry, point clouds have diverse applications. Building Information Modeling (BIM) encompasses technologies, processes, and standards that facilitate collaboration in a digital environment for building planning, construction, and management. It involves generating and handling digital models of a building's physical and functional attributes, guiding decisions throughout the project's lifespan, from early design to ongoing maintenance. Heritage Building Information Modeling (HBIM) involves developing digital representations of historic structures, beginning with the gathering of survey data via ground-based laser scanning and photography, which is then consolidated using diverse software tools. HBIM facilitates the digital representation and management of heritage buildings, considering their historical significance and preservation requirements.

3. METHODOLOGY

The main aim is to examine the processes that autonomously create HBIM parametric objects through the use of AI algorithms on cultural heritage's 3D point cloud, as outlined in the preceding introductory sections **(Fig. 1).** Another goal of this study is to explore the application of advanced digital technologies in this field particularly in process automation by examining the selected articles that reveal, and to provide a framework,

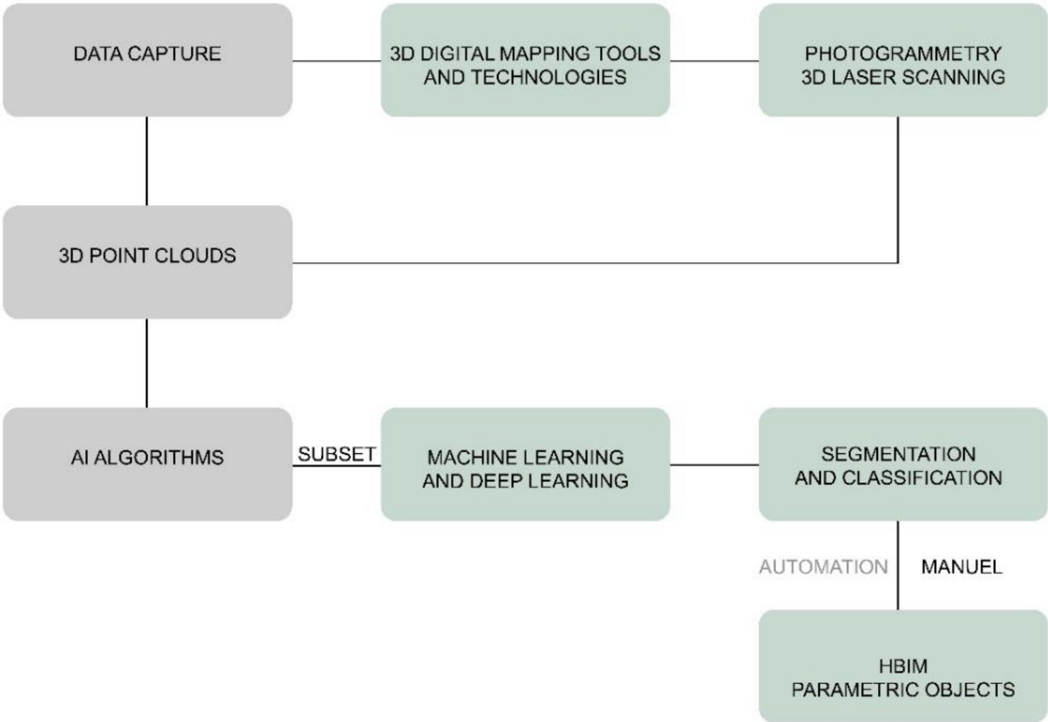

Figure 1. The HBIM workflow from the Data Capture examined in the literature review

Table 1. Applying the framework of Müller and Kranz, a framework for article selection can be established

Table 1

Applying the frameworks of Müller and Kranz, a framework for article selection can be established.

Definition of review scope		Is it possible to use Machine Learning and Deep Learning techniques to automate HBIM modeling through 3D point cloud segmentation?	Number of Paper
Conceptualisation of topic	Title, Abstact,Keywords	Cultural Heritage, Preservation and Documentation, Laser Scanning, 3D Point Cloud, Digitization, Artificial Intelligence, BIM, Automation, HBIM, AI in Cultural Heritage, BIM for Existing Buildings, Heritage Management and Documentation As- Built	50
Database and Journals	Google Scholar, Science Direct, Scopus, Web of Science	Automation in Construction (AIC), The International Archives of Photogrammetry, Remote Sensing and Space Information Sciences (ISPRS),Journal of Cultural Heritage, Survey Review, IEEE Digital Heritage International Congress,	
Literature Research and Literature Analysis and Synthesis	Elimination	Directly Related with Point Clouds	15
Literature Research and Literature Analysis and Synthesis	Elimination	Directly Related with Artificial Intelligence applied Point Cloud studies	11
Research Gap Identification and Results	Consequence	There is no reliable study about the review scope. So, this research gap motivated this article.	

structure, and highlight areas yet to be investigated for future research. Following Müller and Kranz's [10] proposed structure, five key stages were considered: a) Scope definition of the review, b) Topic conceptualization, c) Literature search, d) Literature analysis and synthesis, and e) Research gap identification **(Refer to Table 1).** The main aim was to systematically review the literature in this field to understand its scope and boundaries relevant to the topic, and to examine documents that will serve as a guide for future studies. A general and detailed international literature review was conducted by examining studies in the Google Scholar, Scopus, and Web of Science databases, as well as relevant chapters of books on this topic. Since there have been numerous studies in this field until 2023, articles primarily reviewing the literature on this topic in recent years were examined. In addition, the challenges mentioned above continue to be experienced in this field [2]. Keywords such as Cultural Heritage Documentation, 3D Point Cloud, Artificial Intelligence in Cultural Heritage, BIM, Heritage BIM, BIM for Existing Buildings, and Segmentation were examined. The examined articles consisted of direct content related to the main topic. The articles have made experimental applications containing real data. Therefore, only studies that involve the creation of a point cloud in the BIM field using artificial intelligence were considered. Since the modeling of the point cloud is divided into semi-automatic and automatic studies, articles from both areas were examined, and the difficulties and limitations of manual methods were investigated. Upon reviewing around 50 papers, we have identified 15 articles that align with our initial criteria that we discussed before. However, only 11 main papers using AI applications on point cloud were selected.

4. LITERATURE REVIEW

Preserving both tangible and intangible cultural and landscape heritage, which has been the site of various historical periods and civilizations, is crucial for ensuring that the memory of these eras lives on for future generations. Natural disasters, inadequate maintenance, wars, neglect, and interventions pose significant threats to cultural assets, leading to their gradual destruction, loss of historical and informational value, and potential extinction [11]. The primary goal of conservation efforts is to maintain the authenticity, historical significance, structural integrity, technical characteristics, and artistic value of these assets while preventing potential damage [12]. In essence, documenting cultural heritage serves as concrete evidence in the transmission of knowledge from past eras to future generations. A number of international, national, formal, and semi-formal institutions like UNESCO (1945), ICCROM (1956), and ICOMOS (1965) have the mission of protecting cultural heritage [13]. However, the existing cultural heritage is at risk due to natural and human factors and current practices often fail to adequately preserve their original values and ensure their accurate transfer to future generations due to insufficient documentation and misguided interventions. This scenario underscores the inadequate and imperfect execution of cultural heritage preservation and conveyance. Conservation encompasses the continuous safeguarding, refurbishment, and surveillance of cultural assets to ensure their perpetuation for posterity. Therefore, the process of preserving historical monuments is complex and involves multiple stakeholders, requiring a lengthy and arduous effort, with challenges in managing information and documentation at every stage of cultural property conservation. Effective information management is crucial for protecting cultural property and making informed decisions about future interventions [14]. This challenging process can be addressed most effectively and efficiently through digital methods. Early digital documentation applications, such as CAD software capable of creating 2D and 3D drawings, only provide a geometric representation of buildings [15], lacking topological and semantic data. Meeting this need, Building Information Modeling (BIM), which has gained popularity, aims to manage all geometric, topological, and semantic information of a building within a single database. According to Isikdag & Underwood [16], BIM is a comprehensive information management process that covers the entire lifecycle of a building, from conception to demolition, promoting collaborative and integrated project flow and delivery through the use of semantically rich 3D digital building models across all project phases and the building lifecycle. Although 2D and 3D drawing modeling applications are commonly used to create digital BIM models, this technique falls short in delivering comprehensive geometric, topological, and semantic details throughout all phases of a building's lifecycle (from inception to deconstruction), and it continues to be a basic method for collaborative efforts.

The Industry Foundation Classes (IFC), designed by Built SMART as a common database between BIM application platforms, aims to semi-automatically model experts, striving to automate object design directly from point cloud data. These processes become even more intricate when dealing with historic buildings of cultural heritage. While digital 3D modeling is effective for designing new buildings, it has limitations in providing a comprehensive and integrated data source for creating a unified guideline and reference framework for documenting cultural heritage [5]. As a result, the complex and diverse stakeholder processes in preserving, conserving, and documenting cultural heritage necessitate the collaboration of multidisciplinary teams, including architects, engineers, archaeologists, etc., through a cohesive communication channel [2]. It is essential to update documentation constantly and maintain communication among stakeholders. Therefore, with advancing technology, the goal is to consolidate the documentation created throughout the lifecycle of cultural heritage for each discipline in a shared database for future interventions. Is it possible to utilize the Building Information Modeling approach, known for creating a shared database in the architecture, engineering, and construction fields, for the documentation of Cultural Heritage? However, given the unique nature of each Cultural Heritage site, applying this approach is complex. Numerous applications exist for 3D modeling in documenting structures or cultural heritage [17]. The Building Information Modeling (BIM) concept, prevalent in the AEC industry, has been adapted as Historic Building Information Modeling (HBIM) for around 14 years to address cultural heritage documentation gaps [18]. Due to the complex geometry of cultural heritage, there have been time losses in the initial HBIM workflow due to the use of manual methods [19]. Therefore, it is natural to propose a method as fast as obtaining the 3D point cloud for the reflection of this idea in 3D modeling. To minimize manual modeling, automatic classification and segmentation of the 3D point cloud using AI algorithms is essential [20]. The primary aim is to investigate workflows that automatically create HBIM parametric objects by applying AI algorithms to the 3D point cloud of cultural heritage, as previously discussed **(Fig.1).** It is thought that this application will be an investigation that guides the cultural heritage's needs and the research community in terms of innovative strategies. In this scholarly investigation, the potential applications of artificial intelligence in the context of 2D photographs and 3D point clouds for the purpose of 3D modeling are meticulously explored. The comprehensive analysis spanned across eleven scholarly articles, as meticulously documented in (Table 2 and Table 3). The potential objective of this research later is to develop a tool for experimental analysis of tangible cultural heritage, addressing the automation need in generating diverse parametric features from the 3D point cloud (HBIM) of various cultural heritages.

5. RECENT TECHNOLOGIES: EXAMPLES OF 2D AND 3D MODELING APPLICATIONS FROM POINT CLOUD SEGMENTATION IN CULTURAL HERITAGE

Pertaining to Cultural Heritage, subsets of artificial intelligence in BIM modeling, such as machine learning and deep learning techniques, prepare the ground for creating fast parametric objects for the classification and semantic segmentation of historical features. Designing parametric objects or architectural elements from scratch requires parameters that are necessary in the BIM field, but desired results are achieved faster due to the complexity of Cultural Heritage being more rational and orthographic. When it comes to the diversity of Cultural Heritage, unlike rational objects, the point cloud captured is likely to consist of objects in different measurements, making the work of artificial intelligence and parametric formulas challenging. In the review of literature performed for this objective, the concept of utilizing artificial intelligence techniques to automatically model the parametric elements of cultural heritage, as well as the initiatives focused on generating the HBIM model resulting from this concept in a completely automated manner, were investigated. In this study, the application potentials of artificial intelligence to 2D photographs and 3D point clouds for 3D modeling were examined through 11 articles (Table 2 and Table 3).

5.1. The Application Potentials of Artificial Intelligence to 2D Photographs

Looking at the literature, the modeling of Cultural Heritage is still carried out using 2D photographs obtained in the field. This process can be exemplified by manually drawing high-quality obtained photographs using Autodesk's AutoCAD application with the 'tiff' extension (Fig. 2). However, despite the prevalence of automated modeling discussed in the article, this approach is still being carried out manually by companies in 2024. In the field of 2D photograph classification, there is a significant focus on the application of classification techniques as a separate process from manual drawing. Many studies have been conducted in this area, leading to the examination and creation of tables to better understand the classification of 2D photographs (Table 2). The method of completely modeling the point cloud using manual methods can be time-consuming and lead to erroneous results. As mentioned above, the classification of 2D photographs primarily relies on automatic methods rather than manual methods. However, these methods do not go beyond surface classification and are insufficient for 3D modeling and

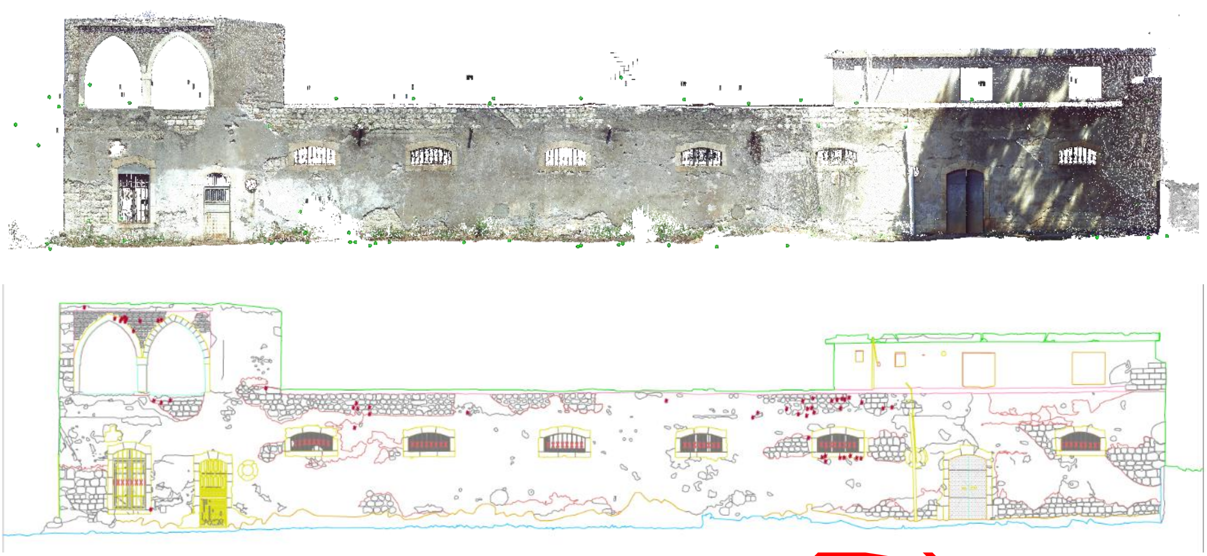

Figure 2. Modeling of high-quality photographs obtained with Photogrammetry in AutoCAD application (Şentürk,2021)

Table 2. The categorization of 2D architectural images applying AI as discussed in scholarly literature. 1- [20], 2- [21], 3- [22], 4- [23]

	1	2	3	4
Reference	Garilli et al.	Oses et al.	Hou et al.	Felicetti et al.
Year	2021	2014	2021	2021
Country	Italy	Spain	Germany	Italy
Tools	UAV, QGIS, CNN,SCP	K-Mean Algorithms	Aerial Photogrammetry,GAN	Mo.Se (Mosaic Segmentation)
Summary Methodology	The aim of this study was to create an automated system that can identify the design of natural stone pavements. To accomplish this objective, the researcher utilized UAV photogrammetry to capture images of the pavement's surface and employed two distinct classification techniques: the Semi-Automatic Classification Plugin for QGIS and a Convolutional Neural Network (CNN). The findings of the study revealed that CNN is an incredibly effective alternative to traditional manual inspection and can be used to analyze other types of paving stones as well.	This study presents a fully automatic framework for the identification and classification of cultural heritage using image-based methods. The study proposes an algorithm that combines image processing and machine learning tools to extract the boundaries of the construction blocks of stone walls and categorize them according to their geometric features. The study evaluates the performance of the proposed framework by conducting experiments on real wall images. K-Means algorithms for clasification in architectural masonry.	GAN's Neural Network implemented to semantic classification in different facades acquired by aerial photogrammetry.	Mo.Se (Mosaic Segmentation), an algorithm that exploits DL and image segmentation techniques, was developed to be implemented in archaeological sites.
Manuel Modelling	X			
Semi Modelling	X			
Full Modelling		X	X	X

classification. After reviewing the literature, 4 papers on automatic segmentation of 2D photographs were reviewed. These are Automatic detection of stone pavement's pattern based on UAV photogrammetry [21]; Image-Based Delineation and Classification of Built Heritage Masonry [22]; A Computer Vision Approach for Building Facade Component Segmentation on 3D Point Cloud Models Reconstructed by Aerial Images [23];

Mo.Se.: Mosaic Image Segmentation Based On Deep Cascading Learning [24]. UAVs serve various purposes, including remote sensing, photogrammetry, traffic control, and monitoring of large facilities [25]. The research [21]; explored the use of UAV photogrammetry to identify stone pavement patterns and integrate them into an urban pavement management system. Two methods, supervised classification, and convolutional neural network (CNN) were employed for automatic detection [26]. The study's outcomes indicate that CNN classification is a more flexible and effective method, providing better performance and greater dependability. Although it necessitates a thorough training phase, it yields satisfactory outcomes even with suboptimal patch sizes and without the need for equalization or pre-processing of images. The use of a U-Net CNN for automatic classification on images captured by UAVs has been shown to be a practical substitute for manual surveys and is applicable to other kinds of stone pavements, including the detection of damage. The paper [22] describes the preliminary efforts to develop an ICT tool for assessing architectural heritage, focusing on the automated, image-based delineation of stone masonry to support the application of emerging protection protocols. The outlined method for automatic stone masonry delineation has been evaluated through classification tasks and has yielded very promising outcomes. Additionally, the paper contemplates the enhancement of delineation with RGB-D cameras and the prospective investigation of probabilistic color and texture gradient maps as comprehensive descriptors. The study [23] indicates that 3D point cloud models can be generated from aerial photographs, with the virtual camera successfully rendering images of facades for the purpose of segmentation. The study found a decrease in segmentation accuracy when transitioning from open-source datasets to assessing rendered images, particularly with the "Unet256" algorithm. Additionally, the research revealed that segmenting windows had higher accuracy than segmenting doors and that semantic segmentation accuracy was higher for buildings in a city compared to those on a university campus. The research underscored the necessity to tackle the issue of imbalanced datasets, which arises due to a greater frequency of window elements over door elements in current databases. The study concluded by proposing that the enhancement of image quality and the refinement of segmentation algorithms could boost the effectiveness of segmentation. The study [24] examines the Mo.Se. algorithm which employs deep learning (specifically the U-Net 3 Deep Neural Network) and image segmentation to autonomously segment tesserae in historical mosaics. Tested on Byzantine mosaics in Jordan's St. Stephen Church, it outperformed earlier methods. Mo.Se.'s potential uses include assisting archaeologists and heritage professionals in forming digital archives, mosaic comparison through database indexing and content-based retrieval and streamlining the manual process of tesserae delineation in CAD/GIS, which is currently standard. It also paves the way for museum digitization tools for inventorying mosaics. Future work aims to automate the recognition of backgrounds, figures, and defects in scenes, enriching semantic information and object extraction in complex mosaics, providing a tool for automatic geometric and semantic data extraction from ancient mosaics. Despite these advancements, the research found that 2D photo segmentation remains not fully automated, with four projects not achieving complete automation, leading to semi-automatic modeling.

5.2. The Application Potentials of Artificial Intelligence to 3D Point Clouds

A survey of the existing literature reveals a concentrated interest in the automated 3D modeling of point cloud data, especially within the realms of cultural heritage conservation and building information modeling (BIM). The integration of laser point cloud studies with BIM is highlighted, with references to the pioneering work of Yusuf Arayici [27]; and the methodology developed by Murphy et al. [18]; in this field. Historic Building Information Modelling (HBIM) is recognized as a crucial fusion of modern technology with the BIM methodology for documenting cultural heritage. It functions as an extension to BIM, providing a distinctive library of parametric objects derived from historical records, coupled with a mechanism for aligning these objects with point cloud and photographic survey data. The process of obtaining point cloud data and manually categorizing it, followed by creating geometric models based on these categories, is entirely manual. This approach is time-consuming and poses a risk of errors when dealing with the complex geometry of cultural heritage. Transforming manual methods into automated steps within the workflow from point cloud data to Historic Building Information Modeling (HBIM) will help bridge the research gap in terms of time and accurately representing the unique geometry of each cultural asset. Unlike the parametric design of new building architectural elements, capturing the uniqueness and historical significance of cultural properties through geometry is more challenging. However, this can be explored using the Revit program, which offers both flexibility and technical limitations in parametric modeling for new building designs within the Building Information Modeling (BIM) domain. Within the domain of BIM, and specifically in the Revit software which facilitates 3D modeling from point clouds, the process still necessitates manual modeling of millions of points even after the point cloud has been imported into the application. Only with the advantage of the parametric model provided by the application, the orthographic drawings of the building (plan, section, elevation, etc.) are generated simultaneously, which is helpful. Therefore, the automation between HBIM modeling and point cloud segmentation will lead us from manual modeling to semi-modeling or full modeling. The studies of individuals who use these methods have been examined and the following table has been created **(Table 3.).** The initial studies that explored the manual modeling techniques of laser scanning data include the research conducted by Murphy et al. in 2011 [28], Barazzetti et al. in 2016 [29], Wang et al. in 2019 [30], and Yang et al. in 2019 [31]. The research by Murphy et al [28] explores HBIM, or Historic Building Information Modeling, a sophisticated approach that combines terrestrial laser scanning and digital photography to collect survey data and establish a parametric element library rooted in historical architectural information. The HBIM output is a comprehensive 3D model that encapsulates details on construction techniques and materials, capable of autonomously producing various drawings and documents for the conservation and study of historical sites and items. Initial efforts were concentrated on capturing the complex details of smaller cultural artifacts, like Michelangelo's sculptures, through laser scanning and digital photography. Present-day commercial systems incorporate these techniques to fulfill the high precision needed for documenting, surveying, and modeling historical monuments and relics. The suggested HBIM process includes gathering and processing survey data from lasers/images, identifying historical intricacies from architectural pattern books, constructing parametric historic components/objects, aligning these objects with scan data, and generating detailed 3D models with engineering surveys and documentation automatically. The study referenced as [29] presents a technique for developing a Historic Building Information Model (HBIM) hosted on the cloud. It utilizes a NURBS-based method to transform images and laser scan data into an accurate 3D model that is memory-efficient and can be accessed remotely on various devices via cloud services. The paper explores the future implications of cloud-based HBIM within BIM technology, particularly its accessibility on mobile devices and its ability to connect office planning with on-site construction. It further examines the use of mobile apps in fieldwork, security issues related to cloud technology, and how augmented and virtual reality (AR and VR) could be integrated into construction projects. A key focus is placed on the visualization of hidden elements and the innovative possibility of integrating a comprehensive BIM within AR applications for direct access. The study of Wang et al. [30], provide a detailed overview of a region-growing algorithm for surface reconstruction. The algorithm is designed to improve the quality of reconstructed surfaces using imperfect point sets. By refining the selection criteria of seed triangles, updating candidate triangle selection rules, and enhancing the hole processing strategy, the algorithm demonstrates favorable reconstruction quality in experiments. It offers advantages such as simple implementation, reliance solely on three-dimensional point coordinates without additional information, and relatively good reconstruction quality for uniquely shaped data and thin parts. However, it may require adjustment of the value of k and could result in poor reconstruction quality for data with numerous incorrect locations not on the original surface. The "value of k" sets the maximum circumcircle radius for candidate triangles in 3D reconstruction, affecting triangle selection for accurate mesh generation, especially in areas with sparse data or fine details. The algorithm is considered a better choice for unorganized points without additional information, especially when the surface contains thin parts. The authors aim to further explore the impact of scanner information on surface reconstruction algorithms and enhance the efficiency of their method for differently shaped point sets in the future. The research by Yang et al. [31] examines the integration of geometric representations of architectural heritage with varied knowledge within the context of heritage documentation, emphasizing the concept of Heritage/ Historic Building Information Modeling (HBIM). The study introduces a novel mesh-to-HBIM modeling workflow and an integrated BIM management system, exemplified by the St-Pierre-le-Jeune Church in Strasbourg, France. The methodology entails segmenting the surface mesh, converting the triangle mesh into a 3D volume, and mapping these primitives to BIM elements, culminating in a semantic model enriched with object-oriented knowledge.

Table 3. Employment of Artificial Intelligence in the domain of geometric reconstructions within Heritage Building Information Modeling (HBIM). 1- [25], 2- [26], 3- [27], 4- [28]

	1	2	3	4
Reference	Murphy et al.	Barazzetti et al.	Wang et al.	Yang et al.
Year	2011	2016	2019	2019
Country	Ireland	Milan, Italy	China	France
Tools	GDL,ARCHICAD	Revit, NURBS, A360,AR AND VR	Deep Learning and Machine Learning algorithms	Revit, Dynamo, Rhino 3D, CIDOC CRM
Summary Methodology	Creates HBIM library using point clouds and historical data.	HBIM uses BIM technology to document, evaluate, and preserve historic buildings. NURBS-based HBIM is generated from image and laser scan data and can be accessed remotely through cloud service.	Algorithm creates surface from point set using region growing and Delaunay approaches. Includes new criterion for selecting triangles to handle input imperfections and a detection and repair approach to reduce number of holes in output.	This article presents a new method to model HBIM using surface mesh and historical information. Benefits include a time-saving process, a semantic model and unified presentation of geometric elements and ontology information in a BIM environment.
Manuel Modelling				X
Semi Modelling	X	X	X	X
Full Modelling			X	X

Table 4. Application of AI in the field of HBIM geometric reconstructions. 5- [29], 6- [30], 7- [31]

	5	6	7
Reference	Tamke et al.	Yang et al.	Wang et al.
Year	2016	2019	2021
Country	Tokyo, Japan	China	China
Tools	RANSAC Algorithms, 3D Laser Scanner, BIM	RANSAC, MRF (Markov Random Field)	MSAC, DBSCAN, RANSAC, DYNAMO
Summary Methodology	An approach for the automatic generation of construction models in IFC BIM format from unstructured point clouds was generated using a RANSAC iterative algorithm. Unfortunately, in the applied case study the algorith is not suitable for complex geometries.	Distinguish themselves in the geometric reconstructions process by include curves in addition to straight lines. The experimental findings showed that the suggested technique is well suited for indoor modelling of multi- room situations with curved walls, laying the first foundations out of the parameters of orthogonality and perpendicularity.	The objective is to establish a fully automated system capable of converting laser scan data into semantically detailed building information models (BIMs) specifically designed for complex mechanical, electrical, and plumbing (MEP) environments.
Manuel Modelling			
Semi Modelling	X	X	
Full Modelling	X		X

Moreover, the study explores the direct application of point clouds in BIM software for authentic modeling of built heritage within a BIM framework, tackling scan-to-HBIM challenges and advocating for mesh-to-HBIM conversion and HBIM-ontology integration via Revit Dynamo visual programming tools to augment BIM functionalities. This ontology integration through Revit Dynamo enhances HBIM with semantic depth, enabling concurrent access to both semantic data stored in an ontology database and the 3D HBIM model. Upon reviewing the four papers, it is evident that manual methods have been utilized in the pursuit of automation goals. However, these studies showcase the progression from manual and semi-automated to fully automated modeling approaches within the point cloud methodology. Furthermore, they shed light on the potential and future advancements of HBIM technology, particularly in enhancing the utilization of laser scanning data for the documentation and modeling of historical structures. To mitigate the risk of inaccuracies, semi-automated instruments are at disposal that can interpret point clouds and construct geometric primitives or frameworks from 3D datasets. Nonetheless, the models produced may not align with prevalent BIM applications such as Revit, ArchiCAD, or Tekla Structures, occasionally leading to data interoperability challenges and necessitating the use of multiple software solutions. To address these issues, specialized software such as EdgeWise and ClearEdge3D for scanning processes in BIM or plugins like Cloudworkx, ImaginIT, and AsBuilt for Revit have been developed. These tools allow users to adapt structural elements to point clouds, but they can only define one surface at a time [2]. However, because of these studies, the modeling process continues to be semi-automatic. Therefore, within the realm of Cultural Heritage, the search for artificial intelligence algorithms that can automatically generate surfaces from point cloud data continues. The potential studies described in the last 3 articles (Table 2.) involves the utilization of artificial intelligence algorithms to create HBIM geometries for fully automatic modeling. These studies are by Tamke et al. 2016 [32], Yang et al. 2019 [33], and Wang et al. 2021 [34]. The research delineated in [32] is centered on the automated generation of building models in IFC BIM format, utilizing unstructured Point Cloud data obtained from 3D laser scans of edifices. The primary aim is to ascertain architectural elements and their interconnectedness, shifting the focus from the conventional point-level operation prevalent in existing methodologies. The team plans to demonstrate the use cases with a software prototype, evaluate the outcomes, and explore future work aimed at establishing automatic semantic links between building design in BIM and simulations within the built environment. The advanced tool aims to address the challenge of creating documentation for historical buildings. The BIM models it generates can serve as a foundational framework for retrofitting or analysis purposes. The tool's output comprises IFC models at a basic level of Detail (LOD 1). Evaluation of the initial prototype of this fully automated approach with a large set of 3D scanned buildings from stakeholders indicates a high level of robustness and reliability, with approximately 87.7% of all walls, window, and door elements in the point clouds being accurately detected. The majority of inaccuracies result from mislabeling windows as doors, and the quantity of unreconstructed elements is relatively small. The tool is currently in a prototype state, and future efforts should aim to broaden the scope of detected building elements and spatial scenarios. Subsequent work may also involve the identification, categorization, and naming of elements based on a set of BIM element families and standards provided by users. The investigation presented in [33] introduces an innovative technique for the delineation of both linear and curvilinear structures, incorporating a specialized assessment for the identification of curved barriers. It employed robust parameters and a novel regularization strategy for linear alignments, realized through constrained least squares optimization. This technique reconceptualized indoor reconstruction as a classification challenge, assigning labels to a constructed cellular complex via energy minimization employing graph cuts. Notably, this method eschewed reliance on viewpoint data, instead leveraging explicit barrier constraints derived from point clouds during the preliminary room segmentation stage. Experimental outcomes affirmed its applicability for interior modeling of complex spaces with curved partitions. Nonetheless, prospective research is necessitated to tackle the challenges posed by slanted walls and to explore feature-centric and vision-integrated approaches for interior reconstruction. The research delineated in [34] introduces an automated methodology for the identification and reconstruction of BIM models of MEP components from point cloud datasets. This approach distinguishes MEP elements into regular and irregular categories based on their geometric intricacy and implements a bifurcated phase detection procedure. The MEP network is autonomously constructed through the ascertainment of inter-component connections and the refinement of their placements. Validation of this method was conducted on point clouds from three different scenes in Hong Kong, culminating in the successful detection and modeling of 285 components. The introduced technique demonstrated superior efficiency compared to manual methodologies, yielding high rates of retrieval and precise geometric fidelity. Nonetheless, the research acknowledges certain constraints, such as the presupposition that MEP components adhere to the principal orientations of the edifice. Further research is needed to improve recognition ability for unseen items and automate the model generation process at a higher level. Recent studies have shown that modeling studies typically use a flat structure with algorithms on the point cloud, facing specific challenges in developing new designs. Despite this, these studies have demonstrated strong performance in terms of percentage. When it comes to the geometry of Cultural Heritage, it has been observed that while the complexity of the geometry may not yield high percentage results, the outcome could be lower compared to the new design, given that the original architecture has not largely endured from historical times to the present day. Therefore, the absence of a study utilizing Cultural Heritage as the primary tool in future research increases the likelihood of exploration or a study in this specific field.

5.3. Justification

Based on the assessments and research, it is evident that there is a significant research gap in the domain of Cultural Heritage. The lack of successful studies in the process from laser scanning to automatic digital modeling of point clouds obtained from laser scanning using artificial intelligence for the HBIM library indicates this gap. The literature review shows a tendency to focus on segmenting 3D point clouds of more recent and flat geometry structures, while overlooking the original and complex geometry of Cultural Heritage. Additionally, the impact of historical natural and human events on the geometry of Cultural Heritage is a factor that has not been extensively studied. Evaluation of Building Information Modeling programs reveals that the Revit program performs better on flat and orthogonal shapes, posing challenges in working with cultural heritage and integrating artificial intelligence tools into these programs. Nevertheless, it is anticipated that this study will establish a framework for the automatic modeling of HBIM libraries of Cultural Heritage for future research.

6. CONCLUSION

The text provides a detailed analysis of maintaining records and creating precise designs for architectural heritage. The main focus is on exploring different methods for implementing BIM platforms before starting a project to preserve architectural legacy. The quintessential objective is to augment conservation and restoration project planning and management through the deployment of virtual models of historical edifices. Critical to this endeavor is the employment of 3D laser scanning, photogrammetry, and historical analysis to document the architectural nuances. Nonetheless, the intricate and non-uniform nature of historical structures coupled with the absence of sophisticated algorithms for full automation renders the modeling process laborious. An efficacious resolution has been the integration of BIM with GIS tools and ancillary software, enabling semi-automatic management and modeling of graphical and semantic data. This methodology promotes fluid communication between stakeholders in architectural heritage conservation. Moreover, H-BIM libraries have streamlined the interchange of semantic and geospatial data among multidisciplinary experts. Despite these strides, there remains ample scope for research in areas such as plugin development for element arrays and algorithmic shape recognition for parametric reconstruction. Moreover, the demand for creating a universal and openly accessible H-BIM library, replete with extensive data beneficial to professionals in architectural heritage, is escalating. This article delivers an exhaustive survey of the extant scholarly works on automated scan-to-BIM methodologies commencing with point cloud segmentation. A multitude of research has employed point clouds to identify and reconstruct geometries pertinent to BIM models. Nevertheless, these methods have been predominantly applied in digital Cultural Heritage, not entirely exploiting Machine and Deep Learning techniques. The deployment of AI within BIM for Cultural Heritage is confined to functions such as surveillance, diagnostic assessments, sustainability endeavors, data stewardship, compliance verification, and enhancement of clash detection accuracy. Yet, the challenge of autonomous geometric reconstruction persists unaddressed. The standard BIM representations and data interchange formats presuppose idealized geometries that are scarcely encountered in actual structures. Given that walls are not uniformly flat, and angles are rarely exact right angles, cell segmentation might not be the most suitable approach. Furthermore, the flawed nature of sensory data in as-constructed BIMs calls for additional representational capabilities beyond what current BIM formats offer, including the depiction of obscured areas and uncertainty in model data. The objective is to ensure that architectural and archaeological elements digitally modeled are verisimilar to their physical counterparts, conserving their distinctive geometric features. Hence, it is imperative to forge novel strategies for the interoperability of precise modeling systems, especially those pertinent to Cultural Heritage.

A considerable portion of the time allocated to building information management is dedicated to the modeling phase. Consequently, it is vital to conceive innovative methods for architectural depiction or to enhance existing methodologies to fill these capability voids, particularly within the realm of Cultural Heritage. The integration of BIM with automation technologies is essential, as stakeholders in conservation and restoration endeavors demand detailed and accurate insights by examining physical and functional parameters, which forms a robust basis for non-invasive measures that promote the appreciation and preservation of Cultural Heritage.
This work will act as a key reference for creating digital cultural models, laying the groundwork for subsequent automatic HBIM modeling studies for future research. Furthermore, the study may help to enhance the evaluation of point cloud semantic segmentation using advanced AI techniques on cultural heritage point clouds with various architectural features.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Hilal Sıla ŞENTÜRK: Gathered data, and conducted research and analysis. Wrote the manuscript.
Cemile Feyzan ŞİMŞEK: Conceptualized the study, wrote the original draft, and conducted review and editing.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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