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Acoustic aspects of the Goseck Circle area

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Abstract This article presents a study conducted to evaluate the acoustic quality of the Goseck Circle, an ancient circular enclosure, also known as a rondel, situated in Saxony, Germany. Goseck Circle is an example of monumental buildings from the Neolithic period, which are called rondels. The facility was discovered in the 1990s. Then the facility was archaeologically reconstructed and opened to the public in 2005. Currently, it is considered to be the oldest known structure of this type, and its creation is estimated at around 4900 BC. Goseck Circle is roughly of a circular shape. It has one ditch and two palisade rings. There are three entrances leading to the interior of this facility. Therefore, the Goseck Circle is considered as the oldest solar observatory, as a worship, or a ritual place. A number of studies on both contemporary and archaeological facilities indicate that the facilities display the characteristic features depending on their intended use. Therefore, it can be assumed that if the Goseck Circle was to be a place of worship, then in terms of the acoustic aspects, it should be characterized by such values of the acoustic parameters, that will also prove this. This concept was the reason for carrying out a series of numerical calculations that allowed for the determining of the selected parameters characterizing the acoustic field inside the analysed facility.

Keywords: numerical simulations, geometrical methods, archaeoacoustics, Goseck Circle, sound field, acoustic parameters.

1. Introduction

Sound, nowadays, is a key feature of most social performances. Based on the literature [1-5] one can assumed that acoustic impressions occurring in the facilities of human habitation seem to have been also important in ancient times. Since the interpersonal communication on many levels is related to the generating and receiving of sounds, the acoustic analysis of archaeological facilities seems to be a significant support for the activities aimed at determining the functions, that the given facilities could have performed [2,4-9]. For this purpose, acoustic measurements can be used in real facilities and, if not possible, also a computer modelling, especially when the archaeological site is no longer present.

Rondels are Neolithic Circular Enclosures occurring in Central Europe, in Austria, Germany, Hungary, Czech Republic, Slovakia, and Poland. It is estimated that there are about 140 structures of this type in these areas [10]. One-third of the installations known so far are located in Lower Austria [11]. Rondels were made in the period between 4900–4700 BC [12] and belong to the Neolithic cultures like the Lengyel culture, the Stroke-ornamented ware culture, the Rössen culture etc. They are usually of a circular or elliptical shape. They are surrounded by at least one ditch, and often also by at least one palisade ring, in which at least two entrance gates or causeways are located. Inner space diameters range from 45 m to 70 m, which means that the areas of such facilities were from 1600 to 3800 m^2. Therefore, it could accommodate from 500 to 1200 people inside.

Rondels are considered to be the oldest facilities of the monumental architecture in Europe. The interpretation of the rondels, on the basis of the finds excavated there, proves to be difficult. Rondels are interpreted as political and cultural meeting places, religious cult places, or as calendar buildings, astronomical observation centres, solar temples, shelters for domestic animals or defensive constructions [10, 11, 13, 14]. All in all, they were of profane and cultic use, a place of togetherness that creates or affirms a sense of community through common actions.

Goseck Circle is the oldest known representative of rondels – architectural facilities included in the group of monumental buildings. It is located in Goseck, Germany. It is dated to about 4900 BC. It is built of two concentric palisade. The inner palisade ring has a diameter of 48 m, while the outer palisade ring has a diameter of 60 m. The palisade rings are surrounded by a ditch with a diameter of 75 m. The wooden palisades are approximately 2.5 m high. Three gates lead to the inside of the facility. The present facility is an archaeological reconstruction of a historical facility, and was opened to the public in 2005.

Goseck Circle could have been the place of profane and cultic use, a place of togetherness that creates or affirms a sense of community through common actions, an exclusion of inside and outside. This can be evidenced by archaeological finds found in its area, such as the remains of what may have been ritual fires, animal or human bones. The interpretation as an astronomical facility is based not so much on the archaeological finds, as on the respective plan or the orientation of the complex. The analysis of the plan of the Goseck complex showed that the "alignment of the southern ends of the palisades results in a line of sight that is precisely oriented to the horizon point of the sunrise at the winter solstice at the beginning of the 5th millennium BC" [15,16]. From this it was concluded that the complex served to determine the time of the winter solstice [16]. However, Goseck Circle is supposed to be, the most of all, a place of worship or a sanctuary [16]. Since there are no written sources that could confirm or disprove this theory, it seems reasonable that the use of acoustic methods can be a significant support in these activities. Therefore, if the Goseck Circle was used as a place of worship or a meeting place, the acoustic field in the facility should be characterized by the acoustic parameters, that would indicate the possibility of using this facility for this purpose.

In order to carry out the numerical calculations, it was necessary to develop a digital model of the object. This model was made on the basis of the literature data and photographs available on the Internet [17-19]. The developed digital model of the Goseck Circle is presented in Fig. 1.

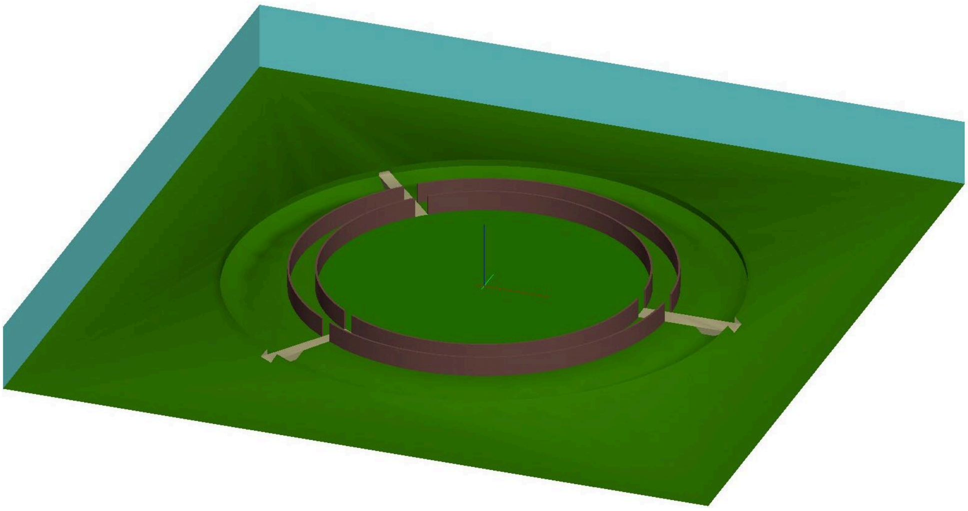

Figure 1. Digital model of Goseck Circle used in acoustic calculations - side view.

2. Method of acoustic field simulation

In order to assess the quality of the acoustic field in the area of the inner palisade ring of the Goseck Circle, a numerical experiment was carried out using the AURA module of EASE 4.4 software, which is based on the geometrical methods of analysing the acoustic field in the facility. 134200000 sound rays were used in the simulations for each of the modeled sound sources. In the model, materials such as grass and wood (for palisades) with appropriate sound absorption coefficients were used to describe the facility. A standard scattering method was adopted with a default scattering coefficient value of 20%. The model resolution was assumed to be 0.5 m. For this purpose, the properties of the acoustic field inside the Goseck Circle were analysed for 4 configurations of the sound source and a set of 7 receivers and also for 4 configurations of the sound source and the whole entire area of the inner palisade ring. Two types of sound sources were used in the simulations - an omni-directional sound source and a source with the directivity pattern like a loudly speaking human. Sound pressure level in 1/3 octave bands for the second type of a sound source used are shown in Fig. 2.

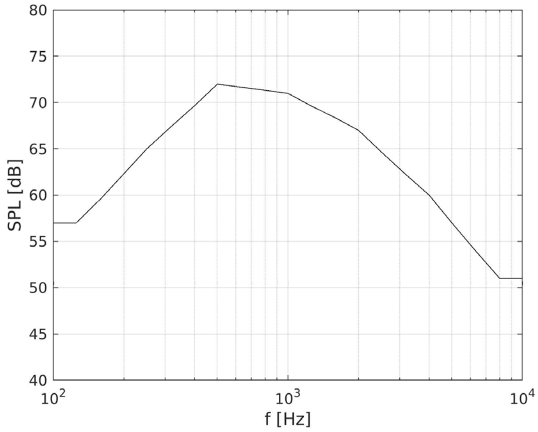

Figure 2. Values of sound pressure level (SPL) in 1/3 octave bands generated by a human speaker, used in the numerical simulations.

The simulations were made for two sound source locations: (1) at the central point of the inner palisade ring - location at S_1 point (0,0,1.7); (2) at the point located in the middle of the radius of the inner palisade ring, in the axis of symmetry of one of the gate opening - location at S_2 point (12,0,1.7).

Seven measurement points (receivers) have the following coordinates: M_1(0,0.75,1.6), M_2(0,3,1.6), M_3(0,6,1.6), M_4(0,12,1.6), M_5(0,23,1.6), M_6(24,0,1.6), and M_7(12,0.75,1.6). The schematic arrangement of sound sources and receivers is shown in Fig. 3.

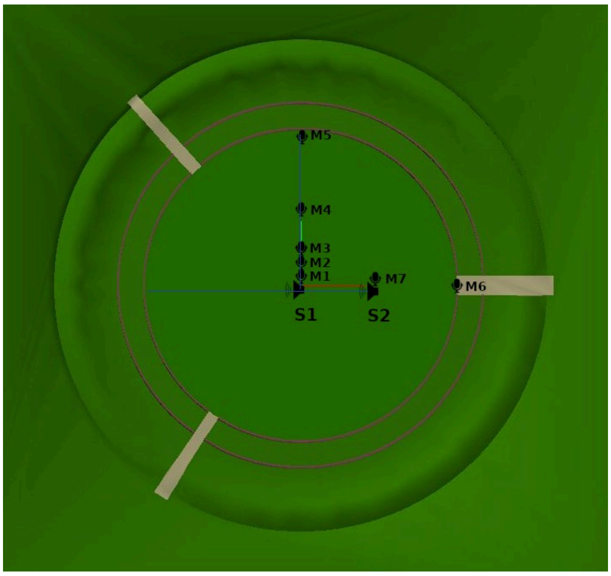

Figure 3. Schematic arrangement of sound sources and point-type receivers in the area limited by the inner palisade ring (blue lines – main radiation axes of the sound sources).

As a result of numerical analyses, a number of acoustic parameters characterizing the acoustic field were determined. These were the following parameters: Definition D, Clarity for Speech C_{50}, Clarity for Music C_{80}, Speech Transmission Index STI, and Sound Strength G. These parameters are defined in accordance with the ISO 3382-1 standard [20].

Definition D parameter is the ratio of the sound energy reaching the receiver within 50 ms after turning off the sound source, to the total sound energy reaching the receiver

$$D = \frac{\int_0^{50} p^2(t)dt}{\int_0^{\infty} p^2(t)dt} \tag{1}$$

and is given in the range of 0÷1, where $D = 0$ means "no speech intelligibility", and $D = 1$ means "perfect speech intelligibility".

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Clarity C_{50} parameter determines the ability to distinguish the individual sounds in the speech signal and the ability to distinguish the sources of these sounds, when several sound sources occur. It is defined as the logarithm of the ratio of the energy arrived to the receiver in the first 50 ms to the energy arrived after the 50 ms. It can be written in the following form

$$C_{50} = 10\ln_{10}\frac{\int_0^{50} p^2(t)dt}{\int_{50}^{\infty} p^2(t)dt} \tag{2}$$

and is expressed in decibels.

Clarity for music C_{80} parameter is defined similar to the C_{50} parameter. C_{80} parameter describes the ability to distinguish individual musical sounds, and the sources of these sounds

$$C_{80} = 10\ln_{10}\frac{\int_0^{80} p^2(t)dt}{\int_{80}^{\infty} p^2(t)dt}. \tag{3}$$

However, in this case the time limit is equal to 80 ms.

The sound strength G is the difference in the loudness at which a source is heard in a given room, compared to the loudness in a free field, at a distance of 10 m from the same sound source

$$G = 10\ln_{10}\frac{\int_0^{\infty} p^2(t)dt}{\int_0^{\infty} {p_{10}}^2(t)dt} \tag{4}$$

Due to the fact that the values of the SPL parameter strongly depend on the parameters of the sound source used, the sound strength parameter was used to assess the uniformity of the sound in the analysed facility.

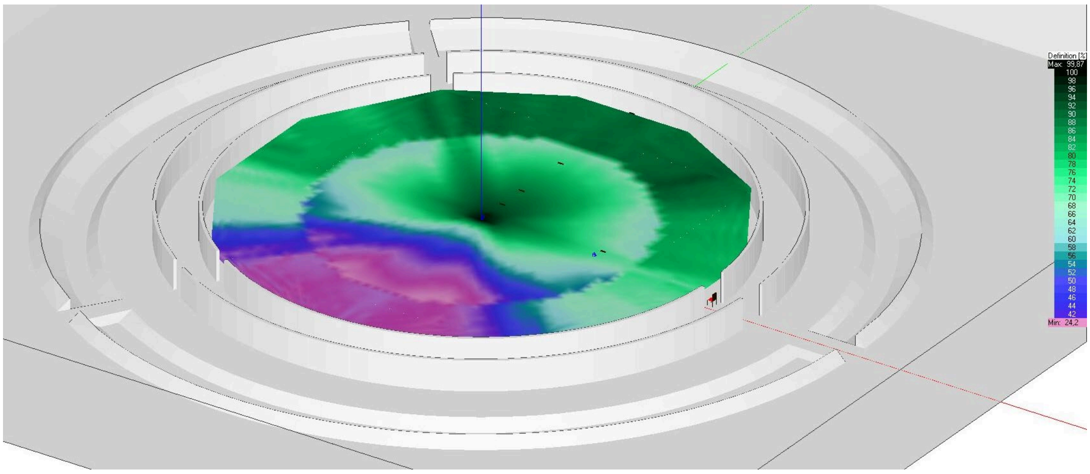
3. Results of the numerical experiment

The acoustic parameters discussed in the previous chapter were determined for the whole entire area of the inner palisade ring. Parameter values were determined for each point of the area separately, as well as the averaged values for the entire analyzed area. The example of the distributions of the acoustic parameter - the distributions of Definition D parameter for both types and for both sound source locations, are shown in Fig. 4-5. On the other hand, a data summary of the average values of the previously selected acoustic parameters for the entire area of the inner palisade ring is included in Tab. 1.

Table 1. Averaged values of selected acoustics parameters for whole area inside the inner palisade ring.

Parameter	S_1 omnidirectional	S_1 man	S_2 omnidirectional	S_2 man
Sound strength G [dB]	-0.42	1.62	-0.20	-0.81
STI	0.68	0.65	0.70	0.68
Definition D	0.80	0.65	0.70	0.69
Clarity C_{50} [dB]	6.15	3.12	5.40	4.30
Clarity C_{80} [dB]	7.00	3.91	8.35	5.99

a)



b)

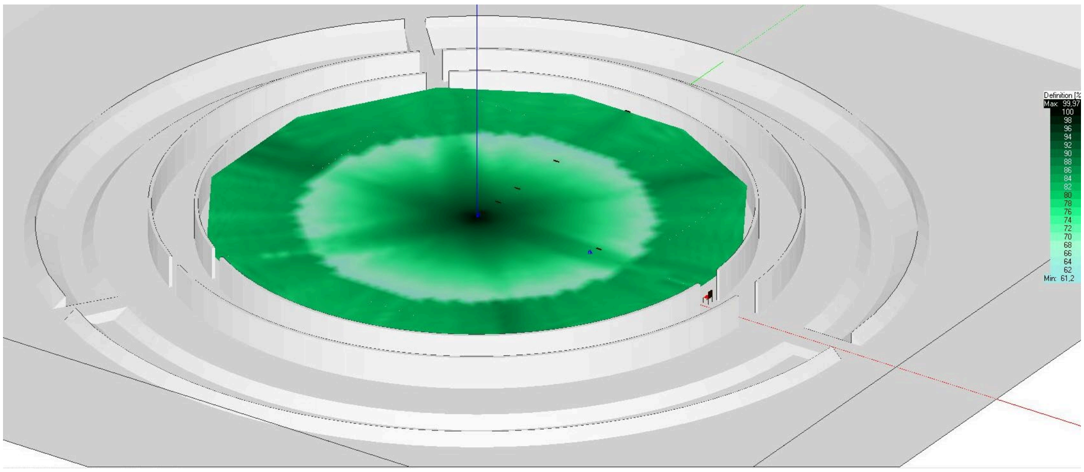


Figure 4. Distribution of the D parameter for sound source located at point S_1: a) directional sound source, b) omnidirectional sound source.

As already mentioned, detailed analyzes were also carried out for 7 measurement points located inside the analyzed area (Fig. 3). These points were chosen based on Pomberger and Mühlhans' article [10] on the Heldenberg Rondel. In addition to determining the values of previously selected acoustic parameters, echograms were also determined in these analyses. Examples of the echograms obtained for the measurement points for the omnidirectional sound sources are shown in Fig. 6-12. Similarly to the Heldenberg facility, also for the Goseck Circle, a flutter echo appears especially at the point located in the center of the inner palisade ring and while the sound source is located at the center of the ring (S_1 point). In this case, due to the size of the structure, this echo is longer than for the Heldenberg Rondel and is approximately120 ms.

a)

b)

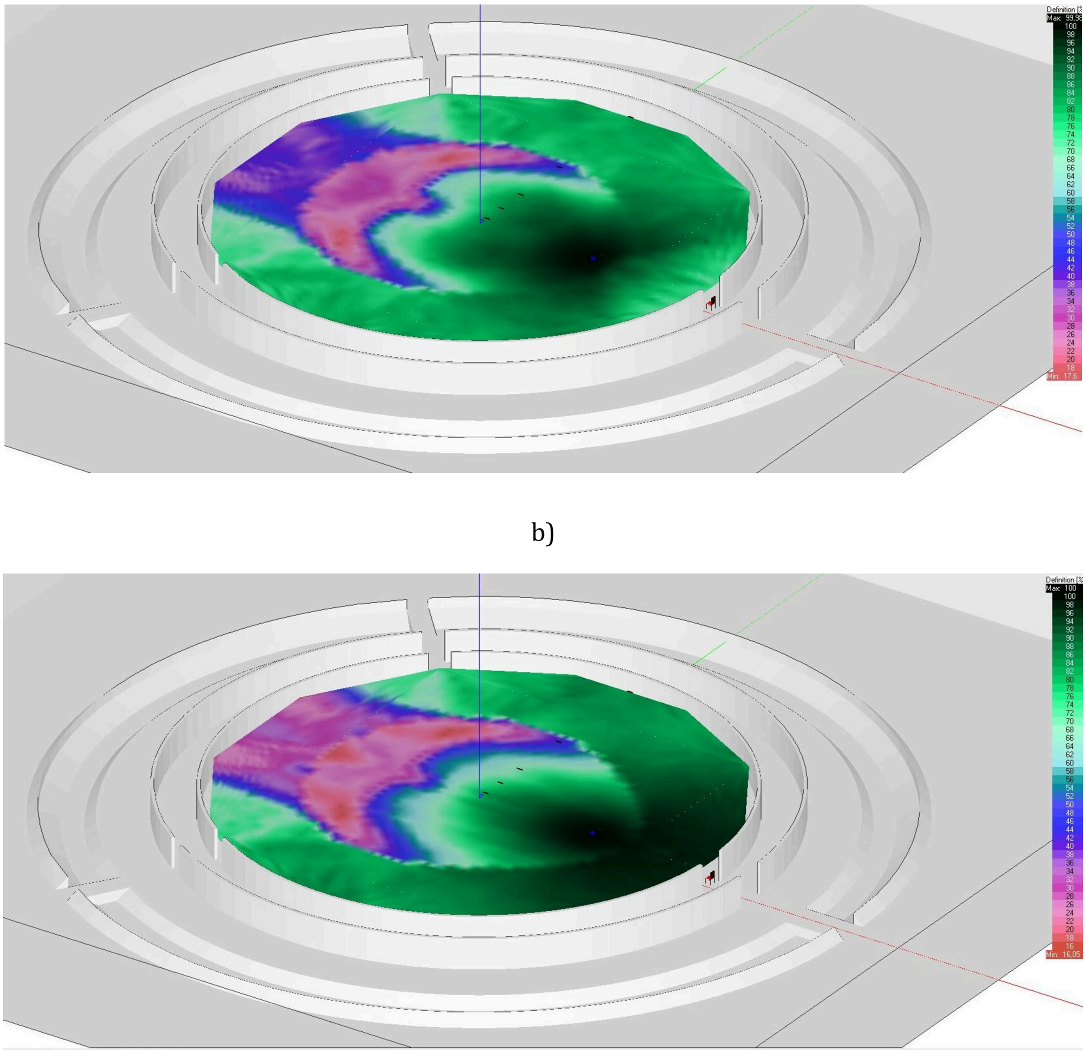


Figure 5. Distribution of the D parameter for sound source located at point S_2:
a) directional sound source, b) omnidirectional sound source.

a) b)

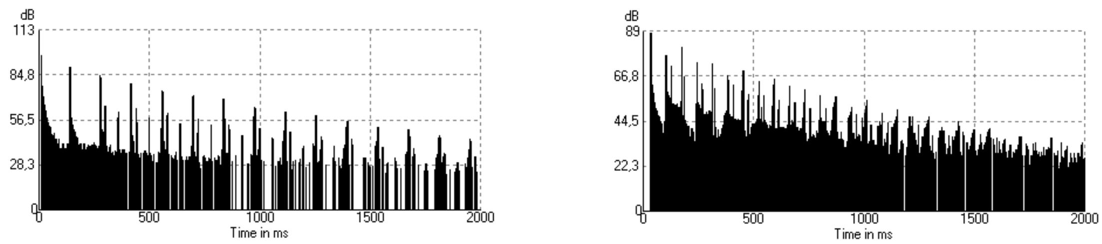


Figure 6. Echograms obtained for the M_1 point for omnidirectional sound source:
a) S_1 location, b) S_2 location.

In order to assess the speech intelligibility, the obtained values of the STI parameter in points M_1-M_7 were compared for both types of sound sources and for both sound source locations. The STI parameter was also determined in the AURA module of the EASE 4.4 program. The assumed background noise level was 30 dB. The STI parameter was calculated using male weighting factors and also including signal to noise correction, signal masking correction, and hearing threshold correction, in accordance with the IEC 60268-16 standard. The diagrams presenting the obtained results are shown in Fig. 13.

a) b)

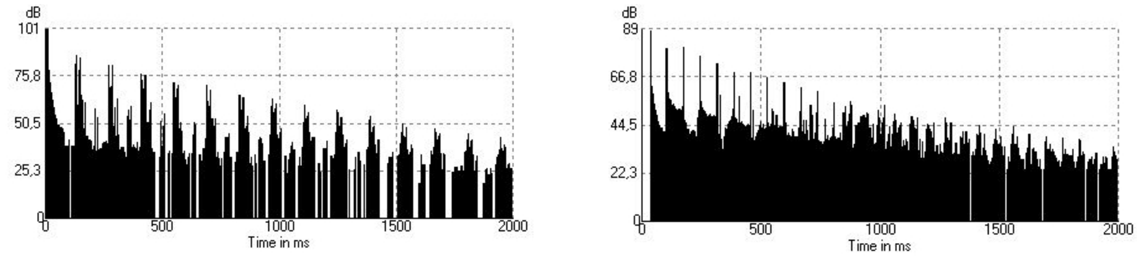


Figure 7. Echograms obtained for the M_2 point for omnidirectional sound source: a) S_1 location, b) S_2 location.

a) b)

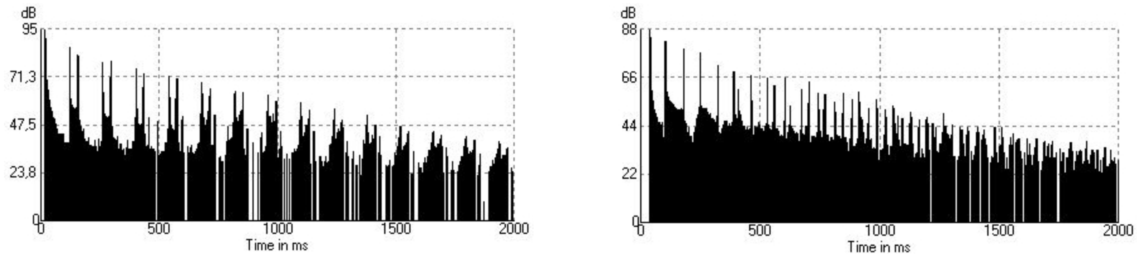


Figure 8. Echograms obtained for the M_3 point for omnidirectional sound source: a) S_1 location, b) S_2 location.

a) b)

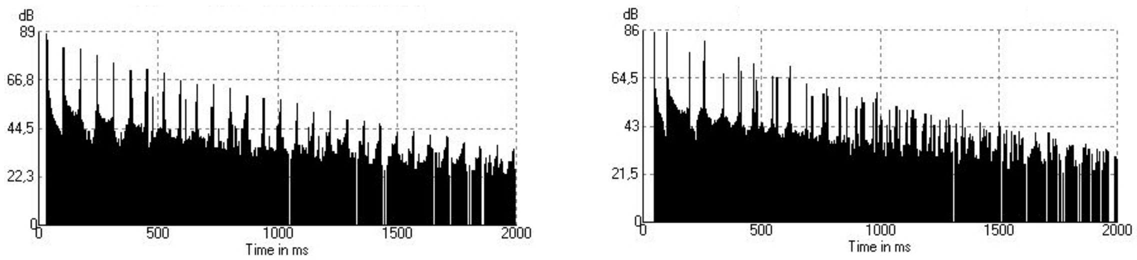


Figure 9. Echograms obtained for the M_4 point for omnidirectional sound source: a) S_1 location, b) S_2 location.

a) b)

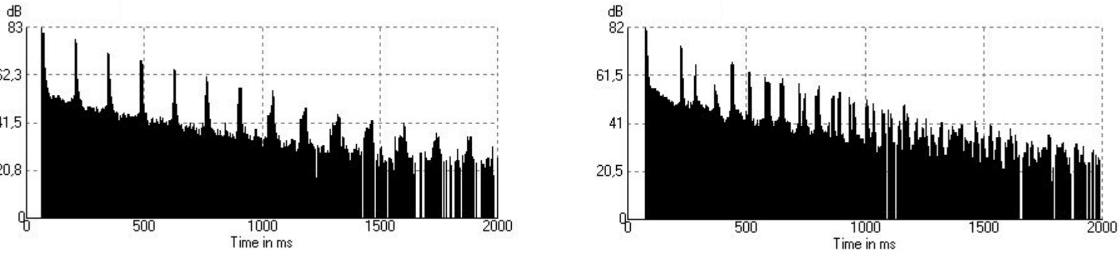


Figure 10. Echograms obtained for the M_5 point for omnidirectional sound source: a) S_1 location, b) S_2 location.

Archaeologists assume that various types of celebrations could take place in the Goseck facility. Therefore, apart from the aspect of speech intelligibility, the music signal were also analyzed. For this purpose, the Clarity C_{80} parameter was analyzed. The results, which are a summary of the obtained values for the one-third octave band in the range from 100 Hz to 10,000 Hz, for all seven analyzed measurement points, and for both types and location of sound sources, are presented in Fig. 14.

a) b)

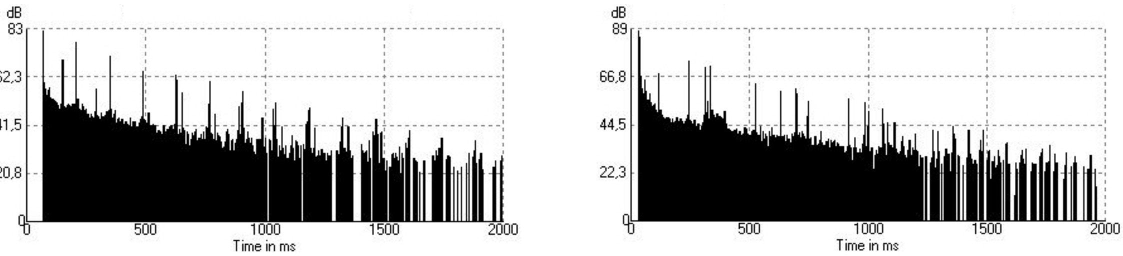


Figure 11. Echograms obtained for the M_6 point for omnidirectional sound source: a) S_1 location, b) S_2 location.

a) b)

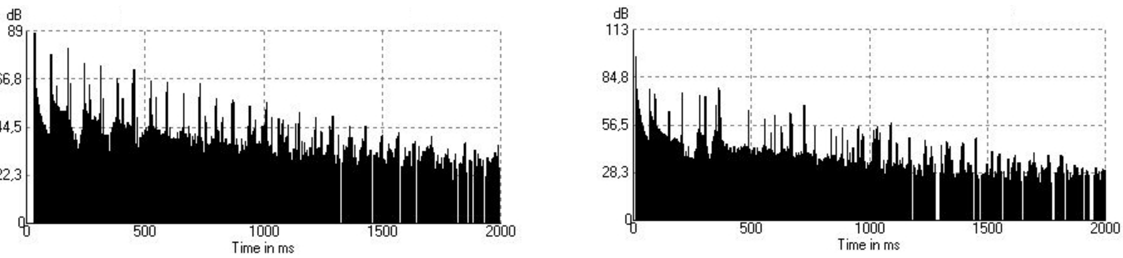


Figure 12. Echograms obtained for the M_7 point for omnidirectional sound source: a) S_1 location, b) S_2 location.

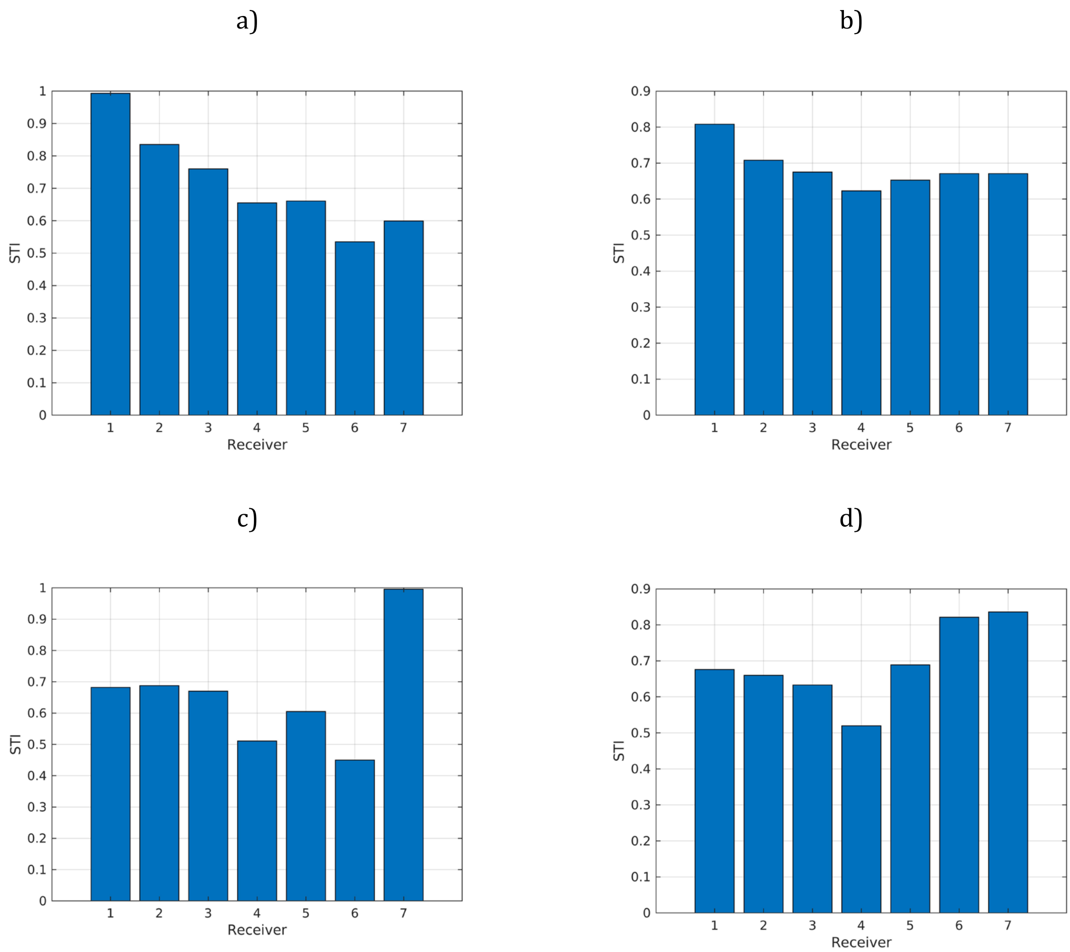


Figure 13. Diagrams of the STI values for both type and for both location of sound sources: a) directional sound source at S_1 point, b) omnidirectional sound source at S_1 point, c) directional sound source at S_2 point, d) omnidirectional sound source at S_2 point.

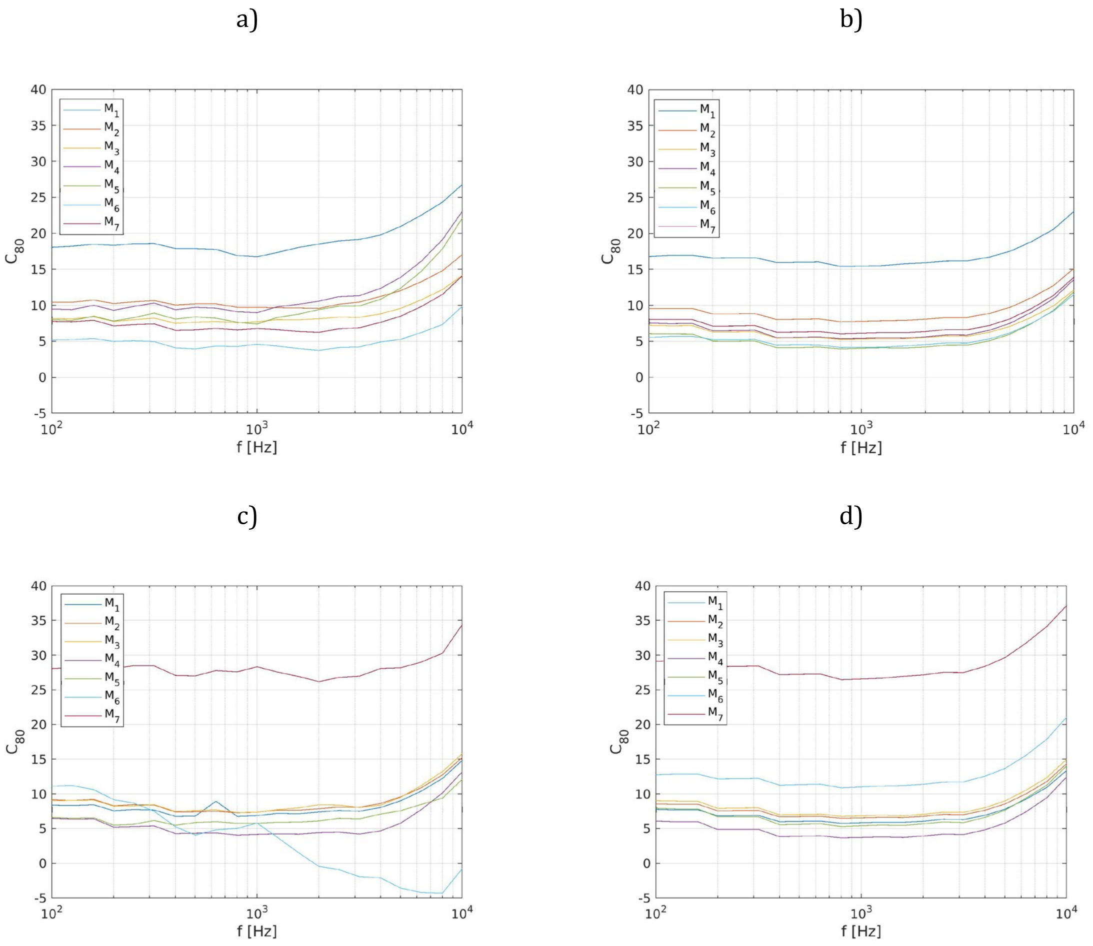


Figure 14. Diagrams of the C_{80} values in 1/3 octave band for both type and for both location of sound sources: a) directional sound source at S_1 point, b) omnidirectional sound source at S_1 point, c) directional sound source at S_2 point, d) omnidirectional sound source at S_2 point.

4. Summary and conclusions

The article presents the results of numerical analyzes of the inner area of the Goseck Circle. These analyzes were aimed at verifying the hypothesis regarding the purpose of the analyzed rondel. For this reason, the acoustic field inside the facility was analyzed in terms of both the speech intelligibility and the music signal reception.

Assessing the overall acoustic field in the facility, it can be concluded that the sound strength in the entire facility is within the range recommended by the ISO standard [20], and speech intelligibility is at "good" level. Archaeological research indicates that primitive musical instruments appeared already in the Neolithic [10,21]. These were such instruments as clay drums, vessels with rattle bases, clay rattles and bells (ceramic sonorous) also of zoomorphic shapes, bowls with small beads, etc. So, these were the instruments that generated sound by clapping or shaking. Taking into account what kind of instruments were used during the Goseck Circle's use, it can be said that this object also could created good conditions for receiving this type of music signal. This is evidenced by the values of the C_{80} parameter equal to several decibels.

The location of the sound source seems to have a significant impact on the quality of the sound field obtained in the rondel. The closer the sound source is to the center of the area, the more homogeneous the sound field. This is clearly noticeable in Figures 4 and 5. When the sound source is moved to point S_2, the area of significantly worse quality of sound appears opposite the sound source. It could be the result of the sound source moving away, of the appearance of waves reflected from the palisade located behind the sound source, or of the resonances of the object. Although this issue requires additional deeper analysis.

As a result of analyses of the inner area in more detail, at selected measurement points, it can be concluded that only for the measurement points located close to sound sources, the obtained values of acoustic parameters differ from the values obtained for the other points (point M_1 for location S_1, point M_7 for location S_2). For the remaining points, the obtained values are similar and the speech intelligibility is at "good" level. As for the obtained values, the diagrams clearly show that, every time, the lowest values are obtained for M_4 measurement point. It may be related to both the distance from the sound source (12 m), which may result in the attenuation of the sound signal coming directly from the sound source, and the distance from the palisade (also 12 m), which in turn affects the weakening of the acoustic waves reflected from the palisade related to their attenuation by the air. This is visible, for example, in Fig. 4, as a ring located in the middle of the palisade radius. However, it should be clearly emphasized that these values do not significantly differ from the other obtained values of the analyzed parameters.

The quality of the sound field in Goseck Circle was assessed based on the criteria currently applicable in room acoustics. These objective criteria are related to the subjective sound impressions of listeners in a given facility. Taking into account that the subjective impressions of sound reception have not changed significantly over the years, as evidenced by the assessments of e.g. ancient theaters, it can be assumed that sound could also have been treated in a similar way when the Goseck Circle was in use. To sum up, as a result of the analyses carried out, it can be concluded that the rondel from Goseck, called the Goseck Circle, could have performed the assumed functions, i.e. it could have been a place of political meeting, cultural meeting, and religious cult. Especially if the sound sources were located in privileged areas.

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Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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