METHODOLOGICAL APPROACH TO THE IMPROVEMENT OF THE PROTECTIVE STRUCTURES ON ARCHAEOLOGICAL SITES MEDIANA AND DRENOVAC

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Summary: *The paper provides a multidisciplinary (archeological, architectural, structural and thermo-technical) methodological approach to improve the efficiency of protective structures from the mentioned point of view, at the locations of Mediana and Drenovac. The aim of the paper is to provide optimal architectural and structural solutions based on an analytical multidisciplinary approach related on measured micro-ambient parameters.*

Keywords: *Protection of Historical Heritage, Improvement of the efficiency of protective structures*

1. INTRODUCTION

Protective structures at archaeological sites have become necessary for the purposes of their protection, conservation and presentation of "in situ" [1]. Examples of covered sites in Serbia and experiences from the world indicate the necessity of applying contemporary structural solutions and materials. Designed as architectural structures, they unequivocally provide the protection of these sites from physical influences, unauthorized access and atmospheric precipitation. In addition to physical protection, the archeological exhibition pieces require a special attention in terms of environmental conditions to be created and managed (lighting, temperature, humidity and biological factors). Depending on the type of artifacts prevalent at the archeological sites, the optimum conditions for preservation and presentation of monuments vary. In terms of achieving micro-ambient parameters, shelters on Mediana and Drenovac do not provide acceptable conditions [2, 3, 9]. The occurrence of condensation and dripping from the roof structure endangered the artifact

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being explored (Drenovac) and those exhibited to the visitors (Mediana). Due to these extremely adverse effects, the sites were covered with geo-textile and in this way, their damage was prevented. Measurements of the temperature and humidity of the internal air, as well as of the protective structures at the Mediana near Niš [3] and Drenovac near Paraćin [9], point to the need for correction of the architectural solution of the protective structures (shelter) of those archeological sites.

The goal of the paper

The research presented in this paper deals with the occurrence of condensation which has a negative effect on the mosaics of the archeological site of Mediana and of the earthen structure of the archeological site of Drenovac. An extensive investigation was performed on the structures which are the subject of this research in order to determine the exact causes for emergence of condensation moisture. After finding the cause, location and time of emergence of the condensation, a model of architectonic – engineering upgrading is considered as a first step, as well as thermo-technical measures which can be introduced in the step two. The research results can be applicable to similar structures with the same problems.

Contemporary scientific knowledge

The condensation problem is closely related to the thermal characteristics of materials built in the bearing structure and roof covering. The problems of thermal characteristics of membranes were explored in past, but they still represent one of the topical areas for research, especially in the buildings where controlled environmental parameters are required (temperature, humidity, lighting). Kostic, Milosevic, Bogdanovic, Vasov, Vucur [4] researched the difference between the thermal behavior of single and double membranes. Rosina et al investigated the reduction of external effects using shelters [5]. The effect of shelter on the archeological excavations were explored by Stewart, Neguer and Demas [6], while Kostic and Gligorijevic [2] used the previous findings systematized in the Cetin dissertation [1].

2. CONTEMPORARY LIGHTWEIGHT PROTECTIVE STRUCTURES

There is a large number of archeological sites in Serbia (189) which were declared immovable cultural property. 10 sites were declared a cultural property of outstanding importance, and only 25 have a status of a cultural property of high importance [3]. The enclosed permanent protective structures were built only on five sites in the last ten years: Lepenski Vir near Majdanek, Sirmuim near Sremska Mitrovica, Viminacium near Kostolac, Drenovac near Paracin and Mediana near Niš [2].

The paper presents two shelters where environmental parameters were measured (temperature and humidity). In addition, they are very similar in their architectonic design. They have a cylindrical shape with a cover from a composite textile membrane.

2.1. Drenovac near Paracin

Scientific-research center for study of the Neolithic period on the Balkan peninsula was formed in Paraćin and the archeological site being systematically explored is a Neolithic settlement in „Drenovac”, and there are around a hundred other registered sites in the area of Pomoravlje area. The most interesting fact is that these settlements exhibited the oldest traces of animal husbandry and farming. The protective structure on this site was built in 2013 as arched system of glued laminated timber (span 30m, high 11m), having cylindrical form (length 40m). It is a fully closed structure with periodically small openings for longitudinal ventilation on frontal sides, covered by a PVC membrane. The basic purpose of this protective structure is a thematic research and conservation of the buildings, but it will have a touristic, educational and environmental dimension as well.


Fig. 1. Shelter on Drenovac (left), Shelter on Mediana (right)-under construction

2.2. Mediana near Nis

The ancient settlement erected near Niš is for the first time mentioned in IV century AD. It was declared an immovable cultural property of outstanding importance. The heyday of Mediana was during the reign of the emperor Constantine the Great. The settlement is famous for its residential buildings, and the complex also contains the auxiliary structures for the garrison, servants etc. The first registered data on the remains of the mosaics and buildings date back to Felix Kanitz from the end of XIX century, and the first systematic excavation began in 30’s of the XX century. The most important building on the site of Mediana is the Villa with peristyle, which was in 2014 mostly covered by a protective structure. The structural system is composed of shallow arches supported on the massive eccentric foundation blocks. The span of the structure is 72,5m and the mutual spacing of the arches is 5m. The frontal parts have the form of semi-domes with radial semi-arches. The cover is a PVC membrane with the polyester core.

3. COMFORT PARAMETERS INSIDE THE PROTECTIVE STRUCTURES ON ARCHAEOLOGICAL SITES

Protective structures should meet criteria in terms of ventilation which will prevent condensation in the October-May period and prevent overheating due to solar radiation in the May-October period, natural sunlight which does not change the solar spectrum.

The fundamental precondition for a successful presentation of excavated structures is establishing of agreeable conditions for the work on further excavations, conservation and presentation of a site, and protection from adverse weather. The necessary micro-climatic conditions under the protective structures are: (12ºC-28ºC) regarding temperature, solar radiation, relative air humidity (40%-65%), as well as minimal natural illumination of 100 lux.

The studies performed to compare the mentioned comfort parameters on the most frequently used materials and their combinations indicate the following [5]:

- The solar irradiation is identified as main cause of heating up of excavated sites in all seasons;
- The air humidity under the open structures is directly connected to the relative air humidity of the exterior, but the dew point occurs less frequently because of more equalized temperatures in the cases when double layers are implemented and solar irradiation is reduced;

4. APPLICATION OF MONITORING METHODOLOGY ON THE MEDIANA SHELTER NEAR NIS

After construction of the shelter, it was discovered that the action of adverse weather effects on the site was not entirely prevented, but only diminished. Namely, one of the problems which was not solved was wetting of the mosaics caused by water dripping from the roof, which in addition to moistening can cause a mechanical damage and salt incrustation of salt on the floor mosaics. For these reasons, in order to protect the mosaics from these “new impacts” they were covered with a protective layer of geotextile and sand, which made them inaccessible both to the visitors and to the researchers.

The cause of occurrence of moisture was investigated by the expert team from the Faculty of Civil Engineering and Architecture of Niš, starting from the preliminary assumptions on the moisture causes. The first assumption was that the condensation is caused by the structure of the arched beams, which due to the fitting technology were composed of three parts which were assembled in situ using metal plate connectors. (Figure 2.a). Metal and wood have different thermal characteristics, so it was assumed that condensation occurred on the metal surfaces of the connectors.

The third assumption on the cause of wetting is condensation on the inner surface of the membrane due to the environment conditions which are approximately the same as outside the building and to the specific thermal characteristics of the membrane. Because the shelter is open, the air temperature is quickly equalized with the membrane temperature during the night, which due to the high humidity and low morning temperatures creates conditions for condensation and wetting of the lower surface of the membrane.

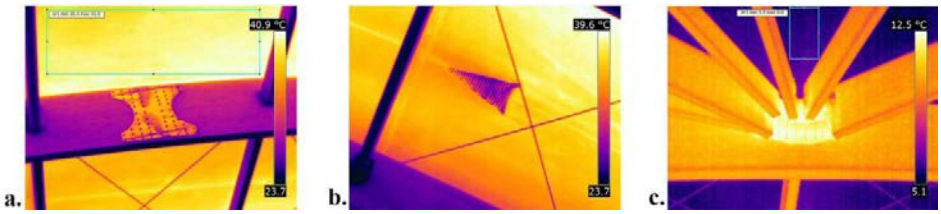

Fig. 2. a,c. GlueLam wood arches with metal connectors, b. Small vents on membrane roof

4.1. Research methodology – Monitoring

After making assumptions, the research team made an investigation plan which comprised acquisition of data on temperature and relative humidity of atmosphere, using the meteorological station WeatherUnderground I20DONJA2, and by measuring the same parameters in the shelter, using TFA Dostmann wireless 868 MHz temperature/humidity station (Fig.3.a, b) Temperature of the surfaces which were assumed to have had condensation were measured using a thermal-vision camera ThermaCam FLIR B20 (Fig.3.c, d). It was decided to perform the measuring at times of daily maximum and minimum temperatures for 10 consecutive days (16/04 to 25/04/2018). The morning measurement was performed immediately before sunrise, at the moment when the external temperatures are the lowest, and the afternoon measurement at the time of day when the temperatures were the highest. The IR camera recorded the temperatures of the wooden beam, metal connectors, vents and membrane cover (Fig.2). Measurements were taken at nine points (A1-A4 and B1-B4, C). The points where surface temperature, air temperature and humidity were measured are presented in figure 4.

Fig. 3. a. Temperature/humidity station, b. Temperature Transmitter c. ThermaCam Flir B20, d. ThermaCam table with applied settings

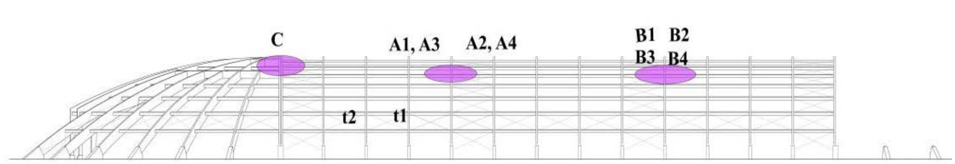

Fig. 4. Shelter cross section with measurement disposition

4.2. Measurement results and data analysis

In order to prove and disprove the assumptions, parallel temperature diagrams of structural elements were formed (Laminated wood / Metal, Membrane). Apart from the averaged surface temperatures of structural elements, also presented are the dew point temperatures Fig.5, Fig.6).

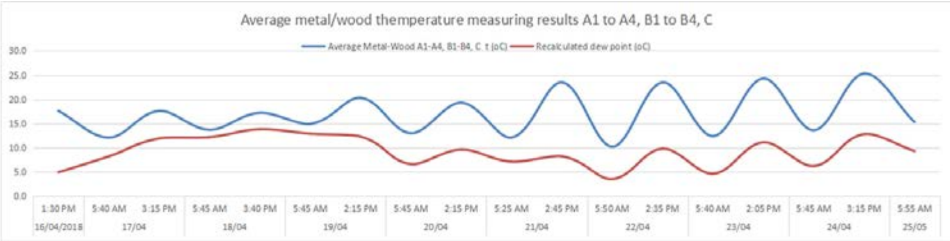

Fig. 5 Parallel average temperature diagram of structural laminated wood and metal elements and Dew point temperature (measuring positions A1 to A4, B1 to B4, C)

By analyzing the temperatures in figure 5, it becomes clear that there is no condensation due to the temperature difference between the metal connectors and wooden beams. The collected data indicate that the temperature difference between these two materials on the building is minimal and that none of them reaches the dew point, and therefore is the cause for condensation. The first assumption is for this reason rejected as incorrect.

It is noticeable that the membrane temperature has far higher amplitudes of oscillation than the external temperature. Thus, during daytime, the membrane has a far higher temperature owing to the Sun radiation in cloudless days, while at night, it cools below the external air temperature which reaches its minimum in the early morning hours before sunrise. The intersection of the Dew point and Membrane temperature diagrams is evident in the morning hours of each day when measurement was performed, which indicates that the conditions for formation of dew on the lower side of the membrane existed. The exact period when the condensation occurred cannot be determined with certainty on the basis of one morning measuring, but it is evident that dew existed for as long as imaging using ThermaCamera lasted, in the period of around 45 minutes.

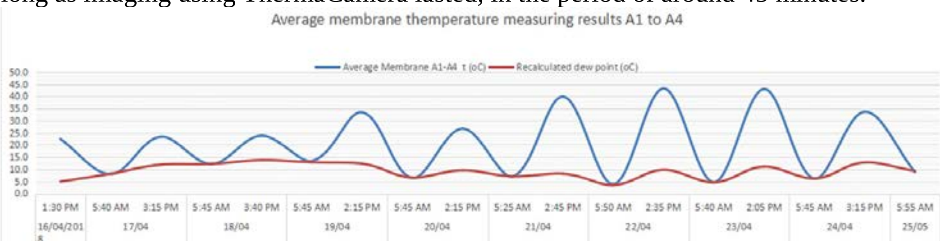

Fig. 6. Parallel average temperature diagram of structural membrane and Dew point temperature (measuring positions A1 to A4, B1-B4, C)

5. APPLICATION OF MONITORING METHODOLOGY ON THE DRENOVAC SHELTER NEAR PARACIN

At the Drenovac site, it was also perceived that the water drips from the roof, that is, from the shelter, which compromised the planned in situ conservations of the Neolithic house remains. Information on the relative humidity and temperature were acquired in order to provide data for risk assessment of material damage and efficiency of protection. The research was realized in the framework with the Archeological institute of the SANU (Serbian Academy of Science and Arts) and the Central institute for conservation on the scientific-research project “Archeology of Serbia: Cultural identity, integration factors, technological processes and the role of the central Balkan in the development of the European pre-historical period” (OI 177020). At the Drenovac site were installed the mini Data-loggers “Testo” type 174H, for continuous acquisition of data on the relative humidity and temperature, which stored the values at every hour. There were initially four instruments: one monitoring external conditions (θ_1, φ_1), then one at the present-day ground level (baseline level, θ_2, φ_2), one at the excavated level (at the depth of 2m, θ_3, φ_3) and one in the Neolithic (θ_4, φ_4). After the works were completed, the data-logger was covered with geo-textile along with the remains of the Neolithic house. The measurements were conducted in the period from 12th of November 2015, to 5th of November 2016. During November 2015, a theft of the logger no.2 was reported.

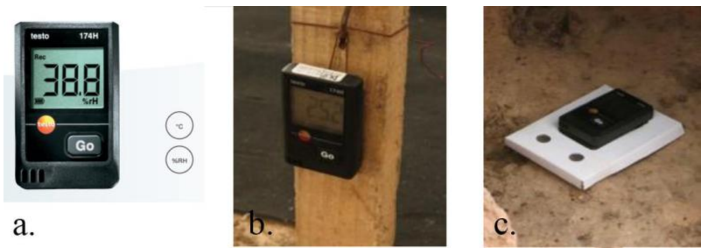

Fig. 7. Temperature/humidity station, a. Overview, b. Probe on level -2m, c. Probe in “Neolithic house” on level -2m covered by geo-textile

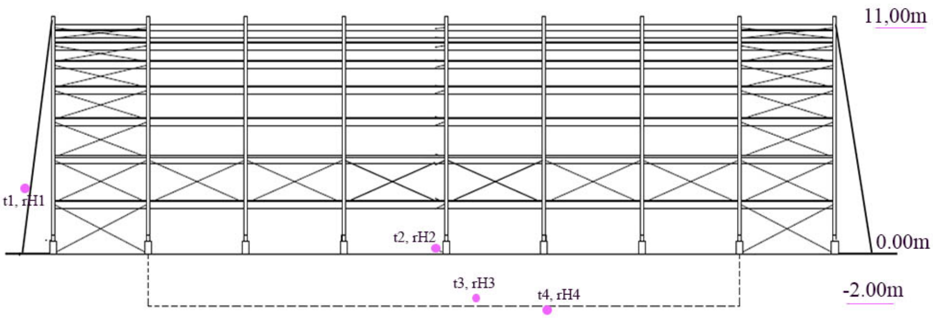

Fig. 8. Shelter cross section with measurement disposition

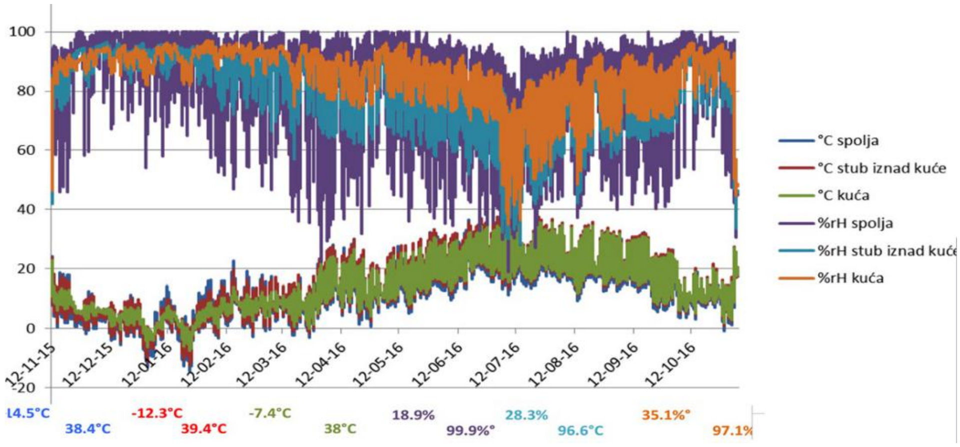

Fig. 9. Measured temperature and relative humidity in Drenovac

The analysis of the data acquired from the official site WeatherUnderground IPARAIN15 and measured values of external temperature and relative humidity have very similar values. The values of relative humidity read out inside the building are very high (exceeding 80%), and the temperatures close to the dew point. The conclusion on the emergence of condensation on the roof membrane in Drenovac is drawn based on the comparison with the known data of environmental conditions at Mediana, where it was found that for the relative humidity higher than 70% in early morning hours the conditions for reaching the dew point and condensation on the roof membrane were created. The conclusion certainty would be higher if the data on the temperature and air humidity next to the membrane were provided. In the case of the Drenovac shelter, it can be expected that the occurrence of condensation is possible during most of the daylight hours due to the higher value of relative humidity and because the structure is completely enclosed – consequently, there is no air circulation.

6. ARCHITECTURAL AND TERMO-TECHNICAL IMPROVEMENT OF THE PROTECTIVE STRUCTURES

First step for elimination of causes of deterioration due to physical action of water, chemical action of crystallization, development of biological agents which are directly related to ambient conditions is architectural correction of protective structure. An example of a successful correction is the shelter of the Viminacium mausoleum, which, 10 years after construction, due to the intensive condensation and lack of natural air circulation had to be remediated. Sections of timber beams next to the roof membrane rotted due to the increased humidity and they were replaced with new sections. The dome-like form was opened at its top to create conditions for natural air circulation and elimination of warm and humid air, and simultaneously, at the lowest points, there are openings for intake of fresh air. Opening of the top is accomplished by the positive pressure inside the shelter, while the lower opening are used for entry-exit points for tourists. The similarity of the geometrical form of the shelter in Drenovac and Mediana implies and identical correction of architectonic design, which is based on the necessity of cross-circulation of air next to the membrane, which would be accomplished by opening a skylight at the top zone of the cylindrical form, as well as with lateral – longitudinal openings at the pavement level.

Advancement of technical characteristics of sensors detecting temperature (of air and surfaces), relative air humidity, material moist, rate and direction of air circulation, illumination level, and connection of sensors to data loggers crated potential to monitor the variations of ambient parameters in real time. Measurements of individual parameters affecting the deterioration are introduced and performed continuously, at equal time intervals. (Fig.10).

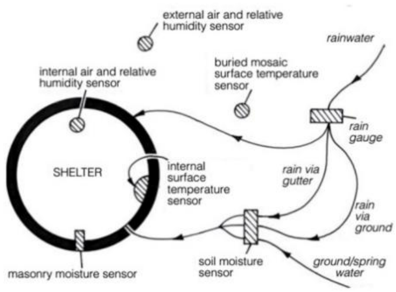

Fig. 10 Common integrated monitoring schema of ambient parameters [5]

Second step is advanced technological solutions for monitoring of selected ambient parameters, software model of analysis of acquired data in real time, and prompt action to eliminate the deleterious impacts represents a dynamical model of management of ambient conditions in enclosed protective structures.

This comprises introduction of thermo-technical solutions related to programmable logical controllers (PLC) which control the units for automatic opening/closing of the openings for natural circulation, or in the extreme cases in the winter period induction of heated air or of cooled air in summer.

7. CONCLUSION

Monitoring of ambient parameters inside shelter is necessary in order to pinpoint the mechanisms which lead to devastation of artifacts. The monitoring performed in real time, by recording of software analyzing data facilitates timely interventions which prevent adverse effects on the excavated remains. The choice of measuring instruments and their arrangement depends on the protective structure, sort of excavated remains and budget for their procurement.

Monitoring at the archeological site Mediana near Niš and Drenovac near Paraćin were performed. During the measuring period, the conditions for creation of condensation were identified in the early morning hours, before sunrise, at the relative air humidity which reached the value of around 70% at the height of 1,7m. Due to the thermal characteristics of the membrane and ambient conditions which change dynamically with the change of external parameters of temperature, humidity and pressure (open structure), the membrane temperature during night time reaches the dew point temperature, which leads to the separation of a moist film on the inner side of the membrane when the interior air humidity reaches the critical value at the measured temperature. It is clear that in the conditions of relative humidity and measured temperatures the condensation occurs.

By remodeling the existing protective structures in Drenovac and Mediana on can prevent formation of condensation on the interior surface of the roof membrane. Remodeling comprises lateral controlled technical openings for air induction, as well as the openings on the top roof zone of the shelter which would enable natural cross-circulation of air next to the roof membrane, by opening/closing. This is accomplished by a programmable controller which on the basis of the measured parameters and recalculated conditions for achieving of dew point on the membrane in the real time controls the technical system for opening/closing.

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METODOLOŠKI PRISTUP UNAPREĐENJU ZAŠTITNIH KONSTRUKCIJA ARHEOLOŠKIH LOKALITETA MEDIJANA I DRENOVAC

Резиме:
U radu je dat multidsciplinarni (arheološki, građevinsko-arhitektonski i termo-tehnički) metodološki pristup unapređenju efikasnosti zaštitnih struktura sa navedenog stanovišta, na lokalitetima Medijana i Slatina-Drenovac. Cilj rada je da se, na osnovu analitički multidisciplinarnog pristupa i merenih mikro-ambijetalnih parametara, da predlog optimalnih građevinsko-arhitektonskih rešenja ovakvih konstrukcija.

Ključne reči: *Zaštita istorijskog nasleđa, Shelter, Unapređenje efikasnosti zaštitnih konstrukcija*