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BIOPHILIC PATTERN AND APPEARANCE OF LEPENSKI VIR HABITATS

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ABSTRACT

Some of the best strategies for biophilic design are natural forms and patterns. Ivy (Hedera helix) is an evergreen creeping plant whose leaf was chosen as a pattern for the biophilic design of the ground plane of Lepenski Vir habitats.

Lepenski Vir is the prehistoric archaeological site on the Danube in Djerdap, Serbia (about 8,000 years old). Its discovery includes the remains of habitat floors.

This appearance of these habitats is based on the answer to the question: 'Why did they build habitats in this manner?' The sun and solar radiation are very important for understanding the purpose of the architecture of Lepenski Vir. The remains of the architecture of Lepenski Vir are the remains of the energy-efficient architecture, which the author has written about before.

In biophilic design, the golden angle of φ=137.507764…° (golden ratio in a circle) is related to the evolutionary tendency of optimal light capture for maximal photosynthetic activity. This appearance starts with an approximate golden angle construction. Finally, we get the shape of the Lepenski Vir habitat which includes a golden angle, an equilateral triangle 360 in size and a dug square – as one of the possible habitat models of Lepenski Vir.

Key words:
biophilic design, Lepenski Vir habitats, golden angle, ivy (Hedera helix)

BACKGROUND

The biophilic pattern could be the role model for one of the possible habitat models of Lepenski Vir. This paper explains the construction of that habitat model. It should be noted that this is not a reconstruction of any specific individual habitat at Lepenski Vir, but a model according to which those houses built. The final appearance of the Lepenski Vir habitat in the ending has a pyramidal shape embedded in the land.
Biophilia has recently become attractive for application in architecture. There are many definitions of biophilia, but it is certainly not just integrating plants into buildings and houses. Several strategies are paramount in biophilic design in architecture. Some of them are natural forms and natural patterns according to Brazilian architect Sami Meira. 'Hierarchically organized relationships in nature are based on the Fibonacci sequence and the golden ratio as mathematical patterns. (...) if we apply this to a circle this ratio is the golden angle (about 137.5°). This is the approximate angle in the leaves, where sunlight is most efficiently used.' [7]

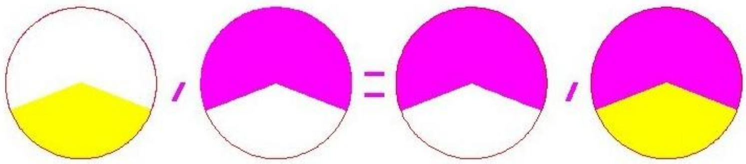

Photo 1. The golden ratio in a circle – the golden angle: φ≈137.5°

This paper shows, step by step, how it was possible to build Lepenski Vir habitats. The appearance of their habitats is based on the answer to the question: 'Why did they build habitats like that?' The sun and solar radiation are very important for understanding the purpose of the architecture of Lepenski Vir. The remains of the architecture on Lepenski Vir are the remains of energy-efficient architecture, which the author has written about before. [10]

SOMETHING ABOUT BIOPHILIA

The theory of biophilia was given by the American biologist Edward O. Wilson in the book 'Biophilia' in 1984 [16]. The idea of biophilic design in architecture arose a little earlier: according to the idea of the Serbian physicist and engineer Branko Lalović, published in Serbian in his book 'The Essential Sun' in 1982, he wrote: 'The basic priciple of passive use of solar energy is that the house is built in such a way that it behaves like a flower, like a tulip or a daisy, i.e. that it opens and turns towards the sun, when it is there, and that it is protected by closing when the external conditions are unfavorable.' [4]
The leaves are also very important. They are structured for optimal light capture for maximal photosynthetic activity due to adaptation and survival. 'Our simulations confirmed previous results by showing that the golden angle of 137.5° is indeed optimal for light capture and that morphological traits can influence the light capture curve.' [15] Also, the situation is similar with phyllotaxis: the arrangement of leaves on a stalk. 'What is the root cause of phyllotaxis? The answer is simple. It turns out that this is the type of arrangement of leaves that achieves the maximum influx of solar energy into plants.' [20]
In energy efficiency, for example, HVAC engineers estimate conduction heat loads in winter due to the influence of different intensities of solar radiation on the walls of the room, which are oriented towards individual parts of the world with the addition of Zs. [17] The angle of 135°, which includes orientation of S, SE and SW walls, has Zs =-0.05. This angle is an approximate value of the golden angle. Also, this angle was recently included in the author's project Neolepenism house [11, 12].
The leaves have eccentric design mainly due to capturing sunlight for photosynthesis. In the other hand, the sun gives light and heat from different directions. It is important for the thermal stability of the house. That is why the house should have similar design to the leaf, i.e. it should be eccentric. [9]
Ivy (Hedera helix) is the evergreen creeper plant and its leaf was chosen as a pattern for the biophilic design of the ground plane of Lepenski Vir habitats. 'In the flora of Djerdap, relics, endemic, rare and endangered dendro and zest flora varieties are of particular importance. The presence of Tertiary relics in the area of the National Park Djerdap (including ivy) indicates its characteristic relict character.' [1]

Ivy is a Tertiary relic – a survivor from the Tertiary period in geology. It is usually a hardy, sun-loving plant. It's generally considered as a weed plant. Since ivy is a weed plant, humans are familiar with its resilience and flexibility. These properties are important for adaptation and survival. When it encounters an obstacle, it crawls over it and crosses it. Ivy, as very old biological species, is constantly present in the human environment. That is why people know ivy and its property well. Ivy (as well as some other creeper plants) symbolizes fertility and eternity life in some myths and civilizations [16, 23, 25 and 26].
The sun gives us not only light, but also heat. Ivy leaves always find their way to sunlight and survive. This is the idea why the author uses ivy leaf in the construction of the habitat floors. In this appearance of Lepenski Vir habitat, the biophilic pattern and the golden angle were used in the construction, not only as a decoration, but also have a function in achieving thermal stability. An ivy leaf is presented on Photo 2. Its veins have the specific design that can serve as a pattern for the biophilic design of the ground plane of Lepenski Vir habitats. Most of the leaf faces the Sun and therefore makes the most efficient use of sunlight. If you look at Photo 2, you can recognize the golden angle (or something very close to it).

Photo 2. An ivy leaf (Hedera helix), its veins and the place of golden angle

BASIC INFORMATION ABOUT THE PREHISTORIC ARCHAEOLOGICAL SITE OF LEPENSKI VIR

Lepenski Vir was discovered in the 1960s. It's settled on the right, Serbian side of the Danube in Djerdap, 15 km upstream from Donji Milanovac or about 160 km downstream from Belgrade. Djerdap UNESCO Global Geopark, because it contains the Lepenski Vir archaeological site, is included in Global Geopark Network in 2020 [2].
The person deserving the greatest merit for the discovery of Lepenski Vir was Dragoslav Srejović, an archaeologist, whose book 'Lepenski Vir – a new prehistoric culture in the Danube region', published in 1969 by SKZ, is the main source of information about this culture [24]. The site is estimated to be about 8,000 years old.
Due to construction of the Djerdap 1 hydroelectric power plant, the original location was submerged, the level of the Danube rose by about 12 m, while the current location was moved by about 150 m, but the original position was maintained. Nowadays, Lepenski Vir is a museum, in a new location.

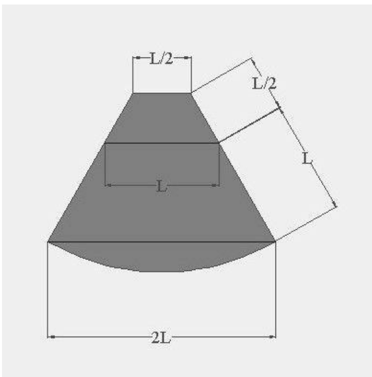

Photo 3. Basis of the Lepenski Vir habitat according to D. Srejović [24]

Only bases of the houses, made from a hardened material resembling concrete, are preserved. The hearth of stone blocks was incorporated in the floor at the entrance of the house as an active heating system. The

third dimension has not been preserved because it was constructed of perishable materials (such as wood, leather, mud…). We can only assume what those houses looked like. The architecture is characterized by houses with the base shaped like a truncated circular sector, with the convex side turned to the river, i.e. sunrise. This shape may also be called a convex trapeze (see Photo 3). The back side is significantly smaller, while the front side is shaped as a circular arch. Lateral sides are inclined. [24]
Many, including D. Srejović himself, wondered: How did these houses look in reality? Almost nobody asked: What was the point of such construction and why were these houses built like that? [10]

WHY WERE THE LEPENSKI VIR HABITATS BUILT IN THIS MANNER?

The remains of the Lepenski Vir's architecture (about 8,000 years old) indicate to recognizable measures aimed at increasing energy efficiency in buildings implemented in the design and construction of habitats and settlements at this site, which the author has written about before. [10]
In winter time, conduction heat losses were reduced by compact envelope, drying of walls and improvement of thermal insulation properties of materials used for walls by application of solar radiation, which is why favourable orientation was used. Ventilation heat losses were minimized by the favourable aerodynamic shape, orientation, and digging (in the earth). The choice of the location, steep hinterland, orientation, digging and vegetal surroundings enable pleasant living conditions in summer. Energy 'production' (heat and light gains from solar radiation) and energy 'demand' (walls need to be dried in the morning after dew) are well-aligned, which is reflected in the choice of orientation. Outside daily temperatures are the lowest before sunrise. That's why the demands for heating and drying are the greatest in the morning. Then the incidence angles from the Sun are favourable for the morning heating up. Good energy harmonization is achieved due to the predominantly eastward orientation of houses, i.e. towards the river. [10]
In this moment we should mention the words of Serbian archaeologist D. Srejović and Russian mathematician S. Kovalevskaya: 'Due to the distinct non-historical nature of the architecture of Lepenski Vir, it is tempting to explain the uniqueness of its forms by the specific features of the terrain and space, i.e. natural environment. The connection between architecture and the environment is really obvious. (…) The architecture of Lepenski Vir has something very mathematical in it, i.e. in all its forms the presence of concrete length and certain numbers (…) is felt and corresponds only with the morphology of the city of the far future (…) The architecture of Lepenski Vir just reads its environment, translates its intricate, condensed content into easy-to-understand language…' [24]. 'Note: the content, ideas and concepts are primary, and the form and formulas are secondary' [21].
The role of the Sun and solar radiation at the site is very important to understand the purpose of the architecture of Lepenski Vir. We may conclude, based on the remains of the architecture, that the purpose of such construction was to ensure comfortable conditions in them, taking into consideration energy efficiency in buildings. The remains of architecture in Lepenski Vir are the remains of an energy-efficient architecture [10].

OBJECTIVES; DESIGNING ONE OF THE POSSIBLE HABITAT MODELS OF LEPENSKI VIR

Having in mind the above, the aim is designing one of the possible habitat models of Lepenski Vir. It will be develop in several steps (phases) and starts from a horizontal base-line at the entrance with an initial measure of 360. Digging in the earth behind the base-line and backfilling in front of it are included in all steps for foundation. After building the foundation, we can continue with construction of the skeleton. Further, the methods of construction of the Lepenski Vir habitat will be presented.

METHODS; STEP 1: AN APPROXIMATE GOLDEN ANGLE CONSTRUCTION

The first step is an approximate golden angle construction. In geometry, an exact construction is not possible. However, using approximate proportions, a golden angle construction can be reported with high accuracy that is acceptable in construction of habitat.

The golden angle is $\varphi=137.507764\ldots^\circ=2.3999632\ldots$ rad.

Then the angle is: $\varphi/2=68.753882\ldots^\circ=1.199905038\ldots$ rad.

The trigonometric tangent function $\varphi/2$ is $\tan(\varphi/2)=2.5720116082\ldots$

The firstly, we can construct right-angled triangle with legs 18 and 7 which has tan (α) – the relation of opposite and adjacent leg. This number 18/7=180/70=2.5714285714… is approximate value of tan (φ/2) =2.5720116082… If we compare tangents of these angles (φ/2 and α), the relative error for tangent is 0.000226685…<0.025%=0.25‰. Recalculating this for the angles, the error is less than 0.063‰! The right-angled triangle with legs 180 and 70 contains half of golden angle with error less than 0.1‰ (See Photo 4 – red colour triangle). The golden angle was got as double right-angled triangle with legs measure 18 and 7. This construction was possible in prehistory. It's a golden angle with very high precision for building house: the error is about 0.1‰.

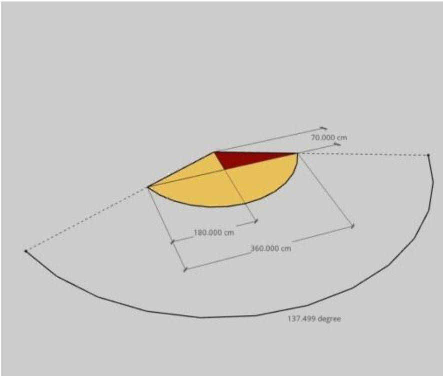

Photo 4. Step 1: An approximate golden angle construction

STEP 2: FURTHER BUILDING OF THE FOUNDATION

Now we have a base-line dimension of 360. If we dig the soil behind the base-line and fill with it in front, we can get the horizontal foundation. The arch of the golden angle is part of the front part of the basis.
The part of basis behind the base-line can be obtained if we construct equilateral triangles in two rows. The first row has equilateral triangles 180 in size; the second row there has equilateral triangles 90 in size. With such a construction, we can obtain the point of the orthocentre of a horizontal equilateral triangle measuring 360. Comparing this with the basis by D. Srejović (compare Photos 3 and 5), the front side is more convex. The construction starts from the base-line and from the inside, as D. Srejović suggested [24].

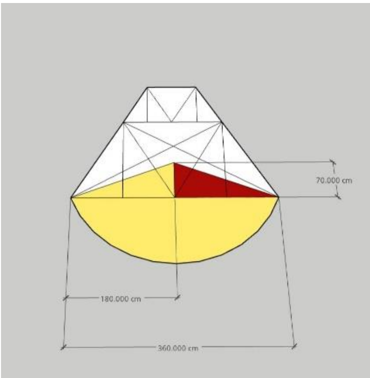

Photo 5. Step 2: Further building of the foundation

STEP 3: THE AUXILIARY VERTICAL STICK

In this moment we are ready to install the auxiliary vertical stick. It prepares the third dimension of the Lepenski Vir habitat. This step can also be done after the fourth step. The height of this stick is the height of the habitat. The bottom of the stick is in the centre of the golden angle. This stick is strictly vertical. The height of this stick is obtained so that the top of stick is also the top of inclined equilateral triangle 360 in size. This inclined equilateral triangle includes the base-line of the foundation.
The height of the stick could be calculated by applying Pythagoreans Theorem, but it could also be obtained geometrically: if the sticks of this inclined equilateral triangle 360 in size are tilted to the strictly vertical stick from the centre of the golden angle that is higher than necessary. Using Pythagorean Theorem, the height of this vertical stick is approximately 304 in dimension (exactly 303.80915…) with the relative error

of about 0.7‰ (see Photo 6). If we don't use Pythagorean Theorem, the apex is where the top of inclined equilateral triangle 360 in size touch the auxiliary vertical stick from the golden angle centre.

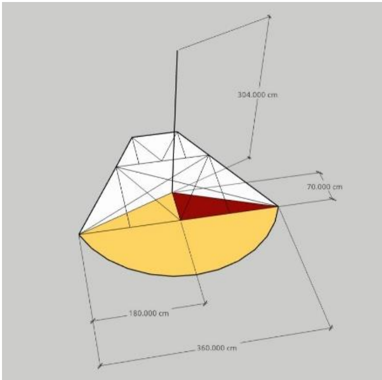

Photo 6. Step 3: The auxiliary vertical stick from the golden angle centre

STEP 4: DIGGING IN THE GROUND AND THE BACKSIDES

All steps of building the foundation of the habitat are followed by digging the earth behind the base-line and fill it in front, while the landscape and the slope of the ground are also included in this shape and appearance. The settlement has a steep hinterland.

D. Srejović stated that the back side of habitat was dug in the ground up to 1 m (the House 34, [24]). Therefore, the author assumes that the back side is an dug square 90 in size (like a quarter of 360) and that it was a part of the habitat. Photo 7 shows how the foundation is dug into the ground. The reader can see the foundation, the slope of the ground, the dug backside as a square, the place of the hearth (black colour) and the auxiliary vertical stick.

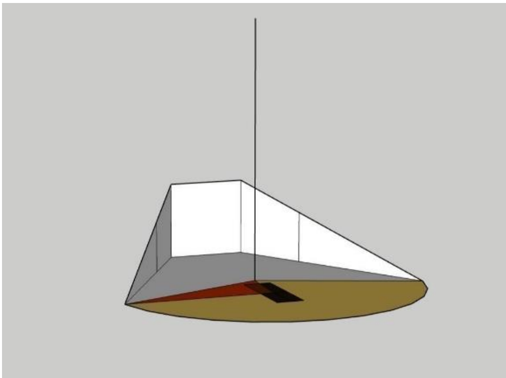

Photo 7. Step 4: Digging in the ground and the backsides

The preserved rectangled hearth is proof that the right-angled triangle was known before. Although the right-angle is not visible in the foundation of the structure of the preserved house floor, it exists in the form of a hearth. The hearth and the dug square in the background are rectangular parts of this biophilic appearance of the Lepenski Vir habitats. In this way, a square 90 in size and an equilateral triangle 360 in size, as ideal geometric figures, are included in the construction of this model. Also, measure 360 was used in geometry on Lepenski Vir.

The square 90 in size could be constructed with deviations because the Lepenski Vir site is located in a steep hinterland. Deviations are possible in the construction of individual habitats in relation to the slope of the terrain and include deviations in shape and size.

STEP 5: THE FIRST PART OF THE SKELETON

The next steps comprise construction of the third dimension of the Lepenski Vir habitat. The first next step is a skeleton construction of three sticks. The apex of that is the top of the strictly vertical stick from the golden angle centre from step 3. The two sticks 360 in size are at front and are the part of inclined equilateral triangle 360 in size that includes the base-line. The third stick has its bottom in the orthocentre of the horizontal equilateral triangle 360 in size. The orthocentre is obtained as the intersection of the heights of the already partially constructed equilateral horizontal triangle, which did not need to be constructed completely. The apex of third stick is the top of the auxiliary vertical stick (See Photos 7 and 8).

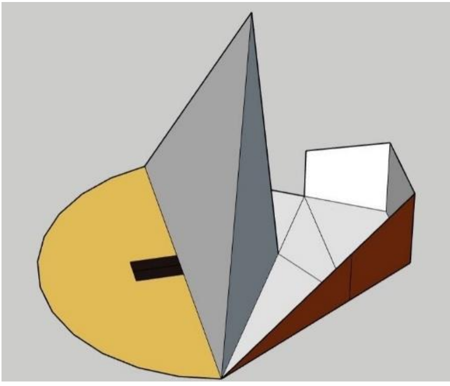

Photo 8. Step 5: The first part of the skeleton

The auxiliary vertical stick could be removed in this step after the construction of the first part of the skeleton or later, due to obtaining more free space in the interior of the habitat. This first part of the skeleton is stronger than the vertical stick skeleton. It has a pyramid shape, can hold more weights and is better from a static point of view.

Architect Predrag Pedja Ristić also had the reconstruction of the Lepenski Vir habitat [22]. His reconstruction did not include the construction of the golden angle. There is no time for further details at this point, but the construction presented in this paper is quite different.

STEP 6: THE SECOND PART OF THE SKELETON

The second part of the skeleton was made of sticks from the apex. It is the starting point for lateral edges of the pyramid-shaped skeleton. The endpoints of these lateral edges are characteristic points on the ground. That's why the back side is dug out like a square. The second part of the skeleton is behind the base-line 360 in size and contains the first part of the skeleton (See Photo 9). The front view of the second part of the skeleton is equilateral triangle 360 in size.

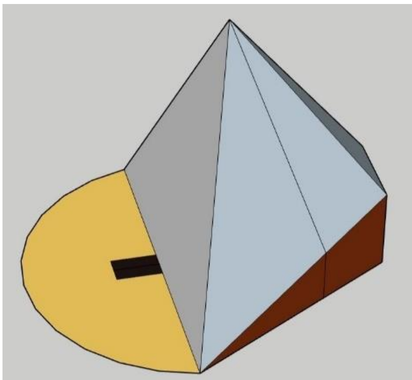

Photo 9. Step 6: The second part of the skeleton

STEP 7: THE THIRD PART OF THE SKELETON

The third part of the skeleton can be obtained by connecting the top of the habitat with the arc of the previously constructed golden angle from step 1. This top is the apex of the upright cone or pyramid.

These rods can be at 15° arc spacing. We can consider that the base-line is the diameter of the auxiliary semicircle with 180°=3x60°. After that, it is easy to construct the angles of 15°. In this way, it is possible to obtain deviations from this model which include the arc of golden angle. Also, it is possible to get a basis more similar to the basis by D. Srejović, which is less convex. The author considers that his model must include the arc of golden angle. The entrance to the habitat is 60° and it is without sticks at the entrance (See Photo 10).

Near the entrance is a place for a fireplace (black color). The hearth intersects the base-line. There is no roof over the hearth. Now, the view of front side is also pyramidal, but very close to coned form.

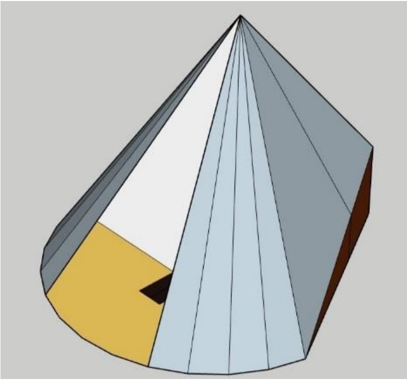

Photo 10. Step 7: The third part of the skeleton

FINDINGS; STEP 8: FINAL APPEARANCE ONE OF THE POSSIBLE HABITAT MODELS OF LEPENSKI VIR

The final appearance of Lepenski Vir habitat could be obtained by carefully removing the auxiliary vertical stick (if not removed in step 5) and the stick from the orthocentre of the unfinished horizontal equilateral triangle 360 in size (See Photos 6, 7 and 8). It enables better functionality of the hearth and increases usability of the living space.
Photos 11, 12 and 13 show the final appearance one of the possible habitat models of Lepenski Vir. The final front view is on Photo 11, the top view is on Photo 12 and the back view of Lepenski Vir habitat is on Photo 13.

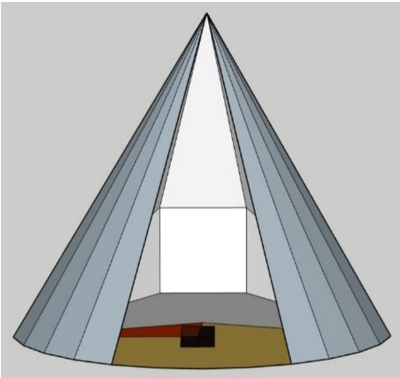

Photo 11. Step 8: The front view

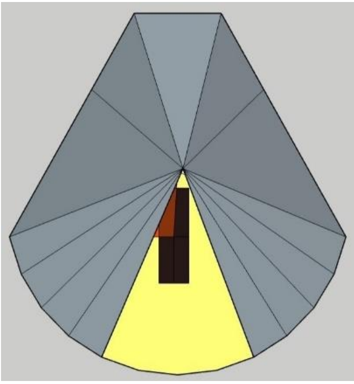

Photo 12. Step 8: The top view

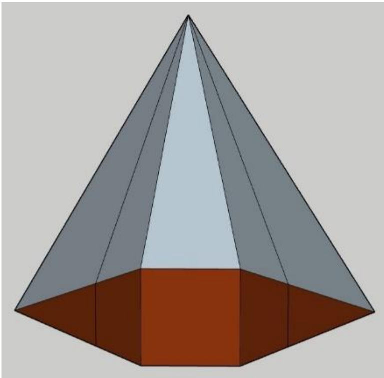

Photo 13. Step 8: The back view

The sticks in the apex can be secured with rope and netting (see Photos 14 and 15) which insure a strong construction. Photo 14 and detail of the apex on Photo 15 presents how it is possible to construct the top of the Lepenski Vir habitat. These two photos are from the National museum in Požarevac (Serbia), where archaeologist Dragan Jacanović materialized prehistoric building techniques. This construction presents the construction of a hearth in Stone Age. A similar technique could be used to constraction Lepenski Vir habitat.

Photo 14. Example: the four sticks

Photo 15. Detail of the apex

DISCUSSION; DEVIATION FROM THIS MODEL

These last two photos explain why the preserved front arc side of the Lepenski Vir habitat is less convex than the basis of D. Srejović and the model from the author. If the basis is less convex, than is easier to obtain and construct the skeleton of this habitat.
With the modified and less convex author's model, the hearth is closer to the entance and performs a better function. The hearth then works better because it uses a similar principle (as Frank Lloyd Wright) that the heater should be placed under the window. [6] This deviation allows combustion products to escape directly into the atmosphere. The dug back side increases the thermo stability of the habitat and depends on the slope and configuration of the ground.

APPROACHES OF OTHER ARCHITECTS TO THIS TOPIC

The golden ratio was known in ancient Greece. In the Second book of 'Elements' by Euclid (≈325 BC–≈265 BC) 'Continuous division' was mentioned [5]. Later, in Roman age, Vitruvius (80 BC–15 BC) used the anthropomorphic pattern in the Third book on Architecture [3, 18]. At the end of the 15th century and in the first decade of the 16th century, Luca Pacioli (1445–1517) called this relationship 'Di divina proportione' and tried to find it application in architecture. Based on this, Leonardo da Vinci (1452–1519) made a drawing of the 'Vitruvian man' at the end of the 15th century.
Andrea Palladio (1508–1580) was an Italian Renaissance architect. He wrote *The Four Books on Architecture*, published in Venice in 1570 [14]. Palladio's work, based on a detailed study of classical Roman architecture, gives the city of Vicenza (Veneto, Italy) its unique appearance and was included as the UNESCO a World Heritage site in 1994 [2]. Palladio was well known in the past by the application of the golden ratio in architecture, especially in the ratio of length to width, and he created the 'Theory of Proportion in Architecture' [13].
Very important for this topic is Frank Lloyd Wright (1867-1959), an American architect. His approach was 'Organic architecture' as a philosophy of architecture that promotes harmony between human habitation and the natural world. Wright is known for adapting the house to the natural environment. Observed from the thermal aspect of construction, the 'Solar semicircle' and 'Prairie houses' stand out from Wright's oeuvre, while a significant theoretical contribution was made by the consideration by the so-called 'Usonian houses'. [8] Frank Lloyd Wright's 20th century architecture was inscribed on the UNESCO World Heritage Site in 2019 [2]. Wright introduced to architecture the principle that heaters must be under windows [6]. A similar principle was used at Lepenski Vir that the hearth was near the entrance. In this model, there is no roof over the hearth (see Photo 12). Combustion products can go directly into the atmosphere without a chimney.
Next is Richard Buckminster Fuller (1895-1983), an American architect, mathematician and inventor. Fuller's most famous invention, the geodesic dome, is related to the field of architecture. The structure of this dome consists of triangles joined together to form a spherical shape (i.e. the shape of a ball or hemisphere). [8, 22] Fuller's certain prior knowledge of mathematics and statics, used for the geodesic dome, enables this construction of Lepenski Vir habitat.
All their approaches are important for this biophilic pattern and appearance of the Lepenski Vir habitats.

CONCLUSION

In this paper, the author presents one of the possible habitat models of Lepenski Vir as the appearance of these houses. This is not a reconstruction of a specific individual habitat of Lepenski Vir but each habitat is a variant of this model depending on the terrain configuration. The resulting appearance is based on the answers to the questions: 'What was the point of such construction and why did they build habitats like that?'
The bases of houses indicate about applied measures of energy efficiency the sense of which may be grasped only when observed within natural (geographic, meteorological, vegetal, and astronomic) surroundings. It was energy-efficient architecture, which the author has written about before. The role of the Sun and solar radiation on the site is very important to understand the purpose of the architecture of Lepenski Vir. That is the reason why the author uses the biophilic pattern and the golden angle in this construction of the Lepenski Vir habitat.
The paper further explains the importance of biophilia and the reasons for its application in architecture. The correct use of solar energy increases the thermal stability of the habitat, and the golden angle and its approximate construction are of great importance. An ivy leaf (Hedera helix) was chosen as a pattern for the biophilic design of the ground plane of Lepenski Vir habitats. The house should have a similar design to the leaf, because leaves use the solar energy for photosynthesis and phyllotaxis.

After a brief introduction to the prehistoric archaeological site of Lepenski Vir and the specific reasons why they built habitats in this manner, the author continues with proposal – step by step – how to design one of the possible habitat models of Lepenski Vir. The final appearance of this model includes a pyramidal form, a golden angle, an equilateral triangle 360 in size, a dug square 90 in size and digging in the ground. In this way, a square and an equilateral triangle, as an ideal geometric figures, are included in the construction of this model. Also, the size 360 was used in the geometry of the Lepenski Vir habitat. Materialized prehistoric construction technique in the National museum in Požarevac by D. Jacanović indicates the possiblity of such construction.
The deviation of the actual construction from this model depends on the specific location on the site. These deviations enable a better function of the hearth, greater static stability and increase the usability of the interior space.
Approaches to the architecture of Palladio, Wright, Fuller and others are important for this biophilic pattern and appearance of the Lepenski Vir habitat.
The author thinks that his model can facilitate reconstruction of these habitats in practice. Materialization of the author's model awaits its realization. The habitat envelop is assumed to be made of light materials.
The architecture of Lepenski Vir was the architecture of the golden angle. This archaeological site is very important for understanding of sustainable development on the planet in the light of energy efficiency in buildings and architecture, saving of energy from fossil fuels for heating and air conditioning of buildings, reduction of greenhouse gas emissions, and prevention of effects of climate changes and global warming in the contemporary age.

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