# St. Petri Cathedral Schleswig: non-destructive geophysical damage analysis of medieval plaster

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**Abstract**
Non-destructive geophysical methods were applied to detect moisture at the St. Petri Cathedral in Schleswig. One of them is thermography, which allows to distinguish between intact and defective medieval plaster. Additionally, the success of a restoration can be determined by ultrasonic surface measurements.

**Keywords**
moisture detection; monitoring; non-destructive; thermography; ultrasonic

## Introduction

Historical buildings such as the St. Petri Cathedral in Schleswig (Federal State Schleswig-Holstein, Northern Germany) are considered as important cultural monuments. Many buildings of this type show serious damages due to moisture content. The application of geophysical methods such as ground penetrating radar (GPR), Infrared Thermography (IR) or Ultrasound (US) are everyday methods in the engineering geology and construction industry. There are examples for the combination of these methods for non-destructive examination of building structures (e.g. Arndt et al. 1994; Rodrígue-Abad et al. 2010; Meier et al. 2015) but it is not yet commonly applied in the field of restoration and conservation. The analysis of deeper structures is currently being carried out with drilling. Coring allows for measuring the moisture content quantitatively, it is however not non-destructive and yields only local information that is to be complemented by non-destructive testing revealing average properties of the entire structure. Here we report on geophysical investigations of altered medieval plaster in the cloister of the Cathedral in Schleswig (Fig. 1) in the framework of a project of the German Federal Foundation for the Environment (Deutsche Bundesstiftung Umwelt - DBU) entitled "Investigations on transformation, mobilization and recrystallization of gypsum on heavily salt-loaded surface of important wall paintings using the Schwahl of St. Petri Cathedral in Schleswig" (Stahlbuhk 2019; Meier et al. 2019). In cooperation with the "Werkstatt für Kunst und Denkmalpflege Kiel" geophysical investigations with ultrasound surface measurements and thermography were carried out in September and October 2017.

The cathedral was built at the beginning of the 13th century and houses early gothic paintings in the cloister (called Schwahl). One reason for the gypsum crystallization could be moisture content in the walls. The following measurements were carried out: Ultrasound surface wave measurements, passive and active IR and GPR.

## Materials and methods

The idea of combining more than two non-invasive geophysical methods to characterize masonry structures exist since the early 1990s. The federal office for material research and testing (so-called BAM) started in 1994 first tests to characterize moisture with non-invasive methods. According to Arndt et al. (1994) they could confirm that a characterization of moisture is basically possible, for

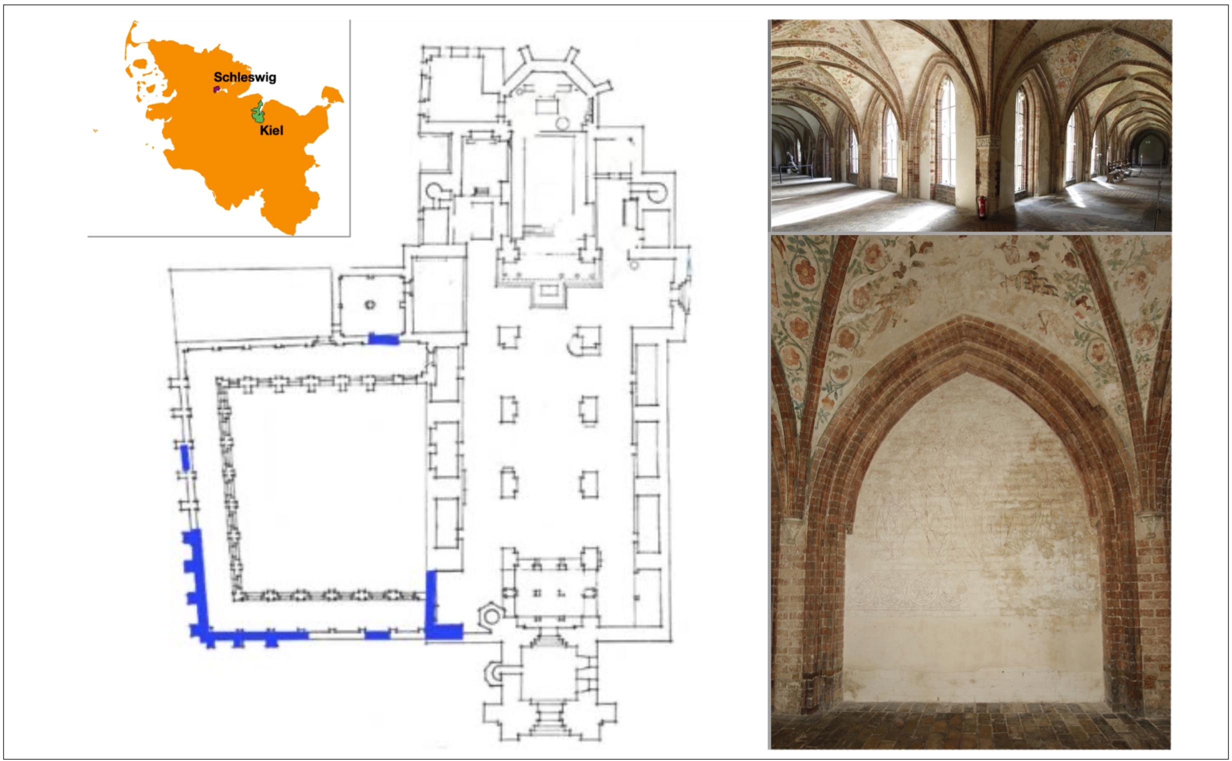


**Fig. 1:** Left: Site plan. Marked in blue are the areas that were measured. Top left: Overview Location. Marked in purple is the city of Schleswig in the state of Schleswig-Holstein, where the church is located. Top right: View into the cloister. Bottom right: Medieval wall paintings with plaster deposits. Photo: D. Schulte-Kortnack.

example, with electromagnetic waves. The success depends among other things on the influence of the salt and moisture content. For these investigations we combined infrared thermography (Fig. 2, left) and ultrasound measurements (Fig. 2, right). Infrared Thermography can give a precise overview of the areal distribution of moisture. Therefore, the investigation of the surface temperature is carried out with a thermal imaging camera from the company InfraTec GmbH. The spectral range lies in between 7.5 and 14 µm. Temperatures can be measured between -40 °C and 2000 °C with an absolute measuring accuracy of 1.5 °C and resolved with a pixel-to-pixel relative resolution of approx. 0.03 K (InfraTec-GmbH 2015). The method can be applied in two different modes. The first one is called passive thermography. It is based on the detection of natural surface temperature variations over a pre-defined time period. The second type is called active thermography. Through controlled heating with infrared heating lamps up to 2 K over a period of 5 minutes and the recording of the cooling phase over 45 minutes after switching off the heat source, a temporal spatial analysis of the measuring surface can be carried out. To get more information about the near surface properties under the plaster ultrasonic surface measurements along profiles were carried out. For this purpose, we used equipment from the manufacturer Geotron. Measuring a profile is possible by using a manual coupling device with a receiver and a transmitter. The transmitter is fixed and the receiver is offset in 1 cm increments from 5 cm to 20 cm resulting in 16 measurements per profile. The frequency range lies in between 10 kHz to 300 kHz. The sampling frequency is at 5 MHz.

## Results

Passive measurements on yoke 5 indicate a defect at the horizontal barrier on the lower right side, which can be identified due to low temperatures above the barrier (Fig. 3b). It also shows temperature differences in the area of the plaster above the barrier (Fig. 3b). The original medieval upper part shows higher temperatures than the lower younger part in the middle. Active measurements in a small part on the right side of yoke 5 were made on so-called test surfaces (Fig. 3, white box in a, c, d). Subsequently,

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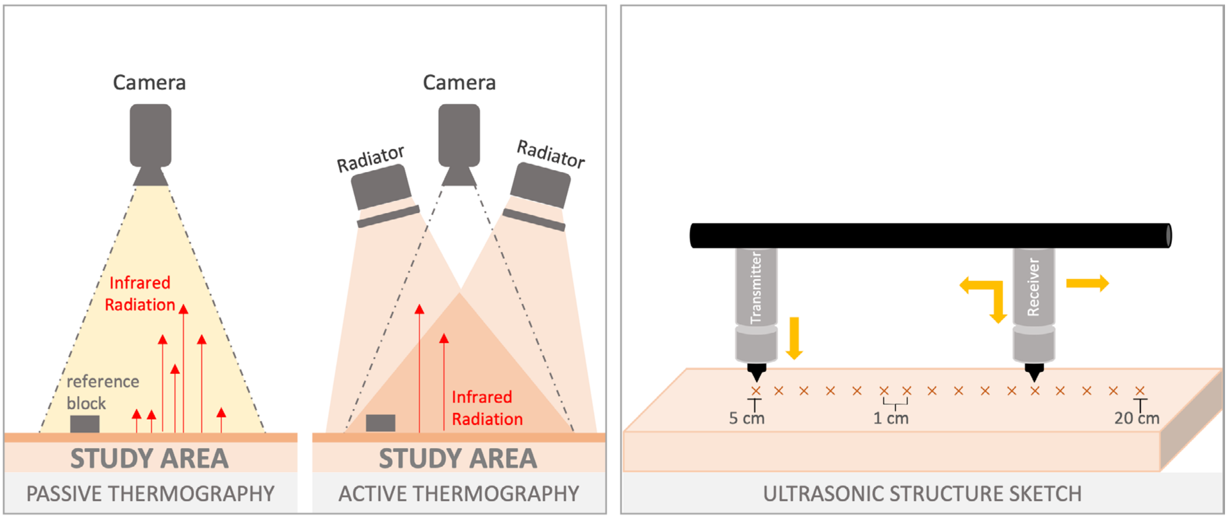


**Fig. 2:** Structure Sketches. Left: Passive and active thermography with camera, reference block and Radiator. Right: Ultrasonic measuring device with transmitter and receiver position. Crosses mark the measuring points.

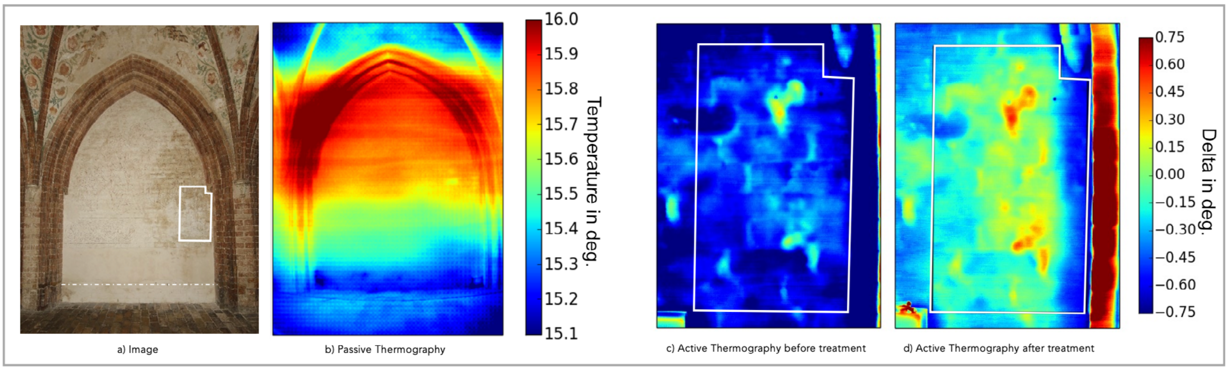


**Fig. 3:** a) Photographic Image of yoke 5 in the cloister. Dark discolorations show deposits due to moisture. The white square shows the area with test treatments. The horizontal barrier is marked by the dashed horizontal line. b) Passive Thermography – Average temperature over about 2000 images. Red colors are warm, blue colors are cool. Visible is a defect of the horizontal barrier on the right side. c): Active Thermography before treatment: Temperature difference to the reference block Immediately after the switching off the radiators in September. d) Active Thermography after treatment: Temperature difference to the reference block in October. Detachments increase the temperature. Cooling is significantly slowed down.

various solvent compresses were applied to reduce the deposit. The measurements were repeated after treatments in test areas to see what effects the different solvents had on the properties of the plaster. Due to successful treatments the porosity is increasing. This leads to a reduction of heat conduction detectable by slower cooling and larger temperatures after active heating (Fig. 3d). Our results show that specially a defect horizontal barrier at section 5 in the cloister could be responsible for moisture ingress. Changes in the plaster due to successful treatment can also be detected by ultrasonic surface measurements (Meier 2019). Damaged plaster with gypsum inclusions leads to higher Rayleigh-wave velocities and decreased scattering of Rayleigh waves. A reduction of the Rayleigh-wave velocity and increased scattering are indications for successful treatments.

## Conclusion

Passive thermography as non-destructive method is appropriate to get a fast and informative overview on damages and moisture at the surface of objects. Results of active thermography show that defect plaster cools down faster than intact medieval plaster. Also, ultrasonic surface measurements can be used for quantifying the plaster conditions. On damaged plaster Rayleigh wave velocities are around 2000 m/s. The average velocity of intact plaster is about 1000 m/s and the waveforms show a higher complexity due to scattering. In conclusion, both measurement methods are useful for the non-destructive analysis of near-surface material properties of plaster.

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