RECONSTRUCTION OF BURIED OBJECTS BY IMPLEMENTATION OF GROUND PENETRATING RADAR TECHNIQUE: EXAMPLE ON ROMAN TOMB IN BRESTOVIK (SERBIA)

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ABSTRACT. The fast development of radar techniques and computer software in the last ten years, play an important role in applied sciences including archaeology. In archaeology, there is lot of excavations and this science is seeking for modernization of detection methods and methods of determining not only buried objects but also defining cultural layers. This paper discusses the possibility of implementation of ground penetrating radar in solving some of the specified problems at a well known, excavated and preserved site which is a tomb from the III c. AD found near the present day cemetery of the village of Brestovik near Belgrade (Serbia).

Introduction

The Late Antiquity tomb in the Brestovik village, near Belgrade, was discovered in 1895 by M. Valtrović. Revision investigations were performed in the 1950s, and in the beginning of the 1960s protection activities have been carried out on the site.

Spatial distribution

The Brestovik tomb is situated within the wider area of Singidunum (Fig. 1 presents the approximate position of the major settlements in the Roman period as well as their relation to Brestovik). The tomb is elongated, with a West-East orientation and consists of three rooms with different shape and function (the condition of the tomb in the 1950s, Fig. 2).
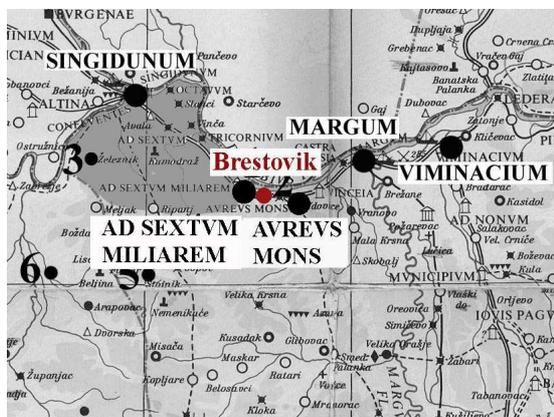

Fig. 1. Position of the tomb

Fig. 2. Location of the Brestovik tomb

At the West side of the structure there is a quadrilateral room (2.60x3.00 m), with three graves that are placed along the South, the West and the North wall of the room. The graves were built by bricks in plaster board. They are capped at a level and plaster boarded from the outside and from the inside, with the plaster board mixed with fragmented bricks. The bottom and the lower part of the structure was built of bricks and stones, while the arches and niches were built only of bricks (34.5x34.5x4.8 cm; 38x14x3.5cm; 29-38x22-30x4 cm; 29x41x4-6 cm), with a thick plaster board. The floor in the middle room and the porch was paved with hexagon floor bricks (10x5 cm). Some of the bricks have seals or printed marks of the Legion IV Flavia or Legion VII Claudio workshops. The jambs and the stairs were dressed with limestone.

The structure was painted. The Brestovik tomb was decorated with frescoes, murals and sculpture decorations and was used for funerary ceremonial services – the whole structure had a memorial character. It was built during the III or IV c. AD (Milosevic, 1993).

GPR method, use and application

In the process of detection of underground objects in contaminated areas, the GPR method of investigation is one of the most commonly used. The GPR is an electromagnetic, non-destructive geophysical method. From the antenna electromagnetic waves are emitted to the subsurface (Fig. 3). The frequency could be from 80 MHz to about 1 GHz. If there is a material with different electromagnetic parameters on the path of the wave beneath the soil, the part of the initial electromagnetic wave will be reflected. The reflected wave travels to the GPR's receiver where it is recorded. The travel time of the electromagnetic wave is known as double time and is expressed in nanoseconds (Motoyuki, 2001).
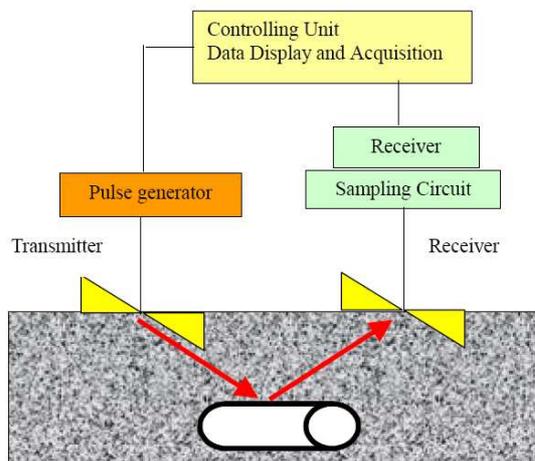

Fig. 3. GPR System

The amplitude of the recordable reflected wave depends on the physical properties of the soil and the object. GPR systems work by sending a tiny pulse of energy into a material via an antenna. An integrated computer records the strength and time required for the return of any reflected signals. Subsurface variations will create reflections that are picked up by the system and stored on a digital media. These reflections are produced by a variety of materials such as geological structure differences and man-made objects like pipes and wire. The results of GPR records are usually in the form of GPR profiles (Fig. 4). This is the descriptive way to show the signal by depth distribution. On every single GPR profile it is possible to determine the spatial coordinates of the signal which represents the position of the subsurface object.

GPR and EM technologies are used in a wide array of applications by diverse groups of professionals around the world. Users vary from construction professionals and public work engineers to geologists and archaeologists. Survey uses vary from pipe and rebar location to tree inspection and military use. New uses for subsurface imagery emerge every day.

GPR usually operates in the VHF-UHF region of the electromagnetic spectrum. The frequency used is a compromise. One desires to use the lowest possible frequency because low frequencies give reasonably high penetration depths into the Earth. But a sufficiently high frequency must be selected so that the radar wavelength is short, allowing detection and resolution of small objects such as pipes. For cart mounted radars, 150 MHz is a typical centre frequency, however 300 and 500 MHz are sometimes used for shallow, high-resolution probing and frequencies as low as 20 MHz are used for locating deep caves.
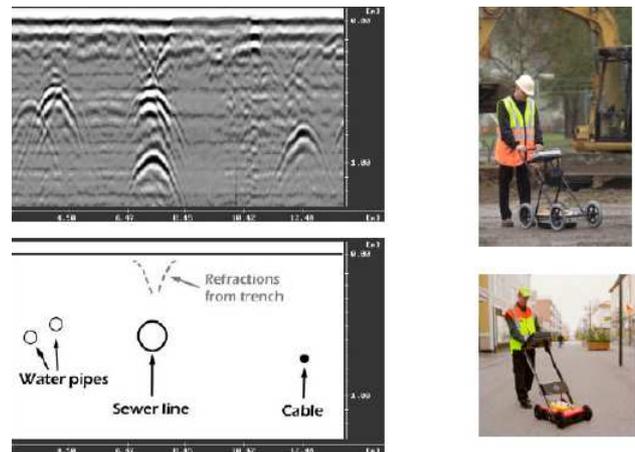

Fig. 4. The GPR profile with the recorded signal (up); the interpreted GPR measurements (down)

Basic characteristics of the georadar method of investigation are: very high precision of the data; continuous surveying; the highest survey resolution; entirely non-destructive; very fast collecting of data; one of the cheapest geophysical investigations; investigations do not have bad effect on people and environment. A georadar profile for the purpose of investigation of road foundation is presented at Fig. 5, so different layers and anomalies of the road foundation can easily be noticed.
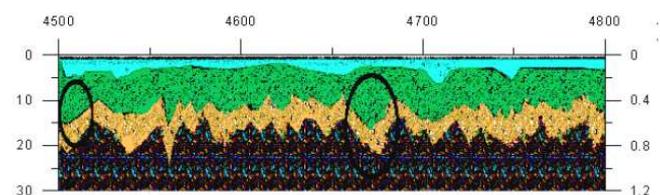

Fig. 5. GPR profile at the Smederevo-Umcari road

Prospecting and post processing

The concept of processing data in the software (for digitalization, visualization and interpretation of the georadar profiles) was made on the example of the recorded profiles over the Roman tomb at the Brestovik location. While some georadar data can be left raw, because the first interpretation during the process of compilation and recording of the data was enough to draw conclusions about the configuration of the underground, data processing in other cases can be the key for the visualization of the objects under the ground surface. The aim of the geoaradar data processing is to improve the quality of data and to present it in a form that is the most

adequate for interpretation. Georadar data is recorded in the .rd3 format and files in the .rad format present a header (terms and conditions of the recording data; with an example – the fourth profile) (Fig. 6).

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SAMPLES:500
FREQUENCY:5010.421677
FREQUENCY STEPS:88
SIGNAL POSITION:-0.028198
RAW SIGNAL POSITION:45200
DISTANCE FLAG:1
TIME FLAG:0
PROGRAM FLAG:0
EXTERNAL FLAG:0
TIME INTERVAL:0.000000
DISTANCE INTERVAL:0.041714
OPERATOR:
CUSTOMER:
SITE:
ANTENNAS:500 MHz shielded
ANTENNA ORIENTATION:NOT VALID FIELD
ANTENNA SEPARATION:0.180000
COMMENT:
TIMEWINDOW:99.792000
STACKS:4
STACK EXPONENT:2
STACKING TIME:0.020000
LAST TRACE:124
STOP POSITION:5.172536
SYSTEM CALIBRATION:0.0000022680
START POSITION:0.0000000000
SHORT FLAG:1
INTERMEDIATE FLAG:0
LONG FLAG:0
PREPROCESSING:0
HIGH:0
LOW:0
FIXED INCREMENT:0.0000000000
FIXED MOVES UP:0
FIXED MOVES DOWN:1
FIXED POSITION:0.0000000000
WHEEL CALIBRATION:263.7000000000
POSITIVE DIRECTION:1
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Fig. 6. Header of the georadar profile number four

The recording of the georadar profiles were made in the beginning of 2007. All together four profiles were recorded over the tomb. The position and direction of the profiles is shown on Fig. 7.
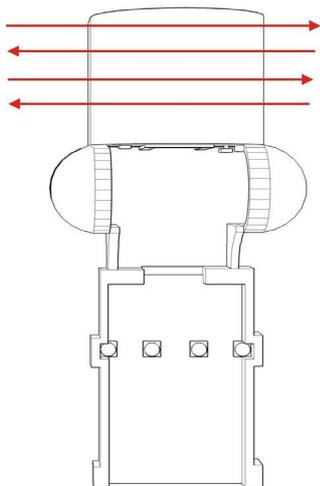

Fig. 7. Position and direction of the GPR profiles

The data processing was made by the software package ReflexW of the prominent manufacturer of software for seismic and georadar data processing Sand Meier geo. This paper presents the process of data processing by this software. By choosing the Convert to Reflex option we are opening the desirable file.

Profile 3 of the Brestovik tomb is shown on Fig. 8. At the raw record the horizontal scale at the top of the radargram represents the distance between the successive data that were collected and the vertical scale usually represents the double reflective time that can be converted into depth. If we place the georadar profiles into the computer (net), three dimensional aspects can be obtained.
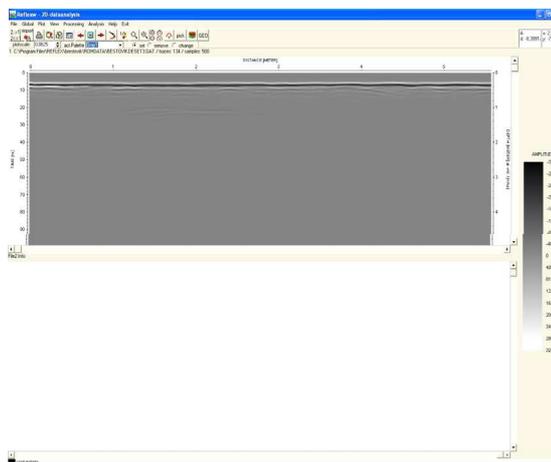

Fig. 8. Raw profile 3

Georadar data are recorded as a function of time. The depth of the reflective signal is plotted as double time (the time needed for an electromagnetic wave to travel to the ground surface and back). The vertical scale can be converted into depth expressed in meters. The next procedure presents the adjustment of these record scales.

When we open the desirable file with the Reflex software, the first step is to adjust the size of the segment on the screen by inserting parameters in certain fields. By changing the parameter X scale in Plot-Options Menu and also by inserting a value of average speed of electromagnetic waves in given environment by parameter v(m/ns) (Fig. 9), we will obtain a record as shown on the screen (Fig. 10). When the signal broadcasted from the georadar unit penetrates into ground, an attenuation of georadar signal occurs. It can be updated by applying amplification of the signal. The next procedure during the data processing is the use of Energy decay option from the Plot-Options Menu which enables equal distribution of electromagnetic waves energy of the whole record along the vertical axis. A much better contrast between object and environment is noticeable (Fig. 11) in comparison with the raw data.
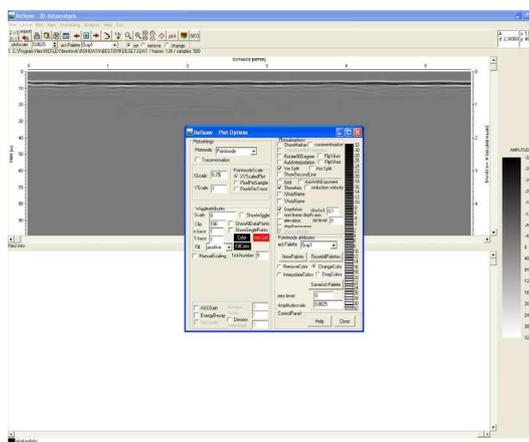

Fig. 9. Change of the parameters of vertical and horizontal scale
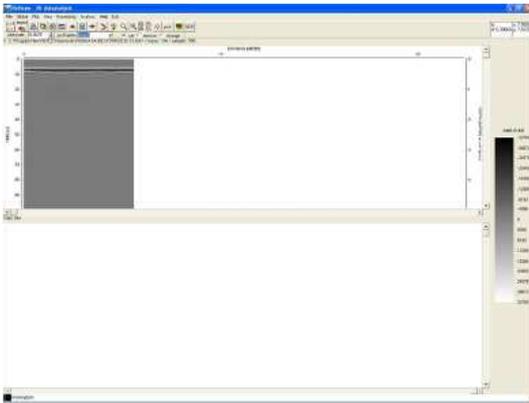
Fig. 10. Profile obtained after the change of the parameters of vertical and horizontal scale
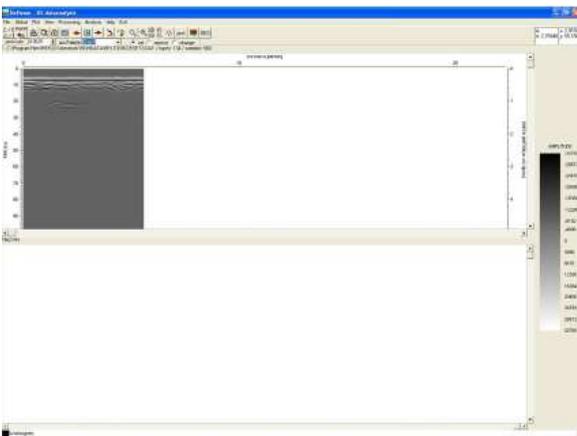

Fig. 11. Profile obtained after the change of parameters Energy Decay

Despite the change of parameters we do not notice change on the radargram for which it is necessary to choose the option Plot-Plot. The next step is the change of static corrections that compensate the time delay of the first waves. These settings remove the effects of change in elevation and the effects of reduction to the level of georadar antenna. There are often big amplitude reflections caused in the air and at the ground surface directly under georadar antenna. A huge contrast of conductance between the air and the ground can create direct wave that is reflected from the surface (the wave that is propagating through air directly from the emitter can mask reflection from important object directly under the surface).

From the Processing-Static Correction Menu we choose Option Static correction and receive at the radargram the air-ground boundary, so the values of these times will be incorporated into a table and later by choosing the Start Option applied to the georadar record.

By choosing the File-Change Second to Primary option the static correction is applied to the georadar record. If you skip this procedure, all the changes will refer to the lower record and will not be applied to the upper record. Static corrections were incorporated by changing initial point of the vertical axis.

The next step of the data processing is to filtrate what we call de-wow or subtract mean. This method of 1-D filtration enables the determination of average value from the wide spectra of all the frequencies and its application to all traces while trying to minimize the effect of wave propagation in all directions and their mixing. Apply of this filter is done, and after its application and loading into the primary record we obtain Fig. 12. We can notice some other anomalies that could not be seen in the previous records that will help us during the future interpretation (Fig. 12).
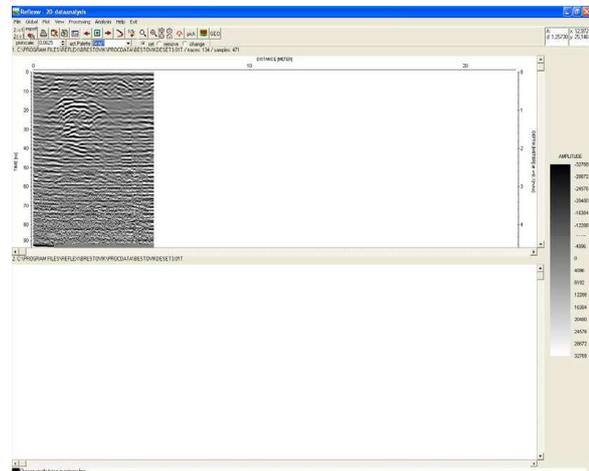

Fig. 12. Record after incorporated 1-D filter

After these adjustments we can filtrate the records because of the better interpretation of the recorded data. Depending on the quality of the recorded georadar data, the signal intensity and the project task, we adjust the parameter Gain (dB). This is done in the cases when we decide to apply manual adjustment after a glance at the recorded material. For the correction of the fast drop of signal energy (signal attenuation) we apply function of amplification (Gain). Linear function of amplification is used for the compensation of attenuation (loss of energy because of the ground resistance to the electromagnetic wave propagation). To compensate the reduction of energy caused by spherical outspread of the wave front, a logarithmic function can be used. In practice, we combine logarithmic and linear factors of the amplification and also add constant factor of the amplification that dos not change in time and can specify value of time after which the amplification curve will be constant. By changing the parameter Gain we adjust the relative amplitude of the shallow and the deep ranges. We can see a record after the application of Gain filter (Fig. 13).

In future data processing we can apply Band pass Filter and AGC filter. In this example we applied these parameters: attenuation (dB) 20, number of filter points 33, frequency points F1 10, F2 20, F3 50 and F4 60. After the Band pass Filtering we apply AGC (Automatic Gain Control) where we enter parameters of automatic gain control: window length (samples), gain percent (0-1000 which are 51 and 400. To raise the level of the weak signal as compared to the strong

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signals so that certain object or boundary can be noticeable, we use digital balance or AGC. Different values of amplifications are calculated along the path with short time intervals (windows).
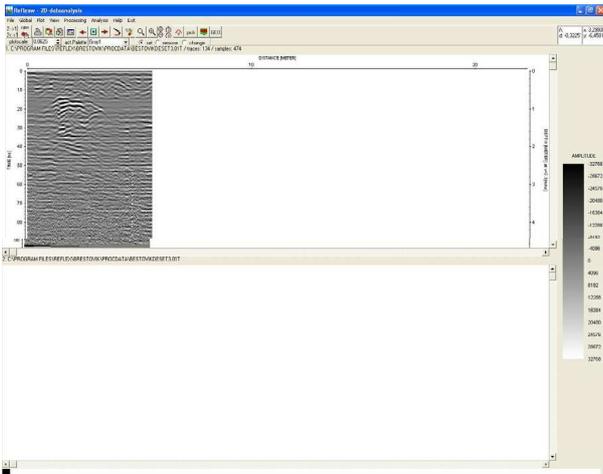

Fig. 13. Record after incorporated Gain parameters

Digital AGC is using sliding windows to define amplification that is going to be applied at every sample of the path. The time window is sliding along the path, the level of the data inside the window is comparing to some certain level and the amplification factor is applied to every sample inside the window. The length of the AGS window determines the level of the amplitude assimilation. Very short windows will almost eliminate the amplitude variations, while longer windows detain lots of original amplitude changes. We can see parameters that were used for AGS and how it looks at the lower record (Fig. 14).
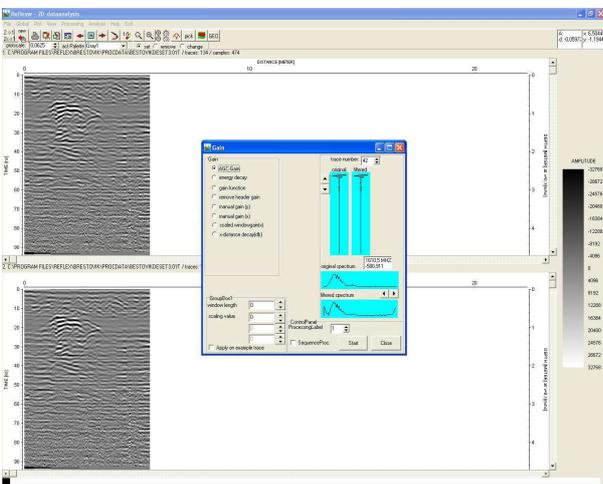

Fig. 14. Record after incorporated AGC filter

The main purpose of the digital filter is to extract certain desirable frequent component from the record and to attenuate all the others. The digital filtering is improving the signal/noise ratio. There are null-phase filters where the zero value is at all the frequencies and the unit signal is at the desirable route. The Band filter passes only through certain frequency zone. The more the components in the band pass filter, the more approximate will be the real record to the desirable one. There is a feature of the 2-D filtering that is called background

removal which removes all the noise from the multiple waves and increases the signal/noise ratio.

Migration is a process of GPR data transformation recorded at the ground surface and transformed into data including the underground heterogeneities located at the accurate positions. At the radargram, the wave ranges are plotted as electromagnetic waves that travel in vertical paths. This assumption is correct if the reflective horizon is without or with little slope. With the sloping layer this assumption is no longer correct. To update this problem, records must be migrated at their exact position in time and place.

Radargram or georadar record can be presented in different colours. At Figure 15 the Brestovik tomb GPR record is presented in a rainbow color palette. The Brestovik tomb GPR record is presented also in blue-grey-red color palette (Fig. 16). It will enable more clear and explicit picture of the underground and if one correlates it to the raw record in Figure 8 one can clearly notice the importance of the data processing.
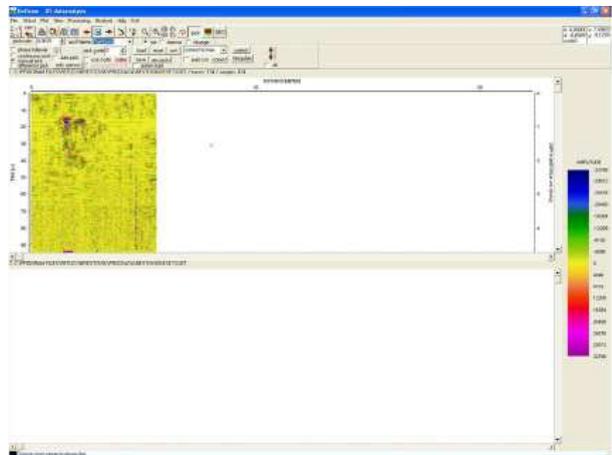

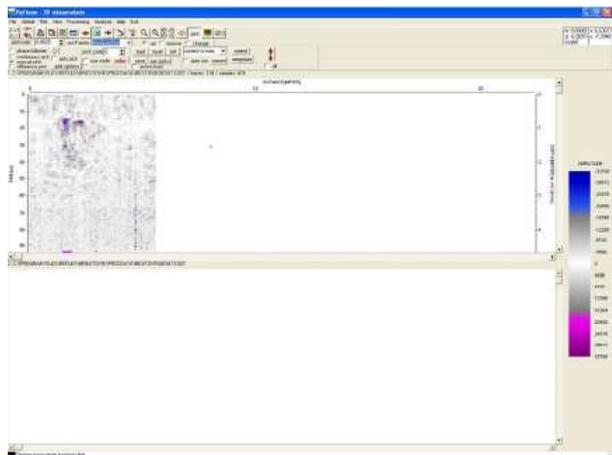Fig. 15. Record of GRP data in rainbow color palette

Fig. 16. Record of GRP data in bluegreyred color palette

The engineer who is doing the georadar data processing should perform evaluation at almost every step of the georadar processing sequences. In most of the cases, the parameters that are used in the processing are determined by the data analysis. There are a number of parameters for every process, so the analysis to determine these parameters must be logical

and methodical. After the filtering and the final operations of recorded material the GPR profiles are ready for interpretation.

3D model

A 3D model was made on the basis of the available georadar data and the data from the excavations. Georadar surveys and records entirely confirm the geometry and the spatial position of the rooms. A model was obtained from the sketches software of the Google Sketch UP 6 (illustration of the final model of the room with the whole environment is given on Fig. 17).
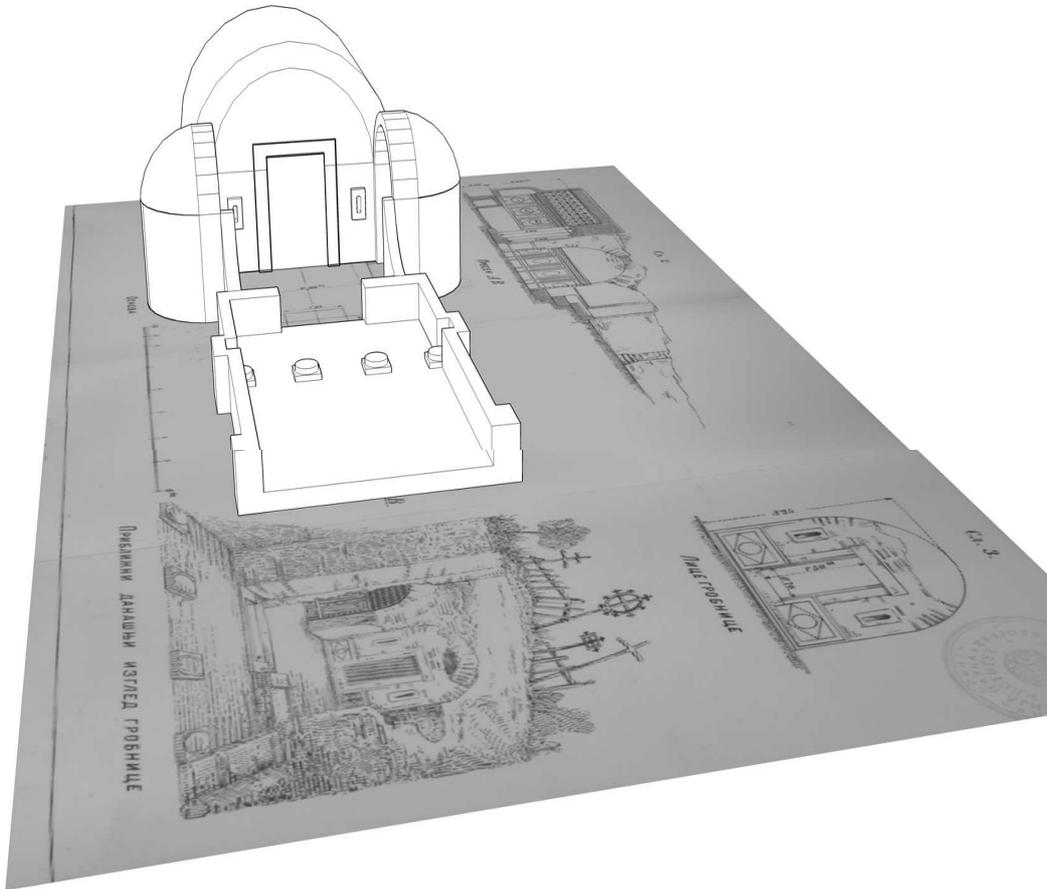

Fig. 17. 3D model of the Brestovik tomb

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