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Two-Dimensional Shape Analysis of Complex Geometry Based on Photogrammetric Models of Iconostases

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Abstract: Three-dimensional digitization technologies have been proved as reliable methods for detailed and accurate spatial data collection from existing cultural heritage. In addition, the point segmentation techniques are particularly relevant for contour detection and classification of the unstructured point cloud. This paper describes an approach to obtain 2D CAD-like visualizations of complex geometry from photogrammetric models so that the detected contours of particular object elements can be used for 2D shape analysis. The work process uses the point clouds derived from photogrammetric models to create the plane visualization of the object’s geometry by segmenting points based on the verticality geometric feature. The research presented is on the case studies of iconostases as the specific art and architectural elements of the Christian Orthodox church that can be appreciated only in situ. To determine relations between the characteristics of the particular shapes and the iconostases’ style origins, the mathematical method of shape analysis was applied. This study aims to numerically describe the stylistic characteristics of the shapes of the main parts of the iconostasis concerning the artistic period to which it belongs to. The concept was based on the consideration of global shape descriptors and associated shape measurements which were used to analyze and classify the stylistic characteristics of the iconostases. The methodology was applied to the representative examples of three iconostases from the Baroque and Classicism art movements. The results illustrated that the proposed methods and techniques, with certain improvements, could be helpful for CAD visualization and shape analysis of complex geometry.

Keywords: cultural heritage; digitization; photogrammetry; 2D visualization; point cloud; segmentation; shape analysis; shape descriptors; iconostasis; church heritage

1. Introduction

Although two decades have passed since the pioneering digital heritage project, the Digital Michelangelo Project [1], three-dimensional (3D) digitization still represents a flourishing field of research and application in cultural heritage. Ever since 3D acquisition and digitizing technologies have been proved as sufficiently developed for extensive application in the field of tangible cultural heritage, they have been used for reconstruction, conservation, digital restoration, and monitoring, as well as for physical replication and remote fruition [2].

Cultural heritage digitization is especially important in the cases of 3D reconstruction, preservation, and conservation of cultural heritage that is in some way unavailable or inaccessible and when no other data about an object is available. One specific branch of such types of cultural heritage is church heritage due to its unique value and context. Church heritage presents a significant type of tangible cultural heritage that can be appreciated only in situ.
In the context of the Christian Orthodox church heritage, the iconostasis represents one of the most notable features and the dominating art and architectural element of the church interior. The iconostasis, whose name originates from the Greek language and means ‘icon stand’, represents a highly ornamented element of the Christian Orthodox church interiors, which serves simultaneously as a vertical frame composed of icons and the physical division between a sanctuary containing an altar and a nave in a church.

Iconostases initially evolved from a very low altar screen, called Byzantine templon, which was later on lifted higher using columns that supported an overhead, to gradually becoming a high icon screen [3–6]. Their development into a multi-tier and richly decorated vertical frame, composed of religious paintings usually painted by the most influential artists of that time, made them the most decorative and ornamental elements of the Christian Orthodox churches. The iconostasis construction is characterized by a mainly flat shape but with complex and irregular geometry of rich ornamental carvings, usually made of wood or marble, with the icons placed from behind into highly decorated frames. The unique frame carving works have an equal place with the icons in the whole iconostasis structure. Moreover, the iconostasis’ decorative woodcarving and plasterworks represent one of the strongest contributions to European applied arts. In addition, art history has noted that there are no two identical iconostases [7].

Given the heterogeneous nature of the iconostasis shape, the question arises whether it is possible to mathematically perceive common style-related shape characteristics of the iconostasis’ main elements. The architectural and visual characteristics of iconostases are mostly related to the period of church origin. Moreover, while the design of the iconostasis’ ornamental structure was based on naturalistic floral motifs that symbolized theological themes, the style characteristics mainly depended on the craftsman’s skills and imagination [4].

Considering the style characteristics of complex geometry are often difficult to define, the mathematical analysis of the real-world building characteristics helps to cope with data uncertainty in the study of an architectural type [8–10]. Mathematical methods based on shape analysis techniques have been widely used in the tasks of object identification, recognition, and classification [11–15]. The shape-based object analysis approach can be used to study, numerically describe, and classify diverse types of engineering and architectural elements [14]. Furthermore, the identification of different components in 3D models of cultural heritage is significant as it can contribute to the more efficient study of digital heritage and integrating it with metric information and attributes [16].

The aim of this study is to numerically describe and classify the stylistic characteristics of the shapes of the main parts of an iconostasis, concerning the artistic period to which it belongs. The working hypothesis was defined as follows: Two-dimensional (2D) shape analysis techniques may be used to numerically describe the stylistic characteristics of the considered shape features of the main parts of the iconostases (icons and constructive elements), derived from their photogrammetric models.

For that purpose, shape description techniques were used to mathematically characterize shapes of the main architectural elements of the iconostases, concerning its style origins. The particular shape descriptors and measurements associated with them were conceptually conceived. The shape measurements were based on the objects’ dimensions and were designed to reflect the main attributes of the real shapes. For numerical characterization of such shape attributes, the shape descriptors were applied to the particular 2D shapes extracted from the digitized 3D models.

The research presented in this paper focuses on the basic application of mathematical shape descriptors, while working with digitized data of cultural heritage inside a computer aided design (CAD) environment. The framework of this study refers to the concepts of the contour-based and region-based shape descriptors [17] as one of the possible methods for analyzing complex or unknown geometric characteristics from the digitized cultural heritage data. The concept was applied to the technical drawings of
contours of the characteristic shapes extracted from the digitized 3D models of the iconostases.

Regarding the archiving of the technical data on iconostases, the project documentation is based either on the hand-drawings created prior to the iconostasis construction or on the traditional CAD drawings resulting from the on-site measurements. The existing hand-drawings created prior to the iconostasis construction were mostly based on simplified schemes that do not contain enough details. This is caused by the long historical origins of iconostases, but also by the fact that iconostases were developed as a result of exceptional knowledge and skills of craftsmen, with no previously created detailed project documentation. Conversely, due to the complex geometry of iconostases, manual CAD drawings based on the current object state may suffer from errors in measurement and imprecise interpretation of irregular and organic shapes of iconostasis’ ornamental elements. The lack of technical documentation complicates preservation, archiving, and restoration processes. Nevertheless, creating the technical 2D documentation for the iconostasis’ complex geometry with many small and irregular details is a challenging task. Producing detailed CAD drawings based on on-site measurements would be an imprecise, demanding, and time-consuming work. The detailed CAD models of such a complex geometry should be based on the different views of the same model, as well as on the different levels of detail and abstraction [18].

The research presented in this paper addresses the challenge of reverse modeling, which is the creation of CAD-like documentation, and contour detection for the complex geometry from digitized 3D models of iconostases. To detect contours and extract understandable plane sections from unstructured point clouds derived from photogrammetric modeling, the method for point segmentation based on the verticality geometric feature was developed. The obtained results illustrated that the proposed method provides detailed 2D visualization of complex geometry that is not easily recognizable from the colored point cloud.

The paper describes an interdisciplinary approach to distinguish different style characteristics of the iconostases. For this purpose, the representative examples of iconostases from the Baroque and Classicism art movements on the territory of Vojvodina (Serbia), that were previously digitized, were compared using the mathematical method of shape analysis. The method was assessed on the third case study of the iconostasis originated from the end of the Baroque period, i.e., the transition period. The comparative analysis of the results illustrated that the proposed 2D shape descriptors could be used to classify shapes according to their belonging to the particular artistic movements. The paper provides details of the processes and techniques used to achieve the following specific objectives:

- Develop a strategy for the accurate photogrammetric digitization of the case studies of iconostases.
- Propose detailed workflow for working with point clouds to obtain understandable CAD-like visualizations of the characteristic irregular and organic shapes of the iconostasis’ elements at different scales.
- Investigate and design the appropriate shape descriptors for the numerical evaluation and classification of the 2D shape characteristics of the extracted contours of the iconostasis’ main architectural elements, in relation to the artistic period to which it belongs to.

The paper is divided into 6 sections as follows: After the review of the state-of-the-art methods in digital cultural heritage (Section 2), we introduced the historical background of iconostases and the case studies of three digitized iconostases (Section 3). Section 4 presents the developed method. A detailed description of each step in the proposed workflow is given. The complete workflow is presented through case studies of two iconostases. The results are reported in Section 5. In addition, the assessment of the proposed methodology on the third case study of the iconostasis is presented.
The main findings of the work, in addition to the potentials and limitations of the proposed methods, are discussed in Section 6.

2. State of the Art

The growing diffusion of novel technologies used in the cultural heritage domain has changed the approach of documenting, understanding, interpreting, analysis, and conservations of heritage objects. Besides the 3D surveying and data acquisition methods widely used to create digital replicas of cultural heritage, the methods based on computer vision, artificial intelligence (AI), and machine learning (ML) have made a breakthrough in digital heritage data management.

2.1. Methods for Cultural Heritage Digitization

Three-dimensional digitization technologies are particularly relevant for accelerating spatial data collection from existing cultural heritage. Actual techniques for 3D surveying such as photogrammetry and laser scanning still present two methods that have been frequently used in the critical analyses and applications of digitization of cultural masterpieces [19]. Three-dimensional scanning uses laser rays to estimate and directly position data in 3D space. Terrestrial laser scanning has been proved as a suitable method for 3D surveying, applied not only to certain structures but also to whole cities and areas representing assets of cultural interests [20]. The digital documentation of large cultural heritage sites such as historic churches can also be accomplished by using integrated techniques (laser scanning and photogrammetry) [21,22] or by combining photogrammetry and drone survey [23]. Photogrammetry is based on a passive system of optical recording sensors that delivers 2D images. It represents a measurement technique that uses a series of photographs taken from different angles and positions to generate a 3D model of an object. Over the last ten years, researchers in the field of cultural heritage digitization have agreed that in most cases, photogrammetry presents a complete, reliable, economical, and flexible approach for a faithful and accurate reconstruction of 3D objects [24–28]. Moreover, the advances of the Structure from Motion (SfM) algorithm have potentiated 3D model generation from their 2D photographs available on web repositories [29]. However, 3D digitization is a complex process and there is no general approach or a default technology for 3D surveying (3D data acquisition) and modeling.

Many case studies illustrate attempts to develop a methodology for the photogrammetric surveying and modeling of fragile cultural heritage sites [30], addressing the challenging texture and complex shape of the object [31]. In addition, for archiving purposes, cultural heritage digitization usually requires high precision of the 3D reconstruction, specially 1 mm or higher for smaller objects [2,26]. Apollonio et al. [32] proposed a photogrammetric workflow for the accurate 3D construction and visualization of museum assets, intended for small–medium museums, that relies on mobile equipment used for data acquisition.

Nevertheless, the method of 3D digitization depends on an individual type and the complexity of objects of cultural heritage, as well as on the specific application requirements. Once created, the digital replicas obtained using 3D data acquisition methods allow various possibilities to document, manage, and analyze the available information of cultural heritage data inside a virtual environment.

2.2. Methods for Point Cloud Segmentation and Contour Detection

Recently, the main challenges facing the management of digital heritage derived from 3D acquisition technologies include the semantic classification of 3D point clouds and/or converting point clouds into understandable CAD-like geometric representations [33,34]. The products delivered by 3D digitization techniques such as laser scanning and photogrammetry present raw and unstructured point clouds with a large number of points that do not contain knowledge-related information. Such inhomogeneous data are
limited for use in the application of cultural heritage identification, analysis, structural organization, etc. Due to that, the point cloud segmentation is a common technique in the geospatial field, used for classifying the aerial-based point clouds into certain generic classes [35,36]. In the field of cultural heritage, point cloud segmentation is a necessary step to allow reverse modeling, from point cloud to building information modeling (BIM), facilitating further work on object management in the form of a geographic information system (GIS) [37–39], BIM [40], and Heritage-Building Information Modeling (H-BIM) [41–44].

The methods for 3D point cloud segmentation are significant as they contribute to the better interpretation of 3D scenes in digital cultural heritage in terms of enriching it with semantic information which allows for its implementation into H-BIM systems. In this regard, the point cloud segmentation and classification methods based on AI, ML, and deep learning (DL) techniques have become increasingly common in scan-to-BIM processes [41–45].

Croce et al. [41] presented a semi-automatic approach to the 3D reconstruction of heritage-building information models from point clouds based on machine learning techniques. Matrone et al. [42] reported a comparison between two different classification approaches for large 3D heritage semantic segmentation based on ML and DL techniques, while Grilli et al. [44] used these two (ML/DL) point cloud classification approaches to automatically recognize architectural components such as columns, facades, or windows in large datasets.

To segment and classify 2D/3D data correctly, the identification of proper geometric features has become a fundamental task [33,34,46–48]. The point segmentations rely on distinguishing points according to their geometric features. The geometric feature describes a geometric shape around a point based on its neighborhood (by calculating the values of its neighboring points). Therefore, segmentation implies the process of grouping point clouds into multiple homogeneous regions with similar properties [46]. Verticality is one of the geometric features frequently used in segmentation and classification procedures of 3D point clouds obtained by remote sensing techniques [33–35,47,48]. It relies on the eigenvector of the structure tensor and is derived by considering the local neighborhood of each 3D point and extracting 3D features encompassing the geometric relations between the respective 3D points. In addition to the other geometric features, verticality is explained by Hackel et al. [34], as one of the methods for contour detection in the unstructured point cloud. The authors defined contours as the lines along which the surface orientation sharply changes and used a set of geometric features extracted from the point’s neighborhood to detect contours in large-scale outdoor point clouds [33,34].

Regarding the contour identification of the particular shapes from the point cloud data, different surface analyses based on the rasterized images derived from point clouds are employed [30,49,50]. For instance, Galantucci and Fatiguso [50] have applied digital photogrammetry and image-processing techniques for damage detection in historical buildings using surface analysis tools. Soto-Martin et al. [30] used a combination of topography and terrestrial photogrammetry to reconstruct historical buildings and the digital imaging tool DStretch to recover its murals. Corso et al. [49] explained in detail the application of the slope analysis for the representation and geometric analysis of stone facade details. The slope analysis can be defined as the angle between the vector normal to the surface at that point and the vertical [49], which is also the characteristic of the previously described verticality.

2.3. Methods for the Shape Analysis of Digitized Cultural Heritage

In addition to the importance of digitization and proper point cloud segmentation, shape analysis techniques are significant when addressing complex and irregular shapes or certain alterations in the current cultural heritage object state.
Shape is one of the fundamental components of a real object, together with texture and color, and as such, it does not require a formal definition. The shape of the object plays a special role among all the visual information [11]. In addition, shape analysis methods present important techniques for object recognition, registration, matching, and analysis. Shape descriptors are widely used in image processing and computer vision tasks such as object recognition, identification, classification, and matching [13].

Shape analysis techniques can be divided into shape representation and shape description. Shape representation refers to the method for describing the original shape non-numerically (as a graph), while preserving the important features of the shape. Shape description implies the method for numerically characterizing the shape of an object by generating a feature vector from a given shape [12]. The term descriptor represents a certain feature of the shape characterized by a numerical value (mainly from the 0–1 interval). According to Zhang and Lu [17], the shape analysis techniques (representation and description) can be classified into contour-based and region-based methods, while these are further divided into structural and global approaches for the shape description. The contour-based methods consider the shape features extracted from a contour only, while the region-based methods analyze the whole shape region. The global approach for the shape description treats shape as a whole, contrary to the structural method where the shape is represented by segments/sections (primitives). Numerous shape descriptors have already been defined in the literature in the field of mathematics and their usability is demonstrated in different computer vision and shape classification tasks [51–53].

For years back, shape analysis, as an integral discipline of mathematics, has found its application in various study fields from mathematics, engineering, and medicine to art [11]. In the context of cultural heritage, the image-processing methods based on shape and visual descriptors have attracted significant research interest in recent years. In the current literature, there are examples of applying different visual descriptors based on DL for digitized art recognition and classification [54].

Interesting analysis approaches on detecting shapes of the surface damages on a photogrammetrically generated 3D model of cultural heritage objects were presented by Galantucci et al. [50,55]. Based on the consideration of important geometrical characteristics of the alterations of the studied surface, the authors proposed parameters such as aspect ratio, roundness, and compactness to obtain quantitative information and classify the motifs according to their shapes [50,55].

In addition to the importance of the collection, identification, and representation of data on the current object state, developing different techniques for shape analysis is also significant for coping with uncertainty in the study of heritage types, as well as for the needs of future conservation and restoration practices of cultural heritage.

3. Materials

In this section, we introduce the background of the iconostasis. The proposed methodology for the shape analysis based on photogrammetric models was applied to the representative examples of three iconostases from the Baroque and Classicism art movements on the territory of Vojvodina (Serbia).

3.1. Iconostases’ Historic Background

Iconostases are unique and one of the most valuable art and architectural elements of the Christian Orthodox church cultural heritage especially considering they hold many icons, usually painted by prominent artists. They initially evolved from a very low altar screen called Byzantine templon [3–6]. Their development into a multi-tier and richly decorated vertical frame, composed of religious paintings, is related to the late 14th and 15th century [6]. This form of altar partition crossed from Russia to Mount Athos and from there, it spread to Greece and the Balkans during Turkish occupation [3,6]. The modern iconostasis evolved during the 16th century [3]. By the 18th century, the mul-
ti-tier iconostases were considered the most decorative elements of the Christian Orthodox churches, distinctive by their artistic, architectural, visual, and theological significance.

The iconostasis’ wooden framework and ornamental carvings were made by skilled craftsmen, while the icons were painted by the most influential artists of the particular period. The architectural and visual characteristics of iconostases are mostly related to the period of church origin [4] and the artistic movement current at the time of its development. An iconostasis’ origin is very often related to the period of church construction, although there are examples of subsequent installation of iconostases.

The design of the iconostasis’ general shape is based on symmetry, while its dimensions are mainly dictated by the width and height of the altar space of the church in which it is situated. There is also a relatively stable arrangement of icons in the rows of the multi-story iconostasis.

The important elements of an iconostasis are icons placed into specifically designed frames. Icons are supported by richly carved frames and a whole structure is usually made of marbled and/or gilded wood construction. The main constructive elements of the iconostases present columns placed on the pedestals (basis) and moldings which are contained on every iconostasis tier. The frames that hold icons are particularly carved into ornaments that represent various motifs related to an artistic style or symbol from the Bible. The number of tiers usually depends on a church’s height, while the most developed iconostases can consist of five tiers. The placement of icons on multi-tier iconostases usually follows the following convention (Figure 1):

- The bottom tier always contains the middle doors, called Royal doors and the North and South doors, each with framed icons.
- On the right side of the Royal Doors is an icon of Christ and on the left side is an icon of the Virgin Mary.
- The rest of the tiers usually contain one central icon and the twelve icons expanded to either side of it, often depicting either the Twelve Apostles, the Prophets, or The Great Feasts, while the last tier icons are arranged around the cross.

Apart from the well-known facts of the iconostasis’ structure design and symbolical meanings of the particular elements, there were no uniform shape characteristics in the design of the iconostasis’ ornamental elements in relation to the style to which it belongs to. Besides the theological symbolism, the design of the carved ornament which holds the icons in each tier and other structural elements were often left to the craftsman’s own inclination [4]. In addition, woodcarving and decorative plasterworks were very often associated with unknown masters.

In Serbia, the iconostasis design differed during the two art movements, the Baroque (beginning of the 18th century until 1790) and the Classicism (1790–1850) period, especially pronounced on the territory of the former Metropolitanate of Karlovci in the Vojvodina region [7]. The stylistic characteristics of Classicism are reflected in the regularity, symmetry, and tendency towards orthogonal forms, in contrast to the characteristics of Baroque in which elliptical and asymmetrical shapes predominated.

We have digitized four iconostases that are representative examples of iconostases from the Baroque and Classicism art movements in the territory of Vojvodina (Serbia), three of which are presented in this paper. The paper presents the outcomes of the collaboration between the university team and one of the most prominent national cultural institutions in the Republic of Serbia: the Gallery of Matica Srpska in Novi Sad [56–59].

The case studies presented in this paper include three multi-story iconostases that originated as a result of the influence of the Baroque and Classicism art movements on the territory of the Vojvodina region (Figure 1):

1. The iconostasis of The Cathedral Church of Saint Nicholas (1780–1781) in Sremski Karlovci, a representative example of the Baroque art movement in the territory of the former Metropolitanate of Karlovci (ICONB) (Figure 1a).
2. The iconostasis of The Church of the Saint Apostles Peter and Paul (1825–1828) in Sremski Karlovci, a representative example of the Classicism art movement in the territory of the former Metropolitanate of Karlovci (ICONC) (Figure 1b);

3. The iconostasis of The Serbian Orthodox Church of Saint Procopius the Great Martyr (1788) in the village Srpska Crnja, originated during the transition period from the end of the Baroque and is situated in the central-east Banat region near the Romanian border (ICONT) (Figure 1c).

In the following text, for the sake of simplifying long case study names, the previously defined unique acronyms related to the iconostasis’ period of origin will be used: ICONB; ICONC; and ICONT, respectively.

Figure 1. Case studies of the three iconostases: (a) ICONB; (b) ICONC; and (c) ICONT.

3.2. Current Issues in Archiving Iconostases’ Technical Documentation

According to the data provided by The Provincial Institute for the Protection of Cultural Monuments of Vojvodina [60], there are certain issues in archiving iconostases’ technical documentation. The existing technical drawings on the current iconostasis state are based on the traditional on-site measurements which do not provide precise information on the small-scale dimensions of the irregular shapes of carved ornaments (Figure 2).

Figure 2. Details of the existing drawings of the iconostases: (a) ICONB [61] (pp. 112–113) and (b) ICONT. Author: Vladimir Petrović, The Provincial Institute for the Protection of Cultural Monuments of Vojvodina, Petrovaradin, Republic of Serbia [60].
The lack of any technical documentation is not a rare case. In addition, the existing archived data is mainly limited to very old hand-drawings which contain too much or not enough detail and thus do not illustrate the exact state of the original iconostases’ structure, dimensions, and ornaments (Figure 3). Archiving accurate data that represent the real state of the iconostases is significant not only for its preservation for future generations but also for the conservation processes that rely on the analysis of its current state.

Figure 3. Examples of the archived technical drawings for the iconostases [60].

4. Method for 2D Shape Analysis Based on Photogrammetric Models

The proposed method is divided into three main phases:

1. iconostases photogrammetric digitization;
2. contour detection and extraction of the plane sections of the iconostasis’ complex geometry based on point segmentation; and
3. shape analysis of the detected 2D contours through the application of shape descriptors and the measurements associated with them.

In the first phase, a strategy for iconostasis photogrammetric digitization has been developed in order to produce detailed and accurate digital 3D models. The strategy is mainly based on designing a surveying plan that is applicable in the general case of the iconostasis photogrammetric 3D reconstruction. For the data processing, the professional photogrammetric software Agisoft Metashape was used. Photogrammetric 3D digitization consists of two main steps:

- surveying, which implies on-site planning and recording, and the result of the surveying process is a set of photographs and
- data processing, which implies 3D reconstruction of the object using photogrammetric software, and the data processing product is a point cloud and a textured polygonal mesh.

To produce comprehensible CAD-like plane sections, in the second phase, we developed a method for extracting characteristic auxiliary views of object geometry based on point segmentation. The semiautomatic point segmentation approach has been developed to create understandable plane sections of the iconostasis’ complex geometry from the unstructured point cloud derived using photogrammetric 3D reconstruction. Instead of extracting pure plane sections through the point cloud, the idea was to obtain more understandable and readable plane visualizations with the reduced number of points that can serve to retrace the exact contours of the irregular shapes of the iconostasis’ structural elements within the CAD environment.

To extract plain sections of the iconostasis’ principal structure, the verticality geometric feature extraction by using CloudCompare was applied to detect contours of object elements distinguished by their spatial orientation. The verticality of the geometric feature extraction of the 3D point cloud distinguishes a geometric shape around a point
based on its local point neighborhood radius. Using this geometric feature, the points can be described with respect to their normal orientation, i.e., the position at right angles to the referent plane (in this case it was XY-plane). The angle between the XY-plane and the normal vector is computed using 3D surface normal values of each point [44-47]. For example, the verticality can be well-suited to distinguish between facades and the ground [45].

The concept based on verticality geometric feature extraction is equal to the method of slope analysis which can also be defined as the angle between the vector normal to the surface at that point and the vertical [50]. However, instead of working with the rasterized image data, the method proposed in this paper is established on point cloud 2D CAD-like visualization. The idea driving the methodology was to create comprehensible 2D plane visualizations of complex geometry by extracting points that define contours distinguished by their spatial orientation.

The 3D model was first segmented on the basis of its Digital Elevation Model (DEM) in order to sort the detected contours according to their depth values within the object. Then, the verticality feature extraction was performed.

The proposed method for detecting contours and extracting plane sections covers processes from point cloud preparation and segmentation, up to the 2D CAD-like visualization. The complete workflow consists of several main steps that contribute to the quality of the final 2D visualization:

- Point cloud preparation from mesh, which implies converting the mesh back to a new point cloud, to produce more homogenous point data of the photogrammetrically reconstructed complex geometry. The mesh was obtained on the basis of the originally generated point cloud.
- Adding ambient occlusion filters to the point clouds for the enhancement of depth information and better visualization of small details.
- Generating height maps (DEMs) and converting object coordinates to the scalar field in order to maintain information on object depths when segmenting its parts.
- Segmenting points by certain values of the verticality geometric feature to identify the boundaries between surfaces of different scales and extract sections.
- Contour detection and working with point clouds in CAD environment.

Such a method has allowed for the detection of exact points defining the contours of the main iconostasis’ structural elements which were further used in the shape analysis.

In the third phase, 2D shape analysis techniques were investigated to achieve quantitative data regarding the geometric characteristics of the particular iconostasis elements. The goal was to mathematically describe and classify the shape characteristics of the iconostasis’ main architectural elements, concerning the artistic period to which it belongs to. The idea driving the experimentation was to design the appropriate shape measurements for the numerical evaluation of the considered shape features. For that purpose, the shape measurements were designed to reflect the main attributes of the real shapes. Furthermore, for numerical characterization of such shape attributes, the shape descriptors were applied to the particular 2D contours extracted from the digitized 3D models. A combination of 2D global shape descriptors was used to determine the relations between shape characteristics of the iconostases and their style origin, with the assumption that they will indicate the differences between iconostases from different periods of origin.

The application of the shape descriptors was performed by retracing the detected contours inside a CAD environment and applying the shape measurements to them. This led to achieving quantitative information of the geometric characteristics of the particular iconostasis elements. The shape analysis method is divided into two main steps:

- designing shape measurements to characterize the main attributes of the observed shapes and
• applying 2D shape descriptors to the retraced contours to numerically describe and classify the main structural elements of the iconostases.

The main steps of the proposed methodology are explained in detail in Sections 4.1–4.3.

### 4.1. Iconostases’ Photogrammetric Digitization

This part of the research presents the strategy for the iconostases’ photogrammetric digitization that resulted from the collaboration between the university team and the Gallery of Matica Srpska in Novi Sad. It is based on creating a detailed surveying plan that can be applied in the general case of iconostases’ digitization.

The three iconostases were digitized using the photogrammetric approach. Photogrammetry uses two-dimensional overlapping images that are further processed to generate 3D data from the 2D image measurements. The method is based on the SfM algorithm for photogrammetric surveying which automatically determines camera positions and orientation parameters. This way, there is no physical contact of the measuring sensor with the surface of the object that is being digitized, thus there is no risk of possible damage to the object. The precision of the SfM models depends on the quality and properties of the available photographs, thus particular attention must be paid to the design of the surveying plan for acquiring photographs [26,56,62]. Photogrammetrically reconstructed 3D models of objects provide a range of information about the real state of the object, such as a realistic representation of the material, texture, and shape.

#### 4.1.1. Photogrammetric Surveying

Designing the on-site surveying plan is necessary to obtain highly accurate 3D reconstruction results in terms of the relationship between the texture resolution and the ground sample distance (GSD). The GSD represents the distance between adjacent pixel centers expressed in an object scale. Considering the specific iconostasis shape, distinguished by significantly lower object depth compared to its width, as well as the highly detailed ornamentation, the goal of the surveying process was to achieve the highest possible resolution of the smallest object details. The quality of surveying directly impacts the precision of the 3D reconstruction, therefore high-resolution measures were required. The surveying plan was designed according to the iconostasis’ shape as well as the specific church location and lighting conditions and constraints. The surveying was conducted using a tripod and a DSLR camera D7000 (NIKON, Tokyo, Japan, pixel number: 4928 × 3275; pixel size: 4.78 μm; sensor size: 23.6 × 15.6 mm; focal length: 18–109 mm).

The strategy was based on calculating several main parameters. The first part of the surveying plan referred to determining camera parameters and locations according to the object geometry and dimensions. We used a wide-angle lens with a 24 mm focal length (c) and the maximum possible distance of the camera to the object (h) that allowed for covering the whole iconostasis height with one stripe of photographs. By determining these parameters, the object scale and the GSD were calculated as follows:

\[ m = \frac{h}{c}, \]

where GSD = m × pixel size .

To select an appropriate camera mode (landscape or portrait), the object space covered by a photograph \( D \) was calculated in the following way:

\[ D = \text{GSD} \times \text{pixel number (width)}, \]

\[ D = \text{GSD} \times \text{pixel number (height)}, \]
where the pixel number width and height are defined by the camera model: \(4928 \times 3275\).

The explained method could be applied in the reverse mode as well by calculating the GSD according to the dimensions of the desired space covered by a photograph in a predefined camera mode.

Due to the nature of the iconostasis’ shape, photographs were taken in a parallel fashion, combined with divergent camera locations. The camera was rotated in the right and left direction by the angle of approximately \(10^\circ\) to introduce detailed iconostasis depth into the 3D model. To provide an average overlapping of \(80\%\) between consecutive photographs, the baseline \((b)\) was calculated as follows:

\[
b = 0.20 \times (\text{pixel number (width)} \times \text{GSD}).
\]

The calculated parameters for the three case studies of the iconostases’ digitization are shown in Table 1.

The second part of the surveying plan implied setting appropriate image exposure parameters to achieve the highest image quality and sharpness. First, the automatic camera mode was used to measure the church interior light. Furthermore, the measured in-site image exposure parameters such as aperture and ISO speed were manually set and the aperture priority mode was employed to determine the correct shutter speed. The lighting conditions of the church interior are usually characterized by a very low illumination which resulted in a long shutter speed (Table 1). For that reason, it was essential to use a tripod and delayed shutter to avoid camera shaking. Considering the shooting distances and the aperture, the focus point was fixed and the depth of field (DoF) was checked to achieve the correct sharpness of the photographs.

| Surveying Parameters | ICONB | ICONC | ICONT |
|----------------------|-------|-------|-------|
| Object dimensions (m) | 9.75 (w) \( \times \) 12.00 (h) | 7.65 (w) \( \times \) 7.40 (h) | 6.65 (w) \( \times \) 7.00 (h) |
| Object area (m²) | 117 | 56.61 | 42.56 |
| \( h \) = shooting distance (m) | 12.5 | 7.5 | 7.5 |
| \( f \) = focal length (mm) | 24 | 24 | 24 |
| \( m \) = scale (m) | \(0.523 \times 10^{-3}\) | \(0.314 \times 10^{-3}\) | \(0.314 \times 10^{-3}\) |
| GSD \(^1\) (mm) | 2.5 | 1.5 | 1.5 |
| \( D \) = the object space covered by a photograph (m) | 12.3 (portrait mode) | 7.4 (portrait mode) | 7.4 (portrait mode) |
| Camera mode | Portrait | Portrait | Portrait |
| \( b \) = baseline (m) | 0.70 | 0.50 | 0.50 |
| ISO | 100 | 100 | 100 |
| Aperture (f-stop) | f/5.6 | f/5.6 | f/8 |
| Shutter speed | 1.6 s | 1 s | 1 s |
| Focus point (m) | 12.5 | 7.5 | 7.5 |
| DoF \(^2\) (m) | 3.70 (near distance) | 3.09 (near distance) | 2.50 (near distance) |

\(^1\) ground sample distance. \(^2\) depth of field.

Table 1 shows that the surveying parameters do not vary significantly between the case studies, which suggests that the proposed methodology for the iconostasis surveying could be repeated in digitization scenarios of other iconostases.

4.1.2. Photogrammetric 3D Reconstruction

The photographs acquired by the surveying were automatically processed using the photogrammetric software Agisoft Metashape [63]. To produce a highly detailed and accurate 3D reconstruction while maintaining an optimal software performance speed,
the image alignment and dense cloud generation were processed with high parameters. The main result of the data processing was a dense point cloud. The precision of the overall reconstruction was estimated after scaling the 3D model properly. The 3D model was scaled within the Agisoft Metashape software by introducing control points (CPs) into the generated 3D reconstruction. The object dimensions were collected through on-site measurements. The calculated round square meter (RMS) errors showed the difference between the real distances and the distances obtained in the 3D models (Table 2). Based on the dense point cloud, the point density of the 3D model can be determined. To calculate the point density, the DEM was also generated. The DEM resolution presents the point density of the produced point cloud. The achieved accuracies of the reconstructions that resulted from using high-quality processing settings are shown in Table 2. The accuracy of the overall reconstructions fell within the limits of the initially determined GSD value (Table 2). The resolution of the DEM depends on the quality parameter set during the construction of the dense cloud. Therefore, considering the dense clouds were generated with a high parameter (instead of ultra-high), the achieved DEM resolution was half the value of the GSD (Table 2). The point density was important for further analysis of the precision of the contour detection during the process of point cloud segmentation. The textured meshes were also generated (Figure 4) and used in the further application for sampling points and creating a new point cloud.

Table 2. Comparison of 3D reconstruction data between the three case studies.

| 3D Reconstruction Statistics | ICONB  | ICONC  | ICINT  |
|------------------------------|--------|--------|--------|
| GSD (mm)                     | 2.68   | 1.10   | 1.20   |
| DEM resolution (mm/pix)      | 5.36   | 2.10   | 2.35   |
| RMS \(^1\) error (mm)        | 5.20   | 2.10   | 2.50   |

\(^{1}\) round square meter.

Figure 4. Textured meshes and the camera positions of the three digitized iconostases: (a) ICONB; (b) ICONC; and (c) ICINT.

4.2. Method for Detecting Contours and Extracting Plane Sections Based on Point Segmentation

In this section, the method that relies on point cloud segmentation techniques has been proposed to detect contours of the shapes representing iconostasis construction and ornamentation and to extract plain sections of the iconostasis’ principal structure.

The aim was to create cross sections through the iconostasis’ constructive and ornamental elements, while excluding the points that represent icons as they present flat paintings inserted into frames. To compute geometric features, as well as to extract points of interest and produce the plane sections, the CloudCompare [64] software was used.
CloudCompare presents an open-source 3D point cloud processing software that provides many options for the handling and analysis of data obtained by remote sensing techniques. There are two common ways for creating sections in CloudCompare: (1) extract cloud sections across polylines and (2) the cross section tool. Both options allow for creating slices of points projected on a flat projection plane. The section through the point cloud extracts all the paints that fit a selected flat plane. Thus, all the visible points that fit a predefined cross-section plane can be extracted as the contours and/or a new cloud subset. This way, the points representing flat icons, which would be normally represented in the technical drawing section as outline contours, remained in the extracted cross-section (Figure 5).

![Figure 5](image.png)

**Figure 5.** Example of the plain section by using the cross section tool in CloudCompare.

Rather than selecting all the points on the same plane as the cross section tool does, computing the verticality geometric feature allows for filtering points according to the values of surface verticality (Figure 6). This way, segmented classes of points with similar space orientation can be represented as a plain visualization, which is more understandable than a standard flat section extracted from the point cloud. In the following sections, the detailed processes used for point cloud segmentation and representation are described.
Figure 6. Workflow of the point cloud segmentation based on the verticality feature (presented on case studies of ICONB and ICONC): (a) verticality computed for the original point cloud; (b) filtering points on the ones with a mainly horizontal orientation by adjusting the normalized value to the interval 0–0.1 (top) and 0–0.05 (bottom); and (c) filtering points on the ones with a mainly vertical orientation by adjusting the normalized value to the interval of 0.2–1 (top) and 0.05–1 (bottom).

4.2.1. Point Cloud Preparation from Mesh

The point cloud preparation implied converting a mesh to a point cloud. As computing geometric features and point segmentation in CloudCompare can be applied only to points, working with point data was required. First, the mesh generated by photogrammetric software Metashape was imported into CloudCompare. Due to the limitations of photogrammetric surveying in capturing high parts of the iconostasis’ structure, the source point cloud used for creating a 3D mesh in Metashape contained cavities on the top parts of protruding constructive elements such as at the top side of the molding (Figures 7a and 8a). On the contrary, the mesh generated from the point cloud interpolated the unbound parts, producing cleaner and crisper results of the reconstruction (Figures 7b and 8b). Thus, the data from the mesh were converted back to the point cloud using the sample points option in CloudCompare (Figures 7c and 8c). When sampling points, it was important to ensure the same point density as the one obtained from the original point cloud as it entails the precision of the reconstruction. In the first case study (ICONB), the iconostasis point cloud was sampled to the same number of points as the original cloud has, which maintained the same point density (Figure 7c). In the case study of the second iconostasis (ICONC), the sampled point cloud was reduced to slightly above ten million points (Figure 8c) as the clouds over this value are difficult to handle and are automatically decimated when moving inside the CloudCompare program. It can be seen that the point clouds produced from the meshed surfaces appear cleaner and more complete. In addition, when converting the mesh to a point cloud, the colors on the new point cloud are improved as well, as it was sampled on the basis of the previously textured mesh.
Figure 7. Digitized iconostasis, ICONB. Workflow of the point cloud sampling: (a) point cloud generated in Metashape, number of points: 6,446,316 (point cloud density 5.36 mm); (b) mesh generated in Metashape, number of faces: 1,296,672; and (c) sampled point cloud in CloudCompare, number of points: 6,500,000 (point cloud density 5 mm).

Figure 8. Digitized iconostasis, ICONC. Workflow of the point cloud sampling for iconostasis 1: (a) point cloud generated in Metashape, number of points: 17,324,365 (point cloud density 2.1 mm); (b) mesh generated in Metashape, number of faces: 3,464,872; and (c) sampled point cloud in CloudCompare, number of points: 9,500,000 (point cloud density 3.6 mm).

The next step of the point cloud preparation was applying ambient occlusion to the point clouds to complement the depth information (Figure 9). The ShadeVis Plugin was used in CloudCompare. Applying lighting processes is useful for the visualization of the 3D models and geometric analysis as it adds realism to the digitized models, allowing for more clear visual perception and identification of the small concavities of the surface that are poorly recognizable [50].
4.2.2. Generating Height Maps (DEMs)

The 3D models were primarily projected to the XY-plane and the Z coordinate was exported to scalar fields in order to obtain and represent detailed values of object depths in visual form (by colors, Figure 10). The depth of the 3D model was displayed as the Z component. Creating DEM and exporting 3D point coordinates to scalar fields provides detailed depth map information for the 3D model, coloring the points in respect to their depths. In this case, rather than generating a rasterized image as an output, the point cloud with the selected coordinate values as a scalar field was created. This way, the 3D model depth was considered as the Z component. The depth information generated from DEM was stored as scalar values of the 3D cloud of colored points representing object depth. This way, the depth dimensions of complex geometry (in this case, coordinate Z) which are otherwise hard to measure can be obtained from photogrammetric models and rendered as an equirectangular projection with elevations, in which blue–green colors indicate lower object depths, and yellow–red colors indicate higher (Figure 10).

The height maps were generated with the aim to split the 3D point clouds of the iconostases into their main parts concerning the depth values. To achieve this, the point cloud needs to be split by filtering points according to the scalar field display parameters. The most protruding parts of the iconostasis’ structure also present the main constructive elements such as columns and moldings, while the rest of the construction contains decorative ornaments and icons which form mainly flat surfaces. The color scale histogram is presented in meters.
4.2.3. Point Cloud Segmentation and Contour Detection

The 3D models of the iconostases were first segmented on the basis of its DEM. The 3D models were segmented on the protruding parts that present supporting constructive elements and the rest of the construction mainly represent ornamental elements and framed icon places.

To split the point cloud into the protruded and the mainly flat parts, we used the CSF (Cloth Simulation Filter) Plugin from CloudCompare, which is a tool to extract ground points in point clouds [65]. If the object is previously projected on XY-plane and an adequate resolution and classification threshold is set, the CSF filter will automatically extract the points which are protruded, compared to the flat surface. In this case, the iconostasis’ columns have been split with respect to the rest of the structure (Figures 11a and 12a).

While maintaining the information about parts’ depths, the points are further filtered by certain values of the verticality geometric feature. Verticality is defined as the angle between the vector normal to the surface at that point and the vertical. It relies on eigenvectors and is obtained by calculating the local neighborhood of each 3D point and extracting 3D features encompassing the geometric relations between the respective 3D points. This way, the classes of points representing shapes with similar spatial orientation can be extracted, which allows for identifying the boundaries between surfaces at different scales.

The verticality geometric feature was considered as relevant to distinguished iconostasis’ structural and ornamental elements from the rest of the mainly flat surfaces as it allows for point description with respect to their normal orientation, i.e., the position at right angles to the vertical plane.

The verticality was computed for each separated part to detect contours of the iconostasis’ main elements. The value of the verticality on the histogram presents the applied threshold, i.e., the local neighborhood radius used to compute the feature. For the calculation of the verticality geometric feature, a threshold based on point density was applied. The thresholds were selected on the basis of the histogram of values for the feature of verticality considering they coincided with the previously calculated point density. Figures 11c and 12c show the extracted points that represent contours of the main constructive elements as well as the contour shapes of their ornaments, with the resultant point densities for the new sets of extracted point clouds.

The verticality feature is normalized to the interval 0–1. A value of $V=0.5$ indicates an almost vertical structure, while the low values indicate almost horizontally oriented surfaces [35]. The high values ($V=1$) indicate vertical surfaces. Therefore, as the 3D model...
was oriented so as to lie on the XY-plane, the contours of the carved ornaments and the constructive elements (green color) of the iconostases demonstrated the vertical surfaces (Figures 11c and 12c) compared to the rest of the structure representing almost horizontal surfaces (blue color). It is noted that by adjusting the normalized value from the 0–1 interval to a specific one, points can be filtered to represent the contours of certain 3D surfaces (Figures 11c and 12c). The 3D model was previously projected onto the XY-plane, thus the XY-plane was considered as a vertical plane instead of the XZ-plane. The value of the local neighborhood radius, displayed by the histogram, implies the point density of the point cloud on which the verticality feature was computed. Thus, the point cloud has been split into the points with the highest density and the rest of them, for which the verticality feature was further recomputed.
Figure 11. IONB. The complete workflow of point cloud segmentation and contour detection: (a) splitting the point cloud into the protruded parts and the rest of the construction using the CSF Plugin; (b) generating height maps for the split object parts; and (c) computing the verticality feature for each part and filtering points to extract the desired contours.
Figure 12. ICONC. The complete workflow of point cloud segmentation and contour detection: (a) splitting the point cloud into the protruded parts and the rest of the construction using the CSF Plugin; (b) generating height maps for the split object parts; and (c) computing the verticality feature for each part and filtering points to extract the desired contours.
In order to obtain better precision of contour detection for the particular element of the construction parts, we additionally split the points of the main parts into smaller ones. For example, the point clouds representing only main columns were extracted (Figure 13a). Thus, the verticality feature was recomputed for each set of points concerning its point density (Figure 13b). By filtering points by a specific normalized value from the 0–1 interval, the outline contours of the columns and the contours of columns’ ornaments were extracted (Figure 13c).

![Figure 13. ICONC. Workflow of the contour detection of the main columns: (a) computing the surface verticality for the point cloud of main columns (point density: 5.8 mm); (b) filtering points by values in the range of: 0.65–1 (left) and 0.04–0.65 (right); and (c) point extraction: outline contours of columns (left) and contours of columns’ ornaments (right), visualized with an ambient occlusion filter.](image)

This way, the slices of points defining contours of different object elements from different object depth ranges can be defined as separated sets of the reduced number of points (Figure 14). The orthogonal projections of the created contours can be directly exported from CloudCompare as new sets of points or as high-resolution image files. For example, the render-to-file option from CloudCompare provides a way to produce high resolution renders with many details that cannot be seen on the screen by choosing an appropriate image size, i.e., the desired number of pixels.
4.2.4. Working with Point Cloud in the CAD Environment

The previous work aimed to produce structured and comprehensible CAD-like layers of cross-sections for the visualization of the complex geometric structure.

Data obtained by remote sensing techniques can be projected into raster images using either CloudCompare or the photogrammetric software Metashape which further allows for automatic contour generation. In addition, a created raster image can be converted into a vector using an external program such as AutoCAD Raster Design. Corso et al. [49] explained in detail the process of creating a raster image and converting it into a vector plane. Figure 15 shows the automatically produced contours from the DEM generated for the 3D model of iconostases. It should be noted that in the case of the high-detail geometry of the iconostases, such a process would require an extensive amount of manual work for editing areas of difficult interpretation.

The detected contours of the particular elements obtained by the previously proposed workflow presented sets of point clouds of a certain density. Considering CloudCompare allows for exporting a file in a DXF format, such point clouds can be easily visualized inside the Autodesk AutoCAD program [66]. The DXF data file format is a representation of drawing files that enables data interoperability between AutoCAD and other programs. As the DXF coordinates are without dimensions, when inserted into the AutoCAD, the point clouds need to be scaled properly to work with the appropriate
drawing units. Figures 16 and 17 illustrate the AutoCAD DXF drawings of different parts of the iconostasis, sorted in separated layers according to their depth dimension. Inside a CAD environment, such a file format can be analyzed, measured, sectioned, annotated, and plotted as a technical drawing of the orthogonal section of the complex geometry. In addition, from such a graphic file format, the precise shapes of the particular elements can be redrawn by using an option to snap the cursor to 2D reference points in AutoCAD.

Working with point cloud file formats inside the AutoCAD environment is also supported if they have been created in Autodesk ReCap [67] before being imported into AutoCAD. Thus, to open a point cloud in AutoCAD, the file format, such as PLY or LAS/LAZ, first must be imported into ReCap software and exported as the RCP file in order to be attached in AutoCAD.

**Figure 16.** ICONB. CAD layers of point clouds from different object depths, representing different parts of object geometry: (a) points extracted from the whole point cloud; (b) extracted points for main constructive elements; and (c) extracted points for ornaments.

**Figure 17.** ICONC. CAD layers of point clouds from different object depths, representing different parts of object geometry: (a) points extracted from the whole point cloud; (b) extracted points for main constructive elements; and (c) extracted points for ornaments.

Figures 18 and 19 show the details that present ornaments of both iconostases, segmented from point clouds by using verticality geometric features. The details are given in a 1:50 scale ratio. It is noted that this kind of graphic visualizations allows for the identification of the shapes of the small-scale ornaments that are not easily recognizable from the colored point cloud. The level of detail and precision of the contour detection depends on the point cloud density. It is also noted that the resultant point densities of the segmented point clouds were slightly lower than the point density of the original
cloud. The calculated point density for the first case study was 7.9 mm (see verticality label on Figure 18) and 3.9 mm for the second case study (see verticality label on Figure 19).

Figure 18. ICONB: Detail of the extracted points in the 1:50 scale.

Figure 19. ICONC: Detail of the extracted points in the 1:50 scale.

Considering the selected thresholds for calculating verticality geometric features for the original point clouds coincided with the point cloud density obtained after photogrammetric 3D reconstruction, the highest possible accuracy of the photogrammetric digitization is of great importance for the detailed point segmentation. As the object area of the first case study is about 117 square meters and about 56 square meters for the second iconostasis, the obtained precision allows for the identification of the small-scale details that, due to the large size of the observed objects, are not visible to the naked eye.

4.3. Two-Dimensional Shape Analysis

In order to analyze the main elements of the iconostases through the 2D visualization of their shapes, specific shape analysis techniques have been investigated. The main idea of the shape analysis was to classify the shapes of the main iconostasis’ components with respect to the stylistic movement to which it belongs to.
In this paper, shape description techniques were used to mathematically characterize shapes of the main architectural elements of the iconostases originating in different style movements. A combination of 2D global shape descriptors was used to determine the relations between the shape characteristics of the iconostasis main parts and its style origin with the assumption that they will capture the differences between particular shapes from different periods of origin.

The shapes of the main icon frames, present on both examples of iconostases, from the Baroque (Figure 20a) and Classicism (Figure 20b) art movements were compared using the mathematical method of shape analysis. In addition, for the analysis and comparison of shape characteristics between different styles, shape descriptors were applied to the plain sections of the main architectural elements of the iconostasis. More precisely, the shape descriptors were calculated for the front and side view cross-sections of the main constructive elements, including bases, columns, and moldings extracted from the digitized 3D models. For the assessment of the methodology, the third case study of the digitized iconostasis originated in the transition period between Baroque and Classicism was used.

Special attention was given to the design shape measurements that will numerically describe certain shape attributes. The designed shape measurements were based on the detailed object dimensions that were extracted from the digitized 3D models of the iconostases.

**Figure 20.** Orthophotos with highlighted characteristic icon shapes used in the shape analysis: (a) ICONB and (b) ICONC.

4.3.1. Designing Shape Measurements

In this study, we focused on the shape description techniques that result in a numeric descriptor of the shape. The global method was considered, as the result of such an approach is a numeric feature vector that can be used for shape description. Furthermore, we considered mainly contour-based methods for the analysis of the observed elements of the iconostasis, with the additional region-based descriptor used for extracting the shape convex hull.
First, we analyzed the shape attributes of the ten main icon frames on both iconostases (from Baroque and Classicism eras). The attributes of the given shapes were analyzed through the shape measurements, such as the area and perimeter of the shape, the lengths of the major and minor shape axis, the minimum bounding rectangle length and width, the areas of the minimum bounding rectangle and maximum inscribed ellipse, and the area and perimeter of the convex hull (Figures 21 and 22). Shape measurements represent the physical dimensional measurements that characterize the appearance of the observed shape. Figures 21 and 22 illustrate the drawings of the main icon frame shapes with the associated shape measurements and the calculated measurements. The shape measurements are designed as follows:

- The length of the long major axis \(a\) is the longest line that can be drawn through the shape. The length of the short minor \(b\) axis represents the longest line that can be drawn through the shape while remaining perpendicular with the major-axis [68].
- The minimum bounding rectangle \(R(S)\) represents the minimum rectangle that bounds the shape. The dimensions of the bounding rectangle are presented as the longer \((L)\) and shorter edge \((W)\) of the rectangle.
- The maximum inscribed ellipse \(Ell(S)\) is the maximum ellipse that inscribes the shape.
- The convex hull of the shape \(CH(S)\) represents the smallest convex set that contains it.

For each shape and its associated measurements, the area and the Euclidean perimeters of the boundaries were calculated. The measurements were computed manually from the contour drawings using AutoCAD. The calculated shape measurements served for further application of the shape descriptors.
Figure 21. Shape measurements applied to the icon frames’ shapes of ICONB.
Figure 22. Shape measurements applied to the icon frames' shapes of ICONC.

The shape attributes of the main constructive elements such as base, column, and molding were analyzed in the same manner. The same shape measurements were applied to the extracted contours from the front and side cross-sections of the iconostases (Figures 23 and 24).

Figure 23. Shape measurements applied to the cross sections (front and side) of the base, column, and molding of ICONB.
Figure 24. Shape measurements applied to the cross sections (front and side) of the base, column, and molding of ICONC.

4.3.2. An Application of 2D Shape Descriptors

Considering the given measurements, the shape descriptors were further employed to quantitatively describe the shape of icons and the shapes of the front and side cross-sections of the iconostasis' main constructive elements (base, column, and molding). They present shape features characterized by a numerical value. In this paper, we used some of the existing global shape descriptors: eccentricity, elongation, compactness, convexity, solidity, rectangularity, and ellipticity. We defined the first two basic shape descriptors as the measurements of the shape aspect ratio:

The eccentricity \( Ecc(S) \) is defined as the ratio of the length of the short minor axis \( b \) to the length of the long major axis \( a \) of the shape [68,69]:

\[
Ecc(S) = \frac{b}{a}. \tag{6}
\]

The result is a measure of the shape eccentricity, given as a value between 0 and 1. The low eccentricity tends to the value of 1, while as the ratio increases from 1, the shape eccentricity is higher.

The elongation \( Elo(S) \) is defined as the ratio between the length of the shorter edge \( W \) and the length of the longer edge \( L \) of the minimum bounding rectangle \( R(S) \):

\[
Elo(S) = 1 - \frac{W}{L}. \tag{7}
\]

The result is a measure of the shape elongation, given as a value between 0 and 1. The lowest possible measure is equal to 0 and implies the square, and as the ratio decreases from 0, the shape becomes more elongated.

The compactness \( Cst(S) \) is a numerical quantity representing the degree to which a shape is compact [70]. It also defines a measure of the sharpness of the shape [71]. It ranges over 0–1 and is defined as follows [68,70–72]:

\[
Cst(S) = \frac{4\pi \times A(S)}{P(S)^2}, \tag{8}
\]

The value of 1 is used for a circle as it is the object with the most compact shape.

The convexity \( C(S) \) measures the irregularity and roughness of the shape boundary. It can be obtained as the ratio of the perimeter of the convex hull of the shape \( P(CH(S)) \) to the perimeter of the shape itself \( P(S) \) [68,72]:

\[
C(S) = \frac{P(CH(S))}{P(S)} \tag{9}
\]
where $P(CH(S))$ and $P(S)$ are the Euclidean perimeters of the boundaries of $CH(S)$ and $S$, respectively. It satisfies the following properties [68,72]:

- the convexity measure is a number from $0$–$1$ and
- the convexity measure of a given shape equals 1 if the shape is convex and will be less than 1 if the shape is not convex, such as by having an irregular boundary.

The solidity $S(S)$ shape descriptor is defined as the ratio of the area of the shape $A(S)$ to the area of the convex hull of the same shape, $A(CH(S))$ [68]:

$$ S(S) = \frac{A(S)}{A(CH(S))}. \quad (10) $$

It measures the density of the shape and satisfies the following properties [68]:

- the solidity measure is a number from $0$–$1$ and
- the value of 1 signifies a solid shape and a value of less than 1 will represent a shape with an irregular boundary or containing holes.

The rectangularity the $R(S)$ shape descriptor is defined as follows:

$$ R(S) = \frac{A(S)}{A(R)}. \quad (11) $$

It is represented as the ratio of the shape area $A(S)$ to the area of the minimum rectangle that bounds the shape $A(R)$. The rectangularity has a value of 1 for a perfectly rectangular object.

The ellipticity $Ell(S)$ shape descriptor [73] is defined as the ratio of the area of the maximum inscribed ellipse $A(Ell(S))$ and the observed shape $A(S)$:

$$ Ell(S) = \frac{A(Ell(S))}{A(S)}. \quad (12) $$

It ranges over 0–1, where a value of 1 signifies an ellipse.

5. Results

The results of the application of the previously described shape descriptors on the particular elements of the two iconostases (ICONB and ICONC) from different artistic movements (Baroque and Classicism) were presented as the comparative analysis of the obtained numerical values. In addition, the classification of the shape descriptors was proposed. It suggests the list of shape descriptors and their range of variation for the elements of an iconostasis according to the different artistic movements. The methodology was assessed on the third case study of the digitized iconostasis (ICONT).

Table 3 shows the obtained results of the calculated shape descriptors for the shapes of the icon frames present on both ICONB and ICONC. The numerical values for all the descriptors taken into consideration in the study are presented. The calculated shape descriptors present values normalized to the 0–1 range.

The comparative analysis of the results obtained for both case studies clearly shows that the most obvious differences in the resulting values are obtained for the compactness, convexity, solidity, and ellipticity shape descriptors (Table 3). It is noted that the icon frames (S1–S8, S10) of the iconostasis originated in Classicism demonstrate more compact, convex, and solid shapes with regular boundaries. The results of the ellipticity shape descriptor reveal that the icon shapes in Classicism have more elliptical boundaries, in contrast to the same ones from the Baroque period that are distinguished by mainly irregular shape boundaries. Furthermore, half of the icons mainly situated on the bottom (S1–S3) and top (S10) tiers of the iconostases showed more rectangular shape characteristics in the case study of Classicism compared to the same ones from the Baroque era. The obtained results coincide with the fact that the stylistic characteristics of Classicism reflect a tendency towards more regular and orthogonal forms in relation to the Baroque stylistic characteristics. Interestingly, the frame-enclosing icon on the top of
the iconostasis (S9), presenting a part of the Calvary Scene, showed almost the same results for the observed shape descriptors. We assume this is due to its specific position on the top of the iconostasis and the fact that its shape is not influenced by the stylistic characteristics but by the unique scene it represents on every iconostasis, together with the same one symmetrically placed on the other side.

It is also noted that the shape descriptors related to the shape aspect ratio, namely eccentricity and elongation, did not provide results that differed in terms of the stylistic characteristics of the observed shapes (Table 3). This was expected considering that the whole iconostasis’ dimensions were dictated by the width and height of the church it was situated in, thus the proportions of the particular shapes were not influenced by the artistic style.

Table 3. Experimental results of the shape descriptors applied to the shapes of icons of both case studies: ICONB and ICONC.

| Shape Descriptor | Iconostasis/Style | Descriptors Values for the Icon Shapes |
|------------------|------------------|---------------------------------------|
| Ecc(S)           | ICONB            | 0.450 0.686 0.534 0.722 0.413 0.415 0.558 0.534 0.819 0.792 |
|                  | ICONC            | 0.464 0.896 0.560 0.630 0.544 0.930 0.908 0.820 0.758 0.650 |
| Elo(S)           | ICONB            | 0.494 0.314 0.438 0.341 0.587 0.588 0.418 0.466 0.181 0.221 |
|                  | ICONC            | 0.536 0.110 0.440 0.370 0.456 0.070 0.090 0.254 0.242 0.350 |
| Cst(S)           | ICONB            | 0.585 0.481 0.445 0.240 0.515 0.446 0.379 0.373 0.983 0.640 |
|                  | ICONC            | 0.815 0.779 0.877 0.919 0.788 0.934 0.838 0.854 0.970 0.931 |
| S(S)             | ICONB            | 0.885 0.802 0.755 0.578 0.875 0.845 0.697 0.703 1 0.842 |
|                  | ICONC            | 1 1 1 1 1 0.994 0.998 1 1 1 |
| R(S)             | ICONB            | 0.919 0.899 0.916 0.904 0.981 0.910 0.963 0.959 1 0.940 |
|                  | ICONC            | 1 1 1 1 1 1 0.989 0.971 1 1 1 |
| Ell(S)           | ICONB            | 0.763 0.785 0.744 0.842 0.932 0.868 0.879 0.926 0.787 0.754 |
|                  | ICONC            | 0.885 1 0.878 0.844 0.941 0.832 0.881 0.926 0.818 0.847 |

According to these quantitative results, it was possible to establish the range of variation of each descriptor for the different artistic movements, which provides the classification of different iconostasis elements [55]. Therefore, in Table 4, the classification of the shape descriptor value ranges for both Baroque and Classicism periods was determined for each particular iconostasis element. Table 4 illustrates the proposal of shape descriptors and their range of variation for each of the iconostasis’ elements (icon shape, base, column, and molding) according to the different artistic movements. The classification was based on the analysis of the quantitative results obtained for each observed element.

In the case of the icon shapes, the eccentricity and elongation were excluded from the proposed classification considering they showed significant variations in the resulted quantitative values. All the considered shape descriptors, except ellipticity which does not seem to be a relevant descriptor here, were also applied to the classification of the front and side cross-sections of the iconostasis’ main constructive elements (base, column, and molding).

Table 4. Proposal of classification for the iconostases’ elements based on the shape descriptors and their ranges of variation for the different artistic movements.

| Iconostasis Main Elements | Shape Descriptor | Classification Values |
|---------------------------|------------------|-----------------------|
|                           |                  | Baroque | Classicism |
| Icon shapes: S1–S8, S10   | Compactness = Cst(S) | 0.24–0.64 | 0.77–0.94 |
### Icon shapes: 59

| Descriptor     | Base (front and side view) | Column (front and side view) | Molding (front and side view) |
|----------------|----------------------------|-------------------------------|-------------------------------|
| Compactness    | Compactness = $Cst(S)$     | Compactness = $Cst(S)$        | Compactness = $Cst(S)$        |
|                | $0.97-0.99$                | $0.97-0.99$                   | $0.97-0.99$                   |
| Convexity      | Convexity = $C(S)$         | Convexity = $C(S)$            | Convexity = $C(S)$            |
|                | $1$                        | $0.80-0.97$                   | $0.96-0.99$                   |
| Solidity       | Solidity = $S(S)$          | Solidity = $S(S)$             | Solidity = $S(S)$             |
|                | $1$                        | $0.97-0.99$                   | $0.95-0.99$                   |
| Rectangularity | Rectangularity = $R(S)$    | Rectangularity = $R(S)$       | Rectangularity = $R(S)$       |
|                | $0.78-0.82$                | $0.90-0.95$                   | $0.69-0.94$                   |
| Ellipticity    | Ellipticity = $Ell(S)$     | Ellipticity = $Ell(S)$        | Ellipticity = $Ell(S)$        |
|                | $0.96-0.97$                | $0.79-0.88$                   | $0.78-0.84$                   |
| Eccentricity   | Eccentricity = $Ecc(S)$    | Eccentricity = $Ecc(S)$       | Eccentricity = $Ecc(S)$       |
|                | $0.24-0.26$                | $0.06-0.08$                   | $0.30-0.34$                   |
| Elongation     | Elongation = $Elo(S)$      | Elongation = $Elo(S)$         | Elongation = $Elo(S)$         |
|                | $0.73-0.74$                | $0.90-0.91$                   | $0.66-0.72$                   |
| Compactness    | Compactness = $Cst(S)$     | Compactness = $Cst(S)$        | Compactness = $Cst(S)$        |
|                | $0.32-0.48$                | $0.12-0.14$                   | $0.46-0.61$                   |
| Convexity      | Convexity = $C(S)$         | Convexity = $C(S)$            | Convexity = $C(S)$            |
|                | $0.80-0.97$                | $0.95-0.98$                   | $0.96-0.99$                   |
| Solidity       | Solidity = $S(S)$          | Solidity = $S(S)$             | Solidity = $S(S)$             |
|                | $0.97-0.99$                | $0.62-0.67$                   | $0.95-0.99$                   |
| Rectangularity | Rectangularity = $R(S)$    | Rectangularity = $R(S)$       | Rectangularity = $R(S)$       |
|                | $0.90-0.95$                | $0.62-0.66$                   | $0.69-0.94$                   |
| Ellipticity    | Ellipticity = $Ell(S)$     | Ellipticity = $Ell(S)$        | Ellipticity = $Ell(S)$        |
|                | $0.96-0.97$                | $0.64-0.76$                   | $0.78-0.84$                   |

It is noted that when applied to the elements extracted from the cross-section, the shape descriptors reveal different behaviors compared to the previously described classification of the shapes in terms of their stylistic characteristics. Even though the value ranges of the solidity shape descriptor illustrated the differences between the Baroque and Classicism periods when applied to the iconostasis base and column, the remaining descriptors did not show clear a distinction according to the particular style origins. However, by analyzing the obtained results for every single shape descriptor, the value ranges of the particular shape descriptor can be related to certain constructive elements. For example, the iconostasis’ columns can be numerically described by the following value ranges observed in both cross sections: eccentricity: 0.05–0.15; compactness: 0.10–0.25; rectangularity: 0.60–0.80; solidity: 0.60–0.85; elongation: 0.85–0.95; and convexity: 0.90–1.00, regardless of the style to which they belong to. Therefore, it can be noted that given individually or mutually combined shape descriptors can be applied to classify the main constructive components concerning both front and side cross sections.

**Assessment of the Proposed Methodology for Shape Analysis**

Considering the main idea of the shape analysis was to numerically describe the shape characteristics in terms of iconostasis style origins, the third case study has been employed to assess the proposed methodology. The iconostasis of the Serbian Orthodox Church of St. Procopius the Great Martyr in Srpska Crnja (ICONT) (Figure 25), which originated from the end of the Baroque period (1788), has been used for testing the methodology in the task of the icon shapes’ classification with respect to the artistic style origins. The shape measurements (Figure 26) were
calculated in the same way as described in the previous case studies and the results of the applied shape descriptors are shown in Table 5.

![Figure 25. ICONT. Orthophoto with highlighted characteristic icon shapes used in the shape analysis.](image)

| Shape Descriptor | S1  | S2  | S3  | S4  | S5  | S6  | S7  | S8  | S9  | S10 |
|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Ecc(S)           | 0.287 | 0.977 | 0.515 | 0.665 | 0.418 | 0.683 | 0.500 | 0.498 | 0.927 | 0.392 |
| Elo(S)           | 0.670 | 0.103 | 0.470 | 0.335 | 0.560 | 0.317 | 0.494 | 0.440 | 0.079 | 0.532 |
| Cst(S)           | 0.403 | 0.811 | 0.489 | 0.621 | 0.677 | 0.648 | 0.687 | 0.737 | 0.714 | 0.616 |

![Figure 26. Shape measurements applied to the icon frames’ shapes of ICONT.](image)
| C(S) | 0.842 | 0.933 | 0.806 | 0.874 | 0.994 | 0.872 | 0.989 | 0.967 | 0.886 | 0.961 |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| S(S) | 0.854 | 0.957 | 0.891 | 0.887 | 0.988 | 0.912 | 0.942 | 0.963 | 0.932 | 0.900 |
| R(S) | 0.792 | 0.817 | 0.745 | 0.764 | 0.953 | 0.795 | 0.892 | 0.772 | 0.754 | 0.738 |
| Ell(S) | 0.697 | 0.753 | 0.761 | 0.655 | 0.825 | 0.645 | 0.807 | 0.833 | 0.660 | 0.806 |

When compared to the results of the shape descriptors for the icon shapes of the typical examples of the Baroque and Classicism iconostases, the obtained results are consistent with the expected results. In contrast to the iconostasis from the Classicism period, where most of the icon shapes are distinguished by absolutely convex and solid shapes, the obtained value ranges for the convexity and solidity show results more similar to the case study of the Baroque iconostasis. The ellipticity shape descriptor also showed the lowest values compared to the case study of the iconostasis from the Classicism period, reflecting a higher level of irregularity of the shape boundary which is common for the Baroque style. The value ranges of the eccentricity and elongation are more similar to those obtained in the case study of the iconostasis from the Classicism period, which is also expected as these two iconostases have approximately the same dimensions. The rest of the resulting shape descriptors vary in between the primary case studies, which can be related to the transition period of origin of this iconostasis but also to the similarity in its proportion to the one from the Classicism period.

6. Discussion and Future Work

In this paper, we focused on the shape analysis of photogrammetric models of the iconostases as the specific elements of the Christian Orthodox church heritage. The paper presents photogrammetric digitization applied to the case studies of the three representative examples of iconostases that originated from the Baroque, Classicism, and transition period between these two art movements in the territory of Vojvodina (Serbia).

The main idea driving the proposed method for creating CAD-like plane sections based on photogrammetric models was to produce comprehensible auxiliary views of the irregular and organic geometry of the iconostasis’ principal structure. The developed semiautomatic point segmentation approach allowed for the detection of exact points defining the contours of the main iconostasis’ structural elements. The detected contours were further retraced and used inside a CAD environment in the shape analysis of the iconostasis’ complex structure. Based on that, it was possible to perform a 2D shape analysis and to report well-founded conclusions about the iconostases’ stylistic characteristics based on numerical descriptors. The significance of this method lies in its contribution to the shape analysis of the iconostasis’ main elements that, due to the irregular shapes, cannot be easily classified as belonging to a particular artistic movement.

Based on the comparative analysis of the results as reported in Section 5, the parameters for the classification of different iconostasis elements according to the artistic period were established. The range of variations of each shape descriptor for the different artistic movements was determined to provide the classification of iconostasis structural elements.

Accordingly, we suggest that the compactness, convexity, solidity, and ellipticity shape descriptors can be used for classifying shapes with respect to the stylistic characteristics when applied to the icon shapes. The numerical results clearly reported the main characteristics of the two analyzed artistic movements. The resulting values for the icon shapes of the iconostasis originated from the Classicism period demonstrate a more compact, convex, and solid shape with the regular boundary, in contrast to those from the Baroque period which were distinguished by more irregular shape boundaries. In the analysis of the third case study as used for the methodology assessment, the obtained quantitative results for the same descriptors tended to the values related to the iconostasis from the Baroque period. The behavior of the results for the third case study reflects its origins from the end of the Baroque period. For the descriptors listed above, the ob-
tained results are in accordance with the general characteristics of the analyzed artistic movements.

This proved the working hypothesis that the 2D shape analysis techniques may numerically describe the stylistic characteristics of the considered shape features when applied to 2D elements such as icon shapes. In this regard, the results of the quantitative analysis allowed for establishing the classification of the elements of the iconostasis. According to this classification, the list of shape descriptors and their range of variations, applied to the icon shapes, can be used to determine the artistic movements of the iconostasis. Conversely, for the remaining iconostasis elements, the range of variations was specific to the descriptor type but not to the artistic movement.

More precisely, in the case of the 2D profile sections of the iconostasis’ constructive elements as extracted from 3D elements, the same shape descriptors did not provide results that differed between the observed elements from the two different style periods. However, it was noted that they numerically described the attributes of the same structural elements, regardless of the style to which they belong to. Therefore, the given individually or mutually combined shape descriptors can be used to distinguish the main constructive components concerning their front and side cross-section.

It should also be noted that the overlapping between the analyzed artistic movements, in regards to the ranges of variation of shape descriptors, can be derived from the fact that styles of iconostases do not strictly follow the characteristics of the artistic movements they belong to. Furthermore, the design of iconostases, in an artistic sense, depicts both complex architectural and theological significance.

The methods and techniques presented in this paper have both potentials and limitations which are summarized in the following subsections.

6.1. Potentials

The potentials of the presented work are synthesized in the following aspects:

- Considering the iconostasis can be seen only in situ, 3D digitization is significant as it contributes to its dissemination through virtual representation such as VR [62] and AR application [56] and web presentation [56–59]. Moreover, it contributes to its permanent protection and further conservation by creating 3D data on the current state of an object.

- Based on designing the uniform surveying plan that satisfies the specific conditions of the iconostasis shape and location, and by setting the consistent 3D reconstruction parameters, the highly accurate digital models of the iconostases have been produced. As the resulted GSD of the 3D reconstruction fell within the limits of the initially determined value, it is evident that the carefully designed surveying plan contributes to the high precision of the resulted digital models.

- Considering the surveying processes differ only in a few parameters between the three case studies, it can be concluded that the developed strategy for digitization could be repeated in the case of other iconostases.

- The 2D plane sections resulted from the segmented point clouds allow for the identification of the shapes of the small-scale ornaments that are not easily recognizable from the colored point cloud.

- Considering that the metric characteristics of such 2D plane visualizations can be analyzed, measured, annotated, and sectioned inside a CAD environment, they can serve as the characteristic auxiliary views of the iconostasis’ complex structure.

- Considering the notable similarity between the iconostasis’ structure characteristics with the highly ornamental facade, the proposed methodology may be applied in particular facade scenarios.

- By employing the shape analysis techniques, we have presented an interdisciplinary approach that uses 2D shape descriptors in the corresponding tasks of analyzing,
identifying, and classifying the shape elements with respect to their stylistic characteristics.

- When applied to the 2D shapes such as the icon frame shapes, most of the proposed 2D shape descriptors can be successfully used to numerically describe the stylistic characteristics of the considered shape features and to classify shapes belonging to the particular artistic movements.

6.2. Limitations and Future Improvements

The main limitations of the presented methods and techniques, as well as the future improvements, are summarized as follows:

- The process of creating 2D plane visualization is based on point segmentation which implies that the point density and quality of the point cloud affects the overall process of contour detection. Due to the large dimensions, as well as the complex geometry and materializations of the iconostases, the produced point clouds contained a large number of points (about 10 million points). Such large point clouds often produce noise and redundant points, which can cause ambiguities in perceiving small-scale shapes and complicate the process of contour detection. Therefore, to produce comprehensible auxiliary views of complex geometry, additional work on cleaning the point cloud from noise and duplicate points has to be performed. Future research regarding this issue aims to investigate techniques for optimizing point clouds without losing the quality of the 3D reconstructed model.

- The extracted plane sections at different depth ranges of object construction are visualized as the new clouds of the reduced number of points inside a CAD environment. For creating clear technical drawings, the vectors of detected contours would be required. Techniques for creating a vector drawing from the generated raster images are already in use but due to the complex geometry of the iconostases with many small details, such a process produces many ambiguities and intertwined or disconnected contour lines. Thus, for future improvements of this methodology, it will be interesting to consider techniques for preparing the 2D digital model for the rasterization.

- Regarding the proposed method of 2D shape analysis, we have focused on the shape description aspect of the shape analysis technique. The method presented in this paper does not consider image-processing techniques and computational shape analysis but focuses on the application of mathematical shape descriptors, while working with digitized data of cultural heritage inside a CAD environment. The framework of this study refers to the concepts of the contour-based shape descriptors as one of the possible methods for analyzing complex or unknown geometric characteristics from digitized cultural heritage data. Rather than using image-processing techniques, the shape descriptors and measurements associated with them were manually calculated. The concept of analyzing, identifying, and classifying shapes would be improved by employing image-processing tools based on shape analysis, as well as elements of machine learning and computer vision. In addition, future projects on this topic are aimed at considering other potential shape descriptors for 2D and 3D shape analysis.

**Supplementary Materials:** The web presentations of the digitized iconostases presented in this paper are available online at [http://racunarska-grafika.com/karlovci/](http://racunarska-grafika.com/karlovci/) and [http://www.racunarska-grafika.com/srpska-crnja/](http://www.racunarska-grafika.com/srpska-crnja/) (accessed on 30 July 2021).

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**Abbreviations**

The following abbreviations are used in the manuscript:

- 2D: two-dimensional
- 3D: three-dimensional
- AI: artificial intelligence
- BIM: Building Information Modeling
- CAD: computer aided design
- CPs: control points
- DL: deep learning
- DoF: depth of field
- GIS: geographic information system
- GSD: ground sample distance
- H-BIM: Heritage-Building Information Modeling
- ICONB: the iconostasis of The Cathedral Church of Saint Nicholas in Sremski Karlovci (Baroque)
- ICONC: the iconostasis of The Church of the Saint Apostles Peter and Paul in Sremski Karlovci (Classicism)
- ICONT: the iconostasis of The Serbian Orthodox Church of Saint Procopius the Great Martyr in Srpska Crnja (Transition period)
- ML: machine learning
- RMS: round square meter
- SIM: Structure from Motion

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