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NATANČNA DOKUMENTACIJA KULTURNE DEDIŠČINE, IZDELANA S TRADICIONALNIMI METODAMI IN LASERSKIM SKENIRANJEM

DETAILED CULTURAL HERITAGE RECORDING PRODUCED WITH TRADITIONAL METHODS AND LASER SCANNING

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IZVLEČEK

Za izdelavo dokumentacije objektov kulturne dediščine se še vedno pogosto uporabljajo tradicionalne metode izmer. Po drugi strani pa lahko geodetska izmera in sodobne tehnologije, kot je 3D-lasersko skeniranje, zagotovijo natančnejše, geometrično konsistentne in izjemno natančne podatke, ki jih je mogoče uporabiti kot podlago za podrobne vektorske načrte ali 3D-modele. Glavni cilj naše raziskave je bil preučiti komplementarni pristop z uporabo tradicionalnih in sodobnih metod za izdelavo podrobnih vektorskih načrtov romanske cerkve sv. Martina v Chapaizu v Franciji, ki so bistvenega pomena za nadaljnje razkrivanje njenega zgodovinskega razvoja. Geometrično je ta cerkev precej obsežna in ima veliko nepravilnosti v obliki. V prispevku je predstavljen in ovrednoten naš pristop k procesu dokumentiranja. Za analizo tlorisov cerkve iz obeh načinov zajema smo uporabili Prokrustovo analizo, ki nam je dala objektivno oceno točnosti. Primerjani so bili tudi oblaki točk zvonika, posneti z dvema različnima laserskima skenerjema.

ABSTRACT

Traditional measurement methods are still widely used for recording cultural heritage objects. On the other hand, geodetic surveying and modern technologies such as 3D laser scanning can provide more accurate, geometrically consistent and extremely detailed data that can be used as a basis for detailed vector maps or 3D models. The main aim of our research was to investigate the complementary approach, using both traditional and modern methods, in order to produce detailed vector maps of the Romanesque church of St. Martin in Chapaize, France, which are essential for further unveiling its historic development. Geometrically, this church is rather extensive and has many irregularities in its shape. Our approach to the documentation process is presented and evaluated in this paper. We applied the Procrustes analysis for the ground floor map, which gave us an objective accuracy assessment. Point clouds of the bell tower acquired by two different laser instruments have also been compared.

KLJUČNE BESEDE

evidentiranje kulturne dediščine, tradicionalna metoda izmere, metoda izmere, lasersko skeniranje, Prokrustova analiza, cerkev sv. Martina v Chapaizu, zgodovinski razvoj

KEY WORDS

cultural heritage recording, traditional measuring method, laser scanning, Procrustes analysis, Church of St. Martin in Chapaize, historical development

1 INTRODUCTION

Recording and documenting cultural heritage objects, architecture and historic places is complex and usually time consuming. However, it represents a fundamental part of the cultural heritage protection and sustainable management process (ICOMOS, 1996; Stylianidis and Remondino, 2016). On one hand, detailed and accurate measurements of the physical shape, dimensions and location of cultural heritage objects are basic and necessary inputs for researches and conservation programs, however they prove to be invaluable when it comes to damage or even destruction of the object or site itself.

Nowadays, we have numerous technologies, methods and tools for metric recording of cultural heritage objects at our disposal (Petrovič et al., 2019; Tobiasz et al., 2019). Manual measurements can provide dimensions and relative positions of small objects but they can become uneconomic for larger objects. Photogrammetry and laser scanning are examples of mass data collection techniques and are suitable for more complex objects (Historic England, 2018).

The decision, which approach is the most appropriate in a particular case depends on a variety of factors, e.g. what is the purpose of the documentation, the physical state of the object, size of the object and its complexity, what resources (tools, finances, time) are available, etc. (Historic England, 2018). No less important is the fact that heritage documentation and especially conservation is a multidisciplinary activity. Documentation is produced and used by professionals and people from different fields of expertise and interests, thus it must be widely useful and understandable. Of special importance are heritage-recording programs that systematically produce measured surveys and other baseline data (Letellier, 2007).

Further on, data collection to acquire spatial and semantic data of cultural heritage objects or site is one of the crucial phase in the Heritage Building Information Modeling (HBIM), which is increasingly utilized to develop accurate and semantic-rich databases for the representation, preservation, and renovation of cultural heritage (Liu et al., 2023).

In this paper, we present the use of traditional manual measurements methods and terrestrial laser scanning (Barber and Milles, 2011; Vosselman and Mass, 2010) to produce detailed documentation of the Romanesque church of St. Martin in Chapaize, France. Over the last two decades, the documentation of cultural heritage using terrestrial laser scanning technique has significantly increased mainly due to the wide availability of laser scanning technology and the ability of providing dense surface models in a short period of time with an increasing accuracy and reliability (Shanoer et al, 2017).

In the history of architecture and art, the Romanesque period is considered to be a style that developed during the High Medieval Period, in the first quarter of the 11th century, and lasted until the beginning of the 13th century, in some parts of Europe as late as the 14th century (Lah, 2019; Reveyron et al., 2010; Sartiaux, 2010; Watkins, 1992). Many believe that the Romanesque style was the first international all European art style, which could be found throughout Europe and amongst all social strata (Zadnikar, 1982). The Romanesque period is linked predominantly to sacral and especially monastic art. It first emerged in France, and spread quickly to Spain, Germany, England and Scandinavia. In a somewhat more modest scope, it appeared also in Italy, especially Lombardy, and other parts of Central Europe (Toman, 2010).

The research was carried out as a part of the interdisciplinary project led by the French International Centre for Cultural and Heritage Studies of the Charolais-Brionnais region in Burgundy (Centre International d 'Études des Patrimoines Culturels du Charolais-Brionnais – CEP). The main goal of this project is to create systematic heritage recordings, especially of the remains of Romanesque architecture in the region, which contribute to its preservation, promotion, and further studies on the past developments of the objects. Additional goal of this project is also to involve international groups of architecture students and their tutors in the field work and elaboration of the cultural heritage documentation. Systematic heritage recording is what enables interpretation of research and investigation results to improve understanding of cultural heritage places. In our project, a group of six architecture students from the University of Ljubljana participated in the field measurements and accomplishment of the graphical outputs.

We aimed to demonstrate that the complementary approach using traditional and modern technologies is efficient and yields detailed and geometrically accurate heritage object documentation. Such detailed graphical documentation is of great importance for the studies of the historic development of the object. The analysis of positional accuracy was performed by comparing the two ground floor maps, one produced from traditional (manual) measurements and one produced from the laser scanning point cloud, to which the Procrustes analysis had been applied. Further geometric accuracy analysis was performed by comparing the two point clouds of the bell tower acquired by different instruments.

2 MATERIAL AND METHODS

2.1 Traditional measurement techniques

Traditional measuring techniques ('manual' measuring) and laser scanning technology were used simultaneously in the creation of the initial documentation of the church of St. Martin in Chapaize (Figure 1).

Figure 1: The use of various technologies and equipment for gathering fieldwork data.

Traditional trilateral measuring technique, in which distances between points on a triangle grid are measured, was used mainly to measure the ground plan and individual architectural details. An explicit weakness of this measurement technique can be found in the separate measurements of the building's interior and exterior. In our case, we additionally encountered a special problem due to the massive pillars in the central nave, which made it impossible to measure the diagonals of the central space (with the central and side naves). As the building originates from the very early Romanesque period, it would be impossible to expect a precise orthogonal plan.

Regardless of the numerous deficiencies, inaccuracies and time consumption, the main advantage of 'manual' measurements is that the terrain investigation of the building is usually performed at the same time as the measurements for the architectural record. The understanding of the building characteristics and irregularities noticed during the measurements, is similar to that in a crime scene investigation: every even so small detail is important, for it can help us explain the building development. An individual detail often becomes important only when viewed with others and can be deciphered only on the basis of numerous comparisons and long-lasting research (Winterfeld, 1998).

2.2 Geodetic and laser scanning methods and equipment

Common to most geodetic measurement methods is that the coordinates of points are determined by measuring quantities, such as angles and distances.. Such methods include measurements with total stations as well as terrestrial laser scanners.

The measurement with a total station is performed in the polar coordinate system of the instrument. The measured quantities are: horizontal direction, zenith angle and slope distance. Given the known position and orientation of the instrument, we can determine the coordinates of all measured points in the Cartesian coordinate system, in which we usually make plans and models of cultural heritage objects. In addition to measuring individual points, total stations, such as multi stations, also enable precise laser scanning and have image support.

Terrestrial laser scanning is a measurement method that, compared to a total station, enables a more complete and faster measurement of an object with satisfactory accuracy. The result of the laser scanning is a point cloud. The working principle of a laser scanner is very similar to a total station. Similarly, the measurements are also performed in the polar coordinate system of the instrument, and the measured angles and distances enable the calculation of Cartesian coordinates. The point cloud resulting from the laser scanning at one scan position must be connected to the other point clouds. The process of connecting multiple point clouds is called registration, which can be performed with the use of tie points or various cloud-to-cloud registration methods (Cheng et al., 2018; Urbančič et al., 2019). The registered point cloud is georeferenced to the selected coordinate system via control points, which can be materialized in various ways.

The accuracy and precision of the coordinates of the laser scanning points and consequently also of the point cloud is influenced by numerous impacts. An individual point represents a footprint or laser light reflection from the surface of the scanned object. The main impacts can be divided into

(i) the technical properties of the used laser scanner (Zhuang and Roth, 1995; Lichti and Jamtsho, 2006), (ii) atmospheric conditions (Pfeifer et al., 2007; Borah and Voelz, 2007), (iii) geometric scanning situation (Lichti, 2007; Soudarissanane et al, 2007; Soudarissanane et al., 2011) and reflective surface structures (Lichti and Harvey, 2002; Kukko, Kaasalainen and Litkey, 2008; Voegtle, Schwab and Landes, 2008).

2.3 Theory on Procrustes analysis

The Procrustes analysis is a statistical analysis method, in which the test set is transformed into a fixed goal set so that the best fit can be found. The method emerged from psychology (Green, 1952). The development of the method based on orthogonal matrices led to its wide spread use in various fields that need to implement statistical analysis in order to determine the similarity of shapes (Dryden and Mardia, 1998; Crosilla, 1999; Gower and Dijksterhuis, 2004; Awange et al., 2010).

We have used the Procrustes analysis to define the similarities of the drawings of the ground plans of churches created with traditional measurement techniques and terrestrial laser scanning point cloud data (Groene and Borg, 2005). In the event of N points in two two-dimensional coordinate systems **xy** and **XY** we get:

$$\mathbf{xy} = \mathbf{XY} * \mathbf{R}^T * s + \mathbf{I} * \mathbf{XY}_0^T + \mathbf{E} \quad (1)$$

in which **R** is the orthonormal rotation matrix, s the parameter of the change of scale, **I** unit vector of the length N, $\mathbf{XY}_0^T$ the translation vector and **E** the matrix of deviations. The matrix equation is solved by minimising matrix **E**, with which we minimise the measurement of the shape difference.

Following the rotation, translation and scaling of the first shape into the second, the similarity of the two sets can be estimated by calculating the Procrustes distance. The Procrustes distance is calculated as the square root of the sum of the squared distances between the corresponding points which define the statistical measure of this difference in shape. A lower value means closer similarity of datasets/shapes and vice versa.

3 CASE STUDY AND FIELD WORK PRESENTATION

3.1 Romanesque church of Saint-Martin de Chapaize in Burgundy

Romanesque church of Saint-Martin de Chapaize is the abbot church of the vast former monastery. The beginnings of its construction reach into approximately 980 AD. Due to its exceptional appearance and cultural importance it was declared a French monument of national importance as early as 1969. It is located in the midst of the settlement Chapaize, which is also a municipality with the same name in the department Saône-et-Loire in the French region of Burgundy. The Early Romanesque church is one of the better known in the region. With its large ground plan of the naves together with the presbytery (35.87 m x 15.36 m), a belltower measuring 45.95 m in height and an external stone image the church offers an archaic and unusual impression (Figure 2).

Figure 2: Romanesque Church of St. Martin in Chapaize, France.

3.2 The geodetic field survey and data processing

The church of St. Martin was measured geodetically and scanned with two instruments. The first was the Leica Nova MS50, which we used to measure the geodetic network, determine the coordinates of the control points for terrestrial laser scanning, and laser scan the bell tower. The second instrument was a Leica BLK360 imaging laser scanner, with which we performed a detailed scan of the entire interior and exterior of the church.

The geodetic network was established and measured around the church. It was measured in three sets of angles and adjusted in Leica Infinity. The coordinates of the control points were determined with an accuracy better than 2 mm. Since the Leica BLK360 scanner has range (up to 60 m), density (5 mm, 10 mm or 20 mm @ 10 m) and 3D accuracy (8 mm @ 20 m) limitations, we decided to scan the bell tower also with the Leica Nova MS50. This instrument measures a point cloud that is georeferenced directly using the instrument orientation data. The laser scanning was performed from four points in the geodetic network. The resolution of the laser scanning was set to 4 mm on the surface of the bell tower. With the point cloud obtained in this way, we were able to determine in greater detail the relative and absolute geometric properties of this part of the church. On the other hand, this data also allowed us to analyse the quality of the Leica BLK360 scanner data from the bell tower.

In total 71 scan stations were needed for the complete scan of the church with the Leica BLK360. Of these, 35 scan stations were located inside the church, 12 scan stations in the bell tower and 24 scan stations outside the church.

We scanned the exterior and interior with different resolution settings. The exterior was scanned with the highest possible resolution, i. e. 5 mm @ 10 m, while the interior (including the bell tower) was scanned with a resolution of 10 mm @ 10 m.

Following a scan with BLK360, the local point clouds need to be registered and georeferenced. In our case, the registration and georeferencing were performed in the REGISTER 360 software. The data quality was determined by the standard deviation of the cloud-to-cloud registration and the mean deviation at 6 control points of 6.0 mm and 3.2 mm, respectively. The source point cloud included 1.1 billion points. The point cloud was used in the RCS format. Before using it to draw 2D plans in AutoCAD, we removed the outliers from the point cloud and filtered it with an octree filter (Han, 2018). When using the octree filter, we chose different values for different parts of the point cloud (exterior, interior, individual details,...). Some examples of the point cloud are presented in Figure 3.

Figure 3: Examples of 3D views of registered RGB-coloured point cloud.

4 RESULTS

Measurements and data acquired in the field were used to create digital graphical documentation. Some examples of maps are presented in chapter 4.1.

In addition, two geometric analyses were performed: comparison of the two ground floor maps produced from different data, using the Procrustes analysis (chapter 4.2); and the comparison of the two laser point clouds of the bell tower, acquired by two different instruments (chapter 4.3).

4.1 Graphical documentation of the church

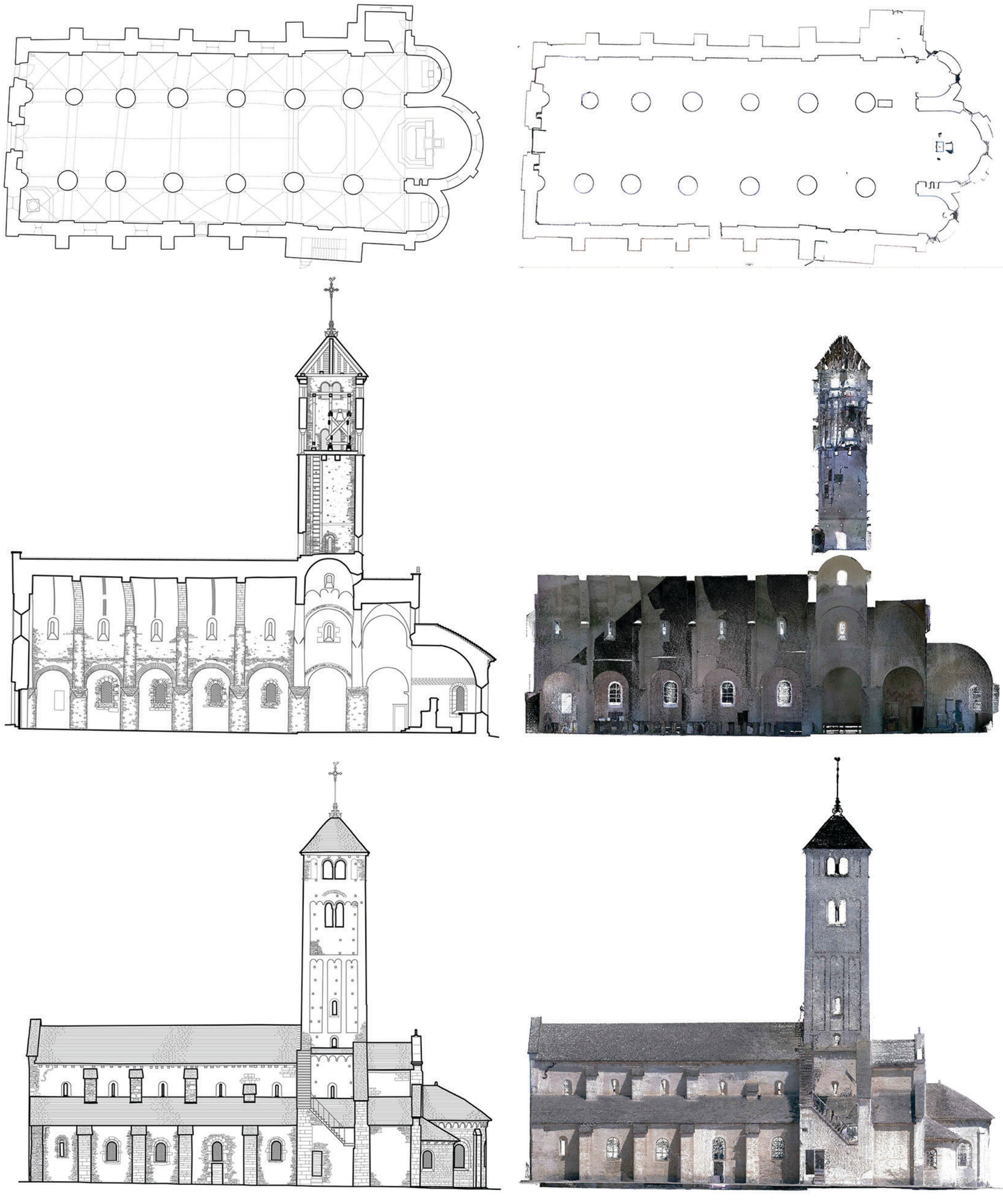

Figure 4: Examples of graphical results produced from the 3D laser scanning point cloud projected onto its viewing plane..

The main graphical documentation of the church exterior and interior was created in AutoCAD from traditional measurement data and a 3D point cloud in the form of 2D vector maps (different vertical and horizontal cross-sections) and a combination of vector and RGB colored points projected onto a viewing plane. The final point cloud is a merged point cloud, where the bell tower exterior is obtained with Leica MS50 and all others surfaces with BLK360. This phase of the project was extremely labour-intensive and time consuming. However, all the details and overall quality of the produced maps can be achieved only by dedicated and skilled interpretation and understanding of the construction and architecture of the building. Figure 4 presents merely a few examples of the created maps.

4.2 Geometric similarity of ground plans with the Procrustes analysis

Two ground plans represented the input data for the geometrical similarity analysis. The first was drawn from the traditional measurements and the second from the TLS point cloud. Since the analysis of the geometric similarity of the ground plans was performed with the Procrustes analysis, we needed a set of identical points in both plans. In total, we selected 155 identical points, 76 points on the church exterior and 79 points on its interior. In this analysis, the coordinate axes are oriented so that the y axis is parallel to the direction from the entrance to the tool, and the x axis is perpendicular to it.

For the calculations, a self-developed Matlab software was used according to the Procrustes algorithm (Awange et al., 2010), The results of the Procrustes analysis can be found in the scale parameter, two translation parameters and rotation. Due to the nonlinear mathematical model, we obtained results with the use of the least square approach. The similarity of the ground plan geometry was analysed separately for the exterior and interior points of the ground plan as well as for all points together. We used the set of points obtained from TLS ground plan as a reference. The differences were calculated from the coordinates of reference points and the transformed coordinates of the points from the traditionally measured ground plan. These differences allow for a more detailed analysis of the geometrical similarity of the drawn ground plans and the identification of critical areas.

The first measurement, called the Procrustes distance, represents the difference between the shape of the two plans, evaluated after the superimposition through translation, scaling and rotation. Other measurements obtained were minimum and maximum values of coordinate differences and 2D positions, respectively (Table 1).

Table 1: Statistical measurements of geometrical similarity of plans following the Procrustes analysis.

	Procrustes distance	Δy [cm]		Δx [cm]		Min_{2D} [cm]	Max_{2D} [cm]
		min	max	min	max		
Interior points	0,39	-9,0	12,0	-10,5	10,2	0,2	15,7
Exterior points	0,16	-18,5	8,9	-13,2	18,9	1,4	22,6
All points	0,32	-10,8	17,4	-21,1	11,5	0,3	21,6

Closer ground plan similarity was found for the church's exterior points as the value of the Procrustes distance is smaller. The results show that we obtain the largest coordinate differences if all points are taken into the Procrustes analysis. The differences between the other measurements are not significant and do not provide us with any additional findings. The largest differences between the ground plans are in the area of the apse and in the lower left pillars (Figure 5).

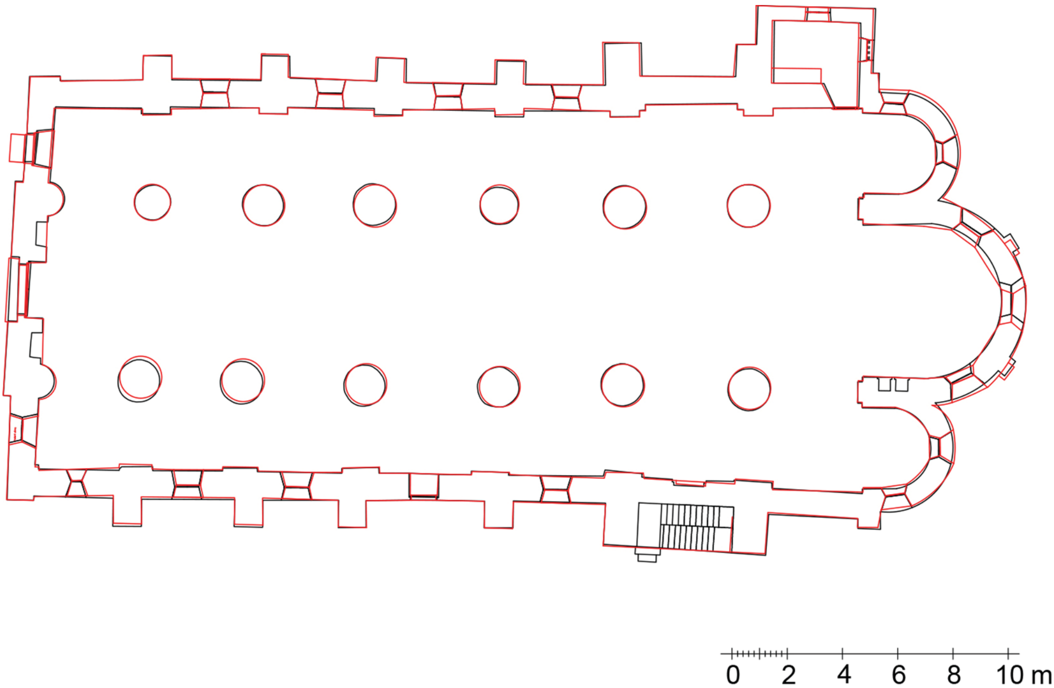

Figure 5: Ground plans of the church: black – from the TLS point cloud, red – from the traditional measurement techniques.

The coordinate differences of identical reference and transformed points are normally distributed with a mean value close to 0 (Figure 6). The standard deviations of the coordinate differences are $\sigma_{\Delta y} = 4.2$ cm and $\sigma_{\Delta x} = 6.3$ cm. Of all the points, only 7 points with differences in x coordinates between 18 cm and 20 cm were identified with excessive deviation. All these points are located on the exterior in the middle of the apse. The fact is that non-orthogonal or irregular shapes are more difficult to accurately measure with the traditional method.

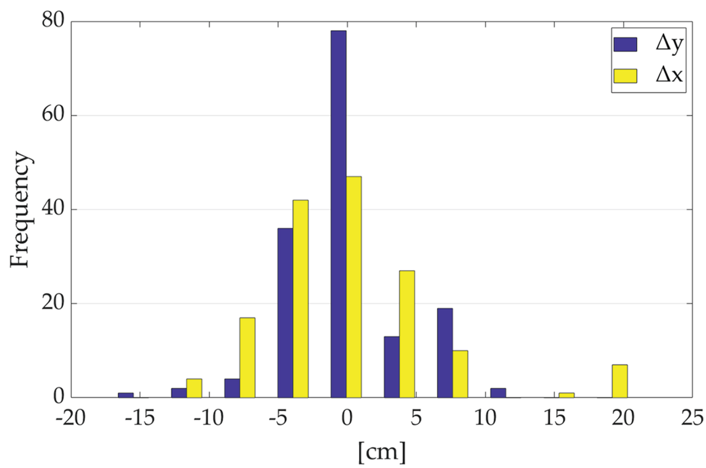

Figure 6: Histogram of coordinate differences between reference and transformed traditional measurements.

4.3 Geometric comparison of laser point clouds of the bell tower acquired with two different instruments

An important feature of the BLK360 laser scanner is the short range (60 m) and poorer accuracy of scanned points over long distances. Therefore, we additionally scanned the surfaces of the bell tower with the Leica MS50. We were interested in the differences in the structure and accuracy of the point cloud on the surface of the bell tower. The quality of the results was assessed by calculating cloud to cloud distances between the point clouds for both used instruments. As Figure 7 shows, 38% of the surface shows distances of up to 3 mm, while 80% of the surface shows deviations of ±9 mm. In a detailed examination of the clouds, we established that distances greater than 7 mm are present in parts of point clouds where the surface was not scanned from the same scan station. In this case, we are dealing with the presence of shadows and different angles of incidence of the laser beam on the scanned surface.

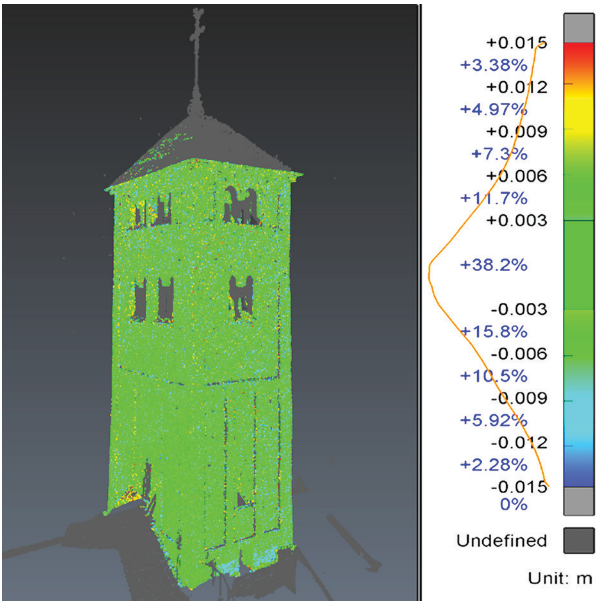

Figure 7: Cloud to cloud distances between point clouds obtained by BLK360 and Leica MS50.

5 DISCUSSION

We can conclude with great certainty that the south wall of the side nave, the pillars in the central nave and the arcades underneath them have been preserved from the first building phase – which lasted until approximately 1030. The top of the walls of the nave and the bay underneath the belltower, the dome as well as the first half of the bay under the choir also belong to this first construction phase as does the lower part of the belltower up to and including the lower level with the bifore windows and most of the front façade.

It is obvious that the current, slightly pointed barrel vault, is the result of restoration works in the distant past, most likely already in the 12th century, when the distance between the supporting walls of the nave led to a deformation or destruction of the semi-circular barrel vault to an extent where it needed renovation. The apses were added in the 13th century.

The church of Saint-Martin survived the French revolution without any great consequences. The study of the available archive sources, meticulous observation of the construction irregularities and the precisely documented state of the object made it possible for us to distinguish between at least eight key construction phases (Figure 8) (Lah et al, 2019).

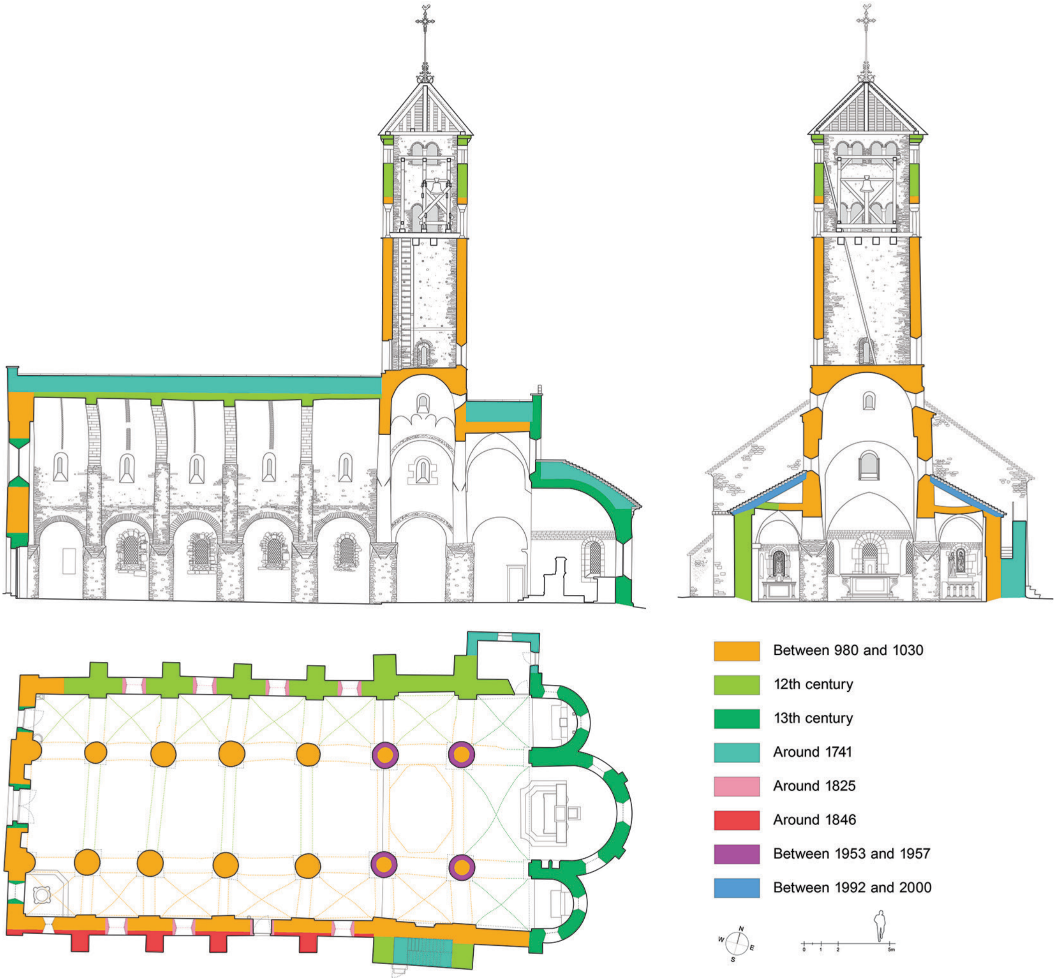

Figure 8: The key monument development construction phases.

5.1 Graphic documentation as the basis for investigating the historic development of the church

In combination with the methodological overview of the monument, the newly created precise architectural record provided us with a whole array of new discoveries and observations that the researchers before us have failed to notice or did not take into account. Alongside the thoroughly presented (minimum) eight key construction phases in the historic development of the monument (Figure 8), we have also ascertained irregularities in the object's plan, which we have recorded for the first time in the architectural record (the architectural plan of the existing condition of the monument). Already a quick overview reveals an array of obvious irregularities. The walls are not straight and absolutely vertical, there are almost no right angles. In the ground plan, the façade is drawn as sloping in relation to the longitudinal axis of the central nave. The columns are not aligned, are of various dimensions and are out of sync with the ideal axes on both sides, thus most transverse ribs are not perpendicular to the axis of the central nave. We have also noticed a small pier (narrowing of the wall) at the height of approx. 5.50 m from the ground, especially on the northern wall of the central nave. The narrowing of the wall or the pier does not run at the same height from one end of the nave to the other. This could be linked to the destruction of the original vault already during its construction and its renovation, which supposedly took place as early as the 12th century.

The conditions in the side naves are even more surprising: the pillars, that support the lower part of the arches in the side naves, are not placed in a (regular) axis alongside the appropriate pillars in the main nave, for they are all positioned to the east in the north and to the west in the south. In the east, where the apses are located, the joint width of the naves is by approx. 0.55 m larger. The general impression is that there are numerous irregularities that emerged at the planning of the building as well as later on, during the numerous recovery or renovation interventions.

We were also the first to notice and present the later extension at the top of the belltower, the Romanesque decorative hinges on the doors, and three types of lombard bands / arcade friezes. Combining architectural records and construction research we have discovered and defined in greater detail the eight main phases of the historical development. Alongside all new discoveries we were also the first to notice traces of wall paintings in the apses (in two different layers).

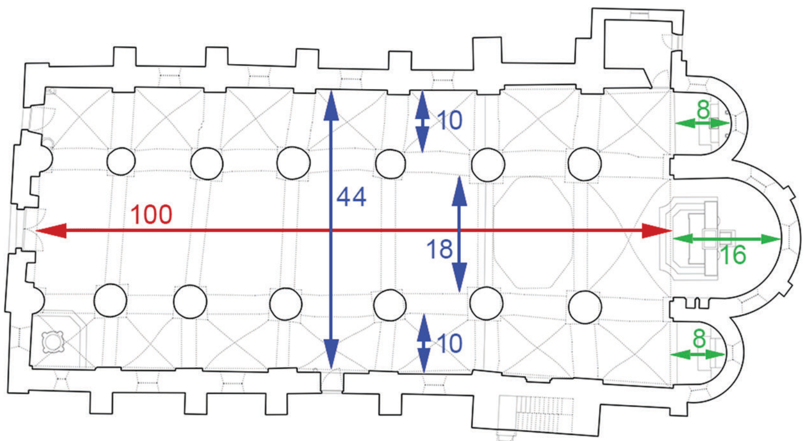

Figure 9: Measurement and modular analysis of the ground plan.

We were also the first to perform the measurement and modular analysis from the precise architectural record (Figure 9). The building was designed as an irregular rectangle with three added apses. The rectangle with all three naves (without the apses) measures precisely 100 Roman feet in length and 44 feet in width (a Roman foot measures 29.574 cm). Lengthwise, the naves are modularly divided into five bays measuring 14 feet and two bays (under the dome and in front of the altar) measuring 15 feet. By width, the total measurement of 44 feet is divided as follows 10:3:18:3:10 feet. The apses measure 10 x 8 feet (side apses) and 18 x 16 feet (central nave) (Lah et al., 2019).

5.2 The importance of a detailed cultural heritage recording

Architectural recording is an essential part of gaining information on the monument with the intent of presenting its current state as precisely as possible, which in turn, enables further detailed research. The architectural record has true value only if it is precise and shows the irregularities and all deformations that have emerged during the aging process. Architectural records are indispensable also for all other types of research: they represent the basis for the understanding of the historic development, as well as serve for mapping damages, probe trenches, materials and how they were worked. A high-quality architectural record can provide key information for the owners, investors, project managers, statics, conservers... which they can use to evaluate the building, prepare the conservation plan, the documentation of the planed interventions and all other tasks associated with monument management.

When should one use traditional measurement techniques and when geodetic measurements? As we have previously stressed, various factors can influence this choice. With relatively extensive and tall objects that are not of an orthogonal design, such as the monument in Chapaize, it is hard to achieve expected or demanded reliability of measurements with traditional measurement techniques. It is hard to achieve high measurement accuracy and acceptable deviances even with a highly experienced team. On the other hand, traditional measurement techniques are associated with advantages that have proven to be a necessary part of the conservation process. 'The act of measuring up for drawings imposes a discipline, requiring systematic observation of all parts of a structure, and it can result in additional information coming to light.' (Menuge and Lane, 2016). When capturing 3D spatial data on the geometry of the object we often opt for contemporary mass terrestrial or aero capturing techniques. In this case we use terrestrial laser scanning technologies or close-range photogrammetry (Xu et al., 2014). The first provides us with a point cloud that needs to be treated and prepared for future use in 3D modelling and planning software. Alongside fast data capturing, the main advantages of this technology can be seen in the absolute and relative precision of data, the possibility of re-evaluating data and extensive archive and information value. The drawbacks of the point clouds include problems linked to large data quantity, loss of details when thinning the point cloud and creating 3D models and the necessary knowledge of the numerous software that is available for treating point clouds.

6 CONCLUSIONS

"Heritage conservation is a multidisciplinary activity. As a result, documentation consists of records produced by professionals and people from different fields of expertise and interests. These records must be prepared with care and preserved for the benefit of future generations". (Letellier, 2007). In the spirit of Robin Letellier's recommendations we have performed interdisciplinary research with a final report on the new conclusions related to the monument in Chapaize (Lah et al., 2019).

The research is based on the cooperation of various experts. We have ascertained that the manner of creating architectural records has developed significantly over the past decades: first with the arrival of stereophotogrammetry, and then with the fast development of laser scanners and various digital tools. This activity is increasingly performed by experts, who are becoming a part of the interdisciplinary expert teams.

We produced two versions of the church's ground plan. The first, preliminary version was created using the traditional 'manual' measurement technique. The second, additionally treated version was created from the point clouds obtained by two different instruments. We used the described scientific methods to verify and compare the geometrical precision of both versions. The comparison shows that the traditional 'manual' measurement techniques offer a close approximation of the results achieved by laser scanning. The deviations were analysed and presented in chapter 4.2. Of course, the results always depend on the precision of the work of the team that performed the measurements.

When contemporary mass record methods were used, the final result was importantly influenced also by the selection of the appropriate tools (the advantages and weaknesses of individual technologies and instruments) and data processing methodologies.

Together with the simultaneous methodologically performed overview of the monument, the newly created architectural record based on laser scans enabled a better understanding of the knowledge we had so far on the historical development of the object and provided us with an array of new conclusions and discoveries.

While performing the measurements and methodological establishing the historic development of the monument we restudied the historic sources and records related to Chapaize. A substantial part of the historical documents has been unfortunately lost or destroyed in the past. Numerous archival documents and additional analysis were included in [35], which enabled a historic social and economic reconstruction of the conditions in the region and with this the possibility of placing the monastery and church of Saint-Martin within the frame of social evolution. It needs to be emphasised that the new research and documentation cannot offer conclusive answers to all issues related to the historical development of the monument and the current state of the monument. However, the performed research offered numerous new observations and conclusions that are presented briefly in this article.

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