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Salt Weathering on Buildings and Stone Sculptures

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The salt-damaged wall paintings in Stroeby Church, Denmark

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ABSTRACT

The medieval paintings on the chancel vault in Stroeby Church suffered severe degradation due to precipitation of salts after a period of constant heating. During a recent investigation, a novel procedure was adapted to determine the distribution of salt across the surface. Salt was extracted with wet filter paper. The electric conductivity of the paper was measured immediately after as an indication of surface salinity. The ionic content of the extract was determined in the laboratory by ion chromatography. The linear relation between conductivity and ionic content was poor, and it was not possible to correlate the salt contamination with the damage. The damage was so extensive that preventive measures were needed to stop further deterioration. A climate chamber was installed to maintain the RH in the range 60-70% all year only by passive control. The forthcoming treatment stabilizing the extensive flaking of the paint layer with synthetic adhesives requires the climate chamber to be a permanent feature in order to prevent recurring damage.

Keywords: wall paintings, salt precipitation, salt content measurements, climate chamber

1 INTRODUCTION

The lime-based paintings on the chancel vault in Stroeby Church dated to ca. 1275 are considered to be among the most heavily damaged decorations in Denmark. Massive damage from salt precipitation occurred after a prolonged period of constant heating starting a little over a decade ago. The location of the decoration on the vault, approx. seven meters above the floor makes condition monitoring difficult. The slow but steady deterioration leading to detachment and de-cohesion of the paint layer went unnoticed (or at least unreported) by the church community for several years. It was only when numerous flakes of limewash and paint started spontaneously detaching and falling to the chancel floor, leaving easily detectable losses on the surface of the vault that an alarm was raised about the obviously deteriorating condition of the painting. An investigation of the state of preservation and plan for treatment was carried out in early 2009 (Brajer 2009). The condition of the painting was so critical that the scaffold raised for the purpose of the examination was transformed into a temporary climate chamber separating the painting from the heated interior. The climate, both inside and outside the chamber, has been monitored since. During the investigation, traditional qualitative and quantitative analyses of ion presence in aqueous extractions of paint, limewash and substrate samples were supplemented with a novel non-destructive method of determining relative superficial salt distribution by measuring electrical conductivity of saline solutions absorbed into wet filter papers. The analyses concluded that both the structure and the surface of the vault were highly contaminated by soluble salts. In 2011, two years after construction of the climate chamber, the non-destructive analysis of surface salt distribution was repeated. This time quantitative and qualitative salt analyses of the filter papers were also carried out with ion chromatography. The plan for treatment calls for extensive use of synthetic adhesives to save what is left of the decoration. Given the high salt contamination and fragile condition, climate control is considered an essential part of the solution.

2 THE VAULT AND PAINTINGS

Stroeby Church was built of limestone ashlars in the Romanesque period (12th c.). Around the middle of the 13th century, the quartpartite vault on which the paintings are found was erected in the chancel using bricks, limestone ashlars, and rubble (a mixture of small limestones, granite rocks and pieces of brick). These materials were not intermixed, but laid in horizontal bands of unequal height: the lower half of the vault is constructed of limestone ashlars, a belt of rubble runs across the middle, and the vault is topped off with bricks. These three sections were laid in a circular fashion as a dome, with the brick ribs subsequently added from below, probably as a decorative element. The entire inner surface of the vault and ribs is covered with a layer of very inhomogeneous lime plaster, of varying thickness (between 3 and 10 mm). Significant for the painting's salt problems is the fact that the limestone ashlars used in the construction were presumably quarried locally from a cliff overlooking the sea. According to practice occurring as late as the early 20th century, roughly hewn blocks plunged into the shallow saltwater, where they rested until masons formed them into ashlars.

The decoration in the chancel is a result of a superimposition of paintings from two periods. A simple non-figurative embellishment of the ribs and upper part of the webs from the mid-13th century, executed directly on the vault's rendering, was augmented approx. a decade or two later when limewash was applied to the remaining surface of the webs and decorated with figurative scenes. The decoration was covered with limewash at an unspecified time after the onset of the Reformation in Denmark in 1536. The limewash crust comprising numerous historical limewashings was removed in 1920 revealing paintings, which displayed evidence of a long history of salt and moisture problems: only the depictions of scenes from Christ's Passion on the north web had survived relatively intact to the 20th century. Furthermore, the paintings continued to deteriorate in the centrally heated interior after they were uncovered (fig. 1a and 1b).

Figure 1a and 1b. Condition of the north web of the chancel vault in 1984 (a) and 2009 (b). Rectangle on 1b marks area consolidated with acrylic dispersion in 1984. Photo: Roberto Fortuna.

Among the multiple figures on the north web are contemporaneous depictions of medieval costume, and in particular, hats that identified the Jews. Despite its fragmentary condition, the vault decoration in Stroeby Church has been placed in the highest category in terms of historical and artistic value and constitutes an important object representing the cultural heritage of Denmark. The condition of the painting had deteriorated considerably by 1984, when a restoration was carried out. During the treatment, a small area with serious flaking on the one of the central figures was consolidated with Acronal® 500 D, an aqueous, unplasticized anionic dispersion of an acrylic-acid-ester-copolymer containing carboxyl groups. As this was considered to be an experimental treatment, its use was limited to about 40 cm^2 (central area on figure1b). It is currently the best preserved area on the vault.

3 INVESTIGATIONS

The goal of the 2009 investigation was to carry out a condition survey and analyses enabling a diagnosis of the problems concluding with a proposal for treatment. Mapping of the losses determined that ca. 65% of the pictorial content of the most important scene on the north web was missing (fig. 2). The scenes on the other webs are even more fragmentary. What remained of the paint layer was seriously damaged, either completely lacking cohesion or detached, kept only in place by cobwebs and dust. Although one can question whether the decoration is at all salvageable, an attempt will be made in 2012 to reattach the flaking paint. The condition of the paint layer was deemed to be so fragile that it probably cannot withstand more cycles of salt deliquescence and precipitation. Immediately after the investigation was completed, the wooden scaffolding raised for this purpose was converted into a climate chamber for the waiting period during which funds were raised for treatment. The ca. 5 cm gap between the wooden scaffolding floor and the wall was tightly plugged with rolled up bubble plastic effectively cutting the painting off from the heated interior.

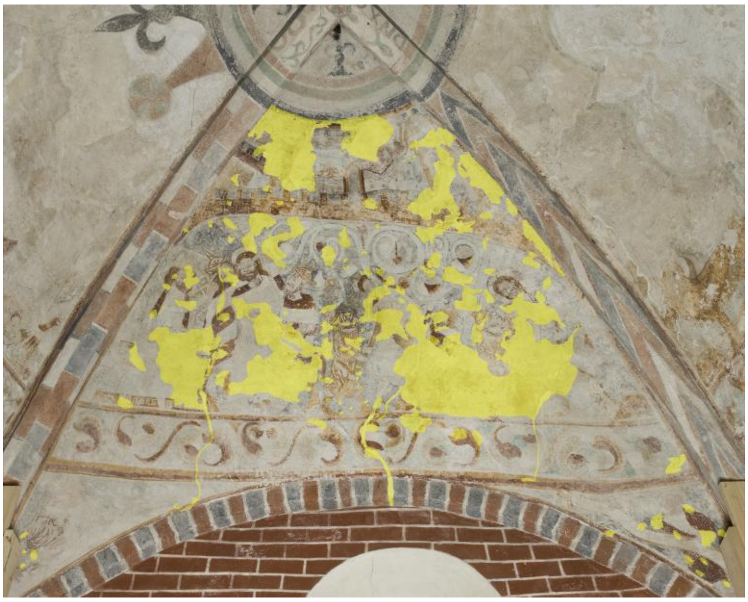

Figure 2. Areas of the north web where the pictorial substance is missing are mapped in yellow.

3.1 Salt contamination of the structure

3.1.1 Salt analysis

Twenty-four samples were extracted from various depths of the vault for analysis of the content of soluble salts. The dominant ions were sodium and chloride, and minor components were potassium and calcium, nitrate and sulphate. The range of precipitation was estimated with the ECOS-Runsalt software (fig. 3). Sodium chloride will precipitate at RH below 70%, and potassium nitrate at RH below 60%. Gypsum will always be precipitated, but will undergo a phase change to anhydrite around 60% RH. This result may not be valid, since the program does not always treat mixtures with calcium and sulphate ions correctly. Nevertheless, it seems that the safe range for RH to avoid salt precipitation is above 70%

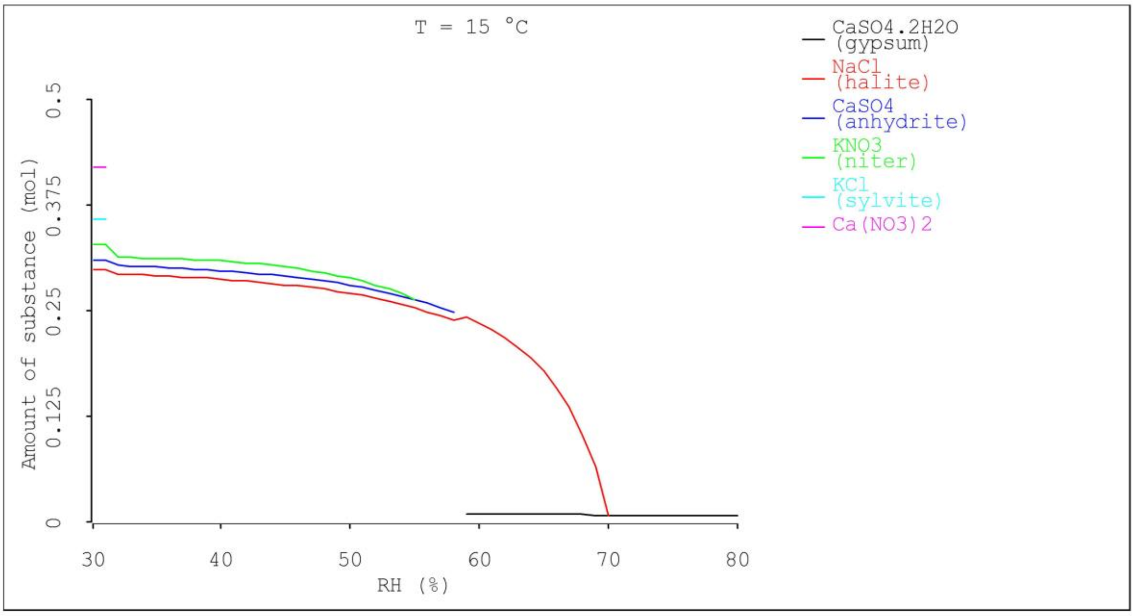

Fig. 3. Estimation of the range of precipitation for the salt mixture found in the vault. Sodium chloride is the dominant salt, which will precipitate at RH below 70%.

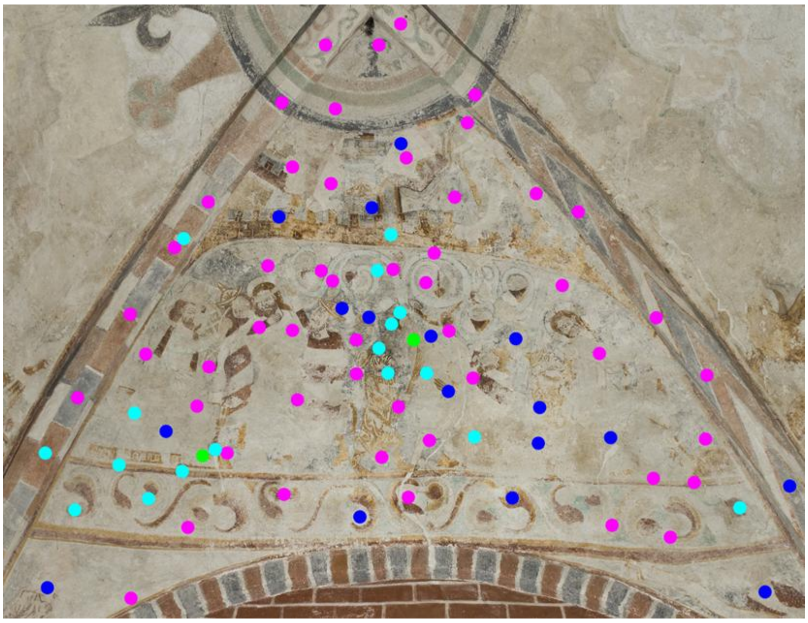

Fig. 4. Mapping of the surface salt distribution on the north web. Colour coding: pink – very low; blue – low; acqua – moderate; green – high.

3.1.2 Surface salt distribution

As part of the 2009 investigation, a novel procedure was adopted to determine the relative salt distribution on the surface of the vault by measuring the electrical conductivity of salt solutions absorbed into wet filter papers. This method was first described in the study of salt efflorescence in indigenous rock art shelters in Australia (Thorn 2008). In Stroeby, discs of filter paper (WWR, 42.5 mm, medium filtration rate) were wetted with deionized water and held to the surface of the vault for 30 seconds, immediately after which the electrical conductivity was measured by a Protimeter (GE Sensing). The individual readings were grouped into categories and mapped (Fig. 4). Distribution of salts on the surface, disappointedly, did not relate to visible damages on the painting. For example, the readings from areas where the paint layer was lost, adjacent to areas with severe flaking, were low. This may be due to the fact that detachment of paint also resulted in loss of surface salts, and gave a first indication of the limitations of the method. The high readings in the center of the web corresponded to the area consolidated with synthetic adhesive in 1984, indicating that variations in surface porosity also produce unreliable readings, which was confirmed when the method was tested again during a condition survey in Gjøl Church in 2010 (Brajer 2010).

The surface salt mapping in Stroeby was repeated after two years, in February 2011. The procedure was the same as in 2009, but the sampling positions were slightly altered to avoid the effect of surface desalination from the previous sampling. This time the filter papers were collected for salt analysis at the laboratory. The soluble anions were extracted in 10 ml distilled water and measured by ion chromatography. The total content of chloride, nitrate and sulphate is plotted against the Protimeter readings in figure 5. There is a linear correlation between the actual ionic content of the filter papers and the Protimeter readings, but the scattering is quite large. This method, therefore, does not reliably indicate surface salt contamination on the wall paintings. But the surface sampling method itself could perhaps replace destructive sampling, where pieces of mortar or scrapings are taken to the laboratory for salt analysis.

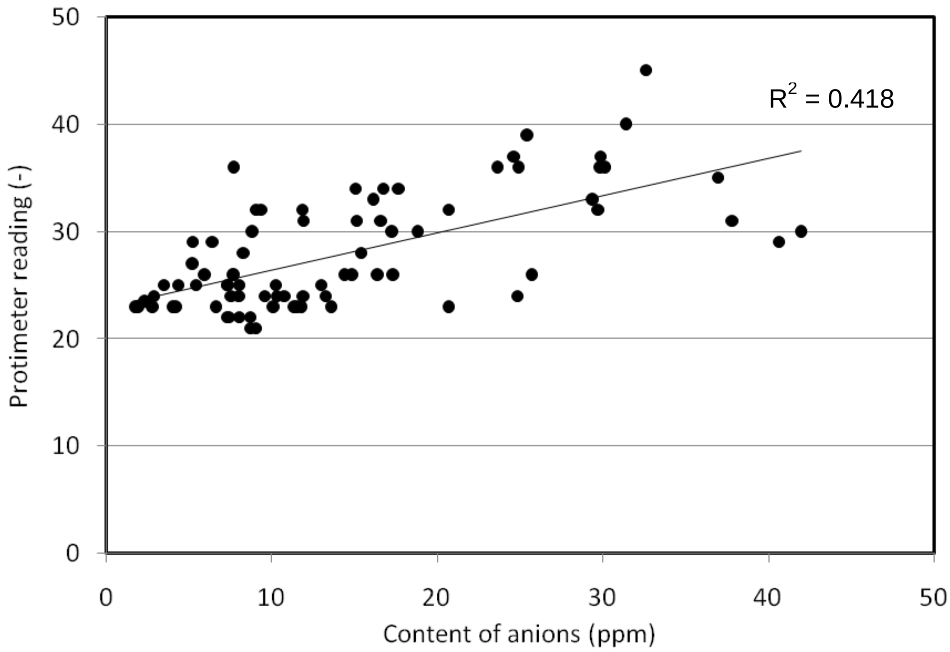

Fig. 5. Surface salt sampling on the north web. Aionic content measured by ion chromatography versus Protimeter reading.

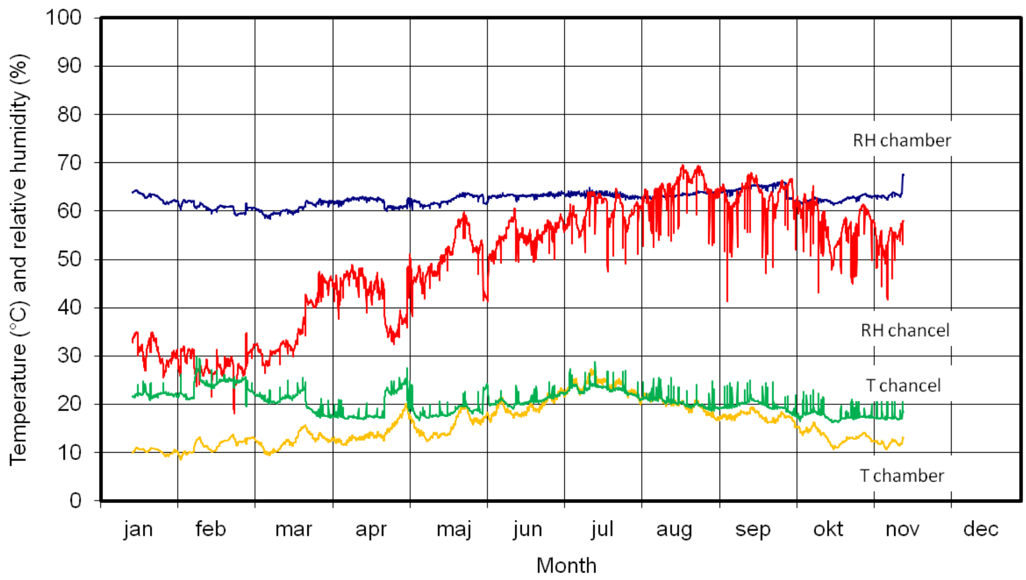

Fig. 6. Climate record from the chancel and the climate chamber for 2010. The temperature in the climate chamber was far lower than in the permanently heated church, and the RH was stable at 60% - 70%.

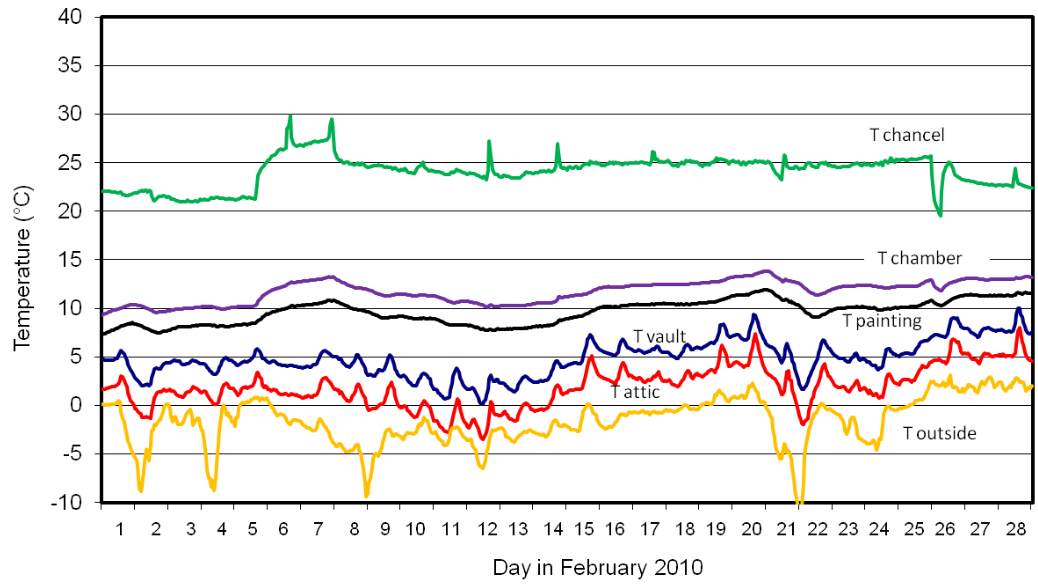

Fig. 7. Temperature record for February 2010. The temperature at the painted surface was always 2 °C lower than the temperature in the climate chamber, due to the lower temperature in the attic above. The temperature at the top side of the vault was always higher than in the attic, but experienced similar diurnal variations.

3.2 Climate measurements

A climate monitoring program was initiated as a part of the 2009 investigation. Temperature and relative humidity was measured in four positions: Outdoors, in the attic above the vault, in the climate chamber below the vault and in the chancel below the climate chamber. The sensors were Vaisala HMP35C connected to a datalogger CR10X from Campbell Scientific Ltd. Surface temperatures were measured with very thin thermocouples on the north web. The wires were gently pushed into the void between the flaking paint layer and the plaster. This way the exact temperature conditions for the paint layer was determined without any influence of radiation or convective air movements.

The climate record for one year is shown in fig. 6. The church was permanently heated all winter, which made the RH drop below 30% in February. The temperature in the climate chamber was down to 10 °C in winter, which kept the RH above 60%. The temperature behind the paint layer is shown in fig.7. The temperature followed the variations in the air temperature of the climate chamber with a difference of 2°C. It is reasonable to assume that the RH behind the paint layer was slightly higher than in the climate chamber due to the lower temperature. Nevertheless, the RH was below 70% RH, which was the limit for salt precipitation according to the ECOS-Runsalt calculation.

4 DISCUSSION

The primary aim of the preliminary investigation was to make a plan for the treatment of the paintings. The condition of the painting is too fragile for salt extraction by poultice application, at least prior to surface consolidation of micro-scaling and reattachment of flakes. The severity of the damage requires ample use of at least two different synthetic adhesives – the first applied initially as an aerosol to stabilize surface micro-scaling, and the second injected individually behind each flake in a more viscous form to re-attach the paint layer to the substrate. Although an investigation of the influence of a popular synthetic surface consolidant (Paraloid B72) on sorption and water vapour transmission has shown that relatively high solutions of 15% have surprisingly low effect (Pinchin 2000), we consider the combination of synthetic adhesive use and subsequent desalination to be an untested operation, requiring further examination. Consolidation treatment with silicic acid ester has been shown to affect subsequent desalination efforts in the crypt of St. Maria im Kapitol (Böhm & Häfner 1996), and no such testing has been carried out with acrylic polymers, which showed promising results in trials for flake attachment in Stroeby. In these drastic circumstances (referring to high fabric adulteration due to salt contamination as well as introduction of synthetic adhesives) permanent climate control is an essential element allowing for the coexistence of salts and synthetic adhesives.

The temporary climate chamber showed it was possible to control the RH between 60% and 70% all year. A similar passive climate control strategy was first successfully tested in a case study in Rørby Church (Larsen 2002). Rørby Church had intermittent heating, but this present study has now shown the benefit of an air tight enclosure also in permanently heated churches. However, in Stroeby, the temporary enclosure was not sufficiently thermally insulated to keep the temperature low enough for the RH to stay above 70%. A permanent enclosure will hopefully solve this problem as the surface separating the two temperature zones will be smaller. The chancel will be separated from the nave by erecting a glass wall with glass doors in the chancel arch, which will open only for services. This solution has provided climatic stability for salt contaminated wall paintings in Dybe since 2005 (Larsen 2007).

5 CONCLUSIONS

The combination of climatic variation and salt precipitation is widely accepted as a cause of decay to wall paintings. The investigations in Stroeby church showed that permanent heating during many years had disastrous consequences for the preservation of the wall paintings in the chancel vault. The relative humidity dropped down to 30%, which enabled the precipitation of chloride and nitrate salts from the structure resulting in massive damage. Surface sampling by wet extraction with filter papers and subsequent measuring of electrical conductivity was tested as a quick on-site procedure to replace destructive sampling for the diagnosis of salt damage on wall paintings. However, in this case, the electrical conductivity readings did not correspond to the damage observed on the painting, and furthermore poorly correlated to the actual ionic contents of the filter papers when analyzed by ion chromatography.

The study confirmed that climate control is essential for the preservation of salt contaminated wall paintings. A simple temporary climatic enclosure was sufficient to keep the temperature below 12°C in winter even though the church was permanently heated. This way the RH was kept rather constant at 60% -70%, which was much more stable than in the heated interior, but not high enough to prevent salt precipitation according to theoretical calculations. To prevent further damage after consolidating treatments with synthetic adhesives, a more effective barrier will be implemented as a permanent solution. This will hopefully help keep the temperature down and the RH up in winter, thus combining the demand for comfort in the use of the church with the need of preservation of its historical heritage.

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