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Original scientific paper

The Vaults of the Subotica Synagogue after 114 Years: Condition Assessment and Repair Recommendations

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Abstract: This paper presents an original contribution with assessment of the current state in exploitation safety and usability of thin concrete domes of the beauteous Subotica Synagogue, built in 1902. The authors are analyzing the condition of the materials used in the Subotica Synagogue, on extracted samples of concrete and steel reinforcement with a binder which was used instead of cement, a gypsum - $CaSO_4 \times 0,5H_2O$. The source of the problem, according to the author, is the lack of lime - $Ca(OH)_2$ from the mixture of gypsum and pozzolanic aggregates made of baked clay. This is the main reason for poor concrete strength of only 7.6 MPa and the present significant corrosion processes in the steel reinforcement of that concrete, which far from the recommended values of pH ≥ 12, have a measured value of only pH = 7.55. These results advise a need for repair of the part of the building that has not been analyzed or investigated yet, partially due to difficult access and also apparently good condition, since cracks, larger deformation or collapse have not appeared yet. The condensation on the domes is damaging the painted decorations with gilding which is falling and reduces the exploitation safety and the mood of the visitors and believers, who came to the synagogue. The authors are proposing a method for rehabilitation of the vaults and ribs of the beautiful Subotica Synagogue domes by simultaneously satisfying the exploitation safety and avoiding the occurrence of condensation and damaging of the painted and gilded ceilings. We believe that the article will inspire and have a positive effect in the professional and scientific society so in other synagogues in Europe and around the world the exploitation usability of vaults will be inspected and if necessary, possible repairs can be made in the same or any similar way as proposed in this scientific work.

Keywords: construction; corrosion; gypsum concrete; repair; revitalization; Synagogue

1 INTRODUCTION

The Subotica synagogue was declared to be one of "The Seven Most Endangered Cultural Monuments in 2014" by the international organization *Europa Nostra,* a movement for the safeguarding of Europe's cultural and natural heritage, on May 4, 2014 [1]. Attempts at the restoration of this exceptional structure have been going for nearly four decades. After this long period, during which many different measures and procedures for technical protection were implemented, finally there is a possibility that in the very near future work on the technical protection of the synagogue will be completed.

The synagogue was completed in 1902 according to the design of the architectural firm of Marcell Komor (*Komor Marcell*) and Dezső Jakab (*Jakab Dezső*). The project started as an entry in an open competition for the construction of the synagogue in nearby Szeged. In the Szeged competition in 1900, the entry of architect Lipot Baumhorn (*Baumhorn Lipót*) won first prize and the synagogue was completed according to Baumhorn's design. At the request of the Jewish community of Subotica the design by Marcell Komor and Dezső Jakab was executed in Subotica [2].

During World War II the Jews of Subotica, a community which numbered about 4,000 people before the war, were deported to Nazi concentration camps from where only a very small number returned.

The weakened Jewish community was not able to maintain such a large synagogue and the building started to decay. In 1975 the Regional Institute for the Protection of Cultural Monuments in Novi Sad issued a decision founding that the synagogue had the status of a cultural monument. Immediately afterwards, a committee was formed at the request of the President of the Municipal Assembly of Subotica. The committee concluded that there was significant damage to the facility and that the central part of the dome was threatening to collapse. In the same year, essential protection work was started on the facility. During 1978, a complete photogrammetric record of the exterior of the synagogue was made by the Institute for Photogrammetry of the Faculty of Geodesy of the University of Zagreb.

During the examination of the synagogue in 1979, further inclination of the wooden structure above the central dome was detected and the conclusion was made that a reconstruction was urgently needed. The same year a contract was executed stipulating that the Jewish Community permanently and irrevocably donated the synagogue as a social property to the Municipality of Subotica as the holder of rights to use and manage it.
During the 1980's and in 1981 the rehabilitation work started on the timber roof structure of the dome to raise it to the intended level and to replace the damaged structural elements [3]. Over the following years, carpentry, sheet-metal, roofing and masonry work was carried out on the restoration and reconstruction of the roof structure, including also the four smaller domes. The galvanized steel roof cladding of the main dome was replaced by copper.

Although restoration work was still ongoing on the synagogue in 1985, the building was reassigned to the temporary use of the National Theatre - Népszinház. In early 1988, associates of Intermunicipal Institute for the Protection of Cultural Monuments visited the synagogue to determine its condition. Their report stated that the National Theatre - Népszínház did not take adequate care of the entrusted building. Various kinds of unskilled work and interventions on the interior and exterior of the building permanently damaged the exceptional cultural monument. In the same year, horizontal waterproofing work on the walls was carried out and the painted decoration on the interior of the central dome was restored, as well as the damaged stained glass windows. During 1989, finishing work was carried out on the water supply, sewerage, and electrical installations in the sanitary blocks of synagogue [4]. In September of the same year, a committee of UNESCO visited the synagogue. Subsequently Samuel D. Gruber, director of the Jewish Heritage Council of the World Monuments

Watch in New York, also visited the synagogue. Since then until today, various international entities showed interest for the destiny of the Subotica synagogue.

In December 1990, the Government of the Republic of Serbia proclaimed the synagogue to be a cultural monument of great importance. In recent years, restoration work continued on certain parts of the building: the central chandelier was restored, the external fence was extended to the part of the site where the Jewish school previously stood, the sewer manholes were restored, and waterproofing and a concrete floor slab were installed in the synagogue [5]. In 1995, the civil war crisis in the former Yugoslavia caused an interruption of the work of restoration. Interest in the restoration of the synagogue still did not wane. The synagogue has been included four times on the list of 100 most endangered cultural monuments, in 1996, 2000, 2002 and 2006, by the World Monuments Watch [6]. During these years, a certain amount of financial support was also gained for continuation of the works from various international organizations. Restoration is currently in progress on the west facade. The east facade has been already restored, and now, by inclusion in the list of "The Seven Most Endangered Cultural Monuments" opportunity has appeared to finally complete the restoration. However, there are still a few open questions about the restoration. One of the problems is the restoration of the main dome and vaults made of concrete reinforced with steel Rabitz mesh[1] [7]

In this way builders of old met the requirements for concrete with steel reinforcement without the modern binder, cement. The first synagogues were built in the Middle East since the emergence of Judaism. Old synagogue-builders were building in a manner and with materials to meet the exploitation conditions of safety and living comfort of worshipers and other visitors in such facilities. Until the present day all religious buildings were constructed in a way that believers and other visitors should feel peace, tranquillity and protection in every moment of their staying in the religious facility, regardless of the season, day and night. Jews live in larger communities all over the world, in almost all continents, in Asia, Europe, America, Australia... It is very hard to apply the same style, with the same architectural and structural principles in totally different climate conditions. Therefore, construction of religious buildings should be adaptable, considering the different climatic conditions and physical laws, as natural sequence to be appreciated. Synagogues, built in Europe, specifically in Southeast Europe have problems related with durability, since these objects were poorly maintained. After the Second World War the Jewish Community was reduced in this part of Europe, as people were being killed and involuntarily or in an organized way emigrated from these areas.

The main reason some synagogues deteriorate faster, lies in the fact that they were handed over for use and taking care of them to governments. Synagogues were turned into objects for cultural events such as theatres and concert areas. In winter time, during public events, it is necessary for such areas to be warmed up.

[1] Note: The term "Rabitz" herein refers to a method of building that involes the spreading of plaster on a stretched wire-mesh surface in wall and ceiling applications (named after German builder K. Rabitz).

Synagogues and other religious buildings have been painted on the walls and ceilings. Decorations of the dome with gilding during the winter would fall off from the ceiling due to the occurrence of condensation (Fig. 1), since they were not insulated from external side as they were built according to the original architectural heritage of Synagogues from the homeland of the Jews.

Figure 1 Damage on the vaults because of condensation

Figure 2 Large cracks on the facade of religious building

Synagogues built in the Middle East did not have insulated domes or walls because there was no need for that. The temperature of outside air is always more than zero degrees and in the summer months it is even very high. During the summer high temperatures, warm air and humidity inside were raising up until the domes, which were usually 6 or more meters high. The colder air, as heavier, tends to be over the floors made of stone, thus making a pleasant feeling for believers and other visitors. Synagogues were attracting large number of their believers and other visitors because of that feeling of comfort, peace and the protection that they were providing, particularly in hot summer days. It is a completely logical conclusion. The same logical conclusion can be made with other religions and nations. A religious building with its structure, function and exploitation requirements must comply with the most stringent terms of safety, convenience and comfort of staying, peace and tranquillity. If a religious building does not meet these conditions, it will attract fewer believers and other visitors. If on an object some cracks would appear (Fig. 2), or other kind of damage, for believers such damage can be interpreted as a higher power against the religion and believers, and that should not be allowed.

All possible damage on religious sites should be repaired in the best and quickest possible way. The design and construction of new religious buildings should not be allowed to slip through even the slightest mistake, precisely from the reasons already mentioned.

2 CONSTRUCTION OF THE SUBOTICA SYNAGOGUE

2.1 Materials used in the Synagogue

The synagogue was built in a traditional way, with foundations and walls made of local materials, stone or a combination of brick and stone masonry, with a relatively weak but a flexible bonding medium, such as plaster (Fig. 3).

Vaults of synagogues were mostly made of concrete using traditional technologies. The basic and oldest binder in the history of construction is gypsum, $CaSO_4 \times 0,5H_2O$. Gypsum as a binder creates an acidic environment. Gypsum binds rapidly, much faster than today's cement. Concrete or mortar with gypsum as the binder can achieve compressive strengths from 5 MPa to 20 MPa. Since gypsum is not a hydraulic binder, it does not harden in wet conditions and is water-soluble.

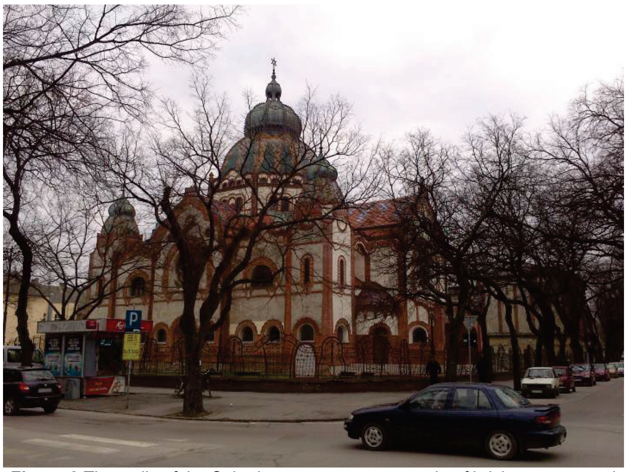

Figure 3 The walls of the Subotica synagogue are made of brick masonry and the foundations of stone

A major disadvantage of gypsum as a binder is that it is corrosive to steel. Gypsum as a binder is compatible with lime which is highly alkaline and provides an alkaline environment in concrete. The authors assume that during the casting of concrete intended to be reinforced with steel, the builders of the synagogue necessarily applied lime, $Ca(OH)_2$, in addition to gypsum in order to make the concrete more alkaline and thus avoid steel corrosion; this will not occur if the concrete alkalinity provides an environment with a pH value greater than 12. For aggregate the builders must have used inert, granular material typical for traditional concrete, such as river sand and gravel with the addition of pozzolanic materials, natural or artificial. For artificial pozzolans crushed fired clay was used (Fig. 4).

For natural pozzolans, volcanic ash, brecciated opal, diatomaceous earth, tuff and quartz sand were used. Pozzolanic materials are the oxides SiO_2, Al_2O_3, Fe_2O_3. These oxides react with the lime resulting in stable compounds: calcium silicate hydrate, calcium aluminate hydrates and hydrates of calcium ferrites. These compounds have good strength, durability and resistance because they are stable in water and in chemically aggressive environments.

Figure 4 Sample from the concrete vault of the Subotica synagogue with a coarse crushed fired clay aggregate and gypsum, which partly dissolved in water

2.2 Structure

The Subotica synagogue is the result of pioneering work by the partnership of architects Marcell Komor and Jakab Dezső. The synagogue was built in 1902 in the style of the Hungarian Secession, with rich floral ornamentation inside and outside, inspired by Hungarian folk art. Its greatest significance lies in the unique structure made of steel columns and beams supporting the vaults and domes made of concrete with steel Rabitz-mesh (Fig. 8).

Instead of the longitudinal layout used in the majority of synagogues in Central Europe, the Synagogue in Subotica was arranged on a central plan around 8 main pillars, connected at the top by steel beams, 80 cm in height, which supported an octagonal perimeter wall, forming the barrel on which the main Rabitz-dome rested (Fig. 5). Central dome has inner diameter of 14.8 meters, strengthened by external concrete ribbing 6 - 8 cm thick, arranged in the form of a star. The dome is 8 meters high and ends at the top with an octagonal opening 2.3 meters in diameter, closed with the stained glass window. The dome is also pierced with windows on two levels: on the lower level are eight large, semi-circular windows, and above them 28 small, vertical windows [8].

The main nave of the synagogue with the transept, was also vaulted with Rabitz-ceilings supported by arches made of concrete, which are in the zone of the roof also reinforced with webs. Ceilings were also protected by a wooden roof structure covered with glazed 'Zsolnay' tiles.

Four smaller towers placed above the corners house the four stairways that connect the gallery with the ground floor, creating a balance of mass emphasizing the verticals of four stairways.

As the central dome is supported by the interior columns the external walls are relieved of the load and serve only as membrane walls. The central outer dome, as well as four smaller towers was at first sheathed with galvanized iron, while the quarter-domes above the side entrances on the corners were covered with sheet lead, but during the restoration all the sheets were replaced with copper sheathing.

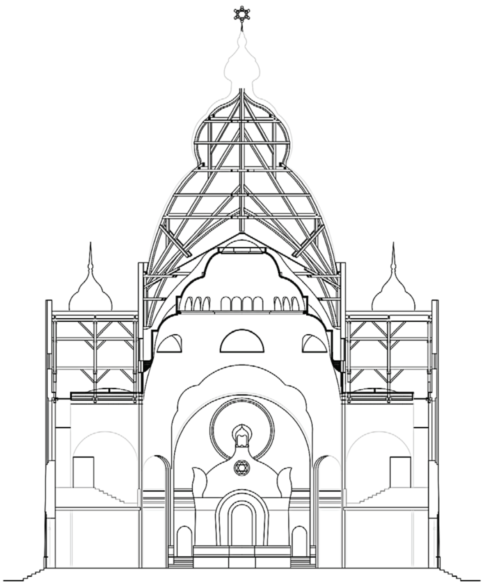

Figure 5 Cross-section of the Subotica synagogue (Source: Međuopštinski zavod za zaštitu spomenika kulture Subotica)

3 PRESENT CONDITION OF THE SUBOTICA SYNAGOGUE

As already noted, modern concrete with the kind of cement produced currently was known in 1902 when the Subotica synagogue was built. Nevertheless, the vaults of the synagogue were built in the traditional way with gypsum binder, $CaSO_4 \times 0{,}5H_2O$. The assumption of the authors is that the traditional concrete in this case was composed of gypsum in addition to lime $Ca(OH)_2$. In the chemical and mineralogical analyses, lime $Ca(OH)_2$ is practically unobservable in samples of concrete taken from the vaults of the synagogue (Fig. 6). Calcium carbonate can be seen only in small amounts. The results demonstrate the presence of gypsum $CaSO_4 \times 2H_2O$.

Concrete test samples from the vaults were analysed for pH-value in the laboratory of the Faculty of Civil Engineering in Subotica. The authors were expecting that this value will at least approximately correspond to the required standards considering that the concrete is reinforced with steel. The measured value of pH = 7.55 is not even close to the present norms for reinforced concrete, which require a pH≥12 (Fig. 7).

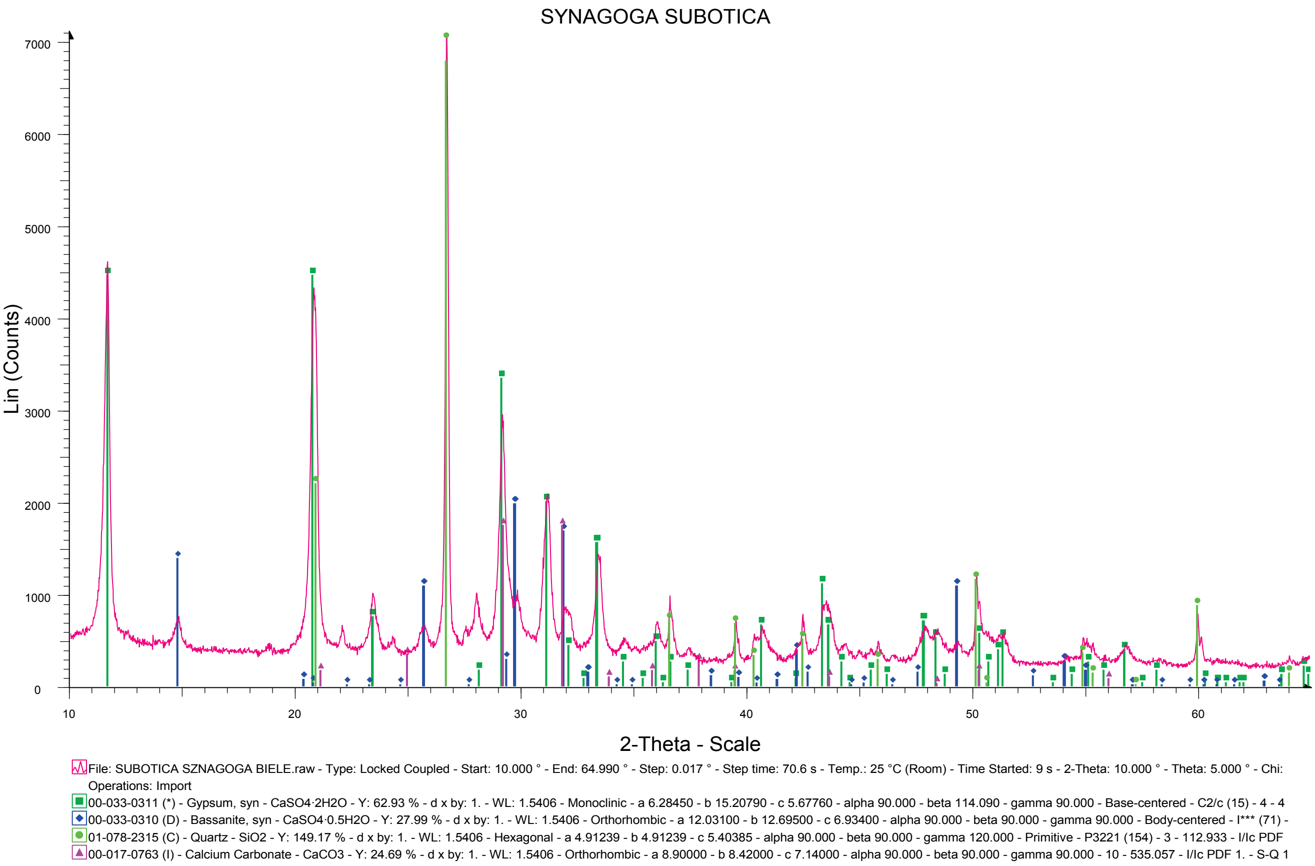

Figure 6 Chemical-mineralogical analysis of a concrete sample from the vault in the Subotica Synagogue

On a sample, obtained from the concrete vaults thin steel reinforcement wires can be seen, corroded over the past 114 years. We have measured the depth of corrosion on the steel wires, reaching 1 mm (Fig. 8).

Testing of the concrete strength on cylindrical samples obtained from the dome showed poor concrete quality with an average compressive strength of 7.6 MPa. This strength was measured on small, 50 mm diameter cylindrical cores. The results presented are not encouraging. The compressive strength of the concrete dome could have been reduced in the past 114 years. Today, we cannot say that the concrete is not good. The concrete is 114 years old and still satisfies stability. What is alarming is the corrosion of the steel in the concrete. Corrosion is clearly visible and measurable. By measuring the pH value of 7.55, we found that the concrete does not protect the steel from corrosion (Tab. 1). The authors are led to assume that some technological mistakes were made in the production of the concrete used for the dome and vaults. Lime as the binder should have been combined with gypsum, at least equal in weight with the gypsum.

Figure 7 Measuring the pH-value of a concrete sample from synagogue in Subotica

Figure 8 Corrosion of steel in concrete sample from synagogue in Subotica

The authors are intensively dealing with materials, including cement and concrete. The concrete was made with aggregate larger than 8/16 mm with pozzolanic origin, namely baked clay. That is not sufficient; the finer fractions of the aggregate should also have had pozzolanic properties. In case the mixture would contain lime, during the time elapsed there would have been a chemical reaction between $Ca(OH)_2$ and oxides (SiO_2, Al_2O_3, Fe_2O_3) from the aggregate of pozzolanic origin and that could provide a concrete strengths much greater than 20 MPa for a period of 114 years. Unfortunately, in the concrete that was used in the synagogue there is no lime, so the aforesaid chemical reactions did not happen, the concrete during the time did not receive any strength or quality and the steel in the concrete does not have adequate protection against corrosion.

Table 1 The loss of cross section due to corrosion of steel bars in concrete vaults of the synagogue in Subotica, a function of the individual rod size

Diameter (mm)	Sectional area (mm^2)	Corrosion (mm)	Reduction of area (%)
2	3,14	0,7	91,9
3	7,065	0,7	71,5
4	12,56	0,7	57,7
5	19,625	0,7	48,15
6	28,26	0,7	41,2
8	50,24	0,7	31,93
10	78,5	0,7	26,04
12	113,04	0,7	21,97
14	153,86	0,7	19,0
16	200,96	0,7	16,73
18	254,.34	0,7	14,95
20	314	0,7	13,51

Figure 9 Sampling of concrete from the dome in Subotica Synagogue

4 PROPOSAL FOR THE RESTORATION OF THE SUBOTICA SYNAGOGUE

4.1 Proposal for the Restoration of the Vaults from Structural Aspect

The vaults in the synagogue have a thickness of 8 to 10 cm and their restoration is more a secondary goal than primary. The primary goal should be the restoration of the reinforcing webs incorporated into the vaults and rising up into the attic section above the vaults (Fig. 10). The webs of the vaults have a supporting role. The degree of steel reinforcement corrosion requires that the webs be strengthened. Strengthening and repair can be carried out by repair of the webs on the vaults using concrete with a new composition, where the gypsum, $CaSO_4 \times 0,5H_2O$, binder is combined with lime, $Ca(OH)_2$, and the aggregate is a mixture of ground fired clay (The oxide composition of the material - SiO_2; Al_2O_3; Fe_2O_3) and riverbed (Danube) quartz sand SiO_2.

The proposed rehabilitation solutions need to meet the requirements of restoration. We think the option of using the improved historical concrete composition would be more suitable for at least two reasons:

- Authenticity of construction
- Easier execution, with the concrete pumped into the formwork under the roof.

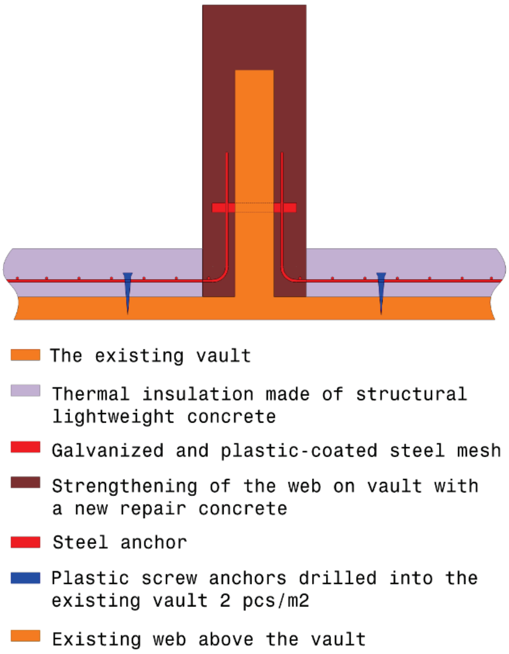

Figure 10 Repair of the webs above vaults in Subotica synagogue using traditional concrete with an improved composition

The repair would have to be solidly anchored in a layer of lightweight concrete with a set of galvanized anchors (one anchor/2 m^2). A 10 cm thick layer of lightweight concrete with a bulk density of 700 kg/m^3 would be cast over mesh reinforcement sheets mounted on the vaults from top, between the roof and vault. Lightweight concrete with galvanized and plastic-coated steel mesh reinforcement should be applied because of structural and physical- thermo dynamical reasons.

4.2 Proposal for the Restoration of the Vaults from a Thermodynamic Aspect, and to Prevent the Occurrence the Water Vapour

As we had already pointed out, synagogues in Europe with its continental climate need to be comfortable with pleasant temperatures and micro-climate in summer as in winter during religious ceremonies. Synagogues in summertime already are comfortable, but in winter they need to be heated. The vaults of the synagogue, according to the original construction, were not insulated. In winter, when warm air inside the synagogue comes into contact with the cold vault, water vapor in the air condenses and turns into water on the material of the vault. Thus a condensate is generated on the bottom side of the vaults. The condensate adversely affects the ornaments painted on the vaults. Also, the condensate droplets separate from the vault and fall on the floor or on worshipers in the synagogue. In order to avoid this, vaults of the synagogue need to be insulated in a special way, that will guarantee it will not be transformed into a "plastic bag" which would be a barrier for water vapor in the summer. A layer of special thermal insulation made of lightweight concrete should be placed over the vault with a thickness of 10 cm. The binder in the lightweight concrete should be a mixture of lime, $Ca(OH)_2$, and gypsum, $CaSO_4 \times 0{,}5H_2O$. The best and most stable aggregate for lightweight concrete from the thermal aspect would be ground expanded polystyrene, a hydrophobic material. The lightweight concrete should have a bulk density of 700 kg/m^3 with a compressive strength between 3 MPa and 5 MPa. That way the layer of lightweight concrete, with a coefficient of thermal conductivity λ = 0,1 W/mK and with ability to prevent condensation, would have a structural role also, since it would be reinforced with mild steel mesh reinforcement - as already described in section 4.1.

Summer would provide an even more pleasant microclimate inside the synagogue. Water vapor in the air beneath the vaults would diffuse into the hygroscopic concrete layer of the vault with a tendency of moving towards the outer layer, made of lightweight concrete, where it would dry with a water saturation pressure value of 0 %. The lightweight concrete would permanently dry due to high temperatures of 30 °C and over, present beneath the roof during the summer months (Fig. 11). That way the synagogue would be naturally air-conditioned over the vaults in the hot summer months. At the same time a new layer of lightweight concrete would not allow the transfer of heat from beneath the roof to the vault. At night, when the temperatures are lower, the heat from the surface layer of lightweight concrete could transfer to the air under the roof. Such heat-exchanges and releases of heat are very important in the summertime.

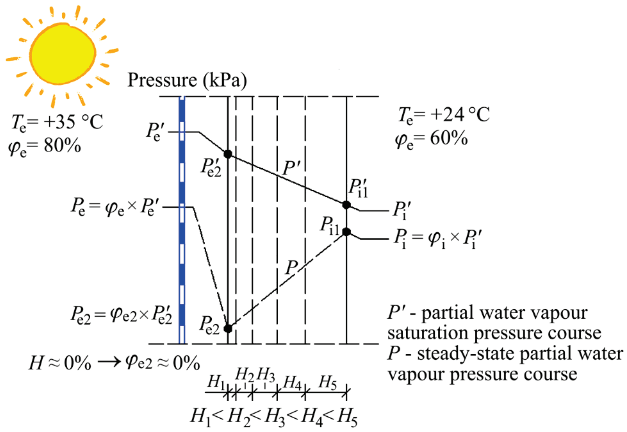

Figure 11 Summer mode of heat and water vapour exchange through vaults - a natural way of air-conditioning spaces [9]

In winter the physical phenomenon of condensation forming appears in all cases when water vapour from the warm air comes into contact with cold materials of the vaults, walls, or floor slabs. The requirement for avoiding condensation is that the structure not be cold. This means that we must prevent the cooling of material that usually happens from outside due to low temperatures. In this case, a layer of thermal insulation of lightweight concrete placed on the vaults, beneath the roof, would be enough to increase the temperature of the vault, enough to evade the appearance of condensation on the intrados of the vault. As the air humidity increases, the temperature of the material should be higher also on the intrados of the vault (Fig. 12).

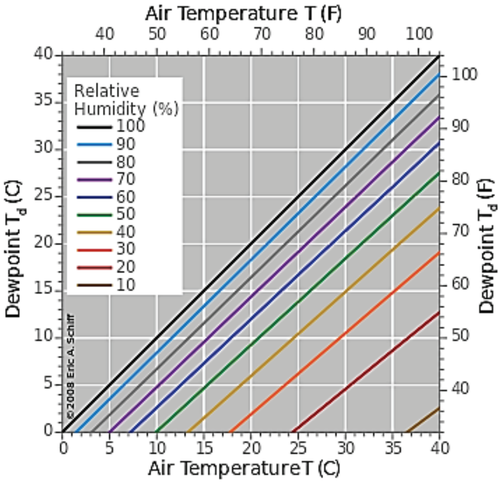

Figure 12 Relationship between the humidity and temperature of the material, as a requirement to avoid the occurrence of condensate [10]

There is a way to regulate the air humidity in winter. The present material of the vaults and the lightweight concrete that would be cast on it could absorb the moisture from the air because of its hygroscopic properties [11]. Another possibility is to cover the walls with a light plaster, where the binder would be a mixture of lime and gypsum dehydrate, $CaSO_4 \times 2H_2O$. Thus, the thermal plaster on the walls at the same time would play the role of thermal insulator and a humidity regulator in winter and summer also.

5 CONCLUSION

The paper gives an insight into the current usability of the synagogue in Subotica, built 114 years ago. As the authors, we carried out specific sampling of materials from the vaults and, based on the results of examination of physical and mechanical properties, we tried to reconstruct the technology of the construction of the concrete vaults. The results indicate that the concrete in the vaults has a relative poor quality. The examined concrete does not ensure the protection of the steel reinforcement in it. The corrosion of the steel reinforcement is visible. The synagogue has no thermal insulation in the vaults and walls. This is a big problem if the synagogue were to be put into function in winter, when heating needs to be provided, that would result in the appearance of condensate on the intrados with the adverse effect of deterioration of the ornaments on the vaults.

The authors suggest measures and methods of rehabilitation with a precise selection of materials. This paper is an introduction to the next study where a concrete with a binder mixture of lime $Ca(OH)_2$ and gypsum $CaSO_4 \times 2H_2O$ is planned to be designed and investigated. The aggregate in that new concrete would be a pozzolanic material originating from the region. The expected strength of that concrete at 28 days would be between 10 MPa and 20 MPa. During a period of several decades that concrete strength should reach a value between 40 MPa and 60 MPa.

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