



Article

The Use of Virtual Reality to Promote Sustainable Tourism: A Case Study of Wooden Churches Historical Monuments from Romania

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Abstract: The accelerated development and expansion of cultural tourism in areas with unique tourist objectives, characterised by a high degree of risk in terms of their physical and chemical integrity, requires sustained efforts by all stakeholders to identify new methods, techniques, and procedures for their conservation, protection, and capitalisation, with respect to tourism. The aim of this study was to propose an optimal methodology for capitalising on tourism related to wooden churches, regarded as a structural item of tangible cultural heritage, with positive effects on the protection, conservation, information, and awareness of all stakeholders in tourism development. This involved the development of a web portal, in which were integrated the 3D models related to the analysed objects, the panoramic images inside them, the audio support, the photographs, and the accompanying text necessary to create and render a virtual reality (VR) production for purposes of virtual tourism (VT). The results obtained consisted of the creation of the website *Bihor360°*, which is freely navigable and whose content, including both textual and graphic information, can be easily accessed by all interested users. The aim involved was to release an online bridge for potential visitors to the fragile tourist attractions, facilitating the development of active knowledge and VR while raising awareness among the population and the local authorities about the role and the importance of the wooden churches in tourism and the local economy.

Keywords: virtual reality; virtual tourism; wooden churches; cultural heritage; virtual tours



Citation: Caciora, T.; Herman, G.V.; Ilieș, A.; Baias, Ș.; Ilieș, D.C.; Josan, I.; Hodor, N. The Use of Virtual Reality to Promote Sustainable Tourism: A Case Study of Wooden Churches Historical Monuments from Romania. *Remote Sens.* **2021**, *13*, 1758. <https://doi.org/10.3390/rs13091758>

Academic Editor: Sara Gonizzi Barsanti

Received: 2 April 2021
Accepted: 29 April 2021
Published: 30 April 2021

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1. Introduction

Perceived reality is a specific feature of living beings that derives from their ability to interact with the other structural elements of the environment, of which they also form a part. Humankind's interaction with the environment takes place due to the endosomatic means with which they have been endowed, along with the help provided by their sense organs. As a result, a multitude of perceived, lived spaces exists, depending on the interaction capabilities of each person over time.

In addition to endosomatic means, humankind has acquired, throughout its evolution as a species, a new way of perceiving the world in the form of 'thinking', which is the ability to reflect and to create an imaginary reality consisting of a mythical, imaginary space. Even if, at first sight, virtual reality (VR) seems to be the prerogative of a highly technological society, virtual-imaginary experiences have existed since ancient times, facilitated by people's imagination and fuelled by texts, paintings, and other representations [1]. Thus, VR reconceptualises the idea of space and time, real and imaginary, with the authenticity of virtual experiences being found in the perception of each person concerned [2].

In recent times, against the background of scientific and technological breakthroughs, humankind has managed to create a new reality, namely, VR, whether or not originating in factual reality. Given this fact, VR can be considered a factual VR, rendering faithfully, or in the best possible way, an objective reality, based on the lived space concerned, or a virtual-imaginary reality, rendering an imaginary space, whether or not created, based on the perceived and lived space. In conclusion, as suggested by Williams and Hobson [3] in one of the early articles in this field, VR is a new way of perceiving experience and imaginary space with the help of derived exosomatic tools and artificial intelligence.

VR is a completely synthetic, computer-simulated environment that mimics the real world and allows the users to feel as though they are present in a real-world environment [4–7]. Loureiro et al. [6] present VR as an environment that is designed to primarily stimulate the users' visual and auditory senses, while augmented reality (AR) uses the latest advances in information and communication technology to stimulate a wider spectrum of senses. Given that VR involves discovering, experimenting, and observing new realities, which are aspects that are closely related to the idea of travel, and hence, implicitly to tourism, VR was quickly adopted and started to be used in the tourism industry, thus individualising a new form of tourism, namely virtual tourism (VT) [8].

Guttentag [9] and Gutierrez et al. [10] define VT as consisting of a computer-generated, three-dimensional (3D) environment through which the users can navigate and interact, resulting in a real-time simulation that is designed to meet their tourism needs.

VT is not aimed at replacing traditional tourism but rather at complementing and revitalising it by providing informational support, which can improve the decision-making process regarding visiting a tourist destination. The above is supported by Huang et al. [11,12], who consider virtual experiences in the field of tourism as opportunities to complement real experiences and to promote destinations. Thus, many physical journeys can now be preceded by a non-physical (virtual) journey, which is intended for the tourist to use to become acquainted with the destination and so as to minimise the number of those situations in which the traveller is disappointed by their own choice making. Simultaneously, the accessing of VT by potential tourists and the ability for them to change their destination are only a click away, with the overall aim of facilitating access to information. Recent field studies, such as those of Jung et al. [13], have come to show the increasing satisfaction of the users of VT applications in relation to diversity and easy access to information, with most of them also wanting to conduct a field visit, following on the virtual experience.

The use of VR, along with non-virtual tourism, can lead to the development of much more sustainable forms of tourism than were available in the past [2,14], thereby balancing the dual motives of economic profitability and the need for conservation [15]. Such a combination would be able to meet the needs of sustainable tourism fully, as defined by the UN's World Tourism Organisation (UNWTO) [16], limiting the '*social and environmental impact*' by reducing the number of tourists present at the threatened sites [6] while simultaneously '*ensuring the needs of all visitors and host communities*' by providing alternative and innovative tourism experiences [15].

The multiple advantages that VT offers are expected to affect positively the tourism industry profoundly, as well as the behaviour of 'tomorrow's' tourist [17]. Among the many different aspects that tend to individualise VT in relation to traditional tourism, it is worth mentioning that the former is very little influenced by environmental factors (i.e., the weather or succession of seasons), social factors (the amount of free time assigned to travel), economic factors (tourists' incomes, considered especially in relation to the prices and tariffs encountered related to visiting a certain destination), political factors (visa regime or social, military, ethnic or religious conflicts) or medical factors (epidemics or pandemics or the diseases that are characteristic of certain geographical regions) [9,18].

Precisely due to the above-mentioned aspects, VT is widely used to create virtual museum exhibitions, both in a museum environment, through the information centres, and on the World Wide Web [19]. Museums, as a means of communication, tend to desire to digitise their collections for the purpose of preserving and conserving their heritage, but

they also aim to promote and facilitate the accessibility of information for the public at large, in (inter)active and attractive ways [20]. The trend that has taken place in the digitalisation of museums has also been adopted in terms of other large-scale theatres of action, including tourist destinations, heritage buildings, and elements belonging to the natural heritage, among others [21–23]. Therefore, these arenas have started to become digitised and made available to tourists through dedicated web portals. The benefit of adopting such an approach is that it allows the users involved to select their own perspective on the scene of operations, as opposed to employing simple photographs that convey a customised reality, and which are offered for view by the moderator.

Given that classic two-dimensional (2D) data taken from the field can capture and render only a limited number of details, which are too few to ‘express a reality’, it is necessary to add a third dimension to the sets of data that are related to the tourist attractions concerned. Doing so can provide an uninterrupted vision of an entire scene, specific to VR and VT, of the settings that surround the observer, as well as convey the feeling of physical presence [24]. The third dimension, as is shown in studies by Keil et al. [25], Hruby et al. [26], or Smaczyński and Horbiński [27], is of great importance to transmitting spatial information to tourists while substantially facilitating their access to the field.

Within the field of tourism, virtual tours tend, most often, to be made by combining 3D models and panoramic images (either 360° or 180°) that represent the visual support involved, with the information that is necessary for gaining an enhanced understanding of the realities presented [6]. The creation of 3D models is often based on using a technique that is related to photogrammetry or 3D scanning [28–30], which aims to obtain accurate metric and calibrated surrogate prototypes of the objects of interest [31]. Of the two, photogrammetry stands out as the method that gives results that tend to favour the development of interactive visualisation (with it generating a very good texture). The method is not time consuming, it is non-invasive, and the related manufacturing and procurement costs of the equipment required are much lower than are those that are entailed in 3D scanning [32]. The results of photogrammetry are achieved by means of interpolation and the dense matching of 2D images within a single reference space [33], which is performed by means of processing the material employed, using dedicated photogrammetric software [34]. Panoramic images are created by means of matching several partially overlapping images [35], which are created by means of using a rotating camera that is statically positioned at a predefined point [36], resulting in the photographs involved being taken from several angles. As a final step in the process, the photographs are arranged in a round shape so as to make them suitable for panoramic viewing [37]. The popularity of these images lies in the fact that they offer the user the possibility of interacting with objects by means of rotating them in different directions, enabling the user to zoom in or out, and enabling the viewer to move virtually from one scene to the next.

An essential step in making the created models accessible and implicitly for the promoting of real elements entails using the interactive tool that is available on the internet by means of creating easy-to-navigate websites for all categories of tourists [38].

In view of the above, the purpose of the current study was to achieve a clear methodology for the implementation of a sustainable form of tourism throughout Bihor County, Romania, by means of integrating 3D and panoramic models. The tourist attractions that were chosen to achieve this goal were the wooden churches (which are historical monuments) that, due to their large number and to the central position that they occupy in the lives of Romanians as a whole [39], are identifying structures for Romania, in general, and for Bihor County, in particular.

The premise from which the study started focused on the needs developed within the trinomial: monument—local community—tourist. Thus, these monuments, due to their age, need to be preserved and passed on in good condition to future generations and, due to the fact that they are very little known on the tourist market, need to be capitalised and promoted. The local communities that shelter them, given that some are in very remote

rural areas, need a form of sustainable tourism that on the one hand contributes to the development of the local economy, and on the other hand, does not threaten local serenity. To the third component, namely, the tourist, must be offered a sustainable framework in which to meet their tourist and knowledge needs, by assimilating the historical past and the elements that define it in this area. Based on the above, in testing out the working method employed, three distinctively different wooden churches were studied, respectively, the '*Saint Martyrs Constantin Brâncoveanu and His Sons*' wooden church in Oradea Municipality, the '*Saint Archangels Michael and Gabriel*' wooden church in the village of Boianu Mare, and the '*Saint Archangels Michael and Gabriel*' wooden church in the village of Botean. The 3D models and the panoramic images made were completed with a series of photographs, a body of textual information, and also audio files, in order to facilitate the access of tourists to high-quality information and to induce them the feeling of immersion and telepresence. All the data involved represented the basis for the creation of an interactive web platform, which was the information vehicle available for their promotion among those interested.

The use of VR, by means of simulating authentic tourist experiences, is seen by Xiao et al. [15] as providing an optimal solution, for the protection of fragile tourist attractions belonging to the cultural heritage of a nation, the dissemination of knowledge, and for encouraging their accessibility to the general public through a sustainable form of tourism. A virtual experience is set to interconnect a wide range of computer interaction techniques of the visitor with a simulated real environment in an attempt to render the sensation of physical presence within a certain environment as faithfully as possible [40]. In the above respect, 3D models and panoramic images with 360° coverage, when they are brought together in the form of interactive virtual tours, are the most effective way of rendering an authentic experience in the field of cultural heritage.

In the above way, in the short term, the current researchers intended to increase the awareness of, and the involvement among, the locals and the local authorities, in whose custody the attractions studied could be found. In addition, the researchers tried to diversify the virtual tourist offer and to improve the tourist destination image of Bihor County while, in the long run, through the spreading of education and awareness, aiming to discuss the effective capitalisation of some packaged tourist services.

2. Study Objects

Wooden churches are part of national, and even international, cultural heritage since they form part of the identified elements and the guiding beacons for the fostering of the spirit of modern humankind. Since their creation is linked to a historical period that was full of events that had a strong spiritual impact [41], for Romanians, they have a special significance, being evidence of the Christian past of those concerned [42,43].

From the information held by the authors, at the time of writing this manuscript, in Bihor County, there is no similar approach on wooden churches or any other objectives belonging to the cultural or natural heritage of the county. At the same time, sustainable tourism in this area is only at the concept level, practiced by tourists only in isolated cases and on a small scale.

All three of the wooden churches that were chosen as the relevant subject matter for the current study are artifacts dating back to the 18th century, having been built in a classic Romanian style, entirely made of wood, and placed on a stone foundation. Since 2010, they have been included in the new list of historical monuments as attractions of local interest. All of the churches concerned are historical monuments, with proven local identity and specificity, and with them still serving the main purpose for which they were built.

The wooden church located in Oradea Municipality (Figure 1) was built between 1760 and 1762 in the village of Letca (Sălaj County), for the 10 Greek Catholic families that were present in the community at the time. The church served as a place of worship for the villagers until 1991, when it was moved to the campus of the University of Oradea, with it becoming the chapel of the Faculty of Orthodox Theology and the Church for the University in Oradea Municipality. Following the move, the painting of the church was no longer

preserved; it was repainted in 1993, and in 2016, the roof was entirely replaced. Indoors, the church was divided into three main spaces: the narthex, nave, and altar. The spaces are displayed one after the other from east to west, which is contrary to the requirements set out in the canons of the Orthodox Church, which specify that the narthex should be located to the east, while the apse of the altar should be set out to the west [44]. With a height of 17 m, the structure of the church forms part of a rectangular base plan, with the five-sided polygonal detached apse of the narthex, and the bell tower that is covered with shingles continuing with a rounded helmet. The porch, which is displayed on the east side alone, acts as a shelter.

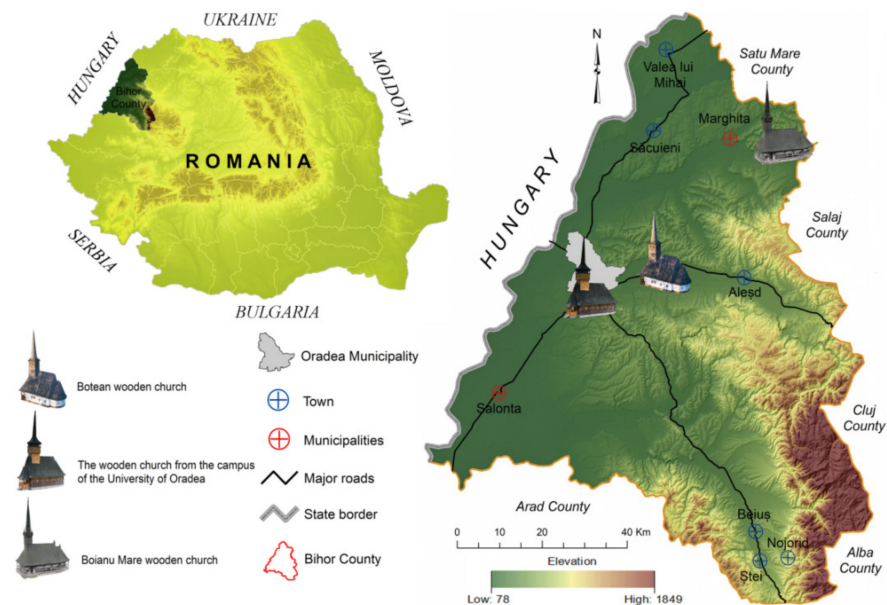


Figure 1. The location of the three church case studies at the level of Bihor County and Romania.

Located on a headland, in the centre of Boianu Mare village (82 km from the Oradea Municipality) (Figure 1), the wooden church dedicated to ‘*Saint Archangels Michael and Gabriel*’ stands out from a distance, especially due to the presence of its bell tower. The presence of turrets can be noticed on the spire of the bell tower, which gives its own charm to the church [44]. Built in 1710, in the form of a nave with a five-sided detached polygonal apse, the church is the expression of the culture and spirituality of the local community of the time. The several different restoration interventions that the church has undergone over time culminated in the one being carried out by the Directorate of Historical Monuments in 1976. The interior painting seems to date back to the middle of the 18th century, with it currently being in an advanced state of degradation due to its age and to the improper conservation treatments that it has experienced over the years. Nevertheless, the church is one of the most beautiful Romanian folk constructions in north-western Romania, which has been recognised by it having been declared a historical monument.

The rich forests in the Crişul Repede River basin provided the local people with sufficient wood for the construction of the beautiful church in Botean (Figure 1), which is dedicated to ‘*Saint Archangels Michael and Gabriel*’. The church was built in 1720, with it, since then, having been declared a historical monument of national interest. With a height of 17 m, the church rises on a hill in the centre of the village on a low foundation made of river stone. Built according to ‘*blockbau*’ practice, its plan follows the same division of spaces as that of the Byzantine, namely, narthex, nave, and altar. The plastered wooden walls support the roof with the bell tower, with an octagonal helmet that is covered in shingles, as is the entire roof. The painting, which was completed at the beginning of the 19th century, is still very well preserved. Inside the church, liturgical activity was still taking place throughout the year at the time of the current study.

The working hypothesis on the basis of which the current study started was aimed at the fact that the attractions studied were well suited for VT (or for a mixed form of tourism, combining VT with the traditional). The suitability for tourism meant that the target market concerned could actively participate in tourism since they would, thereby, have access to a body of information and details that they would not otherwise have been able to access onsite. The limitations of this activity related to a series of factors, among which were the relative frailty of the wooden church monuments and the need to reduce the risk of deterioration, along with the intensification of efforts directed towards their conservation, promotion, and capitalisation (aspects requiring the development of tourism in as sustainable a way as possible).

3. Materials and Methods

The methodology of the research about defining and achieving virtual tours of the three case studies consisted of the following three main stages (Figure 2):

1. The data acquisition and pre-processing stage was characterised by intensive field-work, directed at acquiring the necessary photographic data. Simultaneously, the data gleaned were verified and pre-processed so as to help ensure that it adequately met the stated research objectives.
2. Content creation formed the laboratory stage, which entailed the actual making of the 3D and panoramic models for online publication.
3. Creating and populating the promotion website consisted of the final stage of the project, which ensured the online accessibility, in an interactive way, of all the models that had been created in the previous stages.

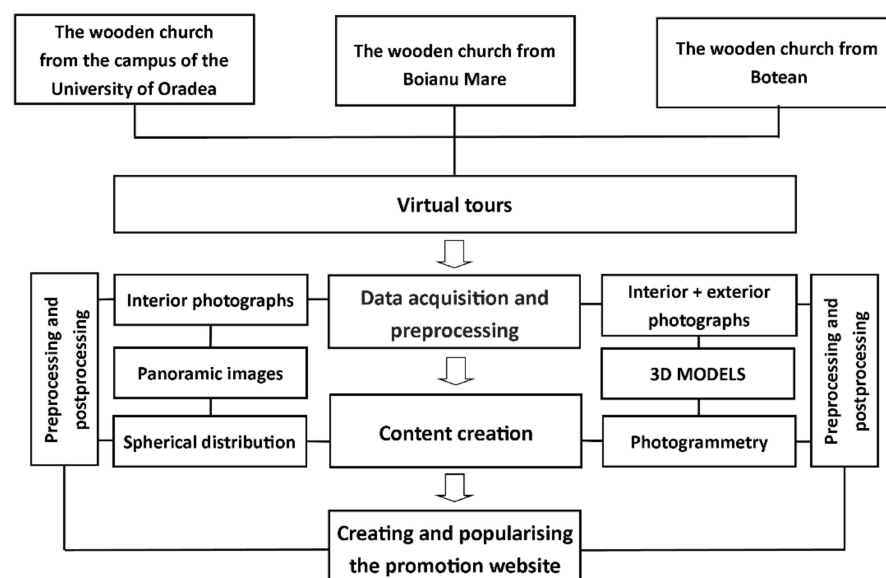


Figure 2. Schematic diagram of the main methodological stages.

3.1. Data Acquisition and Pre-Processing

The data acquisition process was based on using a hybrid approach combining terrestrial close-range photogrammetry (TCRP) and aerial close-range photogrammetry (ACRP) for the obtaining of high-quality models, suitable for interactive viewing. The approach tends mainly to be used for modelling buildings or other large scenes (such as wooden churches) since it allows the smooth procuring of photographs while making even the most isolated parts of the object in question accessible. The many studies that are included in the literature [29,45,46] prove that using this method tends to generate models of a higher quality than those that can be obtained by either TCRP or ACRP alone, due to the enhanced coverage allowed.

Thus, both for the lower part of the churches and for their interior, the data required was acquired by employing the TCRP technique, using a Mirrorless Canon EOS R camera with 30.3 MP resolution, featuring a Full Frame RF 24-105 f4 L IS USM lens. The overflight, using an unmanned aerial vehicle (UAV), of the upper parts of the churches concerned used a DJI Mavic 2 Pro, with a one-inch CMOS sensor and 20 MP, and a camera featuring ND16/PL, ND8/PL, and ND4/PL filters, depending on the time of day when the photographs concerned were taken and on the degree of brightness that was present in the outdoor environment. To obtain the best results possible and a reconstruction that closely resembled the original object, in terms of the geometry and texture involved, all the photographs were taken in RAW format (.DNG—Mavic 2 Pro, CR3—Canon EOS R).

The planning to obtain the required photographs was carried out very carefully so as to inhibit the unwanted influence of external factors (high reflectivity, too much or too little light, shading effect, etc.) in the case of each building's exterior [47,48]. Accordingly, the photographs were taken on pre-set days and at pre-set times when the negative influence of external factors was considered to be minimal. The modelling of the interior spaces was facilitated by the full control that was achieved over the scene lighting. In terms thereof, the acquisition of photographic data inside the churches involved the use of 30 W LED lamps, which were oriented both perpendicularly and obliquely (on either side) on the right plane of the photographed scene, thereby eliminating shaded surfaces and areas with potential discontinuities due to faulty light incidence.

The photographs for the acquisition of the 3D models of the exterior of the monuments were taken following a serpentine route (both TCRP and ACRP). For the 3D models of the interior, the required photographs were taken while keeping a relatively uniform distance between the sensor and the object and ensuring that the overlapping ranges fell between 70% and 80% as much as possible (Figures 3 and 4a). Simultaneously, so as to render as accurate models as possible, the hidden parts of the monuments were taken into account, with the photographic acquisition process being planned accordingly (Figure 4b). The photographic acquisition technique was aimed at limiting the self-occlusion effect and at obtaining a complete 3D model without holes and gaps.

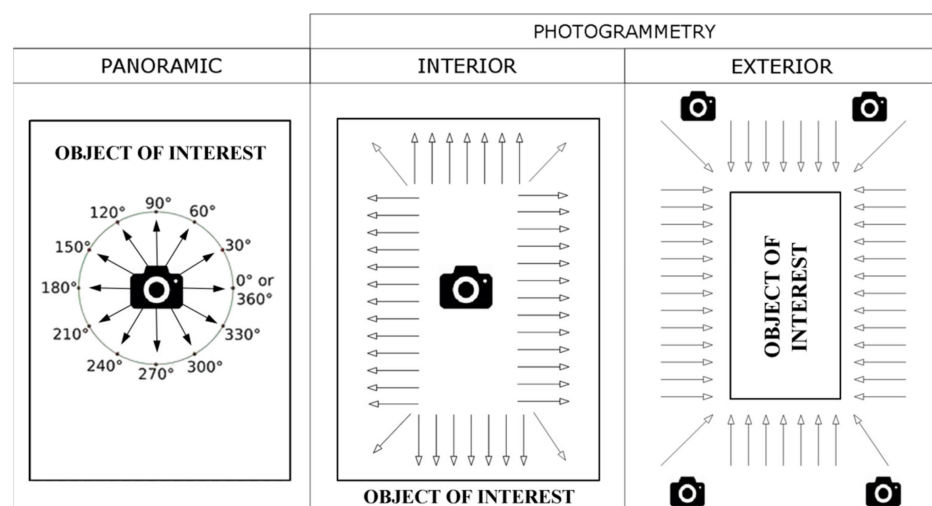


Figure 3. Methodology of photographic acquisition for the interior and exterior photogrammetry and for obtaining the required panoramic images.

In addition, during the specified phase, for purposes of future analysis, reference measurements were taken from the field for the georeferencing of the models used. For the exterior, the measurements were taken by using between four and five (depending on the needs involved) ground control points (GCPs), whose planimetric and altimetric positions had previously been determined using a Stonex S700A GPS-RTK System, equipped with a Stonex S40 Controller [49]. For the interior, the target points (TPs) were attached directly

onto the surface to be photographed, with the distances between them being determined with a rangefinder [50]. All the markers used were 14-bit encoded, in terms of the provisions made by Agisoft Metashape 1.6.2 Professional Edition.

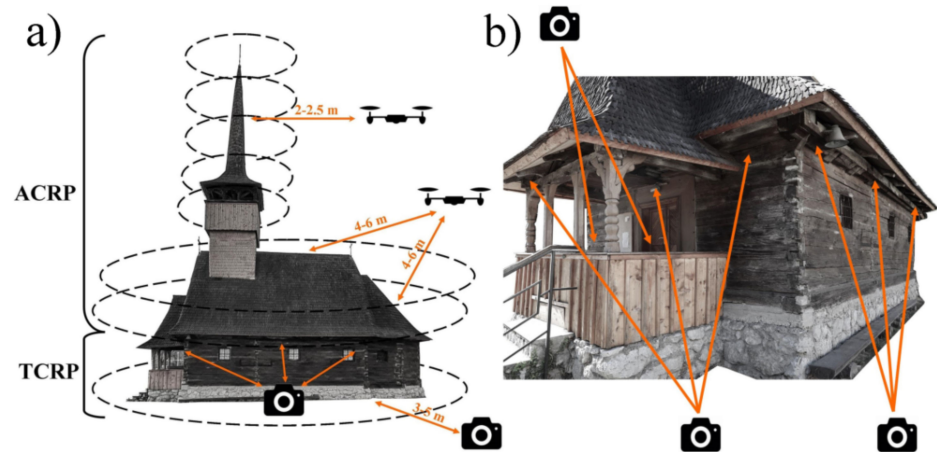


Figure 4. The methodology for acquiring photographs for the creation of three-dimensional models of the exterior of monuments; (a)—acquisition of photographs via ACRP and TCRP and (b)—acquisition of photographs so as to limit occlusion.

The pre-processing of the data was performed by means of manually sorting the data obtained, using the method that was made available for the detecting and annihilating of discontinuities in the photographs by the Adobe Photoshop 2020 and Lightroom 2020 software employed. To determine the appropriate image parameters and quality, the ‘*Estimate Image Quality*’ mode, which was made available in Agisoft Metashape (in terms of which those photographs that were less than 0.5 units were considered to be of low quality and therefore removed) [51] and Digital Lab Notebook Inspector—PG Version 1.0 Beta open source software, was used. The Notebook Software involves the creation of Cultural Heritage Imaging, which, based on an automated calculation algorithm, aims to identify any possible errors or discontinuities within the analysed data sets.

As for the acquisition of photographic data for the creating of the panoramic images required, the current researchers followed an adjusted methodology, specific to the documentation works of the cultural heritage, to design the virtual tours [52–54]. In particular, the use of such an approach depends on the specificity and the characteristics of the scene to be photographed, as well as on the internal parameters of the camera involved.

At the time of the acquisition, execution speed was surrendered for purposes of the overall image quality to be obtained. Therefore, the lens used was not a fisheye (which is the most commonly used, in terms of making panoramic images, due to being easy to use and allowing for the acquiring of an entire scene in between three and eight frames but limited by its severe distortion and questionable image quality). Instead, a broad lens was mounted on the same Canon EOS R, namely, RF 15–35 mm F2.8 L IS USM. The focusing of the camera had been set so that each photograph could be taken identically without the use of autofocus, and with the images being taken in RAW format (.CR3). The device described was installed on a tripod, with an adjustable spherical panoramic head (Nodal Ninja Ultimate M2) consisting of rotating elements that were aimed at allowing for the programming of the camera rotation by an exact number of degrees without the need to anticipate it in terms of the display of the device. Since the rooms inside the wooden churches were usually quite small, and the objects near the device tended to suffer from severe parallax [55], the lens involved was calibrated on the panoramic head so as to minimise the size of the parallax.

Given that the degree of brightness inside the wooden churches was often insufficient and improperly positioned for the taking of panoramic images (for instance, positioning the light sources on the ceiling did not favour the capturing of the vault and the iconostasis

that comprised some of the most interesting features of the monuments), to avoid any possible distortion, a controlled light environment was chosen. In this respect, the same light spotlights and the same working methodology were used as are commonly employed in the case of interior photogrammetry, with the spotlights being, each in turn, positioned in the direction of the scene to be photographed and at a constant distance from each other. Such an arrangement meant that they could receive approximately the same amount of light as each other, thus helping to ensure the luminous balance that was necessary for the panoramic images taken to be able to benefit from smooth translation.

For each church, it was decided to make between three or four panoramic images, depending on the complexity of the monument and the degree of interest that its interior presented. In accordance with the above, with the operator positioned in the middle of the rooms, between 60 and 72 images were acquired for each scene, in spherical format (Figure 3). The lens was arranged in 12 different rows, with a pre-set distance of 30° being placed between each positioning of the camera. Due to the fact that the images were to be procured in portrait format, the lens was focused on only five to six columns, with a distance between them of approximately 60° (Figure 3). The pre-processing of the manual sorting involved the resizing of large files into smaller tiles, so as to maximise the viewing potential of the internet, the changing of the data features concerned, and the covering of the base on which the tripod was positioned (where applicable) were all performed in Photoshop 2020.

3.2. Content Creation

The actual reconstruction of the 3D models was undertaken by way of a typical photogrammetric pipeline in Agisoft Metashape 1.6.2 Professional Edition [32]. The above-mentioned photogrammetric program is a commercial one, which uses a Structure from Motion (SfM) algorithm with the role of determining the internal parameters of the camera, its position, and orientation in each of the aligned images, and to create the rare point cloud; as well as Multi-view Stereo Matching (MVS) algorithm with the role of producing a dense point cloud based on the characteristics of the camera [56,57].

Due to the relatively large databases involved, the working method of the study used additional chunks for enhanced alignment, the shortening of execution time, and the avoidance of memory issues. Thus, regarding the exterior of the monuments, the images acquired with UAV were aligned in a chunk that was separate from those that were acquired with the use of the camera, whereas, inside the monuments, the large number of photographs taken enabled the data concerned to be processed, using two or three different chunks. To reconstruct the final scene, the fragments were joined together on completion of the reconstruction phase of dense point clouds (which tends to be an extremely time-consuming process that requires high performance from the system involved).

Despite the images having been pre-processed prior to alignment, a small number of them registered wrong matches at the time of the alignment. Therefore, to correct them, manual processing and straightening were employed by the user, who matched the images within the reference space by means of setting up correspondences between the images concerned.

After generating the point clouds (both dense and rare), they were processed with the help of filter and selection tools to clean the models of unwanted points that did not form part of the area of interest concerned. Next, based on the dense point clouds and the positioning of the cameras involved, solid colourless and textureless polygonal models were generated so as to be able to reproduce the original colour of the reconstituted objects at a later stage.

For the models to be optimised form wise for online publication, they were processed in MeshLab 2020.07 and Blender 2.90.1, which are open source software intended for the creation and performance of operations on 3D objects. The operations performed in the above-mentioned were aimed at selectively closing the existing holes in the models,

processing and adjusting the texture concerned, compressing their size for publication, and allowing an interactive view that was as easy and smooth as possible.

The images that were dedicated to creating the required spherical panoramic models were processed using PTGui 11.30 software, which is a commercial tool with fast alignment and very little distortion (enabling it to support almost any lens model), while it is almost completely automated, in terms of image overlapping. Before alignment, the setting of the characteristics of the scene and of the final product details was undertaken, with the software involved automatically comparing the characteristics of the photographs to find correlations between them, based on which they were stitched together. In addition, some sections required manual connection between the different images for perfect alignment in the final end product.

Finally, the resulting products were exported into png format as equirectangular images, which were apparently unclear if they were viewed outside the dedicated software. The latest adjustments were then made to ensure that the images were large enough to allow for the best possible quality and so as to allow the user to employ the zoom option to view certain sections in detail, to equalise different exposures, make adjustments in brightness and colour, and remove the used tripod (that was visible in the original data sets) and other unwanted objects.

3.3. *Creating and Populating the Promotional Website*

Therefore, to be able to access and promote the created 3D models and panoramas, it was necessary to develop an integrated website platform that would allow them to be explored from a domestic setting in a dynamic and interactive way. Using such a website required the adoption of a thoroughgoing construction approach, which was different from the way in which ordinary platforms are created, with the latter rendering information in only two dimensions.

For the creation of the website itself, the current researchers chose to use a free platform, which is optimal for creating sites with minimalist content, and which is easy both to manage and access, namely WordPress. The website is the most used CMS, with many plug-ins and substantive support. Prior to the actual creation of the site, an experimental stage was set up, which aimed to test the various plug-ins and scripts for the running of 3D and panoramic models, so as to be able to identify the best and most universally valid versions. The above was performed to ensure that the loading time of the models would be as short as possible, that the running mode would be appropriate on any type of device, and that the quality of the performance would be high. As Büyüksalih et al. [22] show, finding a balance between all of the above-mentioned features is the biggest challenge to be encountered in achieving a platform that integrates VR. In this regard, numerous tests were performed, especially regarding the optimal size of the 3D models involved, but also on the appropriate extensions for exporting them, so as to be sure that they would be compatible with the developed plug-ins. Finally, for the 3D models, the most efficient extension proved to be glb, due to the fact that it maintains good resolution even at a small size, and due to its texture being automatically embedded in a single file. In terms of the panoramic images, the format chosen was png.

For the running of the 3D models, the plug-in used was Woo3D Viewer Pro. The commercial plug-in uses the compression of the models to expedite loading and smooth running, simultaneously proving to be the best running plug-in of the models exported in terms of the glb extension. The plug-in offers the possibility of adjusting the scene (in regard to the positioning of the light source, shadows, background colour, etc.) and adjusting the pattern (colour, brightness, transparency, etc).

iPanorama 360° was used to integrate the panoramas into the virtual tour. The plug-in is a commercial one, which is user-friendly and very easy to work with. It allows the addition of hotspots for interactive navigation from one scene to another, as well as the addition of popover windows for the transmission of additional information in various formats. It also works very well on any browser and on any type of device.

To make a complete presentation of the monuments through VR, as illustrated by Loureiro et al. [6] and Munzner [58], in addition to satisfying the requirements of the visual component, pleasing the auditory sense is also very important. To provide such pleasure, auditory descriptions in the English language were chosen for familiarising the user with the history and the defining components of the wooden churches concerned in the study. Thus, the commercially available text-to-speech software NaturalReader was used, with the property of converting a reading text into MP3 format, which was suitable for uploading onto the website. This operation was favoured by the fact that both the running plug-in of the 3Ds and the panoramic models allow the incorporation of audio files.

The creation of the final interactive virtual tours involved using links to interconnect the models concerned, thus ensuring good traceability and easy and intuitive use by the end user. In order to optimise the site so that it could run on all types of devices, it largely used Elementor for the responsive mode, whereas, for the plug-ins, CSS and Bootstrap were used.

Given the relatively large size of the models involved and the need for a high loading speed, it was decided to procure a package of servers with a large storage capacity, which would be capable of using new-generation hard drives and processors, for increased speed.

4. Results

4.1. The Results Obtained in Terms of Creating 3D Models

For the wooden church dedicated to 'Saint Archangels Michael and Gabriel' in Boianu Mare, of the 712 photographs taken of the interior and of the 862 photographs taken of the exterior, only 674 (interior) and 786 (exterior) were considered to be suitable for alignment, resulting in the remaining photographs being removed from the database. In the case of the wooden church on Campus 1 at the University of Oradea, of the 543 photographs taken of the interior and the 532 taken of the exterior, only 464 (interior) and 494 (exterior) were aligned in Agisoft Metashape. For the wooden church from Botean, at least 1334 photographs were procured for the exterior, of which 1256 were aligned. This procurement occurred due to the fact that the walls, which were plastered and painted in white, either lacked texture or were repetitive in nature, which prevented the computational algorithms from identifying common points of interest for the aligning of the photographic sets [59,60]. For the interior, 623 photos were procured, with 594 being considered optimal for the alignment. Even though the data were acquired and sorted very carefully, some of the images failed to align with the rest of the set (Figure 5). To remedy these issues, the images that were considered indispensable to the projects concerned were manually aligned to establish their correspondence with the images that had already been interpolated within the set reference space.

The process of aligning the photos was completed by means of creating rare point clouds related to the exterior and interior models of the churches. In the SfM process implemented in Agisoft Metashape, the above-mentioned process was conducted by estimating both the intrinsic and the extrinsic parameters of the camera by way of a bundle adjustment process, which was originally presented by Triggs et al. [61]. The results obtained in the current study in terms of the process were characterised by the presence of a large number of raw points, which were directly proportional to the volume of data entered and to their quality (Figure 5). The next step entailed creating dense point clouds using MVS [62], in which the action involved was based on estimating the camera positions and rare point clouds that had previously been created. The operator's intervention consisted of filtering the points in terms of confidence and colour, with those considered to be useless for the construction of the final models being removed.

The third step in the process of creating 3D models involved the creation of colourless and textureless solid models by means of automatically arranging a continuous surface over the dense point clouds concerned (with the algorithm used being that of Poisson surface reconstruction (PSR)) [63]. The quality of the models was provided by the triangulation and by a large number of faces (over five million for each model) and vertices (over two

million for each model). Given that, according to Keil et al. [25], the most important quality criteria of 3D models are their completeness and level of detail, the operator's interventions during the phase in question consisted of smoothing over the processes, removing the lighting, eliminating the surplus, and selectively closing any gaps.

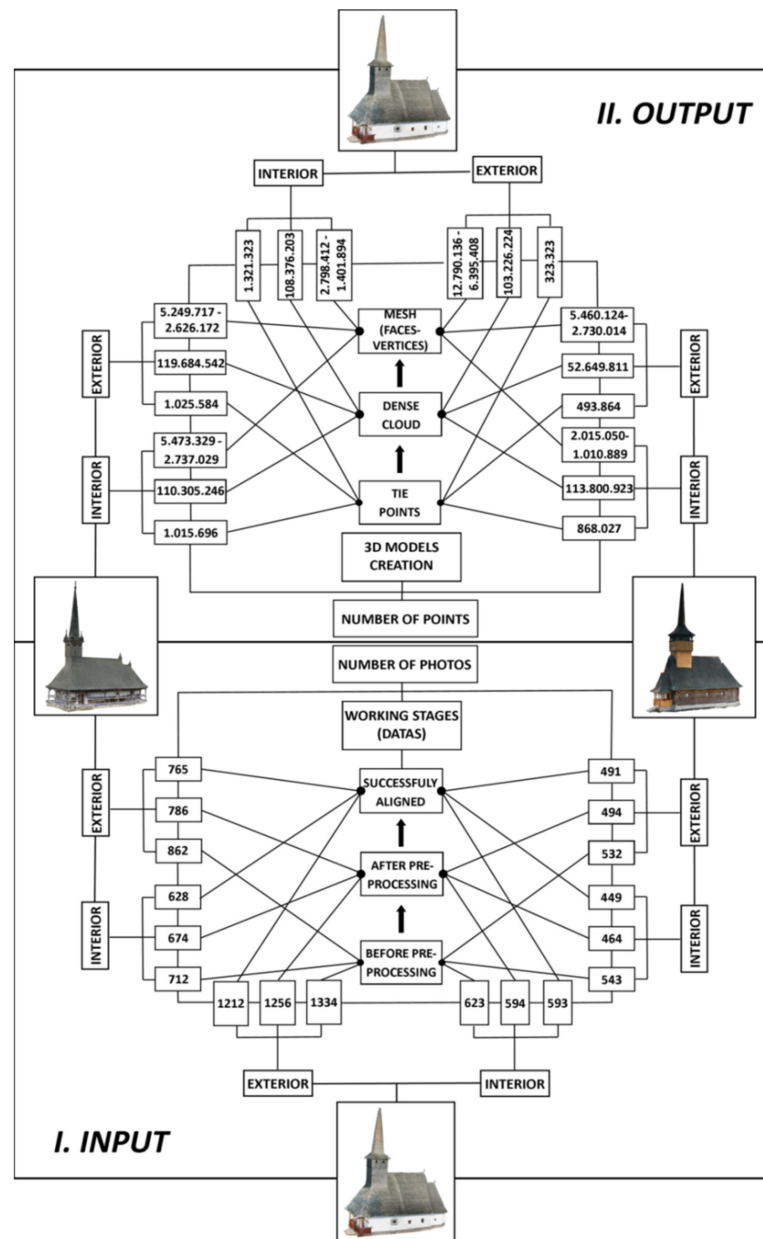


Figure 5. Quantitative graphical representation of the size of the data sets entered, and the results obtained after each stage of the pre-processing and processing.

The colour information, which was obtained in 2D format from the image sets, was used for the process of texturing and creating the final model, in an optimal way for attaining interactive visualisation by means of designs devised on the basis of the solid model created in the previous stage (Figure 6). For the texturing process, as explained by Remondino and El-Hakim [64], taking into account the existing images, the coordinates were calculated individually for each vertex on the surface of the 3D model. The RGB colour values were then projected onto the model so as to result in a fully textured 3D model of the monuments in question.

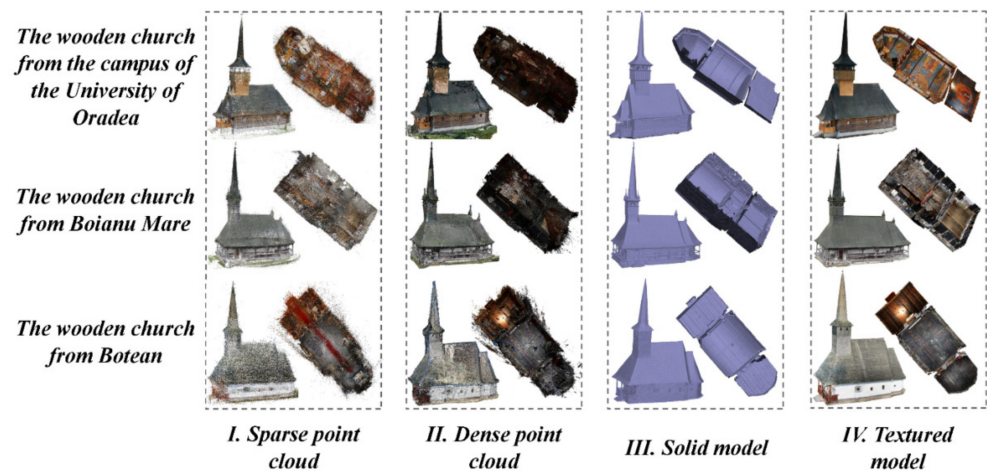


Figure 6. The results obtained during each stage of making the three-dimensional models concerned (with the representation showing the models resulting from the cleaning and optimisation actions that were undertaken specifically to each stage of the construction).

During all the stages that were dedicated to the creation of the 3D models, it was decided to obtain medium-quality results since their online publication required the exported models to be as small as possible without compromising the quality of the texture [27]. However, even under circumstances such as those mentioned, the quality of the photographic databases, along with the sufficiency of their size, generated the development of models that suited their integration into the virtual tour. Taking this action could be supported by the technically quantitative characteristics of the inputs (i.e., the photographic databases) and outputs (i.e., the results obtained) (Figure 6), as well as by the actual visual models that were obtained in each photogrammetric stage of creating the 3D models that were previously presented.

After numerous attempts had been made, it was concluded that, for the optimal running of the 3D models and so as to reduce the waiting times for their loading, it should be recommended that their size should be kept as much as possible between 30 and 35 MB.

4.2. The Results Obtained in Terms of Creating Panoramic Images

The creation of panoramic images was planned to render the most interesting features of the interior of wooden churches clearly visible while simultaneously considering the ease of the data acquisition process and the creation of the images required [54]. For the website visitor to have as much freedom of movement as possible on the site, a panoramic image was made of each of the rooms (narthex; nave; altar) in the three historical monuments. The sole exception to the above was in the case of the wooden church ‘*Saint Archangels Michael and Gabriel*’ from Boianu Mare, in which instance four panoramas were constructed, including the procurement of an interactive representation from the balcony of the church, which succeeded in capturing the original paintings dating from the 18th century highly effectively (Figure 7). As was previously shown in the work of Mah et al. [65], the working conditions and the chosen methodology suited the holistic inclusion of the monuments in the virtual tours, succeeding in maintaining a very good transition from one frame to another.

Suitable panoramas were created to allow the visitor to zoom in on the desired sections of the buildings concerned without altering the quality of the image. For the above, a balanced relationship was sought between the need to obtain very high-resolution panoramas that suited interactive viewing and the restrictions that were set by the limiting requirements imposed in terms of the size of the content that could be published on the web platform. The size concerned was an indispensable aspect that had to be considered to achieve the optimal and smooth running of the website. In the present instance, the most readily usable dimensions of the panoramas turned out to be 4000×2000 pixels, with a size of about 16 MB.

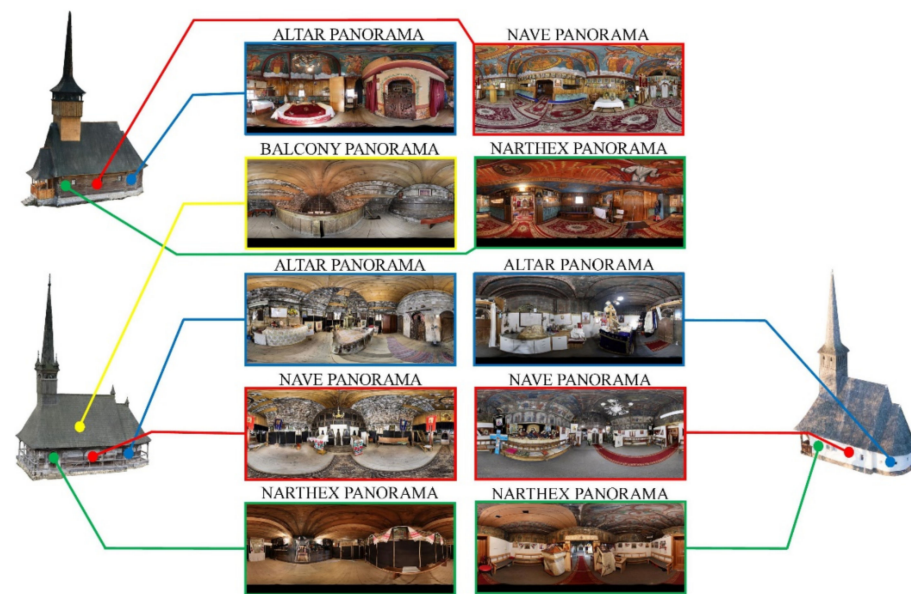


Figure 7. Illustrated presentation of the panoramas developed in terms of each wooden church.

Simultaneously, the balance had to be sought in terms of the colour and the brightness of the scenes (even if the software involved had previously performed multi-band mixing so as to make the results uniform [66]), as well as in terms of the positions of acquisition. The above aimed to smooth over the transition when moving from one scene to another so as to enable the user to experience heightened authenticity. In addition, for the above-mentioned reason, some of the areas in the churches were left deliberately shady, whereas others were better lit and highlighted.

4.3. The Virtual Tours

In the current study, the 3D models and panoramic images created were used to generate a complete and complex virtual tour so as to provide tourists with an opportunity to visit and admire part of the precious treasure of Romanian folk architecture remotely.

The website created during the study now offers visitors the opportunity to move around freely inside the monuments so as to be able to interact with them in an integrated way and to enable them to gain an uninterrupted view of the entire scenes involved, thus providing them with a sense of presence in the areas themselves.

The design of the website chosen was simple, rendered in shades of black and white, and with the interface being kept as user-friendly as possible for the visitors involved. In terms of the above, the user interface was set to include only the necessary guidance buttons, the virtual interaction areas, the sidebars, and key additional information. Such a limitation was directed towards simplifying the exploration of the models so that the prospective users concerned could start to explore the models without first having to become familiar with any complex website features.

In addition to the 3D models of the interior and the exterior of the churches involved, as well as their interior panoramic images, the website was populated with important information related to each monument. The information concerned dealt mainly with the historical aspects of each monument, in addition to the features related to architecture and spirituality. At the same time, the exact location of each church was inserted by way of a plug-in from Google Maps, which has the benefit of showing the visitors the location of the monuments within Bihor County, thus facilitating their access to the relevant information. The insertion of a photograph gallery, featuring both new and older photographs, has captured the evolutionary stages of the churches involved, particularly in terms of their external appearance and their spatial location, with additional information that has not been rendered in the 3D or panoramic models. To the above end, the current researchers

worked closely with the people and the institutions that had custody of the monuments at the time of the study for the purpose of obtaining the relevant information and the archival photographs with which to populate the website.

At the time of going to press, the website included a main page presenting the models of the three churches and some of the most important information about them. The main page allowed visitors to the website to choose the monument that they wanted to visit in virtual format. After selecting a particular monument, the user was taken to an individual page that presented the 3D model of the exterior of the church, along with its description, location, and related photo gallery. Then, by selecting the 'go inside' option situated at the base of the 3D model, the visitor could move on to an interactive viewing of the church interior (Figure 8). From here, the viewer could also see the various panoramas from inside the virtual structure, and navigate within them by means of the use of pop-up buttons that served as a guide within the virtual space (Figure 9). As an alternative option to viewing the interior of the churches through panoramic images, at the touch of a specially designated button, the viewer could explore the desired rooms in 3D format by using the models created by means of the use of the photogrammetry technique.

Simultaneously, both in terms of the page dedicated to exploring the 3D model of the exterior of the monuments and in the case of the panoramas of the interior, audio files were made that gave valuable information about each church. To the home page (Figure 8b) was attached an audio background presenting the history of the church and the identifying characteristics, in general, while the audio text included in each panorama was adapted and individualised to the relevant room of the building concerned to allow for a brief presentation of its contents. For a more pleasant user experience, we chose that the audio files should not be inserted on the site in auto-play format, but rather in voluntary play; this leaves the user the possibility to set his/her own viewing channel without experiencing dissimilar loads of audio files, compared to visual ones (due to different file dimensions). In composing the texts that were transposed in audio format, the specialised literature [67], the priests who had been involved in the conservation and restoration of the churches, or members of the local population, were consulted.

Pasquaré Mariotto and Bonali [23] and Choi et al. [68] claim that enabling the accessing and the visiting of cultural heritage monuments in a dynamic and recreational way on all types of devices is a key objective for any application in the field of VR. Thus, the website created was optimised for optimal presentation of content and for supplying content in the most efficient way possible on computers, tablets, and smartphones. To achieve the specified goal, a solution was sought that required neither a dedicated design nor a distinct creative phase of the platform for each individual access device. The final result was a promotional website that was very easily accessible from any type of device while also providing a user-friendly interface (Figure 10).

Through the platform created during the current study, we wanted to create an interactive tool for promoting the prime pieces of Romanian folk architecture, allowing for access by any interested person from anywhere and on any device. To achieve the above, it was important that the website designed required the use of neither sophisticated VR nor AR devices in order to perceive a reality. In the present instance, all that is required for viewing purposes the information available on the website is an electronic device, such as a laptop, a computer, a smartphone, or a tablet that is connected to the internet.

At the time of going to press, the specified website could be accessed at: <https://bihor360.agts.ro/> (accessed on 30 April 2021).

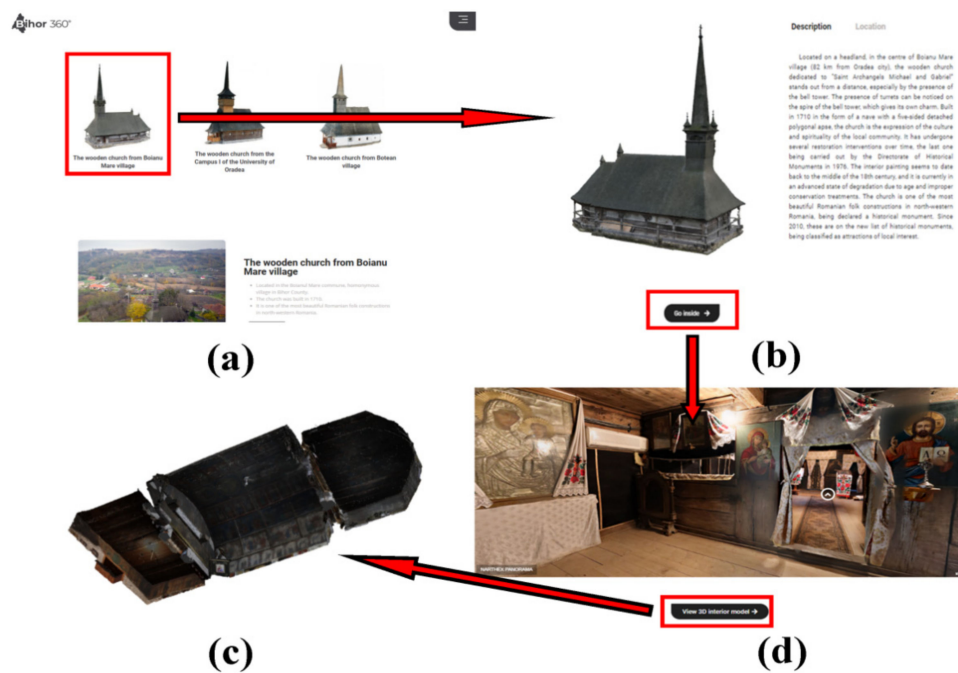


Figure 8. Viewing of the three-dimensional models available on the website; (a)—main page; (b)—the presentation and interaction area, with exterior three-dimensional models and the information related to the description of the monument and the exact location; (c)—the dynamic interaction area with inside panoramas; and (d)—the presentation area and interaction with the three-dimensional models of the monuments’ interior.

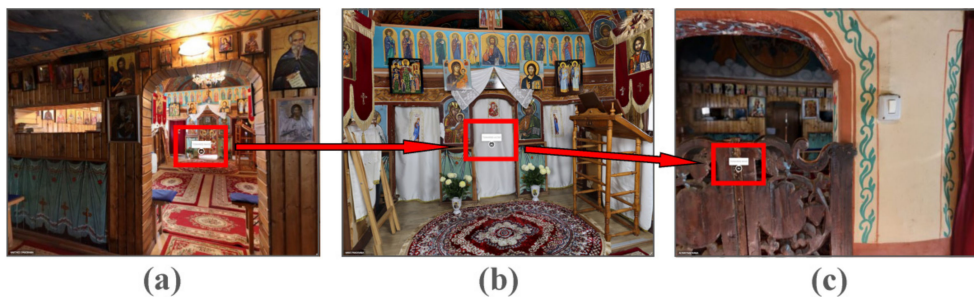


Figure 9. Interactive viewing of the panoramas inside the monuments by means of pop-up buttons, supplied with the function of guiding the visitor to the site through the individual rooms; (a)—panorama of the narthex of the wooden church from Campus I of the University of Oradea; (b)—panorama of the nave of the same monument; and (c)—panorama of the altar of the same monument.



Figure 10. The website interface accessible from desktop computers, smartphones, and tablets.

5. Discussion

The creation of specialised virtual spaces for tourism is a goal that is worthy of consideration, especially when the survival of historical–religious attractions of great fragility is the central concern. In the present instance, all due consideration had to be paid to the fragility of the perishable material (i.e., the wood) involved from which the analysed churches had been built, as well as the monuments' sheer physical antiquity, as they dated back to the 18th century. The nature of the close relationship between VR and sustainable tourism, in terms of the wooden churches studied, lay both in the fragility of the monuments themselves and in the need to ensure the ongoing privacy and lifestyle of the local communities (especially the rural ones) that hosted them. Accordingly, the simple daily life of the rural communities, who lived in close connection with both nature and God, could have been disturbed by too many tourists arriving to visit the wooden church located within the parameters of the local community. Generally speaking, homogeneity, in terms of the economic, social, and cultural characteristics of the communities concerned, can drive the residents of a particular area to develop feelings of repulsion towards the city-based tourist, whom they can perceive as a person who is likely to disrupt the local serenity and desecrate the sanctity of their sanctuary.

Under these conditions, VR and VT currently seem to be the preeminent means for granting sustainable access to the historical monuments studied, which are of great value to the history of Christianity. This understanding also came about against the background of the positive attitudes and opinions expressed by the study participants regarding virtual sightseeing, in line with those found in the studies of Jung et al. [13,69]. In addition, Huang et al. [11,12] and Xiao et al. [15] mention that, through these virtual experiences, users are prone to become more aware of, and more concerned about, the cultural heritage viewed than they might otherwise have been. Virtual tours can, accordingly, also serve as a means of facilitating public involvement in the processes of the conservation and the transmission of heritage monuments [22].

The promotional website created during the course of the current study with the help of VR can also be seen as an educational tool, which can assist with the process of learning and the disseminating of information [70] by means of synthetically creating and transmitting the feeling of presence in a particular place. Such an interactive and often fun form of information transmission has the ability to capture the attention of the youth, thereby promoting the local cultural heritage among them [23].

Bec et al. [71] and Huang et al. [12] suggest that adopting the above-mentioned approach can simultaneously serve as a very good destination marketing tool, increasing the desire of tourists to visit such places. Improving destination marketing through the use of state-of-the-art technology has, as its main goal, been improving the decision-making process of tourists by means of providing them with pretravel informational support [72–74]. Bec et al. [71] and Jung et al. [13] consider the use of VT and mixed as a destination consumption alternative if traditional tourist experiences are difficult to obtain due to various causes (e.g., unexpected catastrophic events, whether natural or anthropogenic, pandemics, such as that caused by the spread of COVID-19, or epidemics, such as the outbreak of Ebola in Africa from 2013 to 2016). In the case of the wooden churches, which were the historical monuments that formed the subject of the current study, target marketing carried out similarly could add value and bring significant economic growth to the local communities [15]. However, the marketing must be accomplished with all due attention being paid to the responsibilities involved, and in a sustainable way (preferably through the administration of a mixed form of tourism) so as to prevent unwanted repercussions for the monuments and communities concerned.

Even if the advantages offered by VR, and implicitly by VT, are difficult to overlook, the relationship between virtuality and authenticity remains controversial for the time being, as Mura et al. [2] demonstrate in their work. The questions that arise regarding the ability of the virtual environment to simulate reality as accurately as possible reside in the fact that current technology has the necessary resources for simulating only two

human senses, namely, those of sight and hearing. The other senses of touch, smell, and taste are often overlooked when constructing virtual tours due to the technical limitations involved, although the three senses can work together to create a reality that is as intense as is humanly possible [9,10,18]. Currently, AR seems to be the potential future solution for the transposing of human senses such as touch, smell, or proprioception into a simulated reality. However, for now, the applicability of AR is confined to the concept stage [75].

An even more intriguing issue than the relationship between virtuality and authenticity is whether the virtual experiences that are used to visit a place are considered a form of tourism in themselves, or whether they even have the potential to be considered as such [9]. The same issue intrigued Williams and Hobson [3], who ask, *'Is it entertainment when you can experience traveling around the Himalayas from the privacy of your living room—or is it tourism?'* The answer to the question concerned seems to lie in the definition of tourism, the industry of which can be seen as involving those activities taking place in the field of tourism that are carried out by people *'who travel and stay in new places, other than those of permanent residence for a period of at least 24 h...'* [76]. If traveling to places other than one's primary residence and the visiting of new targets can also occur through the taking of virtual tours, spending at least 24 h in the places that you visit has still to be realised. Thus, the question at hand seems only currently to be capable of eliciting an answer that is just as ambiguous as the previous one. However, in contrast, virtual experiences tend to fall within the realm of tourism by means of providing a specific *'travel experience'* [77], with virtual destinations having the potential to evolve as stand-alone attractions if tourists can accept them in this way.

6. Conclusions

VR is becoming increasingly present in daily life because it allows for escape from everyday realities and for entering into different virtual worlds. For tourism, VR is a way of including even the most fragile attractions in the tourist circuit by granting access to a form of non-corporeal and non-destructive mobility. It also offers the opportunity to visit places that are difficult or even impossible to access in real life [78]. Regarding the field of study of the present paper, namely, the wooden churches forming historical monuments in Bihor County, Romania, VR is currently known to meet all the necessary characteristics required to help ensure durability over time while satisfying tourists' need for knowledge [10].

The present study was aimed at establishing a suitable methodology for integrating the legacies of the past into dynamic virtual tours so as to increase the former's accessibility. The techniques used in fulfilling the goal pertain to obtaining essential information in a non-invasive way, for promotional purposes and for reasons of assessment, registration, and conservation. Thus, in an attempt to create a sustainable form of tourism, 3D models and panoramic images can be used to represent the information vector, along with the use of photographs and associated information in both textual and audio format. Reality and virtual space were built up around the images concerned, while the website portal became used to represent the mobile dimension, through which information can come to be spread in terms of both time and space. The selection of the three wooden churches with different characteristics demonstrates the wide applicability of the methodology developed for the execution of the virtual tours covered in the current study.

The promotional website created during the course of the present research is a multilateral information tool, which, in addition to the traditional databases, was designed to boost the way in which wooden churches are preserved and passed on to future generations. The environment is a synthetic one, in terms of which the tourist can interfere in an interactive, flexible, and portable way with the monuments. Cheong [79] argues that adopting such an approach has a dual implication; on the one hand, it reduces the impact of tourism on fragile areas and objectives and, on the other hand, enables the functioning of VR as a marketing tool. Accordingly, the website that was created as a VR mechanism is not meant to replace the actual visiting of the monuments concerned but rather to offer those who are interested in visiting the area additional information and a superior understanding of the

cultural-historical objects of interest to be found there [16] while also contributing to the development of a sustainable form of tourism in the area.

7. Future Work

In the future, the current researchers aim to develop the website designed and to organise virtual tours using 3D models and panoramic images as many wooden churches as possible in Bihor County. They also want to expand the typology of tourist attractions promoted by *Bihor360°* by including other monuments belonging to the Romanian cultural heritage, and even to the natural heritage.

The researchers also intend to create an opinion survey, which will be made accessible by way of the website, and in which they will encourage the users to participate. In this way, the researchers aim to develop advanced knowledge of the user perceptions of VT and, in this particular case, of the patrimony of Bihor County, Romania. Relevant feedback is, accordingly, required to show whether the virtual tours are likely to make the tourists concerned more eager to visit the sites in reality, or whether, on the contrary, the virtual experience will come to be regarded as sufficient to promote understanding of the reality concerned.

Author Contributions: Conceptualisation, T.C. and D.C.I.; methodology, T.C. and G.V.H.; software, Ş.B., A.I. and T.C.; validation, A.I. and I.J.; writing: original draft preparation, T.C., G.V.H., N.H. and D.C.I.; writing: review and editing, I.J. and Ş.B.; visualisation, A.I. and N.H.; supervision, T.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by grant PN-III-P1-1.2-PCCDI-2017-0686.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study may be obtained on request from the corresponding author.

Acknowledgments: The research was made possible by the equal scientific involvement of all the authors concerned. The authors wish to thank the anonymous reviewers for their thoughtful suggestions and comments.

Conflicts of Interest: The authors declare no conflict of interest.

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