Raphael Project

Analysis, Protection and Preservation of Medieval Wallpaintings.

Historical wallpaintings have always been a connecting link between the nations of Europe. They bear eloquent witness to their time of origin and reflect the cultural developments over the course of time. Nevertheless, paintings which have been preserved in their original state, are hard to come by and therefore are highly regarded in Europe's cultural heritage.

A Raphael-Project financed by the European commission is developing innovative preservation strategies combined with an extensive information network.

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Raphael-Project

Analysis, Protection, and Preservation of Medieval Wallpaintings

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Britsum Church (Netherlands)

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Raphael Project

An important goal of this Raphael project is the development and application of methods for cooperation. The innovation of the project consists in the creation of a close network of research in different countries and institutions to improve restorations that means to intensify cooperation through learning by doing.

On the other hand a practise-oriented system of documentation is planed in Raphael. It should use standard software products as innovative tool.
It must be stressed that conservation documentation must be an integral part of a (conventional and/or computer aided) conservation system whose guide lines are ISO 9001 / EN 29001 and VDI 3798.

The definition for conservation documentation in Raphael is: the systematic collection, structuring and creation of access to data and documents from anamnesis, diagnosis and therapy to monitoring and quality control in a multitemporal cyclical process.

The application of the different tools for conservation documentation (conventional and / or computer aided) depends of the specific requirements of the treatment. Thereby heterogeneous informations must be understood, evaluted, networked and interpreted. They must then be converted into a therapy concept.

The most important support information for the Raphael system is:
- Visual information (that means photos existing schemes, mapping, and so on)
- Textual information (for construction, for wall paintings, for phenomenal mapping and for analysis data)
- Analysis data.

The problem that exists with these numerous information sources is that the relationships between the sources need to be configured and networked so that vast interaction is made possible:
- Interaction between the information sources
- Exact position of the information sources
- The information sources dependance on the time factor.

The conservation of wall-paintings is a never ending cyclical process. Each single stage must be related to the existing steps which were taken and the time continuum between them also has to be compared. The most important phases (Analysis, Diagnosis, Therapy, Monitoring/Quality Control) lead to the formation of new conservation procedures.

A tightly scheduled interative process should be made possible. Therefore effective links between the different information sources such as mapping, textual information and photos must be be created in Raphael.
With this conservation documentation system to be evaluated, the specific information sources could be able to specify the damage potential of the wall-paintings in Tirsted, Britsum and Königslutter as pilot objects.

In addition to these conservation evaluation plans a multi-disciplinary evaluation of art history is anticipated:

Traditionally the work with wall paintings has beed divided between historians, art historians and conservators. The new electronic possibilities would create opportunities of cooperation with the result that each part will have access to new and important information. So the creation of new electronis tools to combine the different resarch interests is necessary.
The creation of a common database could entail many opportunities of: cooperation between different partners - fascilitating monitoring and restauration of the wall paintings - inspiration and invitation to other similar institutions to join and cooperate. So the creation of a common database will result in better efficiency and economic utilization.
It is the intention by this pilot project to show possibilities of multi institutional and multi professional and technical cooperation. The project will result in the creation of a common server with connected cd-rom's (subject to the development of the electronic standards). It should be a starting point of a continuing elaboration and expansion of the common server and the common electronic productions. It is not intended only to be a working tool for the participating institutions. It can be used by other institutions and persons and they can participate with their results of research in the paintings and the conservation of them.
Being presented on the Internet it will be an open and democratic structure of information to people and institutions all over the world as well as a workable tool to the participating partners. The cd-rom productions are necessary in order to present images of high resolution.

The pilot project will create a platform for future cooperation including other conservation institutes and research departments first of all in nothern Europe but ideally in all European countries. It could be a starting point of a growing multinational and institutional cooperation that deals with the uncovering, preservation, monitoring, registration, interpretation and presentation of one of the most important subjects of the cultural heritage from the European Middle Ages.

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Raphael Project

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Information System – Preliminary Steps by 3D-Visualisation Tests

Within the Raphael Project, a HUBAU-document (an exact planning and financing instrument) was planned for the restoration project of the wall paintings in the church in Königslutter. This document was created both for the wall paintings and the architectural structure surrounding them. A co-operation with the Department of Geodesy at the Ruhr-Universität in Bochum, headed by Prof. Ing. Scherer, that had started with the documentation of the country parish church in Stiepel was resumed with the works on the Kaiserdom.

In this context, optimal procedures for creating an automated building survey system were tested and further developed. Missing parts of the building in the subject maps could be measured and incorporated. First, actual comparisons could be done on location. As a result, there are floor maps for the Kaiserdom on entrance and clerestory levels, as well as the roof truss. Additionally, the church was charted in all four elevations, and sectional views were carried out along the length, through the nave and lateral naves, as well as the transepts and the westwork. In the transept new technologies of laser scanning were tested to visualise the building and its wall paintings in a comprehensible three dimensional form.

Intensive talks with the former supervisor responsible for the extensive reconstruction measures at the Kaiserdom in the mid-1970s answered many questions regarding the development of damage and the restoration, especially concerning the wall paintings. He provided us with numerous documents from the time of his activity. The fact that these documents had no longer been available to those in charge of the monument now, and that knowledge acquired during the restoration as well as the precise details of the measures taken then were temporarily lost, once more illustrates the urgent need for prioritising a structured and comprehensive information system with suitable visualisations.

Numerous areas inside the church show signs of a failing roof drainage system. Humidity problems are appearing in the inner parts of the building influencing the important wall paintings. In order to examine the capacity of the roof gutters, model calculations based on the survey data have been carried out.

A 3D model was also created in Tirsted Church. A large amount of scientific data pertaining to the conservation of the wall paintings in Tirsted Church had been collected in the course of the Raphael Project. In the present situation, it is difficult to project this data in a visually comprehensible form. Therefore, it was very important to expand the plan for scientific consultation to also include the provision of a three-dimensional form for documentation. A surveying company (Mads H. Boll Landsinspektorfirma), which specialises in the creation of three-dimensional digital images, provided a ground image on which the scientific data pertaining to salt treatment and moisture movement can be plotted. This tool will also be of enormous benefit to graphically document information pertaining to other aspects of the conservation project, such as the location of original material vs. plaster reparations and reconstructions. This way, a true representation of the situation in Tirsted Church will be possible, and a link will be provided to the detailed mapping that is being carried out on the particular scenes.

This pilot project provided the Raphael Project with initial knowledge about the spatial classification of heterogeneous data belonging to an object. The spatial classification of data with statistical evaluations is needed as a basic for a monitoring system. Furthermore, a three dimensional representation of the surface of an object could provide an economic basis for the rectification and mosaicing of monitoring images.

Critical evaluation

One of the long-term goals of mapping is the introduction of a third dimension, which could detect and monitor changes in the architectural structure. This has been included in the general requirements for the establishment of a data acquisition system. While the practical work of mapping in a 2D system is a question of training and experience, and can be seen as part of the work of a conservator expert in computerised documentation, the specific knowledge needed to produce and work with 3D images requires special skills, such as those of surveyors, civil engineers and architects. The surveyors have to make the measurements, the CAD specialists have to manage the 3D data, have to prepare the 2D planes needed to make the mapping, and finally, have to incorporate the additional information provided by the conservator into the complete 3D system. What is needed is a software tool for interpretation of the 3D data, which will allow the conservator to formulate questions in

order to extract useful information.

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Monitoring Systems

Introduction

Wall paintings are sensitive, complex systems, which can react abruptly or slowly to changes in the environment. In order to determine the degree of change that necessitates active intervention on the part of the restorer the continuous monitoring of the paintings and their surroundings is indispensable. In the past changes taking place on the paintings were evaluated with the help of manual procedures, such as visual observations or percussion tests. Data collected in this manner were presented in a written report, or documented graphically. The main drawback of these procedures was the introduction of an element of subjectivity by the person interpreting the data. This weakness in the data acquisition system could lead to radically different evaluations, and it was necessary to accept a large tolerance field in order to document alterations. Standardised monitoring systems similar to those established for the protection of environment are proposed for use as a condition control in the protection and care of objects of cultural heritage.

The following main requirements are necessary for the establishment of a data acquisition system:

- the method must be clearly reproducible
- the procedure must not have any time limitations
- data collection and registration can be carried out continuously or cyclically
- there is a clearly defined data structure

The requirements for a system monitoring of wall paintings, in particular, requires the detection of the following phenomena:

- visual alteration of the surface (soiling, discoloration, lacunas, poor adhesion, poor cohesion)
- alteration of sub-surface adhesion (voids, cavities, interlaminal and intralaminal separation)
- 3D movements of the paint and ground layer (vibrations, salt efflorescence)
- changes in the climate triggering possible alteration processes (temperature, humidity)
- changes in the architectural structure

Within the framework of the Raphael project an interdisciplinary evaluation of various measurement procedures was carried out. The methods tested form a part of a monitoring system which fulfils the general requirements of a data acquisition system, and permits the detection of selected phenomena on wall paintings:

- multi-spectral imaging and analysis
- coherent optical measurements (video holography, vibration measurements, correlation measurements)
- thermohygric and climatological measurements

These methods had significant advantages, as they are non-destructive, require no surface contact, do not require the erection of costly scaffolding, and are partially automated, which saves time and money. The initial results are presented in the following reports. The findings are being analysed and evaluated by the working groups participating in the Raphael project.

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Monitoring Systems

Multi-spectral (multi-band) Analysis

Introduction

Multi-spectral analysis within remote sensing techniques for describing the earth surface has been particularly developed and extensively applied in the field of evaluation of aerial characteristics and land exploitation. A comparable application used in close range for the description of architectural surfaces is still not available as a tool, but is a target of actual research projects.

In the past, different research projects carried out by the German Mining Museum in co-operation with the Office for the Care of Cultural Heritage in Lower Saxony applied the basic techniques of multi-spectral analysis for the documentation and monitoring of wall paintings. The practical applications of multi-spectral analysis were discussed within the framework of the Raphael Project. The basis for the application of multi-spectral analysis was the fact that all partners agreed on the use of photographic techniques for documentation of wall paintings. Normal photographic techniques for documentation of wall paintings are a standard procedure in the treatment process, which does not differ much from everyday photographic applications. But the scientific potential within these photographic images is not utilised. This potential lies in the possibility of defining optimal recording techniques for a given material in a specific condition by isolating the spectral information in several close bands according to the spectral behaviour of the surface. This approach is very different to standard photography, which applies the same method in all situations.

The potential of multi-spectral images and multi-spectral analysis was tested on chosen areas in the three churches participating in the Raphael Project: Tirsted (Denmark), Britsum (The Netherlands), and Königslutter (Germany). The main aims of the extended photographic techniques are:

• Objective recording of a given condition at a specific time with the help of scientific and technical photography.
• Enabling the intensification and/or reduction of specific data for a unambiguous visualisation of phenomena.
• Detecting changes through the comparison of images from different recording periods (monitoring).

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Monitoring Systems

Data and methods

Data

The basics for image analysis, and , more specifically, multi-spectral analysis is a recording of a surface by a sequence of different pictures produced by calibrated and repeatable photographic procedures. Each single picture of a sequence shows a defined amount of surface characteristics according to the spectral behaviour in a chosen spectrum.

Experiences of research projects for the documentation of wall paintings have shown that a picture sequence should consist of multi-spectral images, in addition to those taken by conservators with common photographic techniques, such as normal and raking light, and UV fluorescence.

Generally, normal light photography with customary colour film gives an relatively realistic impression of the object if the whole photographic process can be handled optimally. Such photographs can be produced with a good cost-effectiveness, and their inclusion in the documentation of wall paintings is considered to be compulsory conservation practice.

Artificial lighting engineering based on high-pressure discharging lamps with their defined spectral power distribution do not falsify the colour impression. With optimal handling and this lighting, the recording of the image on the film gives an very close approximation of the colour rendition. The main disadvantage of colour film is the instability of the colour layers during long-term storage.

Raking light photography visualizes the surface structure depending on the amount and the direction of the radiation of the light source. The shadow play of the surface structure leads to qualitative information about the configuration of the surface structure. These so-called relief images can be used to support classification operators, if - for special formulations of questions - the geometric shape of the object is of interest.

UV fluorescence photography. Materials stimulated by UV light emit radiation of a longer wave length, which is visible and possible to capture photographically. The main application of this type of photography is to enhance the difference of material properties.

Multi-spectral photography.
Using multi-spectral recording, the radiation reflected by the object is divided into several spectral bands, by using different absorption filters, that only permit a restricted latitude of the entire wavelength range to pass where only a fixed part of the wavelength range can pass. The spectral bands are exposed sequentially on black and white high-resolution film. Thus, each object is represented by a series of images, geometrically identical but radiometrically different, according to the light permeability of the spectral filters.

For the optimal design of multi-spectral techniques the spectral properties of the wall painting materials should be known, or smaller areas with a typical representation of the whole scene must be chosen to define these properties. By these means, the information content of photographic images can be optimised by choosing a variation of the number and width of the bands. This is the principle governing remote sensing techniques for describing the earth's surface.

This is nearly impossible for the description of wall paintings because this type of knowledge is not available, and the resources of state institutions for the care of monuments are too limited for the investigations in this direction.

Because of this drawback, certain band combinations, were chosen for their photo-technical applicability, as seen on Tab. 1: Multi-spectral bands for the recording of wall paintings.

This method guarantees a defined and long-termed objective colour documentation of the object by separated recording of red-green-blue bands.

Furthermore, it permits the detection of metamerism with the help of the intermediate channels orange and cyan. In addition, information invisible for the human eye is recorded in the adjacent ultraviolet - and infrared-sections.

Image 1, Band 1	Multispectral Ultraviolett (UV)	360-380 nm
Image 1, Band 2	Multispectral Blauviolett (BV)	390-470 nm
Image 1, Band 3	Multispectral Cyan (Cy)	455-540 nm
Image 1, Band 4	Multispectral Grün eng (Ge)	495-550 nm
Image 1, Band 5	Multispectral Orange (Or)	570-640 nm
Image 1, Band 6	Multispectral Grün weit (Gw)	480-570 nm
Image 1, Band 7	Multispectral Rot (R)	625-695 nm
Image 1, Band 8	Multispectral Infrarot (Ir)	715-740 nm
Image 2	UV-Flourescent	Colour Image
Image 3	Normal Light	Colour Image
Image 4	Raking Light	Colour Image

Multi-spectral bands for the recording of wall paintings

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Monitoring Systems

Data and methods

Methods

To support the computer-aided processing the photographic images are scanned in a calibrated process. By using the colour charts in the photographs the brightness and contrast can be normalized. Subsequently, the digitalized spectral bands and the additional photos (see Tab. 1: Multi-spectral bands for the recording of wall paintings) are stacked into one multi-band image. If a geometric ground control is available the image can be rectified and referenced to its origin position according to a given object co-ordinate system.

There are different methods to use the potential of multi-spectral images for the documentation of wall painting. The information can be extracted by:

Visual monitoring on single and multi-band images

Each pigment or phenomenon is characterised by a typical spectral reflection. With this knowledge, visual monitoring can start by examining single bands (this visual interpretation is defined by a set of rules, according to those established for the interpretation of aerial photographs) or any two or three bands can be stacked to achieve a pseudo-colour image to enhance the visualisation of the phenomena. For the visualisation of the typical colour impression one can choose the red, green and blue band, e.g..

Creating new image files by mathematical or statistical combination of several images and / or band combinations

Common image processing techniques create new information by mathematical combinations of bands, mostly the difference or the quotient of two bands (index image). The difference image shows the absolute difference between two bands, whereas the index image shows the relative differences between the input bands. Using these methods one can achieve new artificial images or layers containing information which either enhance or even extract information of the original or primary bands.

Automatic grouping of similar image segments (Classification)

Here, two methods can be distinguished:

Pixel-based: Pixels are sorted into a finite number of classes, or categories of data , based on their data file value If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criteria.

Structure-based: This method is based on the concept that important semantic information necessary to interpret an image is not represented in single pixels but in meaningful image objects and their mutual relations.

If the typical statistical or typical structural property of a phenomenon can be described by mathematical means, algorithms can be applied to isolate specific elements in the image. By this kind of image segmentation a certain degree of automatisation can be introduced into the mapping process.

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Results

Unless otherwise specified, the results were generated with the Software Erdas Imagine , Version 8.4.

The paintings on the vault in the church in Britsum

The photographs were made on January 23, 2001 at the medieval church in Britsum. An area of approximately two square meters was recorded.

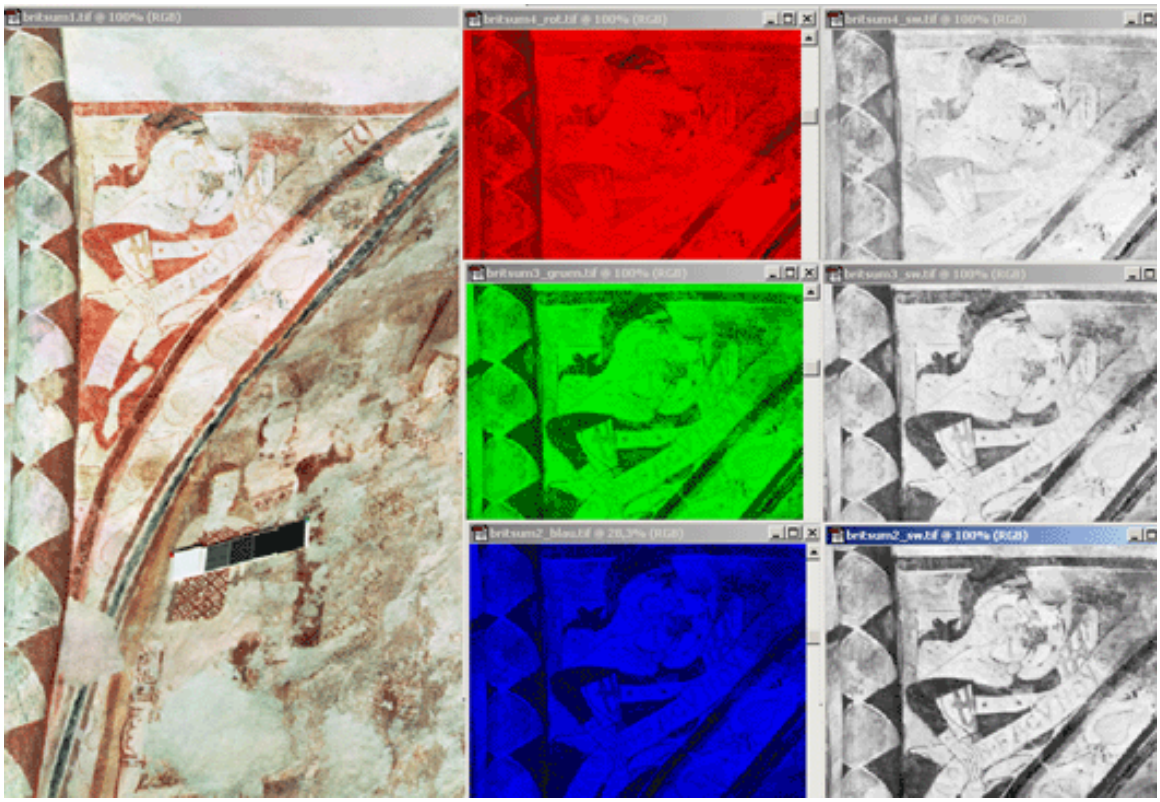


Image of the painting in Britsum, composed of the red, green and blue band

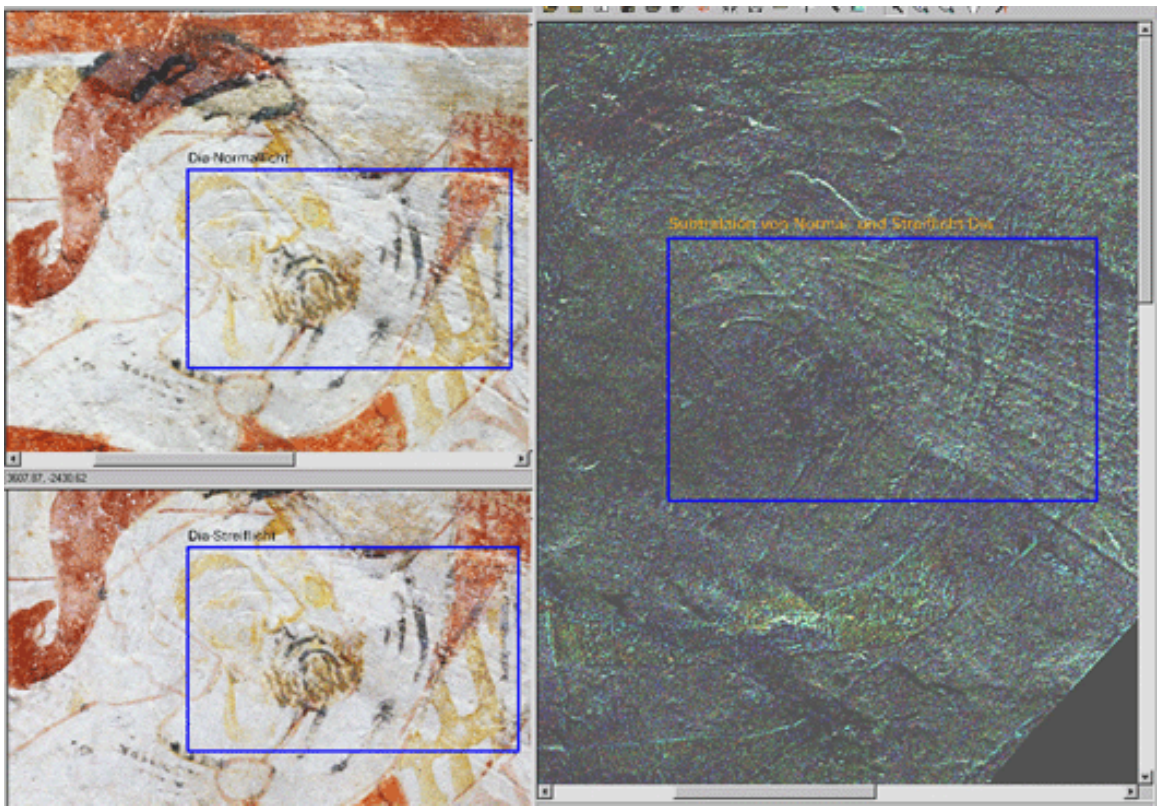
In addition to the photographic documentation of the actual condition of the wall painting with the help of the multi-spectral images phenomena were enhanced and classified.

On the painted textile robe, traces of an applied decoration technique can be seen. The negative imprints are also described as “circles surrounded by dots“. This phenomenon is hard to recognise on a color-slide. The

examination of the UV- band leads to a much better visualisation and a precise localisation in unexpected areas.

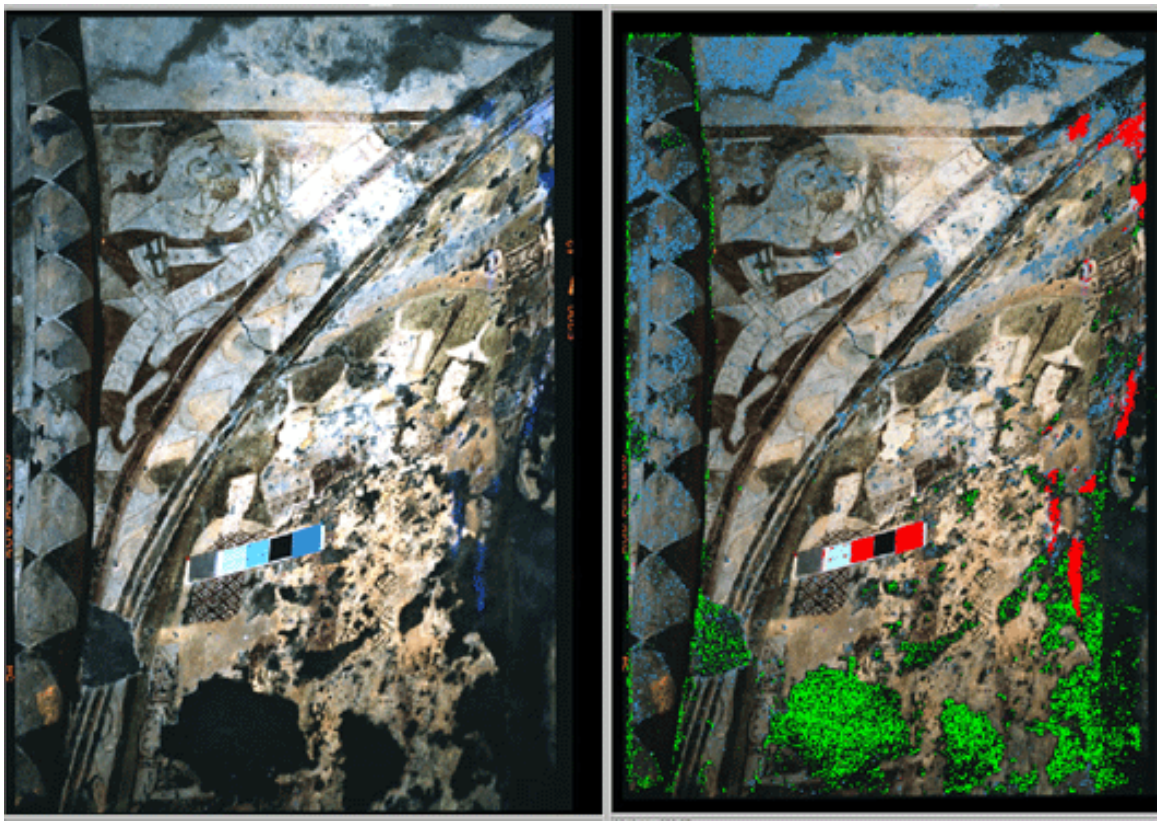
Visualisation of a special decoration technique in a colour image and the UV Band

In order to show the difference between an original part of the painting in contrast to a conservation treatment another method is used. The 3-dimensional brushstrokes of the limewash in the background of the painting give a specific relief in the raking light image. A discontinuation of a specific area shows local repair works (fillings) which are seen on areas with a flatter surface texture. For better visualisation of this phenomenon a new image was computed by the mathematical difference between the normal light and raking light slide.



A mathematical composition of normal and raking light image, showing the differences in surface textures

A combination of the phenomena pertaining to the painting technique and the conservation treatment are shown in the UV fluorescence recording in different shades of blue/grey colours Some parts in the image, which are coloured dark blue, were identified as areas treated as fillings or retouchings. Both phenomena show a special spectral signature in the UV fluorescence image and the multi-spectral bands, so a statistical classification algorithm could extract these areas.



UV fluorescence Image of the wall painting (left side) and classification of the blue, grey-blue, and dark parts, shown as a red, blue and green overlay

The colour chart in the image was also classified as related to a conservation treatment. The classification algorithm has to be modified or extended, or the resulting image of the classification must be cleaned manually.

Remark: Another attempt at classification dealt with the tiny cracks which were found all over the surface. This damage was not seen in this light because of the image scale. A bigger image scale has to be chosen for this purpose.

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Monitoring Systems

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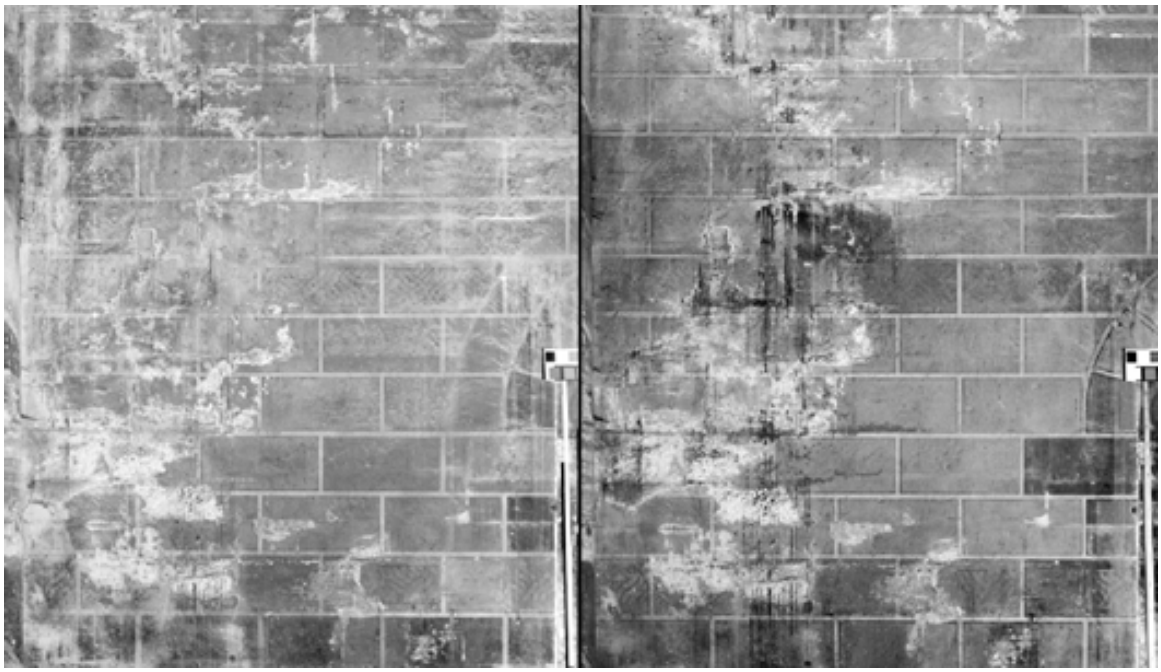
Unless otherwise specified, the results were generated with the Software Erdas Imagine , Version 8.4.

The paintings in the Kaiserdom in Königslutter

Certain areas of the decoration in the Kaiserdom were examined prior to the Raphael Project within the framework of another project, with the aim of developing a conservation strategy. Some areas were documented by normal photography, and later on by multi-spectral imaging.

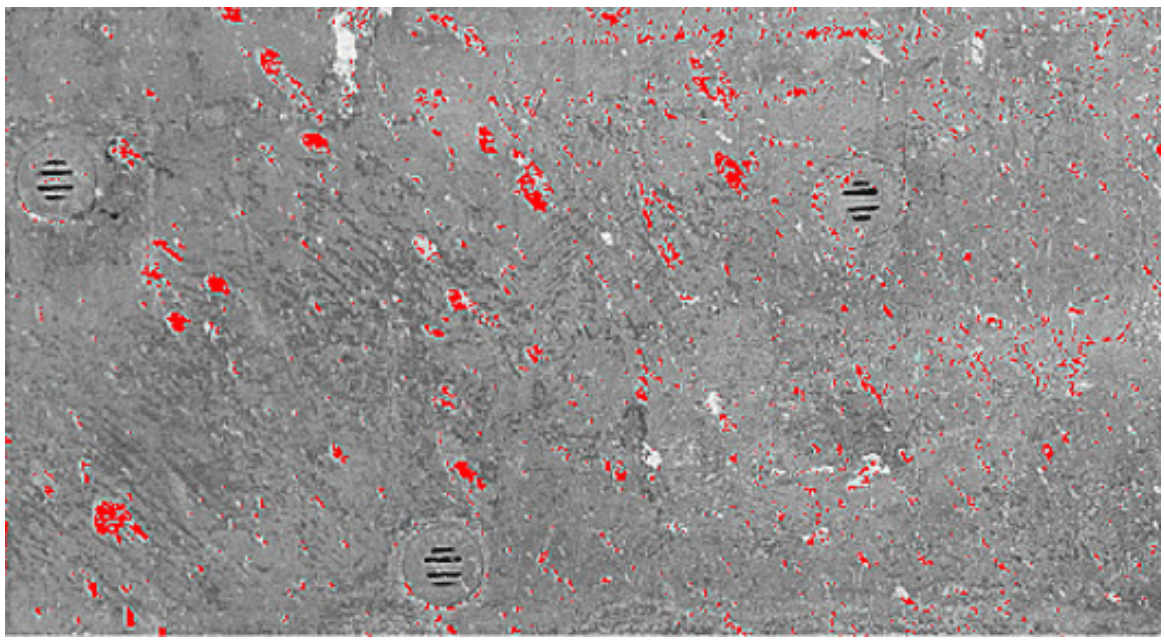
Image map of the north wall in the northern transept of the Kaiserdom, taken in 1994

The wall is contaminated by cement, which was poured into the space between the facade and inner wall during a treatment in the 1970s attempting to stabilise the fabric. The cement suspension has spread through the drilling holes and is visible on the surface in the form of grey running drips. Multi-spectral bands taken in 1998 show this phenomenon very clearly.



Detail of the north wall in infrared band (left) and UV band (right). The infrared band suppresses the visualisation of the cement. The UV band enhances this contamination

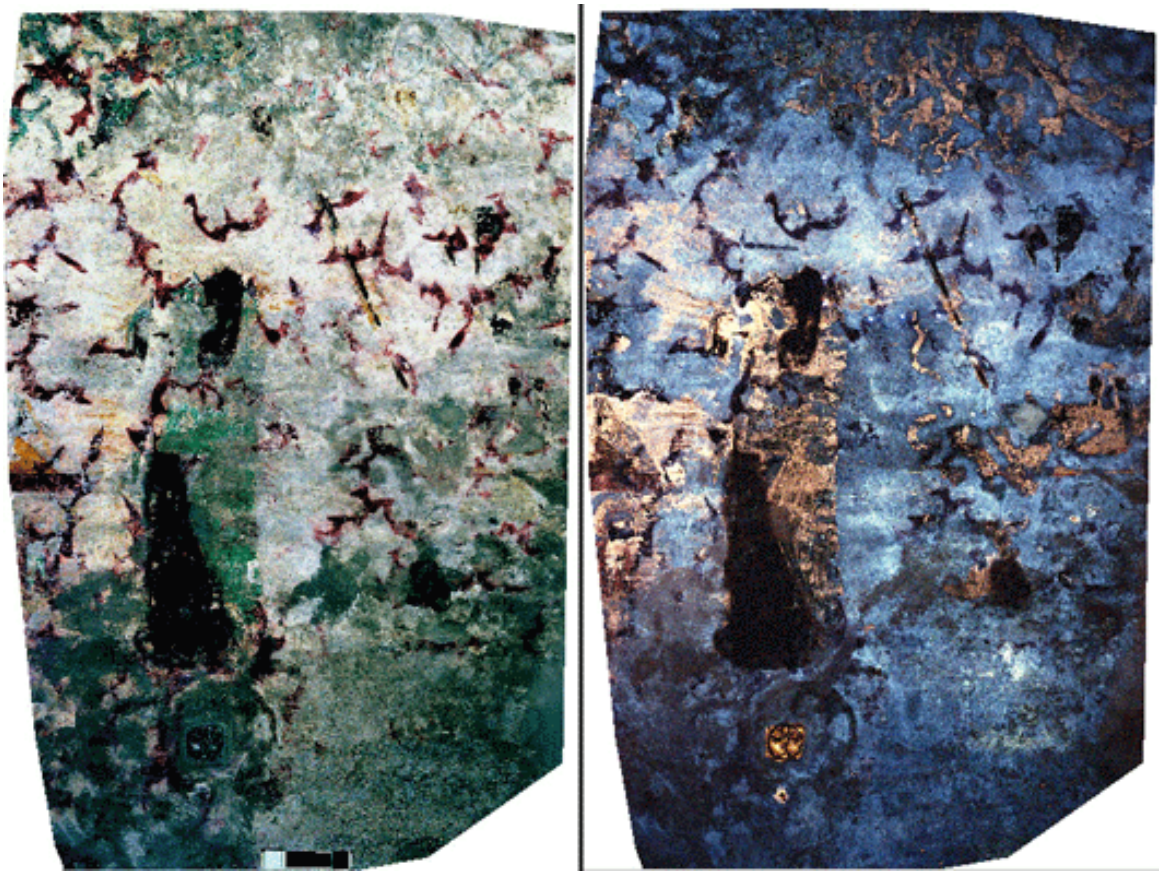
Within the framework of the Raphael Project an area from the wall with this damage was chosen for the multi-spectral photography for the purpose of isolating this phenomenon.



A black and white image of a single painted stone from the wall in the northern transept, where the classification of the cement contamination is overlaid in red

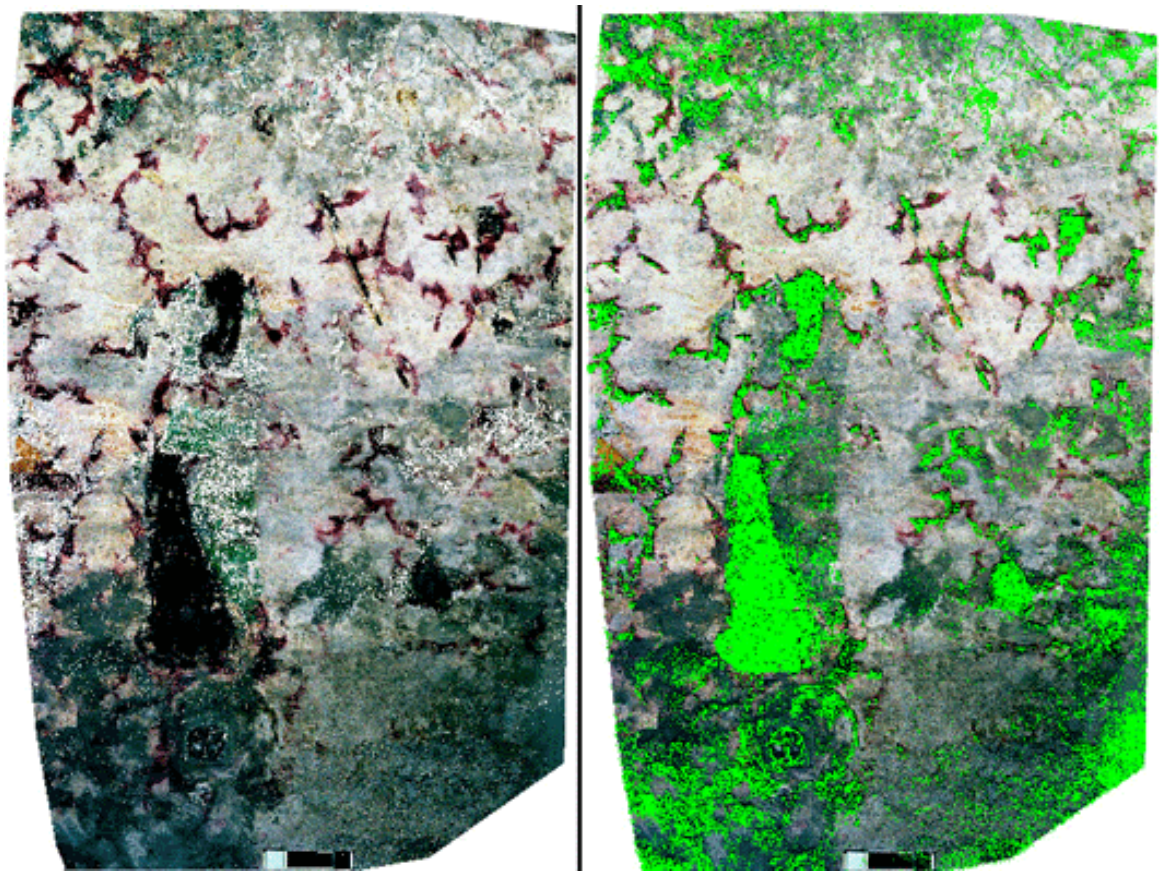
Because the cement has specific spectral characteristics, extraction was possible by statistical methods, which allow for the isolation of all pixels with the same properties. This resulted in a thematic map of the cement damage.

A second area was chosen on the vault in the western part of the church, which was photographed in the winter of 2000/2001 and the summer of 2001 for multi-spectral imaging and monitoring.



This image shows the condition of the painting on the vault with a combination of the red, green and blue bands (left), and the UV fluorescence (right)

The greyish brown and dark areas were noticeable. Their extraction was possible because of their special spectral behaviour, but the explanation for this phenomenon has not yet been determined.

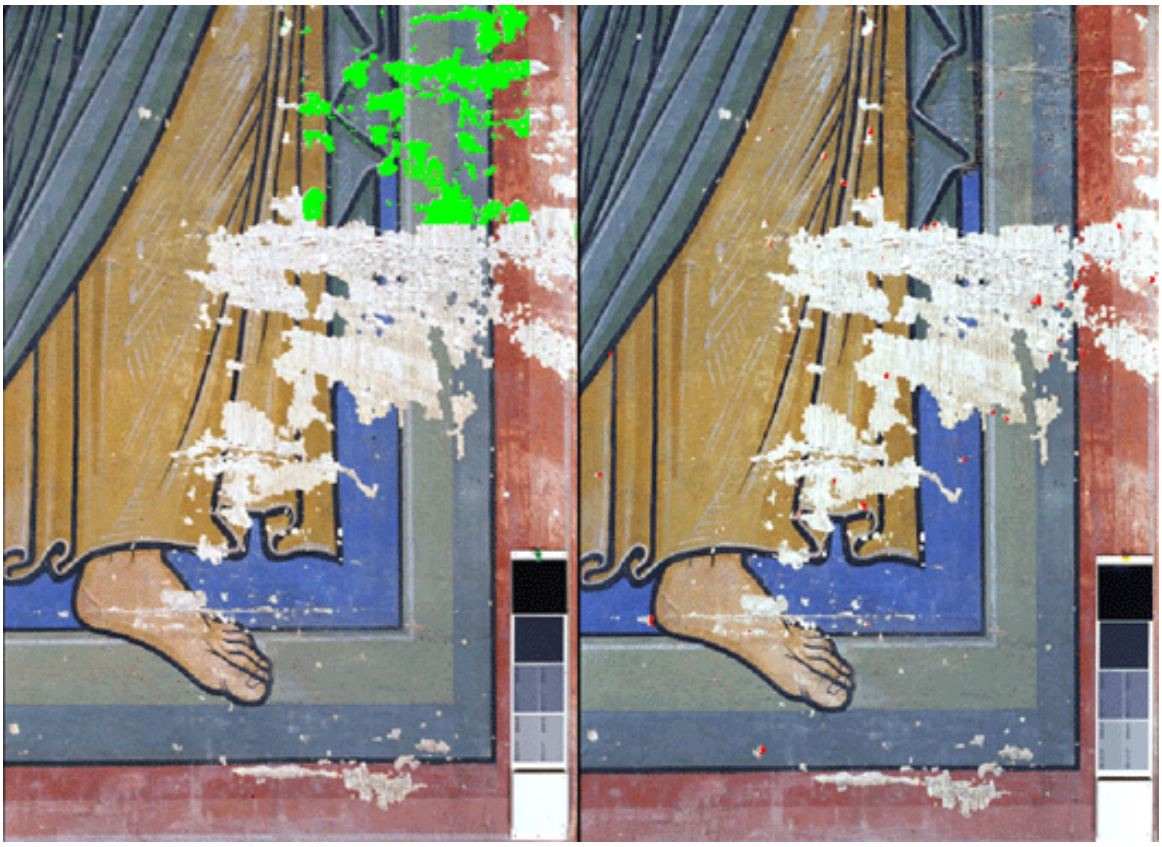


Classification of the greyish brown areas shown as white (left), and the dark areas shown in green (right) overlaid on the colour image

In order to compare the condition of the wall painting in the two monitoring phases a first attempt was carried out by computing a different image based on the colour slides, on the example of a wall painting located on a pillar in the crossing of the transept.

Condition of the wall painting in winter (left), and summer (right)

By computing a new image (winter minus summer) and making a contrast stretching to reduce the influence of lighting difference an image with two classes is produced. One class, depicted in green, shows added paint by retouching; the other class, depicted in red, shows lacunas of the paint layer.



The green colour on the left image shows the areas that were retouched. The red areas on the right image show lacunas of the paint layer occurring in the period between the two monitoring phases

Read more

Monitoring Systems

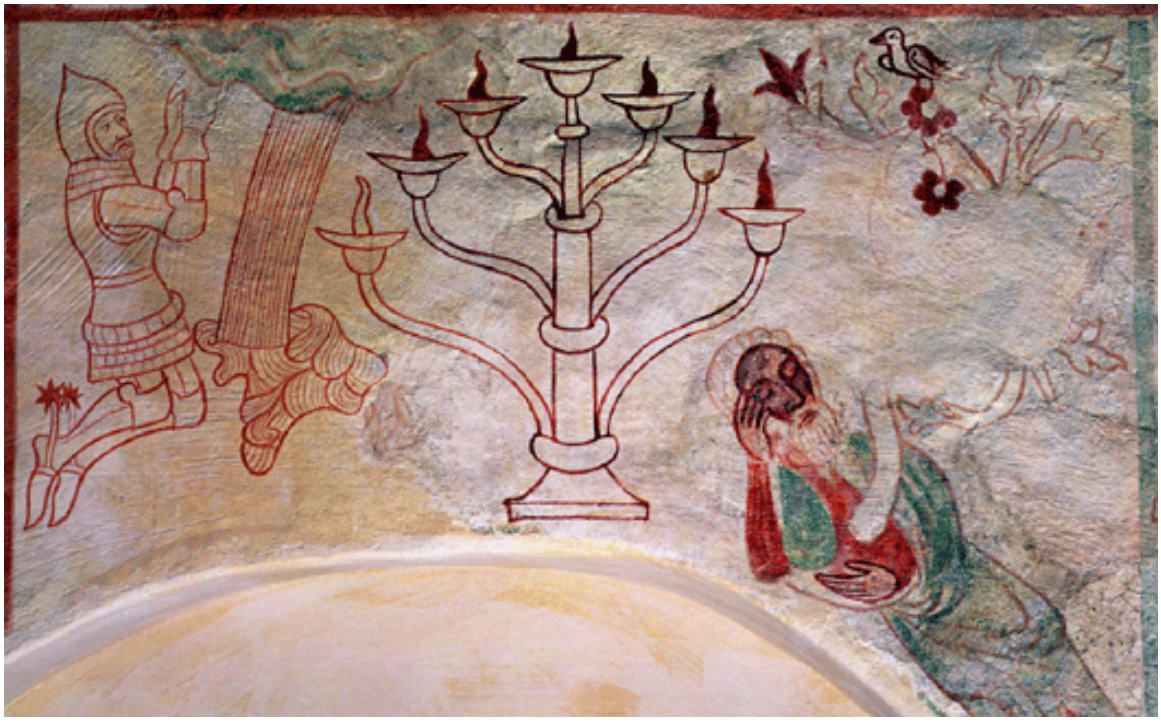
Data and methods

Results

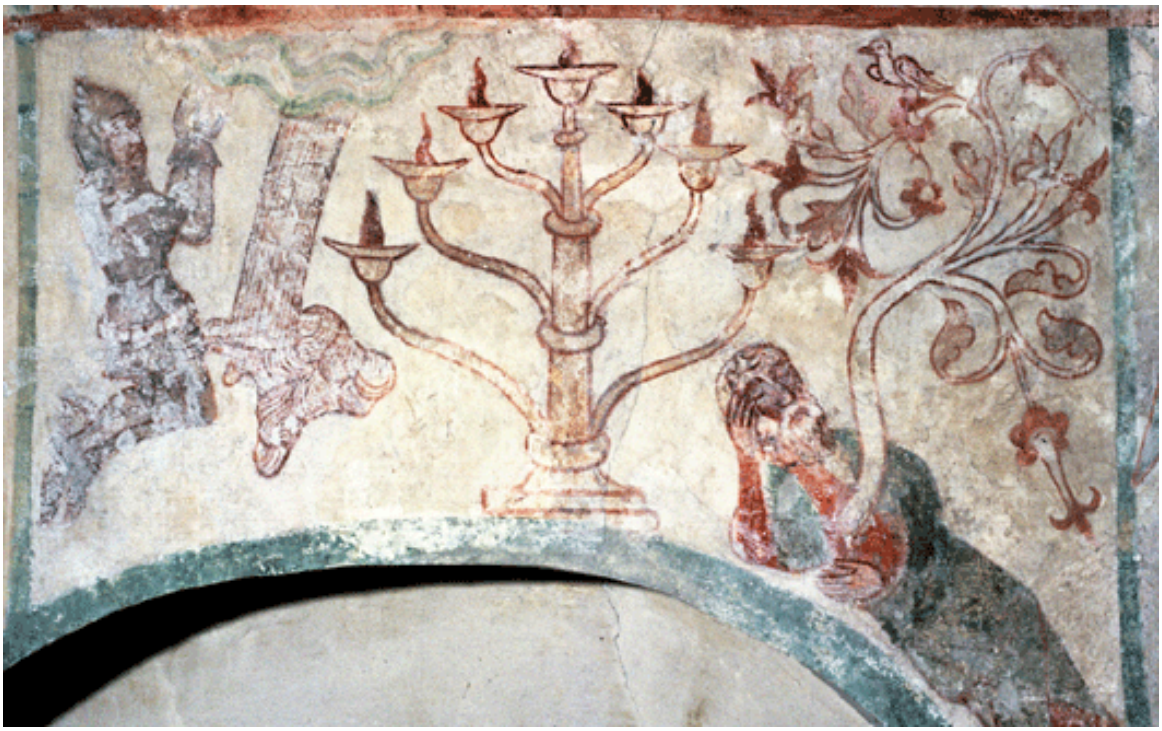
Unless otherwise specified, the results were generated with the Software Erdas Imagine , Version 8.4.

The Wall paintings in Tirsted Church

The multi-spectral photographs of a selected scene were taken on the 21st of August in 2000. The selected scene (Scene 45) was very damaged, and contained very much non-original material, such as plaster repairs and fillings.



Condition of the painting immediately after treatment (August 20, 2001). This image is a combination of the red, green and blue bands



Condition of the painting before treatment (Dec. 1999)

The UV fluorescence image taken after the treatment clearly shows the reconstructed parts of the pictorial image. The plaster repairs are the dark areas, while the original materials are seen with a high reflection value.

UV fluorescence image taken on Aug. 20, 2000

Using only the reflection values it was not possible to extract the dark areas because they are not homogeneous. The dark parts of the image contain a juxtaposition of opposite values, and the isolation of the dark areas would lead to loss of data (pixels with a high reflection value). Another image can be achieved by the application of the method of edge detection, which produces a clear structural differentiation between the original material (dark areas with painting) and the non-original material (mottled grey areas).

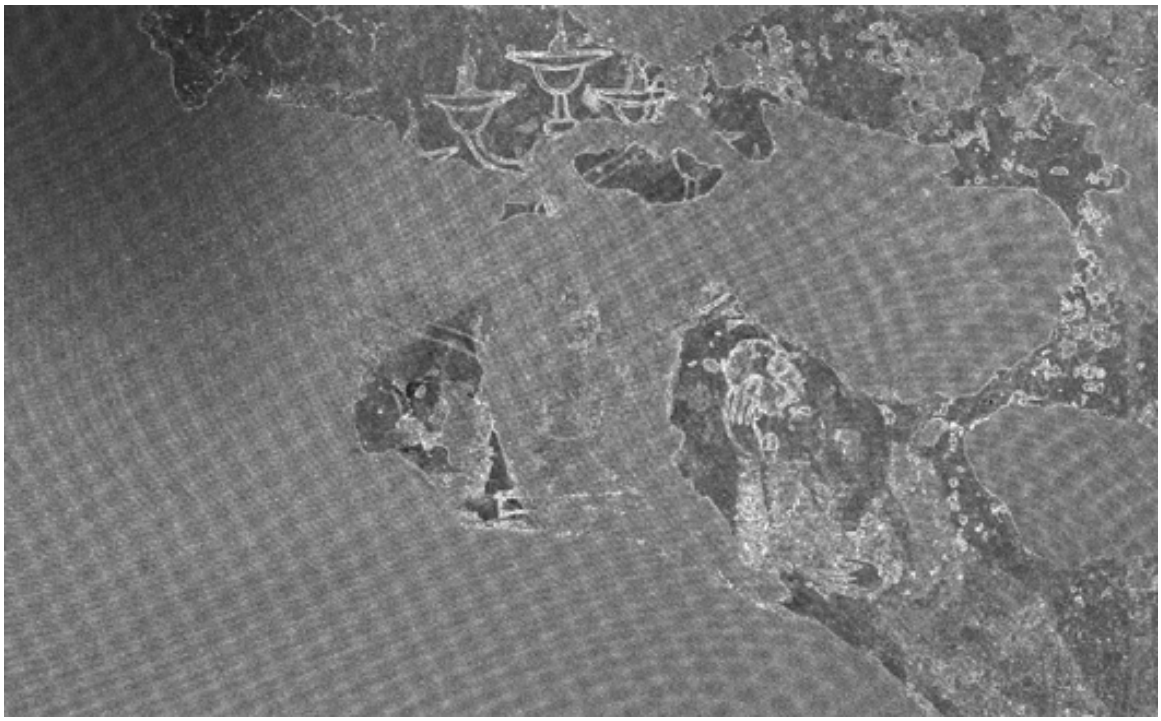


Image produced by edge detection in the UV fluorescence image

Utilising image processing methods which can isolate parts of the image dependant on the structure may produce better results. This was initially attempted by applying the software “Ecognition” by Definiens (Munich) to detect the two techniques that were used by the conservators for replacing lost pictorial content: solid monochromatic lines and hatched monochromatic lines.

This image shows the two line types used for reconstruction: solid (left) and hatched (right)

The classification of the two line types was possible by examining minute areas containing line ends. If such an area contained several line ends, it was classified as the hatched type and depicted with a black colour. The purple colour denotes the solid lines.

Classification of the two line types was carried out on a selected area (green field). The image shows a first attempt, with a correct classification result of about 70%. A better result would require further modification of the definition of the search mask

Read more

Monitoring Systems

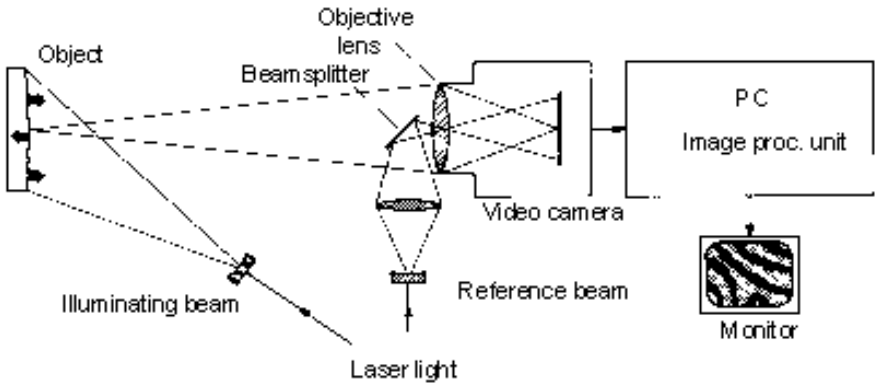
Optical and Acoustical Measurements

The methods were developed and applied by the Applied Optics group, Department of Physics (www.physik.uni-oldenburg.de) together with the Institute of Technical and Applied Physics GmbH (www.itap.de). Both institutions are situated at the University of Oldenburg

Identification of poor adhesion of plaster in murals using video holography

Vib ESPI

Video holography makes the measurement of displacement and vibration fields in objects possible, even when these are of sub-micrometer magnitude. Laser light scattered from the object surface is imaged by a video camera, where it is superimposed with a reference wave coming from the same laser (Fig. 1). The resulting interference of these waves depends on their relative phase and is therefore changed when the surface of the object deforms. Appropriate computer processing of sequences of such images yields, for example, the vibration amplitude for each imaged location on the object.



Setup of a typical speckle interferometer as part of the Vib-ESPI

The technique is used for an automated monitoring of loose regions in murals, thus extending the traditional percussion method. Sound from a loudspeaker causes the loose areas to vibrate, which is registered by the optical method. While the sound frequency is tuned through a range of typically a few hundred Hertz, all resonances of the object surface are recorded. The data is turned into a pseudo-colour plot that indicates how often a certain region vibrated - thus giving a measure for its loss of adhesion. In order to protect the valuable historical painting vibration amplitudes are kept well below those induced by manual percussion. A considerable advantage is the remote applicability which avoids costly scaffolding.

Read more


Raphael-Project


Königslutter

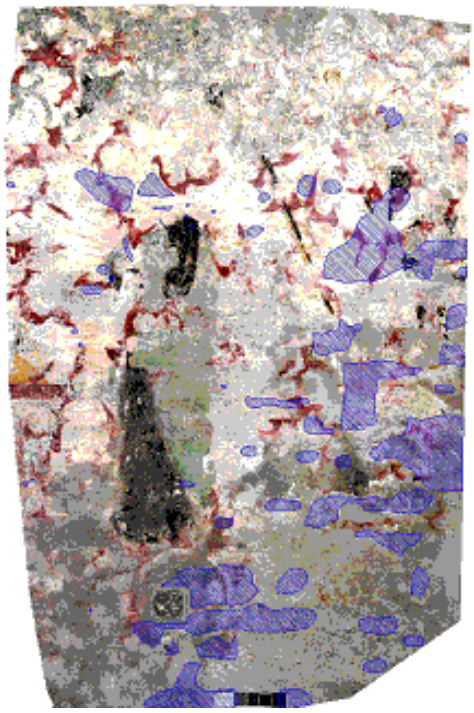

Tirsted


Britsum

Results

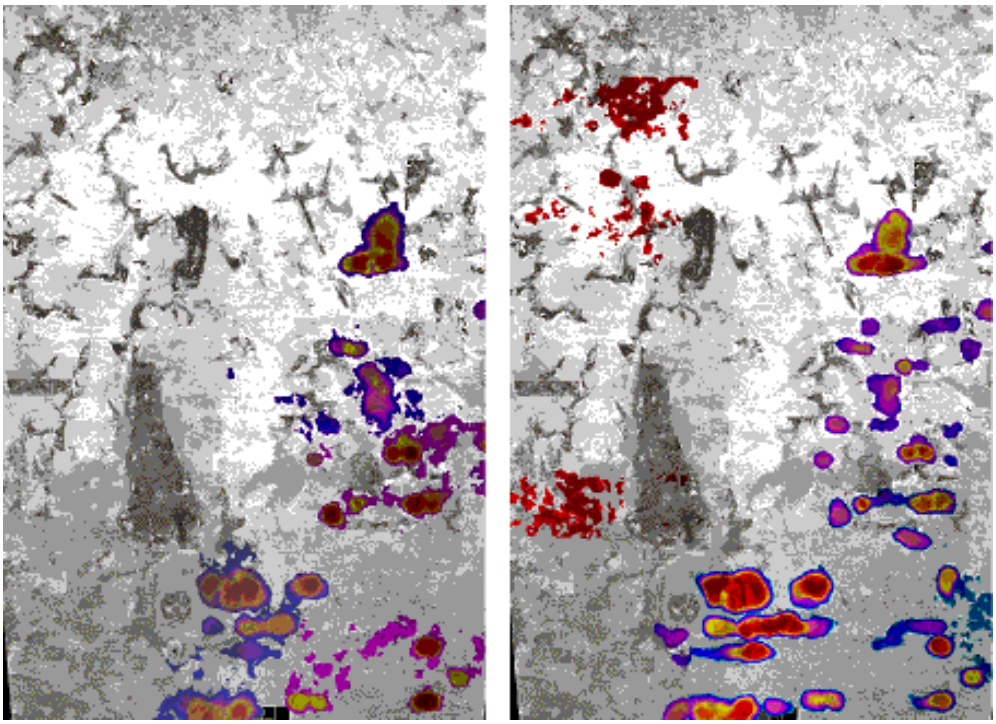
The barrel vault of the Kaiserdom Königslutter

Sections in the barrel vault of the Königslutter Kaiserdom were examined with the new method. This examination was done twice, the first time in January 2000 and again in July. Fig. 2 shows the result of a manual mapping with the conventional percussion method produced by the Landesamt für Denkmalpflege Hannover (Recker et al.), which was done in January.



Mapping of poorly adhered plaster recognized by the conventional percussion method

The detaching plaster is marked by blue hatching. Scaffolding was required because the painting is located about six meters above the floor. The height of the area under investigation is about two meters. Fig. 3 taken in January and Fig. 4 taken in July give the corresponding results from the holographic method obtained with the set-up on the floor.



Measurements taken in January (left side) and taken in July (right side)

For orientation a black-and-white image of the painting is included as background. Areas marked red indicate vibrations over a wide frequency range. Here, the plaster has certainly detached. The green/blue regions showed no vibrations and are considered sound. Fig. 4 shows increased loose areas and also additional detached parts compared to the result found in January.

A comparison of the results of both methods shows agreement in most regions. At the moment, the causes of the differences between the two phases are thoroughly discussed by the interdisciplinary team.

Read more

Results

The vault in the church in Britsum

The measurement was carried out in January 25th at the medieval church in Britsum near Leeuwarden. A small part of about two square meters has been observed. The region, about three meters above the floor was part of an arc on the left side in the apse. It was divided into an upper and a lower part with a small overlap.

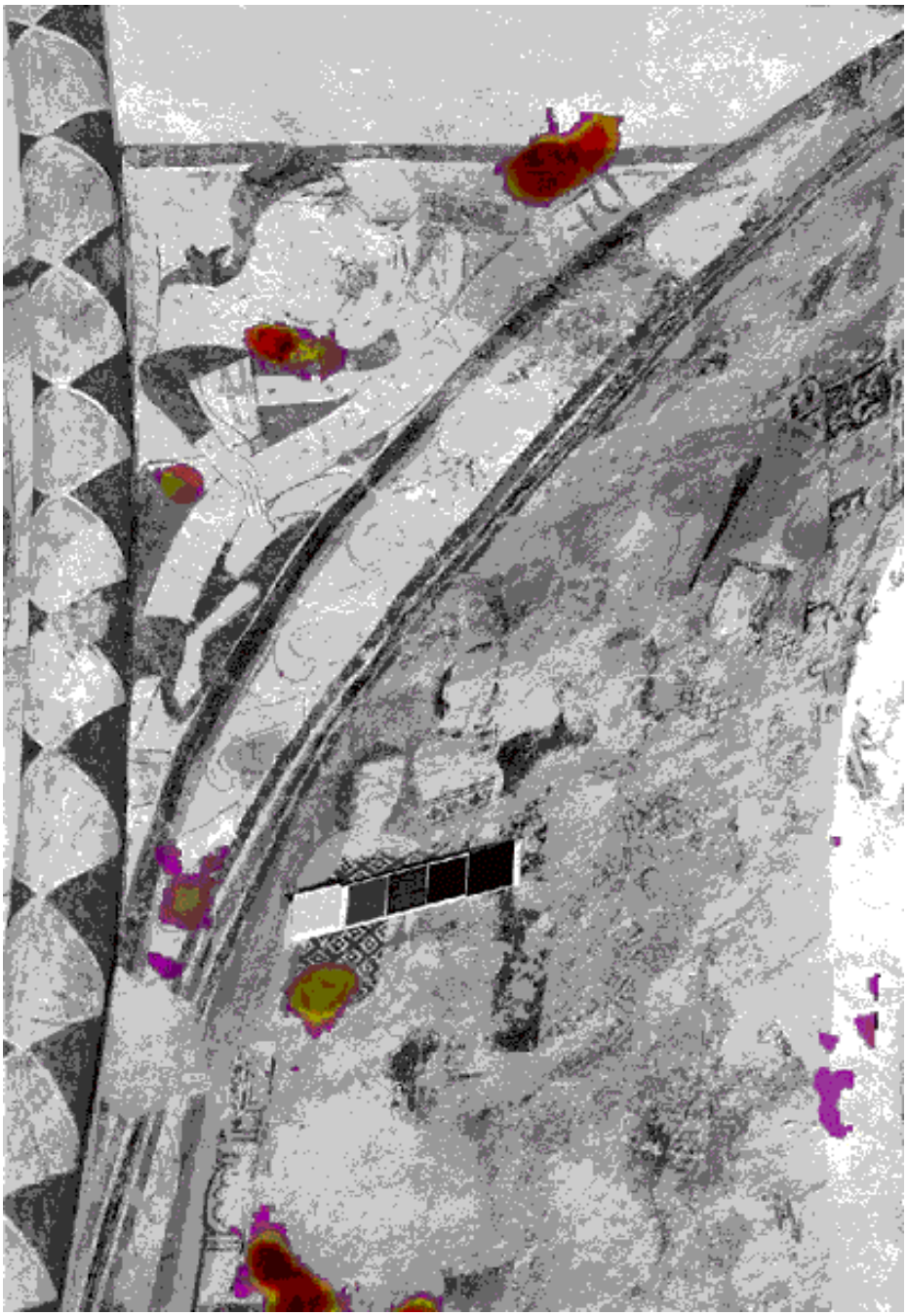


Image of the painting in Britsum showing areas where plaster has detached

For orientation a black-and-white image of the painting is included as background. Areas marked red indicate vibrations over a frequency range from 250 Hz up to 1200 Hz. Here, the plaster has certainly detached. The violet/blue regions show only vibrations in small frequency domains and are considered sound.

Read more


Raphael-Project

Königslutter

Tirsted

Britsum

Monitoring Systems

Influence of vibrations caused by aircraft overfly on wall paintings inside Britsum Church

Description of the actual situation

The medieval church in Britsum lies in the vicinity of a military airbase. Several times per year lowlevel flight practice takes place. The assumption was that these flights may cause vibrations inside the church that might damage the wall paintings.

A plan was therefore devised to measure these vibrations inside the church with two different systems. In a typical arrangement for vibration measurement a sensor sensitive to acceleration is placed on the wall. From this signal one can derive the frequency dependence or the spectral distribution of the velocities. In Germany, a norm [DIN 4150 / Teil 3] exists for this quantity, which establishes the level the vibration should not exceed in the case of historical monuments.

The disadvantage of this method is that the sensor has to be in direct contact with the floor or wall. This means fixing by wax, glue or screw. All of these possibilities are not applicable in the case of a wall painting. Therefore, a laser vibrometer was used, which measures the local movement of light scattered from a small spot on the wall under investigation. This method is less sensitive than the acceleration measurement, but well above the demands of the mentioned norm.

Measurement equipment

All of the results shown in this report are derived from acceleration measurements done with a DJB piezoelectric accelerometer (model: A/1600/V ; series no.: 020). Calibration was done with a Brüel & Kjaer calibration exciter (freq.:159,2 Hz; acc.: 10m/s² ; vel.: 10 mm/s; series no.: 4294-1749839). The signals are stored by a SONY dat-recorder (model.: TCD-D7). The sensor was glued to the floor in the vicinity of the wall on which the paintings of interest were located. The fly over test was performed by single jets and also in sequences of up to twelve jets passing within a few seconds of each other over the church.

The first tests show that the effects are below the sensitivity of the optical instrument. Therefore, it was not possible to derive the influence on the wall paintings directly from a signal coming from the surface of such a painting. Also, for all of the following measurements, only the accelerometer signal was recorded.

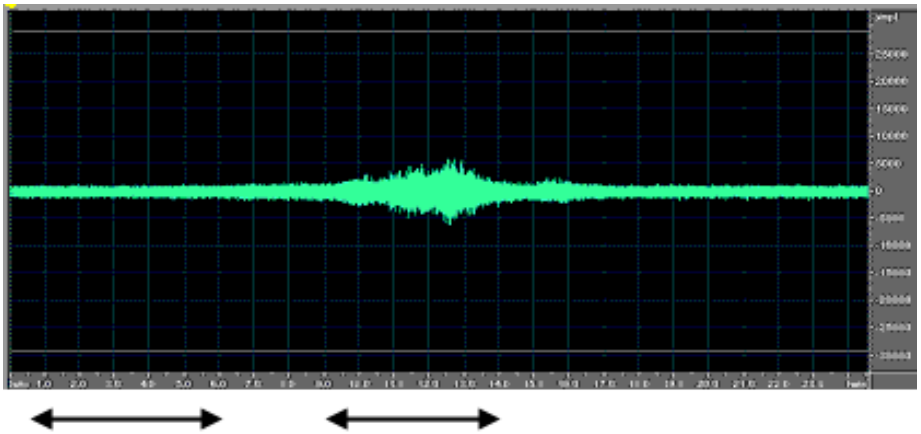
The dat-recordings were resampled and then analyzed by software from head acoustics. The time signals were converted to wav-file format and stored on CD for use with typical PC based applications software.

Results

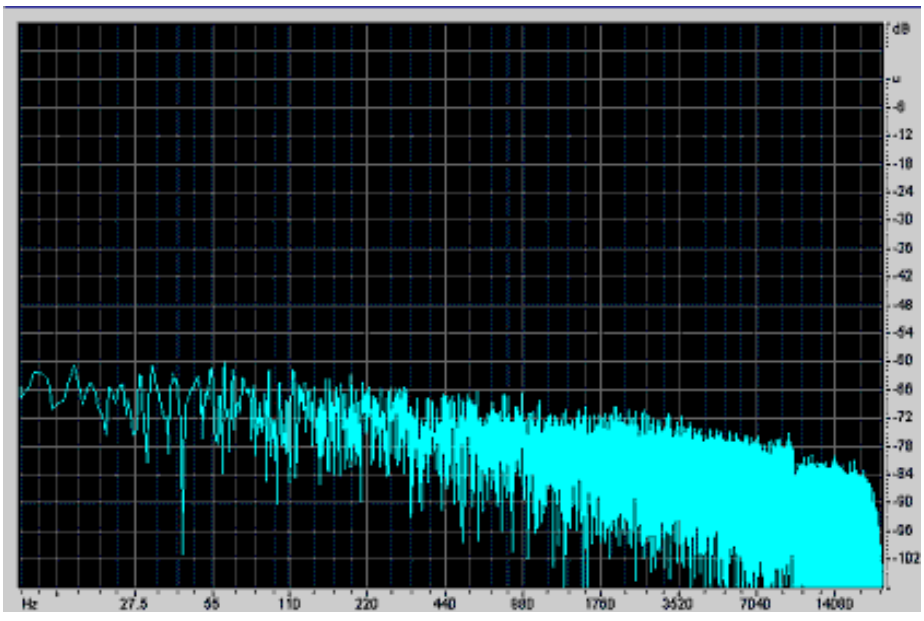
One first has to compare the energy in the spectrum with the values given in the norm mentioned above in order to derive the velocity spectrum from the given acceleration spectrum. In this new spectrum one has to integrate the area below the curve for different frequency domains as given in Table 1 of DIN 4150 / Part 3 and to compare the result with the values given in the table. The spectra shown are derived from an acceleration measurement. Thus, the spectrum has to be weighted by a frequency dependent factor. The correction above 159 Hz will cause a linear decrease of the amplitudes with increasing frequency. Thus, the uncorrected spectrum is regarded as a pessimistic estimate for the real velocity spectrum.

The signal in fig. 1a shows a typical signal caused by an overfly. Part I shows only the background noise without jet noise. The second part shows the burst produced during the flight above the church. A comparison of the spectra in b) and c) shows an increase of the noise level in a range from 50Hz up to 1.7 KHz of about 20db during the flight passing the church. But the mean value is still about 50 db below the reference signal, which is 10 mm/s (0db). In this range, the DIN Norm allows values between 3 mm/s and 10 mm/s. The measured values are roughly a factor of 300 below the values at which damage is expected.

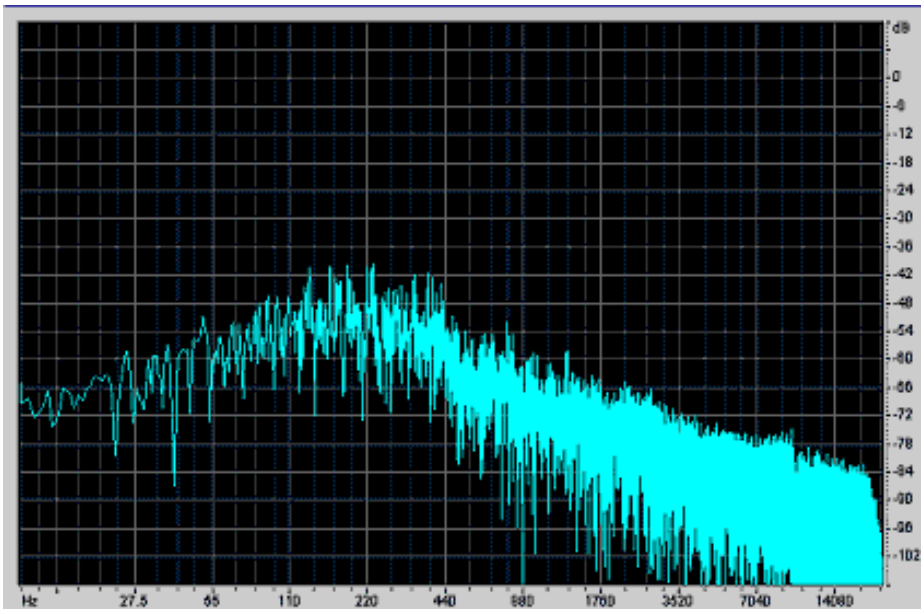
In fig. 2 the signal and spectrum of the organ music are shown. The influence is higher than that of the aircrafts, but still the peak values are at 40 db below the given limits. The spectrum shows typical lines caused by the resonances of the pipes. Fig. 3 shows the result from the ringing of the church bell. In addition to the lines of the typical bell sound, we find an increase of the lower frequency levels, which is probably caused by the mechanical parts moving the bell.



I II
1 a) Time signal of measured acceleration

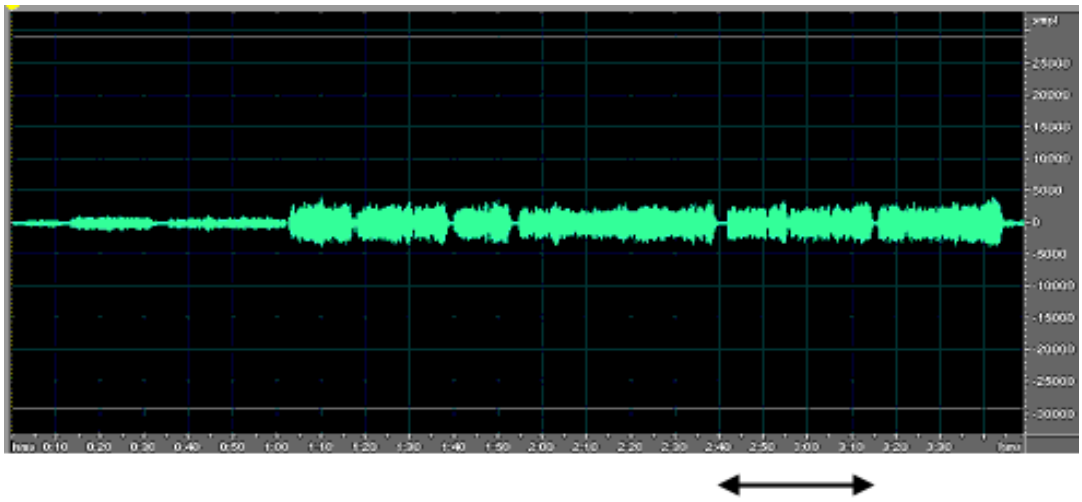


1 b) Spectrum of part I of signal shown in a)

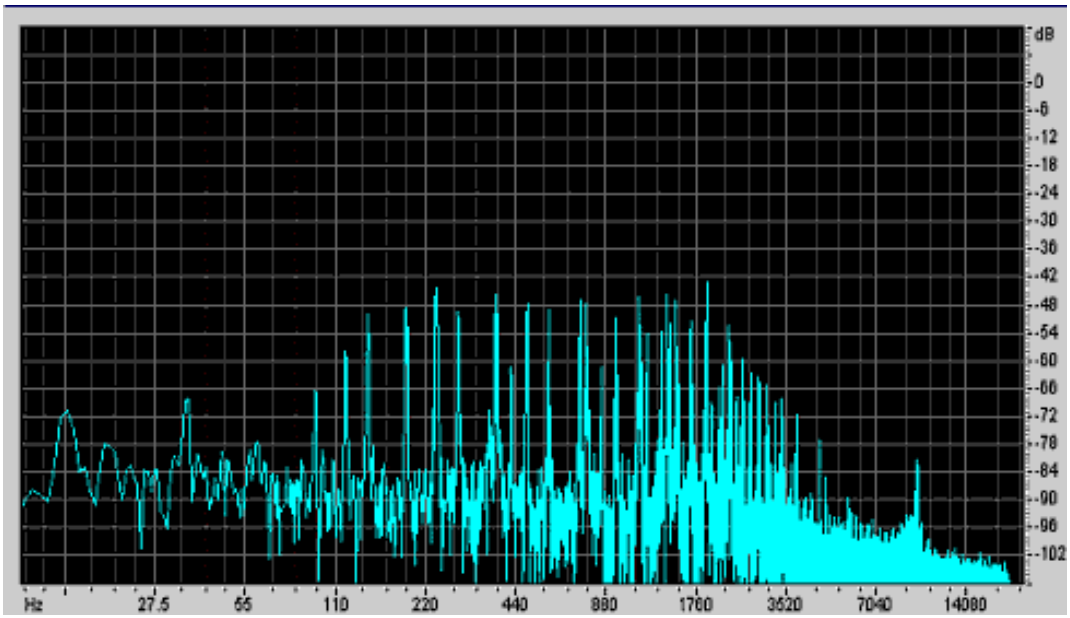


1 c) Spectrum of part II of signal shown in a). An aircraft is passing above the church

Fig. 1: Typical spectra of acceleration signals without and with an aircraft passing the church in Britsum. The spectrum in c) shows an increase of the noise level in a range from 50Hz up to 1.7 KHz of about 20 db during an aircraft passing the church.

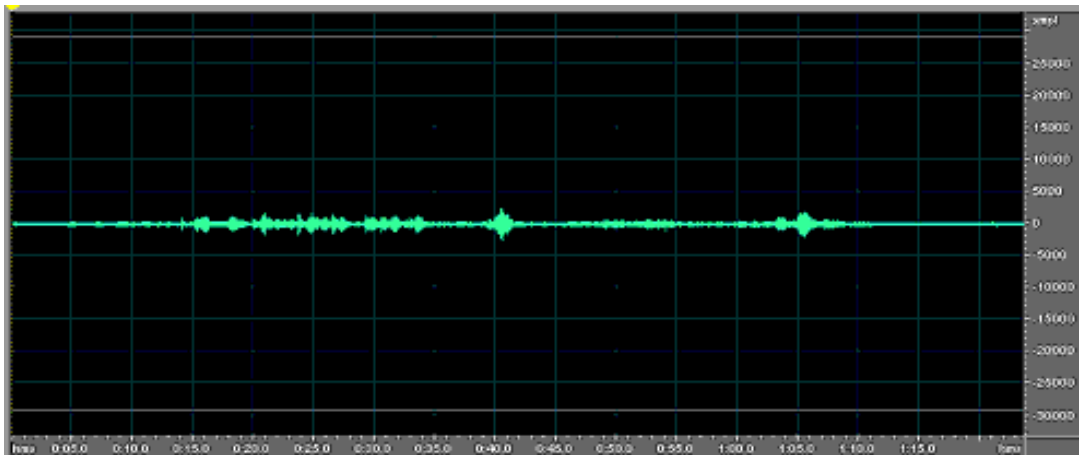


2 a) Time signal of pipe organ

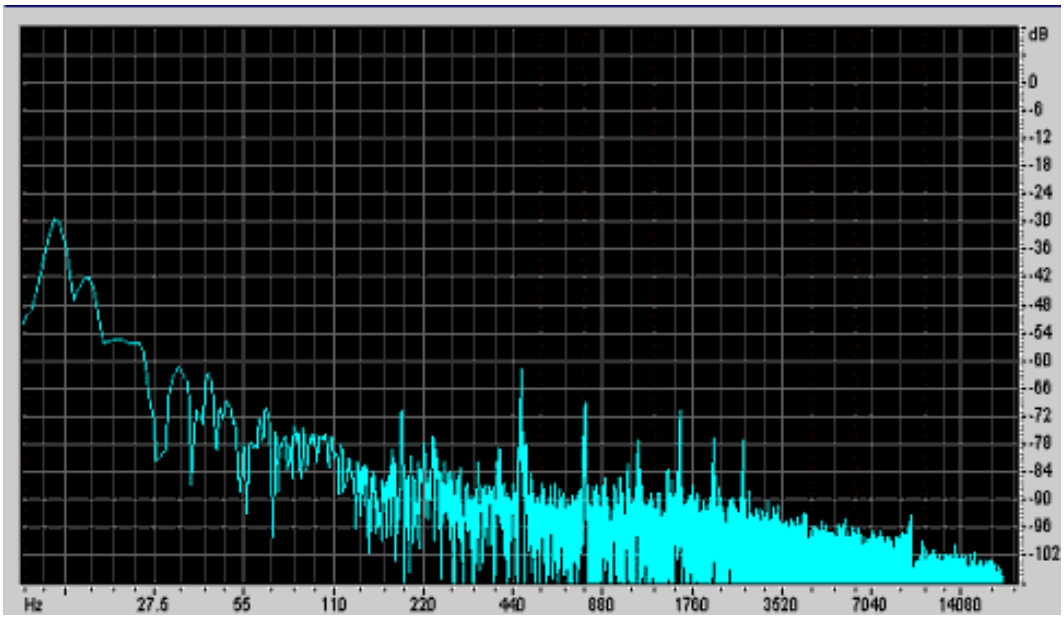


2 b) Spectrum of marked region in a)

Fig. 2: The typical spectrum of the pipe organ shows discrete lines which might lead to resonance of parts of the loose plaster. This works in a similar way as the excitation of such parts of the wall painting by the sinusoidal signals produced by the Vib-ESPI. In both cases the derived velocities are not in a region that might cause damage if compared to the norm.



3 a) Signal of church bell



3 b) Spectrum of marked region in a)

Fig. 3: The discrete lines in this spectrum above 180 Hz correspond to the typical sound of a bell. But, additionally there is a lot of energy in the spectral region below 30 Hz. This is probably caused by the mechanical parts moving the bell. If the bell-driving mechanism is directly supported by the walls of the church tower, part of the energy will be coupled into the walls and then travel inside the walls of the church.

Assessment

The measurements have shown that the vibrations caused by the aircraft overfly are well below the limits where damage can take place. A comparison with the load produced by organ music and also by church bell ringing shows that there is no additional risk for the wall paintings. Additionally, one can expect that the outer wall of the church acts as a shielding against the noise from outside. Also, the coupling mechanism into the wall from noise propagating through air is fortunately very inefficient. The influence of the noise source - in our case an aircraft - is strongly distance dependent. Therefore, the altitude at which the training flights take place should not be lowered.

Read more

Monitoring Systems

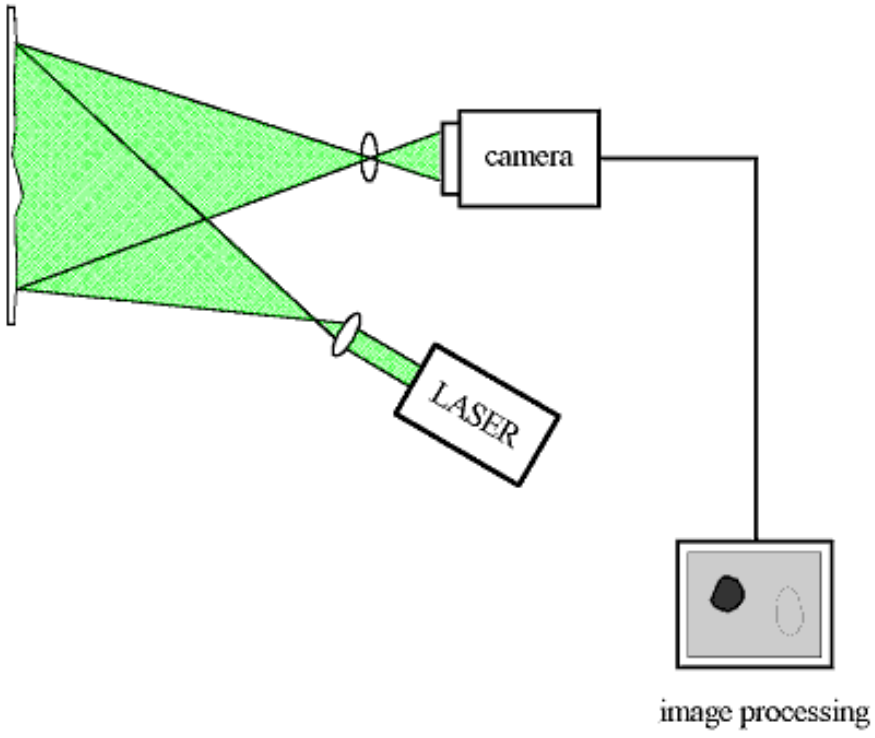
Correlation Measurements at the Medieval Church in Tirsted

Description of the problem

As part of the RAPHAEL project a correlation method has been tested. The test was carried out at a medieval church located in Tirsted on Lolland. The wall paintings there suffer from a damaging process caused by salt efflorescence. The idea was to monitor the crystal growth by a correlation method during a typical heating cycle in the church. Therefore, the air temperature was altered from about 11C up to almost 16C. The change in humidity would probably start crystal growth and therefore alter the microstructure of the wall surfaces.

Correlation method

A simple method for monitoring changes can be carried out by subtracting successive images taken in regular time steps. The method is not very sensitive but easy to apply. The speckle correlation method used here is much more sensitive, especially to changes of the surface microstructure, which could not be resolved by the camera in use. The surface has to be illuminated by a coherent light source, as a laser. The rough surface of a wall illuminated by this light produces a phase sensitive texture, or, commonly called a speckle pattern. This pattern is used to detect local changes in the range of less than a micrometer.

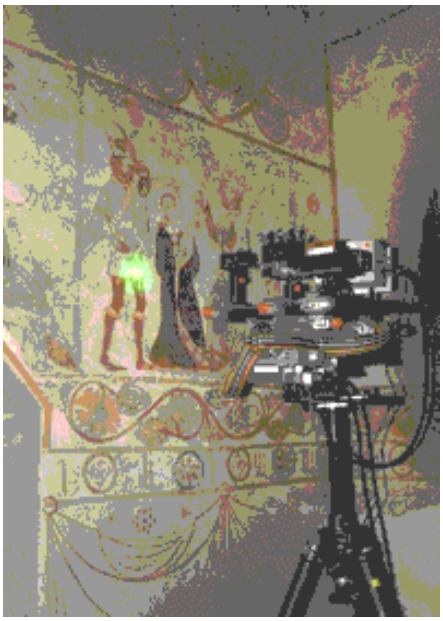


Typical set-up for speckle correlation measurements. The laser illuminates a rough surface which produces a speckle pattern recorded by a camera. Surface changes are detected by performing a cross correlation between successively recorded images

Successive recordings of these images are taken during a forced process, which should change the surface under investigation. During the interrogation step one image is taken as a reference. By performing a local correlation algorithm the similarity of a chosen second image is tested. The outcome is a map which tells how similar an area is to the initially taken state, or reference image. A second outcome is a vector plot. This plot shows the local in-plane-movement of parts of the surface. This is of interest, for example, when looking at cracks in walls. Here, this information mainly serves for corrections that have to be carried out for tripod movements. A typical error is a global shift caused by expansion of the tripod legs during heating up. The three legs don't expand equally, which results in an image rotation. This has also been corrected with the available data. The remaining movements are caused by the surface itself, and shown here as vectors in an overlay.

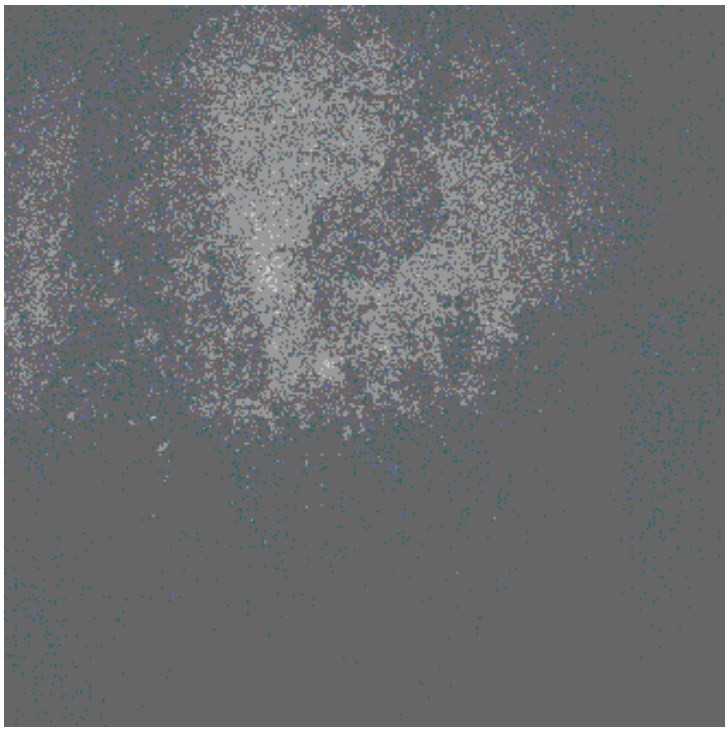
Results

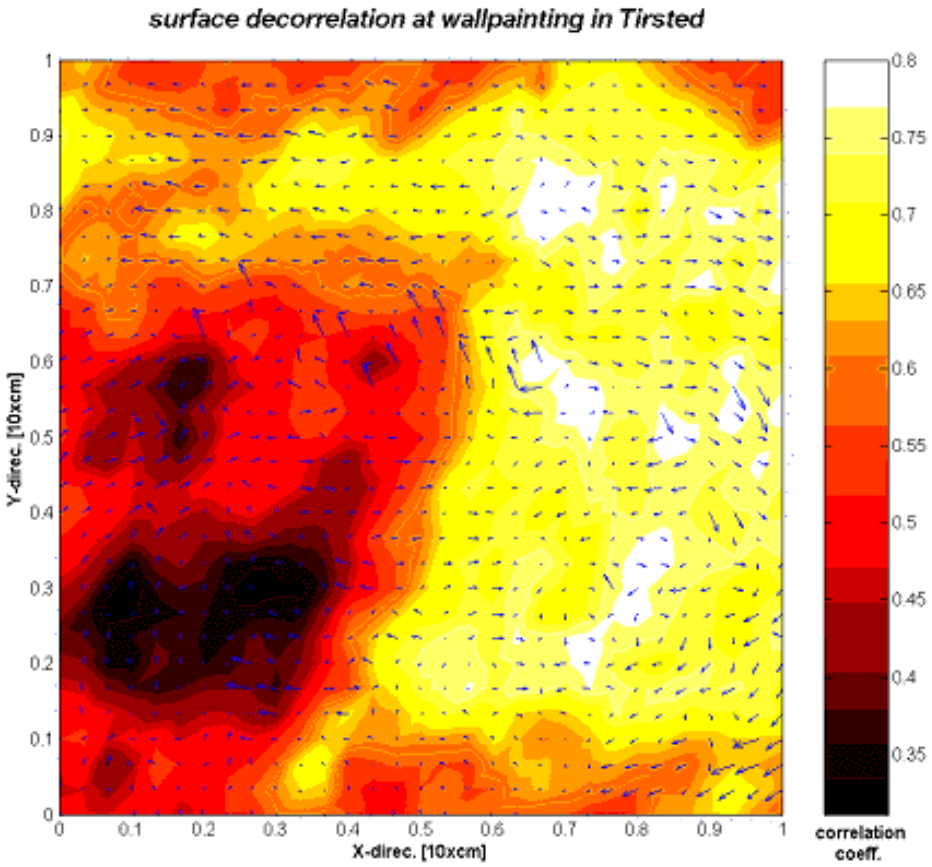
Figure 2 shows the setup used in Tirsted for the correlation measurements. The results shown in figure 3 and 4 demonstrate that there still is a surface activity after the last restoration process. The images correlated here are taken at the beginning of the monitoring period at 11 C, when the heating system was switched on and after reaching 15 C about 12 hours later. The biggest changes are seen in the first three hours. This means that the surface does not change linearly with time. The process which alters the surface is probably the crystallisation of the salt, but has to be deriven from additional information about the wall construction. The correlation method shows that changes are occurring, and at what quantity, but can not give the reason for them. Also, it is possible to look at the development of the crystal growth over time by using the data for an animation.



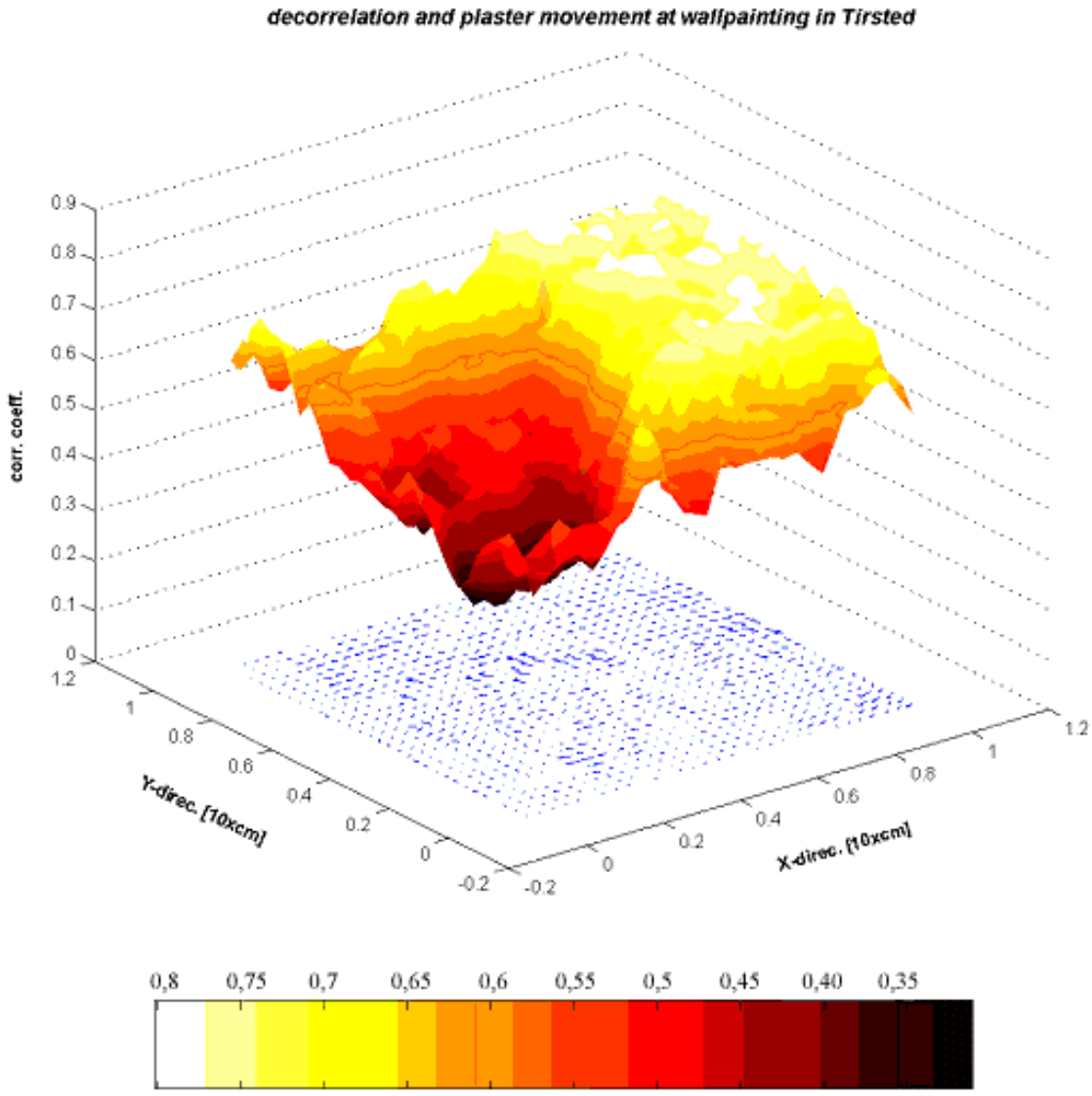
Setup used for correlation measurements in Tirsted. The laser illuminates a larger area than seen by the camera because the beam has a Gaussian beam profile. The arrangement guarantees an almost uniform illumination of the central part

Camera image of the wall painting illuminated by laser light (532nm)





The upper image is one of two images used in the correlation process carried out to obtain the result shown below. The overlay shows the remaining local movements after several corrections, as mentioned in the description of the method



The same result as in figure 2 presents a better idea of the differences in the correlation coefficient in different areas of the painting

Remark on the meaning of the correlation coefficient:

A correlation coefficient of one implies that there has been change in the surface structure between the recordings of the reference image and the actual recording. If the correlation coefficient decreases the surface texture has changed for example due to aggregation of water at the surface or due to the growth of salt crystals. A correlation coefficient of zero has the meaning of a complete loss of the similarity between compared images.

Read more

Monitoring Systems

Thermohygric and Climatological Measurements

Investigation Campaign in the Emperor's Cathedral (Kaiserdom) in Königslutter

The methods an measurements were applied by Dr.-Ing. Helmut Berling, Ingenieurbüro, Bauphysik, Gebäudetechnik, Denkmalpflege in Braunschweig.

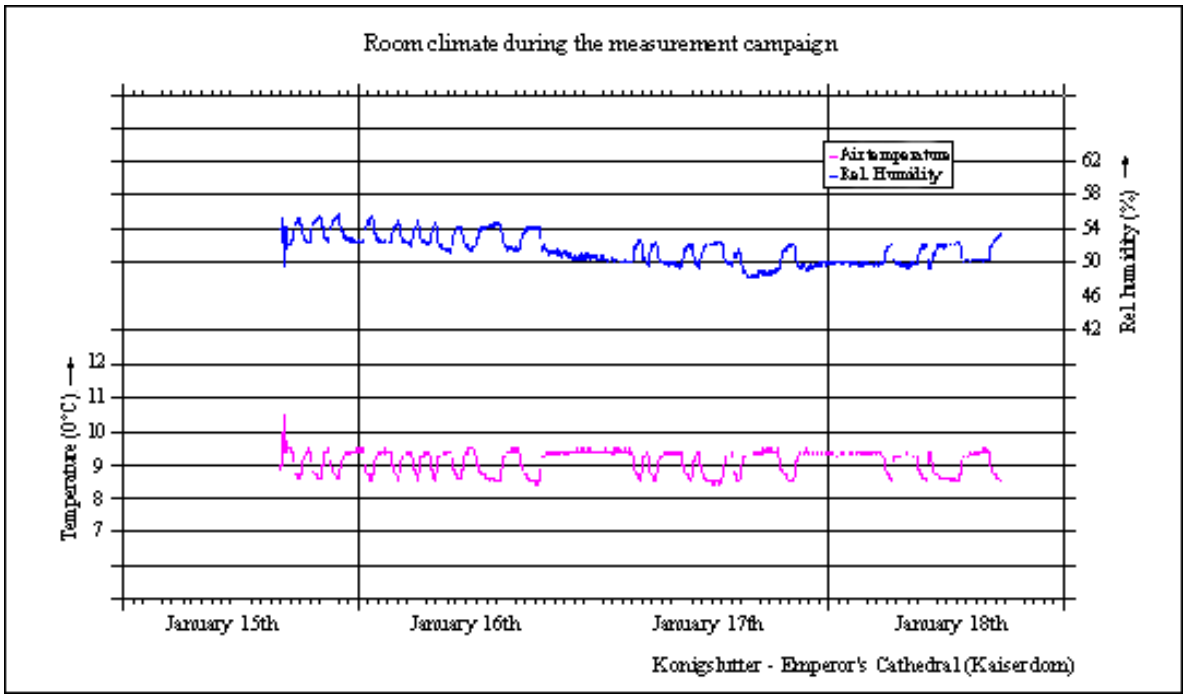
Introduction and purpose

Within the scope of the Raphael project, mappings of sample surfaces were taken in the Emperor's Cathedral (Kaiserdom). Areas where the plaster was loose and where the paint layers lost adhesion were studied by means of different measurement methods. As the thermal/hygric behaviour of the building construction has serious effects on the dynamics of loose plaster and painting surfaces, surface temperature distributions were developed in parallel to the mapping works. Due to the integral project registration, the investigation encompassed not only the areas chosen for the monitoring phase, but also additional surfaces.

As mural paintings are found on these surfaces, the temperature distribution had to be captured without contact. Thermographical systems are appropriate for this purpose. They capture the radiated heat of the construction material (infrared radiation in a wavelength range of 8 - 12 µm). The intensity of the heat radiation also depends on the emission coefficient of the construction material. The infrared radiation captured by scanning the surfaces shows the temperature distribution. Different temperature levels on the surfaces can originate by means of heat bridges, which are caused by material or humidity factors, as well as by areas of loose plaster. If there is a temperature difference between the inside and the outside, heat bridges and humid construction materials show higher heat conductivity, leading to lower temperatures on the inner surfaces. Areas of loose plaster show a higher heat flow resistance, and thus a lower heat conductivity, due to the air-filled cavities between the plaster and the wall. In such conditions, these places show higher temperatures than undamaged areas.

Room climate

The temperature control in the church is dependant on the relative humidity. The registered results of the room climate measurement during the monitoring phase are represented in the subsequent graph.



Room climate from January 15th until January 18th, 2001

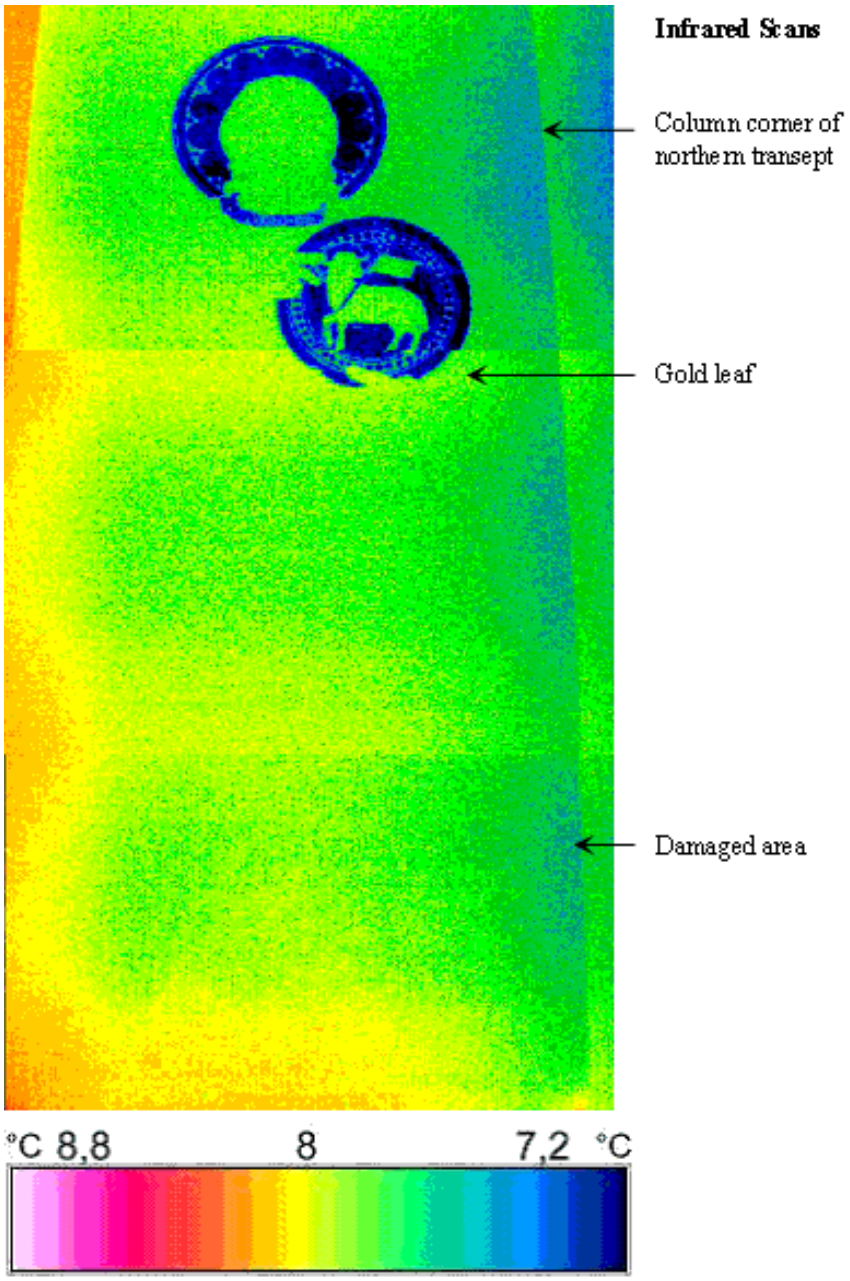
With the external temperature a little below 0, the average temperature of the inside air was approximately 9°C during the entire investigation period. The temperature variations moved within a very small range (+/- 0,5 K). The relative humidity was approximately 52 % +/- 4 percent points.

Surface temperatures (infrared scans)

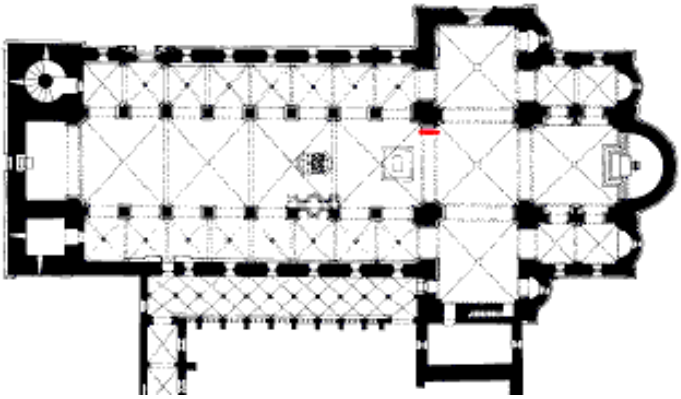
The thermal behaviour of the surfaces was investigated in different places; it is described and represented in the following figures. Figures 2 - 4 show partial areas of small surfaces, enabling a higher resolution. The other 3 thermographies, on the other hand, show surface heat distributions of larger surfaces, of building parts in overview scans.

Northwest quadrature column

The peeling painting, which was applied directly to the natural stone, is a very thin layer and, therefore, does not show any thermal influence. Furthermore, the column has an even thermal load, as it is surrounded by inside air. For this reason, the infrared scan hardly shows any temperature differences on the investigated surface. Instead, the thermography shows a surface temperature decrease of about 0.5°C over the surface. The fact that the temperature of the right side of the scan is lower can be explained by the airflow influences of the northern transept caused by the geometry of the building. The fact that the mural painting damages are predominantly on the right half of the investigated area is distintive. The areas of the mural painting covered with leaf gold can be distinctly recognised due to the different reflection and emission behaviour of the metal; they do not show the actual surface temperature in the infrared scan.

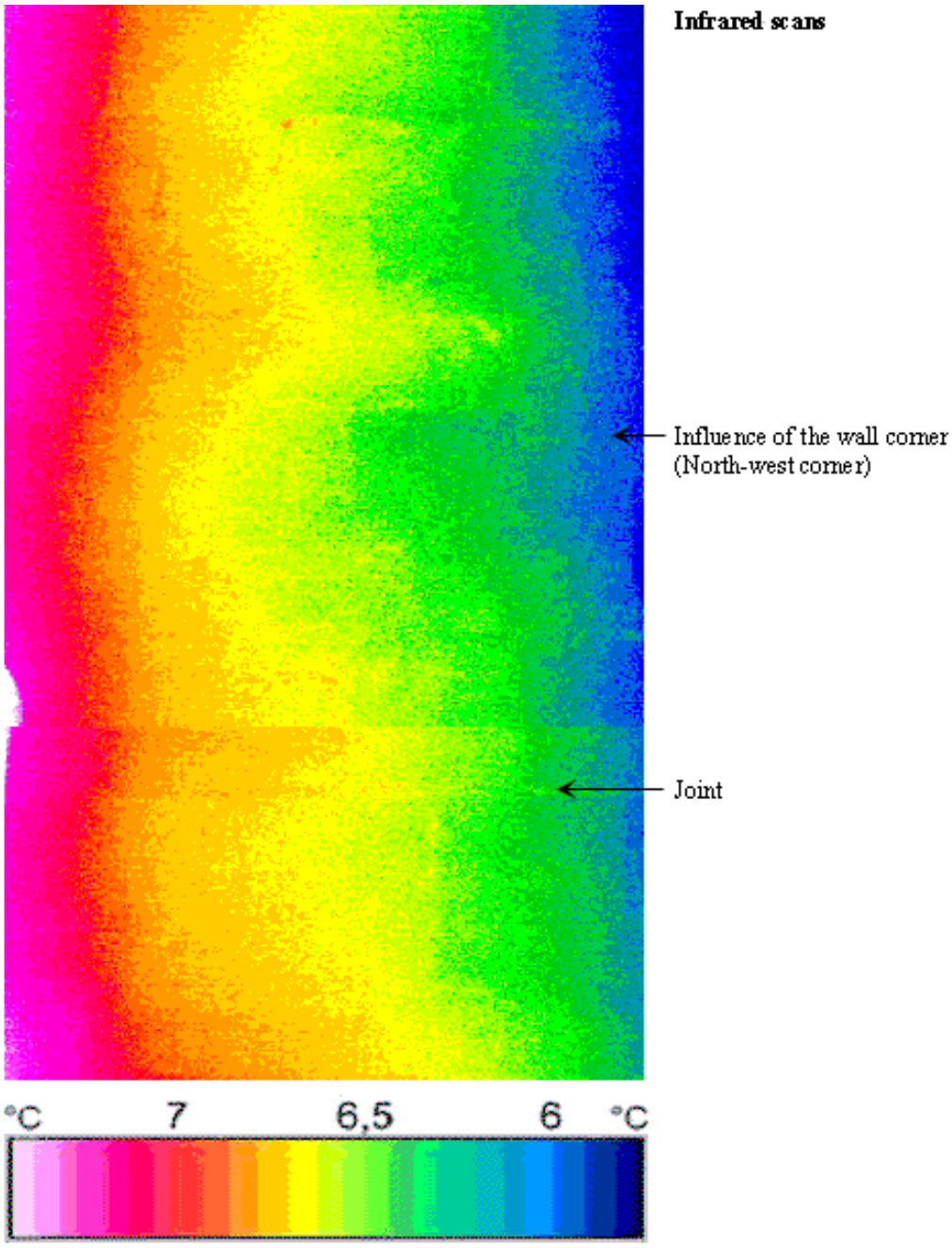


Infrared scan of quadrature column, south side

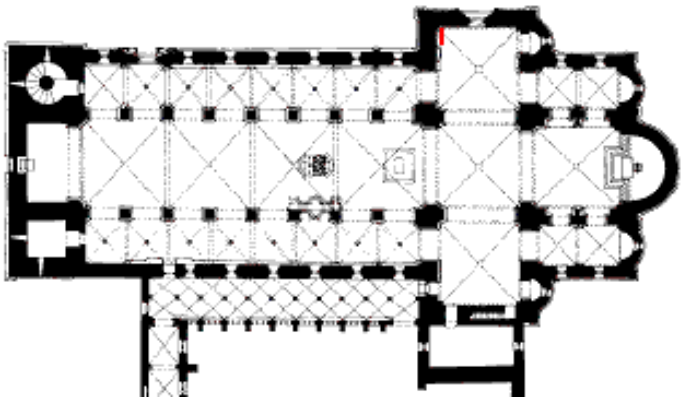


West wall in the northern transept

The west wall is an exterior wall. Due to the influence of the outer climate (air temperature approximately -2°C), the surface temperature level is significantly lower than for the column. At the right border of the infrared scan, the influence of the north-west corner can be seen. The insufficient air circulation in this area causes the existing lower surface temperatures (about 5.5°C). The infrared scan of the wall surface shows the joints between the individual natural stone blocks of the outside masonry. Furthermore, temperature differences between the individual stones are visible. Surface temperature differences can be seen in the area of the visible mural painting damage; however, a definite determination of the causes for these is not possible.

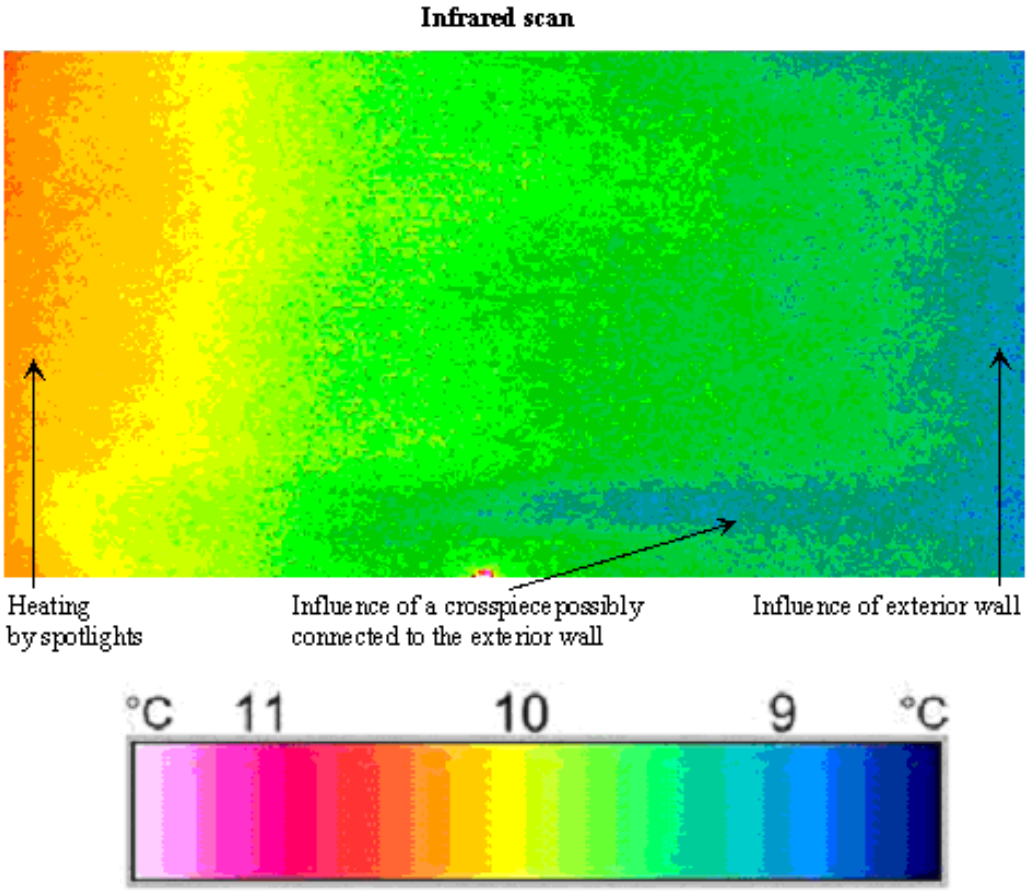


Infrared scan of a partial area of the west wall of the northern transept

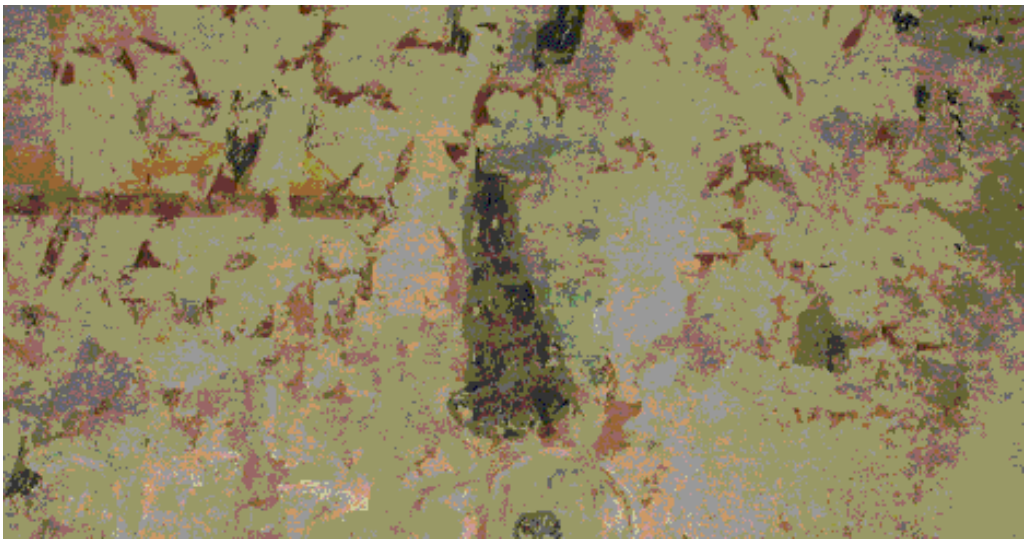


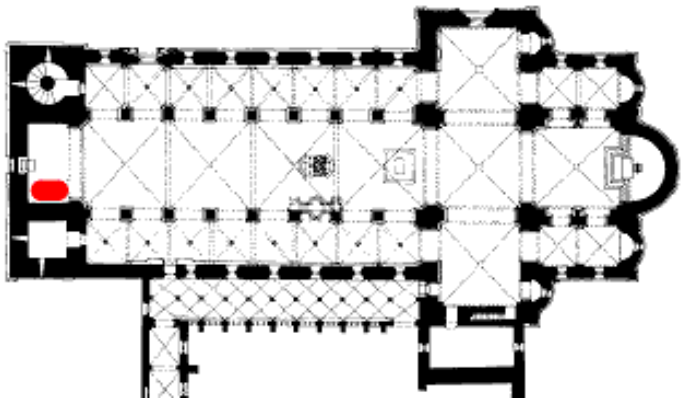
Southern vault in the western end

The western end is covered by a barrel vault witch separates the church room from the organ platform. Laterally, on the side to be investigated (southern side), the vault touches the installation stack, next to the heating room. In the lower third of the scan, a horizontal line-shaped area with distinctively lower temperature can be seen (approximately 8.7°C). Here, the influence of a crosspiece connected to the exterior wall is possible, leading to a lowering of the temperature due to high heat conductivity. The influence of the exterior wall can also be seen in the junction area by the lower surfaces temperatures on the right side (approximately 8.7°C). Due to the low temperature gradient between the inner room and the organ platform, the present thermography does not give any information about loose plaster or peeling paint layers.



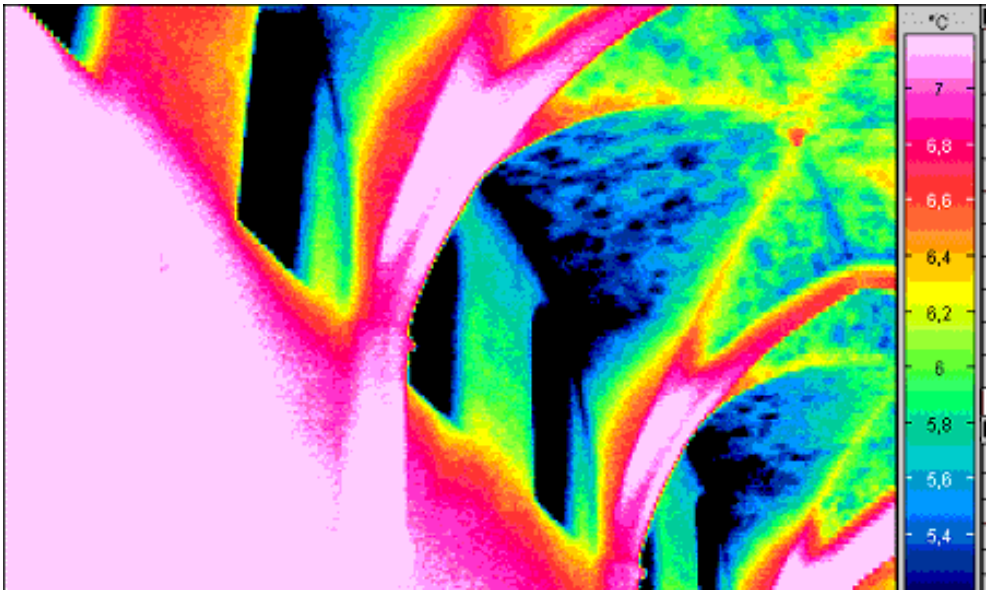
Infrared scan of a partial area of the vault in the western end



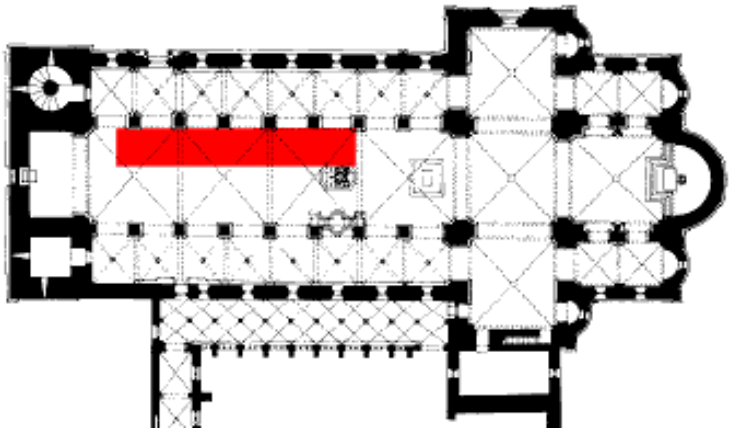


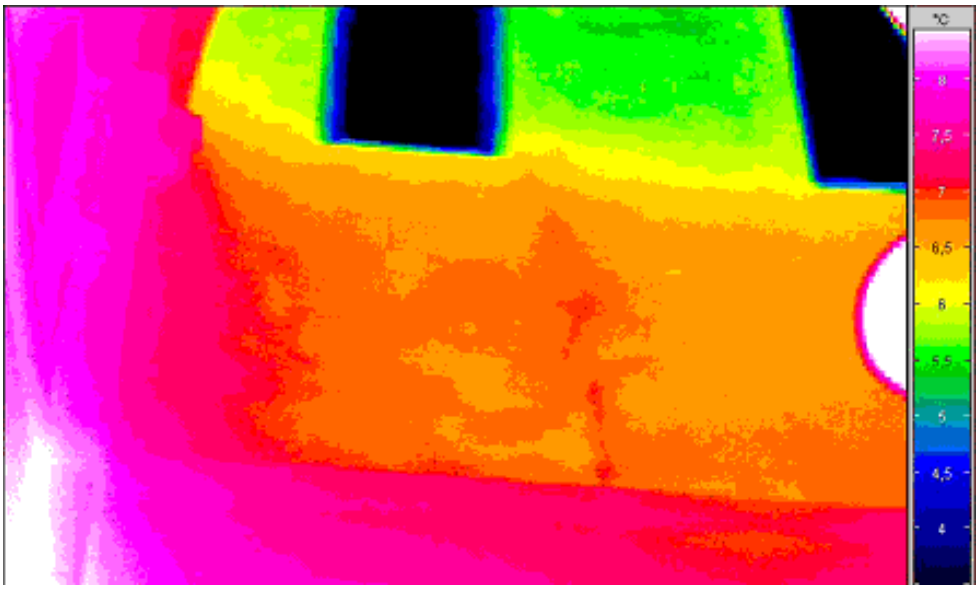
Vault and northern wall of the main nave

The infrared thermographic scan (Fig. 5) shows distinctive temperature differences in the vault area as well as in the wall area. The vault ribs can be recognised by their higher temperature. The different surface temperatures of the vault webs can possibly be explained by the influence of cement injections and the heat conductivity change caused by this. Not only the vaults, but also the wall surfaces show different surface temperatures (Fig. 6). The side walls of the main nave show three temperature zones distinctly separated from each other. The lower, warmer area is the interior wall touching the lateral nave. The centre part is influenced by the unheated roof room above the side naves, which are located behind these walls. In the upper part, the low temperatures are caused by the reduced thickness of the walls, and by the direct influence of the outside air (exterior wall).

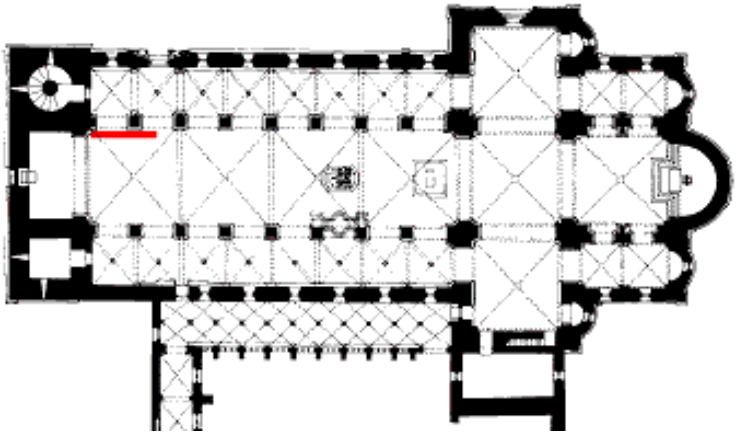


Infrared scan of the vault and the northern wall area of the upper clerestory in the main nave



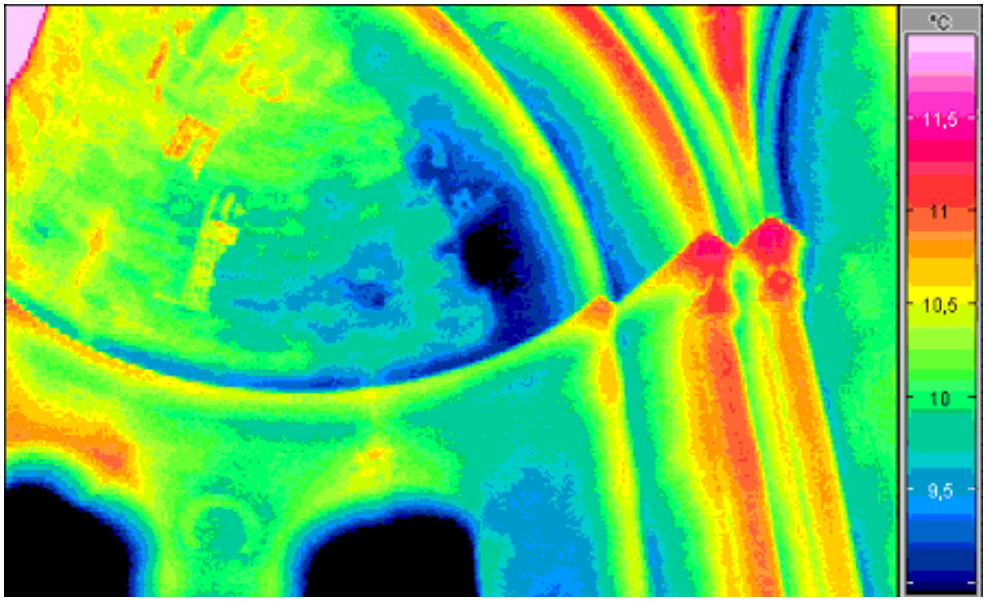


Infrared scan of the northern upper clerestory wall

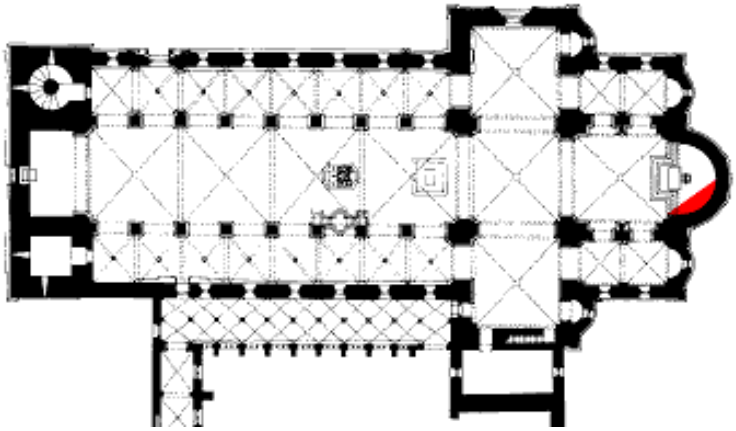


Chancel vault

Some areas in the southern part of the vault, show low surface temperatures. These are caused by humidity (water penetration from the outside).



Infrared scan of the chancel vault



Summary

The contact-less determination of the thermal charge of the building envelope, painted in the interior, was performed with an infrared thermography. It was not possible to determine peeling plaster areas without additional measures (e.g. heating). During the integral analyse, thermal weak-points due to humidity, cement injections, metal armatures and airflow influences were found. These places correspond quite well to the damaged areas. There are extremely low surface temperatures in certain areas. In case of unfavourable climatic conditions, this might lead to the formation of surface condensation water. Taking into account the current salt charge, this condensation would cause further damage.

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Raphael Project

Mapping Structure and Glossary for Wall Paintings

Introduction

Explanation of the Directory Structure

Structure and glossary list for mapping

Division of structure and glossary list into categories

CATEGORY 1.
Materials
Damage phenomena
Treatments

CATEGORY 2.
Photographic information

CATEGORY 3.
Environmental conditions

CATEGORY 4.
Painting technique
Pictorial content

CATEGORY 5.
Sampling

Using the layer codes to map specific data

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Raphael Project

Mapping Structure and Glossary for Wall Paintings

Introduction to the mapping system

The digital mapping system developed within the framework of the Raphael Project is a tool to facilitate the exchange of knowledge and the extraction of information from data collected about various aspects of the investigation, monitoring, conservation and restoration of wall paintings. This communication is enabled by the establishment of a structure, where various terms and phenomena are defined, divided into groups and assigned codes. This particular approach has been created with the intention of using standard CAD software for the handling of the collected information. During the project all participants used Autodesk AutoCAD-Map 2000, but the basic method described here can also be applied to other standard CAD software products. A rectified image (black/white, colour, or special multi-spectral channel) provided the objective reproduction of the scene chosen for mapping at a resolution of 0.1mm/pixel.

In order to be able to use the method, the conservator must abstract from the traditional approaches commonly used for graphic documentation. When creating traditional, hand-drawn maps conservators are mostly fixated on recording phenomena, such as damage, or treatment connected to a particular layer, such as the plaster or paint layer, without first making an attempt to structure the information they will be recording. Among the various types of damage which figure prominently on condition maps are lacunas in the paint or plaster layer. According to the technique of handling data in geographic information systems (GIS) used in geosciences, which has been applied in the Raphael project, lacunas are not recorded, because they denote empty space. What is recorded instead is the existence of the various materials (layers) that wall paintings are composed of. Damage phenomena and various treatments provide additional information about a particular layer. A result of structuring data according to this method is the creation of a quality management system, which is an innovation in the field of conservation of wall paintings.

*Germany, Königslutter, Stiftskirche. The Raphael-team is working **ad situ**.*

The philosophy behind the digital mapping system is the establishment of a flow of data by following a procedure according to a fixed sequence:
1) collection of data (on-site mapping).
2) generation of information by the transformation of the data in a structure.
3) creation of knowledge by handling the information.
The knowledge and information generated by this procedure can then be visualised according to the rules of

thematic cartography (as, for example, the maps created in Tirsted Church – graphic documentation).

Data can only be generated by first establishing the borders of the area to be mapped, and then providing information about the location of the particular layer, i.e. the extent of the plaster on the wall, or the areas where the paint layer is present. The location of the various layers, or, in other words, the distribution of the various materials on the area to be mapped, can be provided by a special multi-spectral photographic technique. If this photographic technique is not used to supply the basic information to the system, this data must be provided by mapping the location of each layer in a separate file manually. By doing this first step, information about the missing areas (lacunas) is computed (according to mathematical set theory rules), and therefore this particular phenomenon is not present together with other damage phenomenon on the structure list.

However, before collecting the mapping data, an organised directory structure must be established.

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Raphael Project

Mapping Structure and Glossary for Wall Paintings

Explanation of the Directory structure

The directory structure proposed here provides an organised system for filing and retrieving information. Here are two examples of the structures implemented for projects in Königslutter Church and in Tirsted Church:

Directory structure.pdf ->

File names in the directory
In order to structure data on an operational system level it is necessary to name data files according to their content. The basic rule for building file names is as follows: year for creation of file_location of mapped area_topic of map. For example, the file **2000_scene45_materials.dwg** contains information about materials mapped in scene 45 carried out in the year 2000. The file **2000_scene45_materials_damages.dwg** is a file with information generated out of two files: **2000_scene45_materials.dwg**. and **2000_scene45_damages.dwg.** In a third example, the file **2000_scene45_plotting.dwg** is the name of the file containing cartographic information, such as legends, map borders, etc. It is important for data security to avoid using the same file names in different directories. By using this structure it is also possible to integrate additional descriptive information via links to external multimedia files (internet, intranet), and from attached databases.

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Mapping Structure and Glossary for Wall Paintings

Structure and glossary list for mapping

This system has been developed as a tool to facilitate the exchange of information using common terminology. Simple and clear definitions of terms used by conservators of wall paintings have not been standardised to date. In order to be able to use the system definitions for all the terms have been discussed and agreed upon within the Raphael working group. A short definition of the terms are included in the structure. An attempt has been made to include terminology referring to all materials, phenomena and aspects of wall painting conservation/restoration, documentation, monitoring, research and investigation.

The structure and glossary list has been divided into 5 categories. Within each category, various types of damages are listed as groups. For example, within the category Damage Phenomena, one can find groups listing, for example, salt damage, cracks, poor cohesion, poor adhesion, etc. Each type of damage is assigned a particular layer code, which is a combination of the first three letters of the category name with the first three letters of the group name. For example, salt damage is assigned the code **dam-sal** (Damage phenomena - salt damage). If desired, the particular types of damages can be divided into subgroups, and the code is extended. For example, if a detailed map is to be made of the location of various types of salts within one painting, one will extend the code with the type of salt: **dam-sal-nit** (nitrates), **dam-sal-chl** (chlorides), etc. Or, if mapping the visual effects of salt damage: **dam-sal-cru** (crust), **dam-sal-pow** (powder), **dam-sal-nee** (needles).
Similarly, within the category Treatments (tre), the areas where different cleaning (**cle**) methods were applied can be mapped: chemical cleaning (**tre-cle-che**); mechanical cleaning (**tre-cle-mec**); enzymatic cleaning (**tre-cle-enz**).

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Mapping Structure and Glossary for Wall Paintings

Structure and Glossary List Categories

Several structure models are proposed, in which topics that are closely related are grouped together. Information within these groups can be combined to provide multi-faceted information about a particular area of a wall painting. At the present time, all information in the system is defined by two dimensions. In the future, the addition of the third dimension will allow for the handling of data where the thickness of a layer, or the space in a room can also be taken into account.

CATEGORY 1. Materials Damage phenomena Treatments	The category Materials is used for creating maps indicating the presence of particular materials in the wall painting. Various damage phenomena listed in the structure can be linked to a particular material. In a similar way various conservation/restoration treatments can be linked to a particular material. In cases where historical treatments are mapped, the year, or general time period for their execution is added to the file name.
CATEGORY 2. Photographic information	This category allows for the indication of specific areas in the painting that were photographed in a special way: a detail where photographs were taken in UV-fluorescent light, or raking light.
CATEGORY 3. Environmental conditions	The information gathered here pertains to the mapping of climatic data on the surface of the walls, such as surface temperature, or areas particularly affected by sunlight. Also included in this group are other physical phenomena, which can affect the condition of the wall painting, such as the occurrence of vibrations.
CATEGORY 4. Painting technique Pictorial content	The category Painting technique provides information about the manner in which the painting was created. This information may or may not have an influence on the condition or treatment, and can be linked to a particular material, damage phenomenon or treatment in Group 1. Also included in this group is information useful for art historical studies. For example, areas of the painted decoration containing images with iconographic content can be differentiated from non-figurative decorations. The location of inscriptions can be recorded, or the participation of different artists in one decoration.
CATEGORY 5. Sampling	This category includes the location of sampling sites, where the extraction of material for analysis provided information about the material, painting technique, environmental conditions (for example humidity), damage phenomena, treatments and so on.

Download category1.pdf
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Download category4.pdf
Download category5.pdf

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Raphael-Project


Königslutter


Tirsted


Britsum

Mapping Structure and Glossary for Wall Paintings

Using layer codes to map specific data

In order to extract data by mathematical computation the mapping structure requires that layers are coded by the rules. The codes for the categories are combined with the groups in the category, together with the year pertaining to the data that is being recorded. The information from two categories can be combined, but the file name must be constructed according to the following rules.

The first element in the layer name is a year – **2000**, for example, will denote that the condition in this year was being recorded in the mapping. In the case of recording the location of previous interventions, the year of that intervention may be used, or if this is unknown, term such as **pre2000** can be used. The second element in the layer name is separated from the year with an underscore (_). This is the code that is a combination of the category and the group **(mat-pla)**, which is the code for Materials and Plaster. A file with the name **2000_mat-pla** will contain information about the distribution of the plaster within the field being mapped. If the purpose of the mapping is to monitor the condition of the plaster, another map can be made in, say, ten years with the file name **2010_mat-pla**, and these two maps can be compared.

It is possible to combine data from two categories to generate more specific information. The layer with the code **2000_mat-pla_tre-rep** contains information about the repairs (rep), which are a group in the category treatments (tre), that were carried out in the plaster layer (pla), which is a group in the category materials (mat) in the year 2000. Other examples:
2000_mat-pai_dam-pad-fla (material-paint layer_damage phenomena-poor adhesion-flaking
2000_mat-pla_tre-con-sil (material-plaster_treatment-consolidation-silicone esters)

2000_mat-pla_sam-che-sal (material-plaster_sampling-chemical analysis-salt content)

Germany, Königslutter Stiftskirche. Medieval wall painting in the lower storey of the westwork, detail of the tree of jesse. Original AutoCAD-mapping of damage phenomena on the base of a rectified color image. Foto: Deutsches Bergbau-Museum Bochum

figure02.dwf->
figure02.pdf->

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Raphael Project

Mapping Structure and Glossary for Wall Paintings

Guidelines for visualisation

Specific colours have not been assigned to the mapping of different phenomena. This is due to the creation of an open system, where numerous combinations between groups and categories are possible. Depending on the type of information one wants to extract from the mapped data different colours, hatching and symbols must be chosen in each individual case. When choosing these visual elements it is important to be aware of what colour combinations work well together optically, resulting in an easily understood map. For example, when a thematic map for the visualisation of damage phenomena on plaster is planned, one could choose orange lines for cracks; green hatched areas for cavities, pink hatched areas for mechanical abrasions, and blue hatched areas for areas deteriorated by salts. If a more detailed study of the different types of salt efflorescence in one area is planned, it would be necessary to assign a different colour to each type of salt.

It is advantageous to create one layer for mapping the outlines and another for the mapping of hatching that will fill these areas. For example, information about the location of salt damage in the plaster layer will be placed in two layers: **2000_mat-pla_dam-sal** will be the layer name where the outlines will be mapped; **2000_mat-pla_dam-sal_hat** will be the layer where the hatching will be done. The separation of the outlines and the filling allows the visualisation of an area where the boundary is not very sharp. This is done by freezing the outline layer and plotting the hatching.

Read more

Raphael Project

Databases of Medieval Wallpaintings in Lower Saxony

Object databases and Internet activities

The "Database of Medieval Wall Paintings in Lower Saxony" – Service Possibilities for the Care of Monuments and Cultural Science

Historic wall and ceiling paintings are important evidence of our cultural heritage. The decorated painting of rooms has been an essential part of interior design in different cultures and epochs. Through illustration, they can convey cultural values and norms. As eloquent witnesses of their time of execution, they reflect cultural developments and provide information about changes or continuity in customs, morals, religion, world view, art perception and taste over time. Moreover, a chronological history of craftsmanship and technology can be demonstrated.

From the Middle Ages alone, Lower Saxony, Germany, has a stock of more than 234 important painted interiors. In recent years, it has been possible, within the framework of an areaspecific computer-aided inventory, to document and evaluate this stock according to diffusion and age, principal damage and art-historical content. A future advancement of this inventory project will be a corpus with a corresponding graphic documentation catalogue relating to the condition of the works.

In order to quickly obtain first results, a reduced version of a practice-orientated database, containing basic information, was developed cooperatively between documentation specialists and heritage managers. It can be iteratively extended and contains the following elements:

- Data referring to buildings (owner, contact person, heating, material, damage to building, etc.).

- Abbreviated description of the iconographic context (evaluation of the representations according to the art-historical classification system ICONCLASS of the Dutch Academy of Sciences.

- Location of the individual paintings within the building, with graphic orientation through reference maps.

- Stock-taking and condition recording of the wall paintings technique, previous restoration, decay, etc.).

- Documentation photographs as a visual aid.

- Literature quotations according to international standards, with annotations of statements relevant to the building and the paintings.

Through a search module, it is possible to answer a variety of queries for daily cultural heritage management. Possible search questions out of the wide range of art-historical and management queries could include:

- In which cultural monuments in the district of Hildesheim do medieval wall paintings exist?

- Which Lower Saxony wall paintings from the 14th century depict the birth of Christ?

- Which wall paintings in the Braunschweiger Dome show damage due to algae growth or salt crystallization?

Once the potential for development has been fully exploited, a whole host of problems deriving from the care of monuments can potentially be solved. For a global conservation management plan, this would include the possibility of creating an object-orientated monitoring system for maintenance and quality management, or – considering the stock of Lower Saxony wall paintings as a whole – a damage catalogue based on graphic documentation, covering the entire territory.

The "Database of Medieval Wall Paintings in Lower Saxony" : Excerpt.

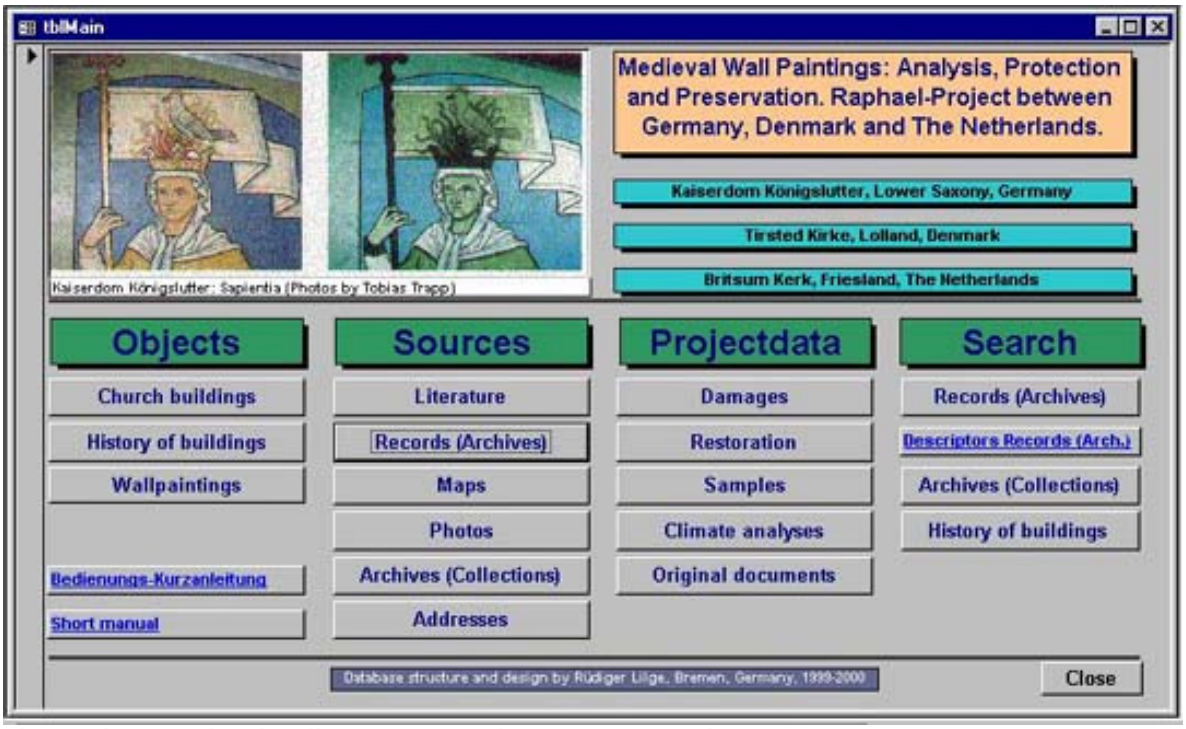
In context of the Raphael project, the structure of this database has been modified and the database has prepared to be linked to"www.medieval-image.org", which is a network of Scandinavian databases about medieval wall paintings, administered by the server of the University of Copenhagen.

The data about the wall paintings in Lower Saxony can be retrieved here and consist of:

- Illustrations of painting scenes
- Scene descriptions and classifications
- Datings
- Restoration history
- Additional information such as names and places of the churches

The Database "Medieval Wall Paintings in Königslutter"

This database contains detailed information particularly about the building and restoration history of the Stiftskirche Königslutter which has been investigated and collected anew during the Raphael project. A result was the extension of the data about the Stiftskirche Königslutter in the database "Medieval Wall Paintings in Lower Saxony" (see above) of approx. 700 archival proofs and approx. 1350 photo proofs. In addition, the possibility of the recording of archival and photo proofs of all the other objects in the database of wall paintings could be created through this.



The Database "Medieval Wall Paintings – Analysis, Protection and Preservation": Frontpage.

It has been planned to put a modified extract out of this specific database in the internet. Following data can be retrieved:

- **Painting specific data**
- Scene descriptions (partly with illustrations)
- Classifications by Iconclass
- Restoration history

- **Object related data**
- Basic data (address) with illustration
- Building history
- Literature proof
- Archival proof

"Thesaurus for wall paintings"

This controlled, logically structured and expandable headword vocabulary to the main categories "wall paintings" and "restoration" was developed in various projects since 1990. As a result of the international co-operation within the Raphael project, it is available in a bilingual version for the first time, now.

The "Thesaurus for wall paintings" has a particular meaning to the understanding of thematically relevant documents as well as to the input and retrieval of these documents in databases.

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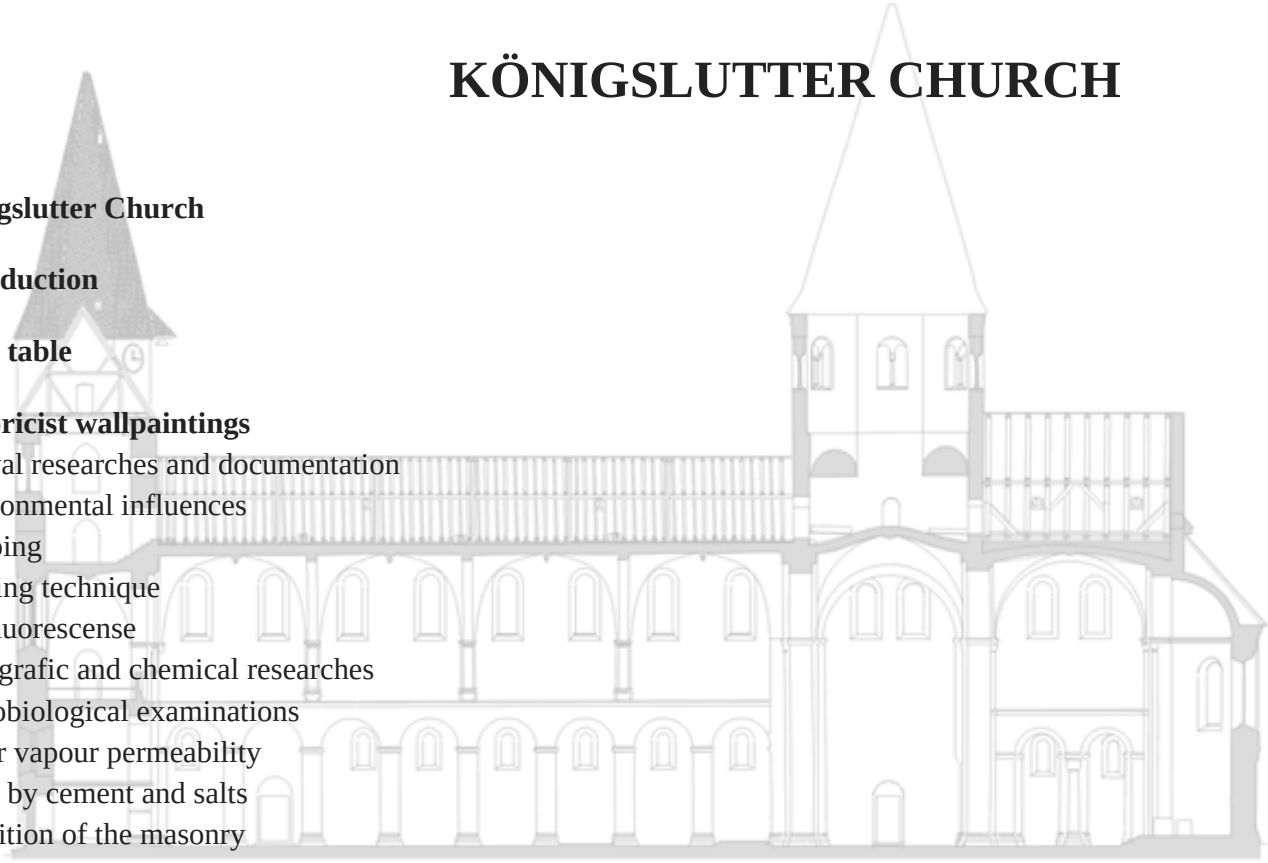
KÖNIGSLUTTER CHURCH



Literature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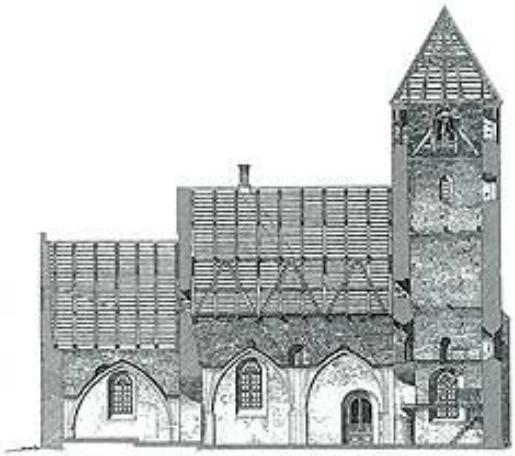
Introduction

Tirsted Church is located on the island of Lolland, in the southern part of Denmark. The church consists of a chancel, a nave with two bays and a tower, built in the Romanesque period – around the beginning of the 13th century. At that time the church had a flat ceiling, and the earliest decoration on the red brick walls was of a series of simple consecration crosses. This situation did not last long, as it seems that a rendering was applied to the interior walls in the 13th century, and around 1400 – 1425 the walls were decorated with Gothic wall paintings In the second half of the 15th century quadripartite vaults were erected.



The limewashed surface of these vaults was decorated with late Gothic wall paintings around 1500 by the Elmelunde Workshop, which was active in southern Denmark and the westernmost part of Sweden (at that time a part of the Kingdom of Denmark). As in the case of most of the medieval wall paintings in Denmark, the decorated vault in Tirsted church was limewashed after the Reformation, possibly in connection with the Pietist movement in the 17th century. The porch on the south side of the church was erected during the renovation of the church in 1891-92. The wall paintings seen today in the chancel were uncovered in 1889 – 92, and are the remainder of the decoration from 1400 – 1425, which originally existed also in the nave.

An extensive renovation took place in the church in 1891 – 92. The uncovering of the early 15th century wall paintings in the chancel took place at this time. This was done at the expense of the late Gothic paintings on the vaults, which were dismantled in keeping with the European trend in the renovation of architecture in the second half of the 19th century, whereby later additions to the original structure were removed in an attempt to bring the monument back to its first form. Throughout the century following the uncovering and restoration of the paintings in 1892 there had been many interventions, including four major re-restorations of the entire decoration – in 1929 , 1940, 1964-65, 1999-2000, and several local attempts to preserve deteriorated scenes – in 1972, 1982, 1994 – ending in the detachment and transfer of several scenes to chipboards in 1985 and honeycomb plates in 1994.

The deterioration of the wall paintings can be primarily attributed to salt efflorescence. Large portions of the painting have been lost, and the various earlier reconstructions have made decisions pertaining to the aesthetic presentation of the decoration difficult during the most recent restoration, which took place in 1999 – 2000.

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The earliest painted decoration in Tirsted Church

In the 13th century the interior of Tirsted Church was decorated very simply. Mortar was applied only in the areas where a series of round consecration crosses were painted. The circumference of the circles was incised in the fresh plaster with the help of a compass, the point of which sank deeply in the centre. The circle (ca 20 cm in diameter) was divided into quarters by a bold white line, about 2 cm wide, and the four fields formed by this division were painted with a red-ochre colour. Finally, a wide white line was painted around the circumference. The paint was applied very quickly, and the impasto of the white paint indicates that a slaked lime putty was used.

The remaining surface in the interior consisted of red bricks. The bricks were laid with one header alternating with two faces, forming a pattern where the headers were lined up vertically, forming the so-called monk's bond. Recent investigation of the original brickwork has revealed that a layer of red paint was applied to the bricks, leaving the white mortar of the joints uncovered.

It was not possible to determine whether this practice was confined only to the slightly discoloured and deformed bricks, or whether all the bricks were painted. In any case, it seems that the appearance of neat brickwork was important, and that in the least, corners and edges were retouched so that they would appear to be straight and sharp.

During the renovation of the church at the end of the 19th century, an attempt was made to re-establish the impression of the early decoration in the nave, without resorting to actually painting the bricks. A few of the consecration crosses were replicated on the brickwork. These, however, have none of the spontaneity of the original crosses.

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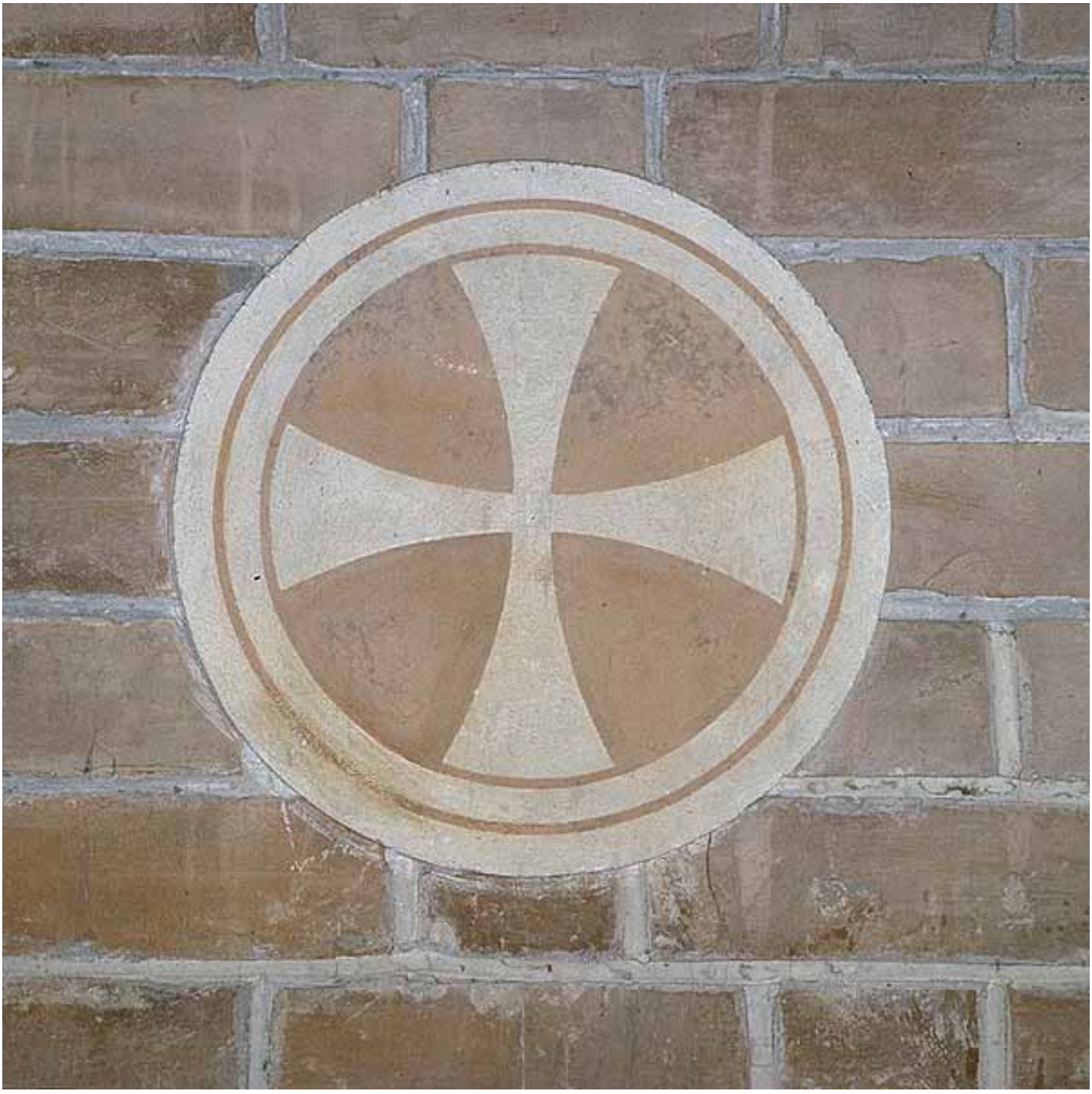

Raphael Project

The Late Gothic Wall Paintings on the Vaults

In 1889 Jakob Kornerup (or, rather, workmen under his instruction) knocked off the limewash on the vaults in the nave of the church, uncovering some well-preserved wall paintings. The vaults had been richly decorated by the Elmelunde Workshop around 1500. Three of the scenes were documented graphically by Kornerup, the rest were described by him in his written report.

A precisely executed watercolour shows a very interesting scene on the north web of the western bay: a large figure of a naked man was painted in the centre of the web, and seven dragon heads were painted sprouting from various parts of his body. Small figures were painted in the gapping mouths of the dragons. Each of these figures symbolised a particular deadly sin that was connected to the part of the body the dragon sprang from. Inscribed scrolls identify these sins: a man drinking from a flask symbolises gluttony – gula (inscription is missing) (connected to the mouth); the embracing couple placed in the mouth of the dragon springing from the groin symbolises lust - luxuria; a man holding a dagger and a knife represents anger - ira (connected to the left hand); a man holding a gold ring symbolises arrogance - superbia (connected to the right hand); envy – invidia – is depicted by a man holding two sacks (springing from the stomach); the dragon wound around the feet holds a sleeping man in his mouth, symbolising sloth – acedia (misspelled as accidia on the scroll); avarice – auaricia – is depicted by a man gnawing on a bone (springing from the heart).

An embracing couple is depicted in the pendentive to the left of the scene presenting the seven deadly sins. The man is being coached by a large devil resembling a cat who is clinging to the man's back. Beneath them is a couple – the man is beating a drum, while the woman is playing a flute.
Other scenes from the vault crowning the western bay in the nave described in Kornerup's report indicate that the theme on this vault was a mixture of secular and religious scenes of a moralising nature, some of which are difficult to interpret. On the east web two columns flanked a saint standing over a kneeling man, and placing a hand on his head. Two small figures were painted falling off the top of one of the columns, while a dove was painted sitting on the top of the other. Also included on this web was another man kneeling before a seated figure who was protected by a patron saint. The upper triangle of the web near the keystone of the rib crossing was filled with clouds surrounding the figure of God the Father.
The south web contained a large naked figure of Christ holding his arms out away from his torso – the nail holes visible in his palms and feet, and the lance wound was seen under his chest. A poor man and a rich man knelt at his side. Each of the man's thoughts or prayers were depicted in the form of lines connecting the mouth to an object. The poor man's thoughts were connected to the wounds on Christ's body, while the lines drawn from the mouth of the rich man ended in his worldly goods – his moneybox, his wine cask, his fireplace where a woman was cooking food, and his child wrapped in swaddling clothes. An inscription over the poor man read: Deus propitius esto mitri peccatori – May God have mercy on my sins.
On the west web a devil tempted a poor man with a purse; three devils lured a young man; a procreating couple was painted in one pendentive; a man relieving himself in a chamber pot was painted in the other.

The eastern vault nearer the chancel was devoted to Biblical themes, though not exclusively, as seen on another of Kornerup's watercolour drawings, which shows a man cutting the tail off a horse. This scene was placed in the corner of the west web, which contained three other scenes: the Annunciation, the Temptation of Adam and Eve, and the Nativity. The north web contained a scene depicting the Three Kings arriving to Bethlehem on horseback, bearing their gifts; another showed the kneeling kings presenting their gifts to Jesus, who was sitting in Mary's lap. In one pendentive two women were seen sitting on a bench, behind which two devils were standing, one of whom was embracing one of the women. The main portion of the east web was

devoted to the scenes of the Murder of the Infants and Adam and Eve's expulsion from Paradise. Two figures, probably Abraham and Isaac, with firewood on their backs were placed in one pendentive. The other pendentive showed a man with three cats, one of which was getting his claws clipped off by the man, as seen in a watercolour drawing. The main theme depicted on the south web was the Flight to Egypt. A soldier asked a peasant with a scythe if he has seen Joseph and Mary, who were also depicted on another part of the web. A large church with three towers was also painted on the same web. A devil sitting on the tower in the middle broke off the spire in order to cast it down to the earth.

All of the scenes described here were destroyed when the vaults were dismantled in 1891. The vault in the chancel was torn down without investigating what scenes were painted there.

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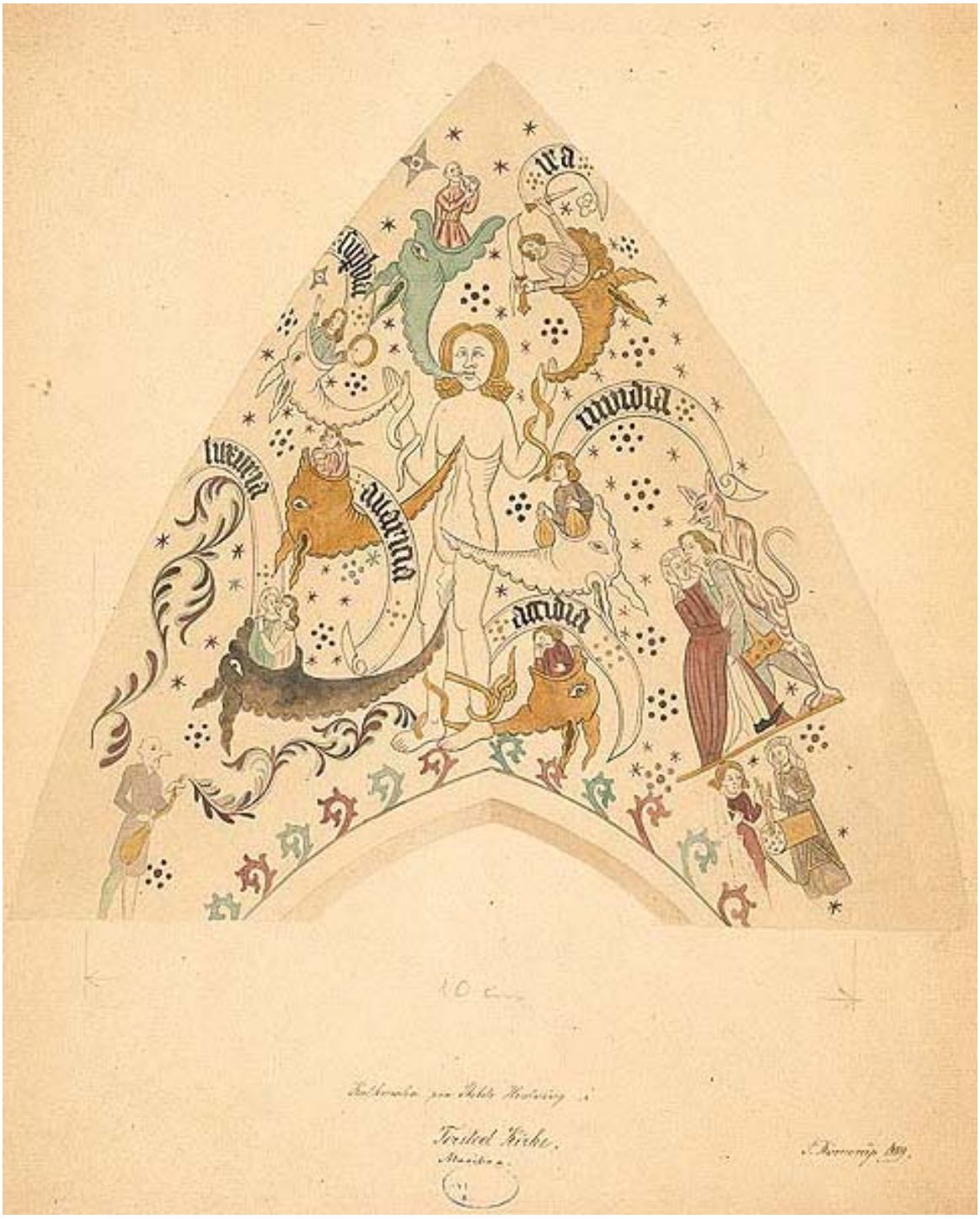
Tristel Kirche.


Vestbed Kirke.

Raphael Project

Dismantling of the vaults

When Jakob Kornerup uncovered portions of the Gothic wall paintings on the walls in the chancel in 1876 he knew the paintings hidden by the vaults were of high iconographic value. The notion of destroying the vaults crystallised even before Kornerup uncovered the wall paintings on them. According to him the original monumental and imposing character of the interior could be recreated by removing the vaults. The arguments for this plan were strengthened by the discovery of a decoration on the wall that belong to the pre-vault period, and the desire to uncover this decoration most likely influenced his evaluation of the paintings on the vault. In a letter from 1892 to the director of the National Museum – Christian Herbst, Kornerup wrote: “In the case of a possible restoration of the church there can be no doubt that the chancel vault must also be removed, and the older painted decoration in the chancel should be preserved and renewed.” The word *also* in this citation proves that there already existed a plan for the removal of the vaults in the nave at that time. In the summer of 1889 the late Gothic decoration on the vaults was uncovered in the nave, it seems only in order to see what would be destroyed. Kornerup’s attitude toward the late Gothic paintings was negative from the start. “Referring to the pictorial content, these paintings are not only strange, but in several places highly indecent, as to their execution [they] belong to the crudest of what has yet been found of wall paintings.” He decided only to document three scenes in watercolours. “Should it be necessary to draw everything, which [these paintings] hardly deserve, 2-3 additional weeks would be needed.....The question of what is to be done with these paintings is not relevant, as the vaults are intended to be dismantled, so that Tirsted Church can regain its original loftiness and beauty.” The Directory Board for the Preservation of Antiquarian Monuments agreed with Kornerup: “there is no ground to regret the loss of the decoration on the vaults.” The priest in Tirsted also expressed his approval of the plan so that the: “...highly offensive paintings will fortunately disappear again.” So, Tirsted Church was closed for a year and a half, and the renovation of the church began in 1891.

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The renovation of Tirsted Church in 1891-92

The major renovation of Tirsted Church (in recent times) initiated with the dismantling of the vaults in the summer of 1891. The architect Ove Petersen was in charge of the project, but Jacob Kornerup (a professor at the art academy working also as an archaeologist and restorer), was very much involved. The idea of removing additions to the original architectural structure in an attempt to return to its initial appearance was not a new or provocative idea at the end of the 19th century. Stylistic restorations of monuments had been carried out in Europe since the end of the first half of the 19th century.
After the removal of the vault in the chancel, the decoration from beginning of the 15th century was uncovered in this part of the church. A fragment of the same decoration depicting St. Anthony was found by Kornerup in the nave before the vault was torn down. However, no paintings from this period survived the vault-removal operation in the nave. Instead, the raw brick wall was exposed, in keeping with appearance of the interior in the earliest stage after the church was built, before the Gothic paintings were created. The removal of the vaults did not really enable the recreation of the original interior. This could only have been achieved had the paintings in the chancel also been knocked off the brick walls.

The situation was additionally confused by Kornerup, who was allowed to design the interior of the nave after the removal of the vaults. Two years previously, when he removed portions of the limewash revealing fragments of the paintings from the 15th century in the chancel, Kornerup avidly studied the non-figurative decorative scrollwork. He had two artists come to the church in August of 1889 to help him draw samples of the ornamental features because he considered these to be the uniting elements in the Gothic decoration.

He chose to reuse these decorations around the arches and on the splays in the windows in the nave. These decorative bands, executed on a layer of plaster (in contrast to the surrounding exposed masonry), were supposedly introduced in the nave in order to provide a harmonising element that would create a visual bridge between the two rooms. An additional accent was created by inserting the altarpiece from 1848, a copy of a relief by Thorvalden depicting Christ in Emaus, into the east wall of the nave, above the chancel arch. In keeping with the earliest decoration in the church, a few consecration crosses were reconstructed on the lower walls in the nave.

The renovation of the church also involved the re-opening of the original high-sitting windows in the nave as well as in the chancel. At the same time the larger windows that were created when the vaults were erected were bricked to. In addition, a cement floor was cast, and red bricks were laid out on it in a herringbone pattern. But the arguably most significant modernisation was the establishment of a central heating system with radiators in place of the iron stoves. The removal of the vaults, the introduction of central heating, and the liberal use of cement mortar created a drastically altered interior climate in the church. In hindsight, one can see that more attention should have been paid to improving the drainage around the foundation of the building. As it was, the moisture entering the walls filled the pores of the plaster and bricks with solutions of water-soluble salts, which migrated to the inner surface as a result of the central heating. As they passed into a climate of low relative humidity, the salts crystallised, causing much damage to the plaster and paint layers. In less than twenty-five years the paintings in the chancel were in need of re-restoration.

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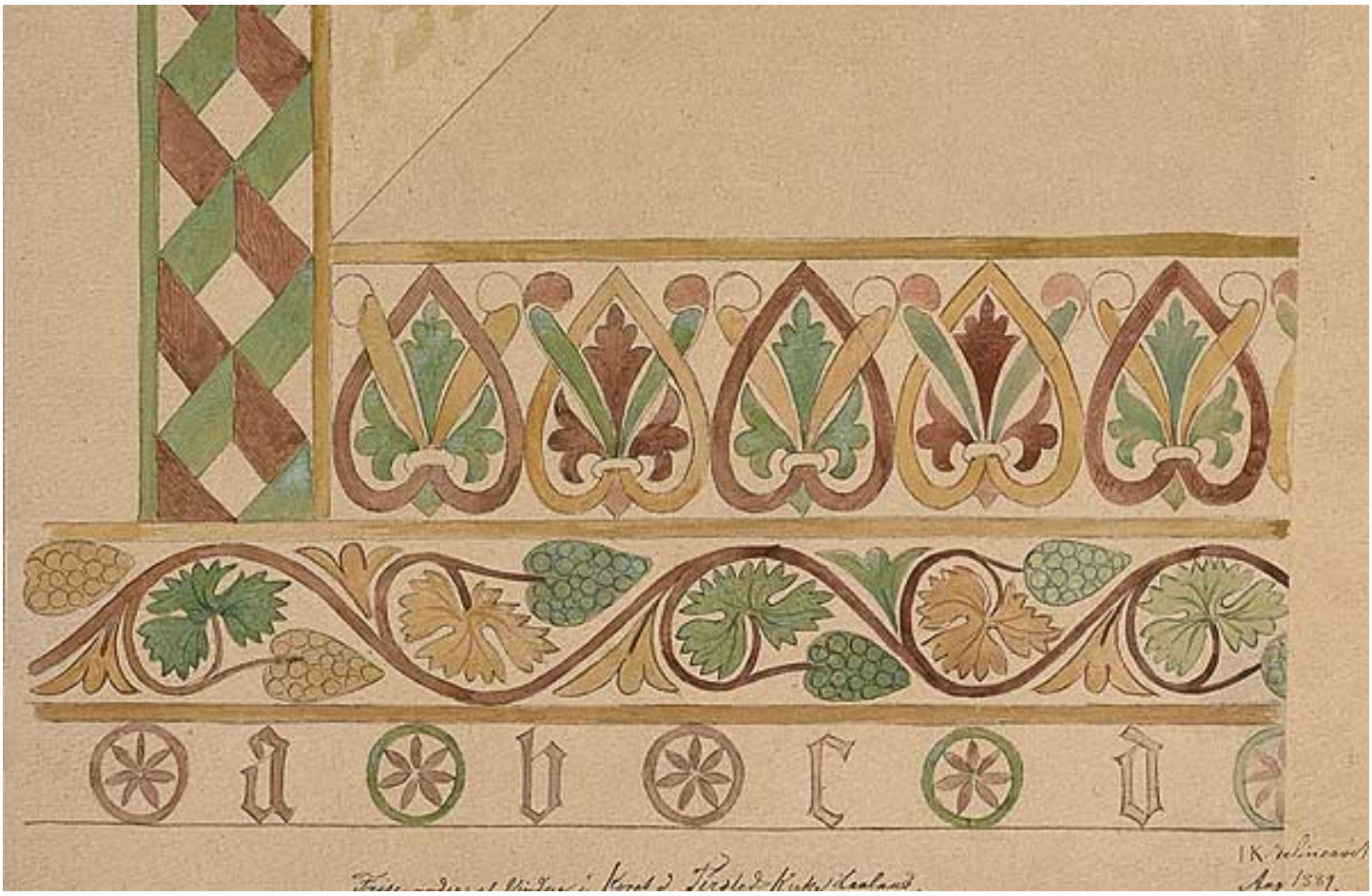

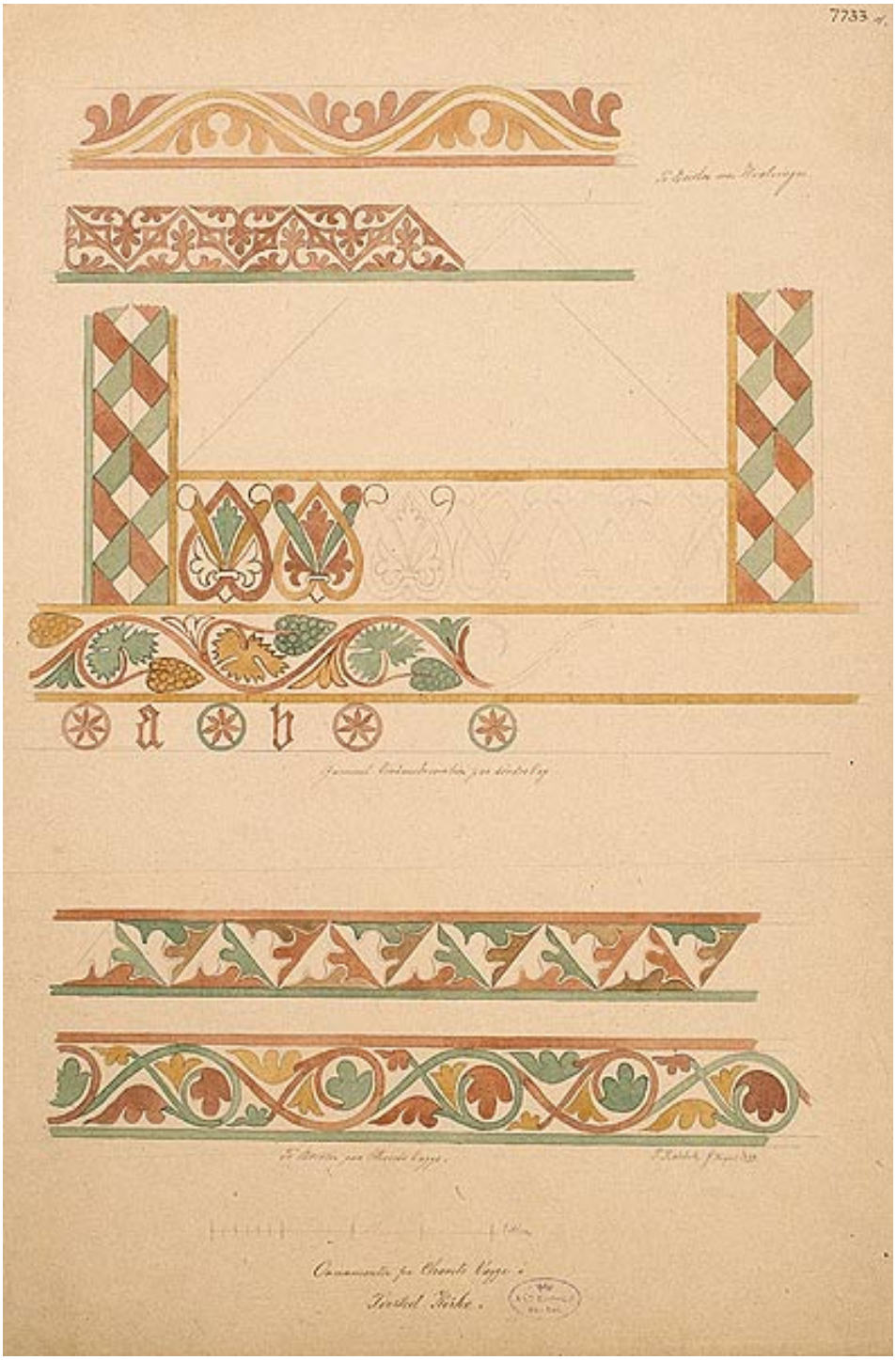
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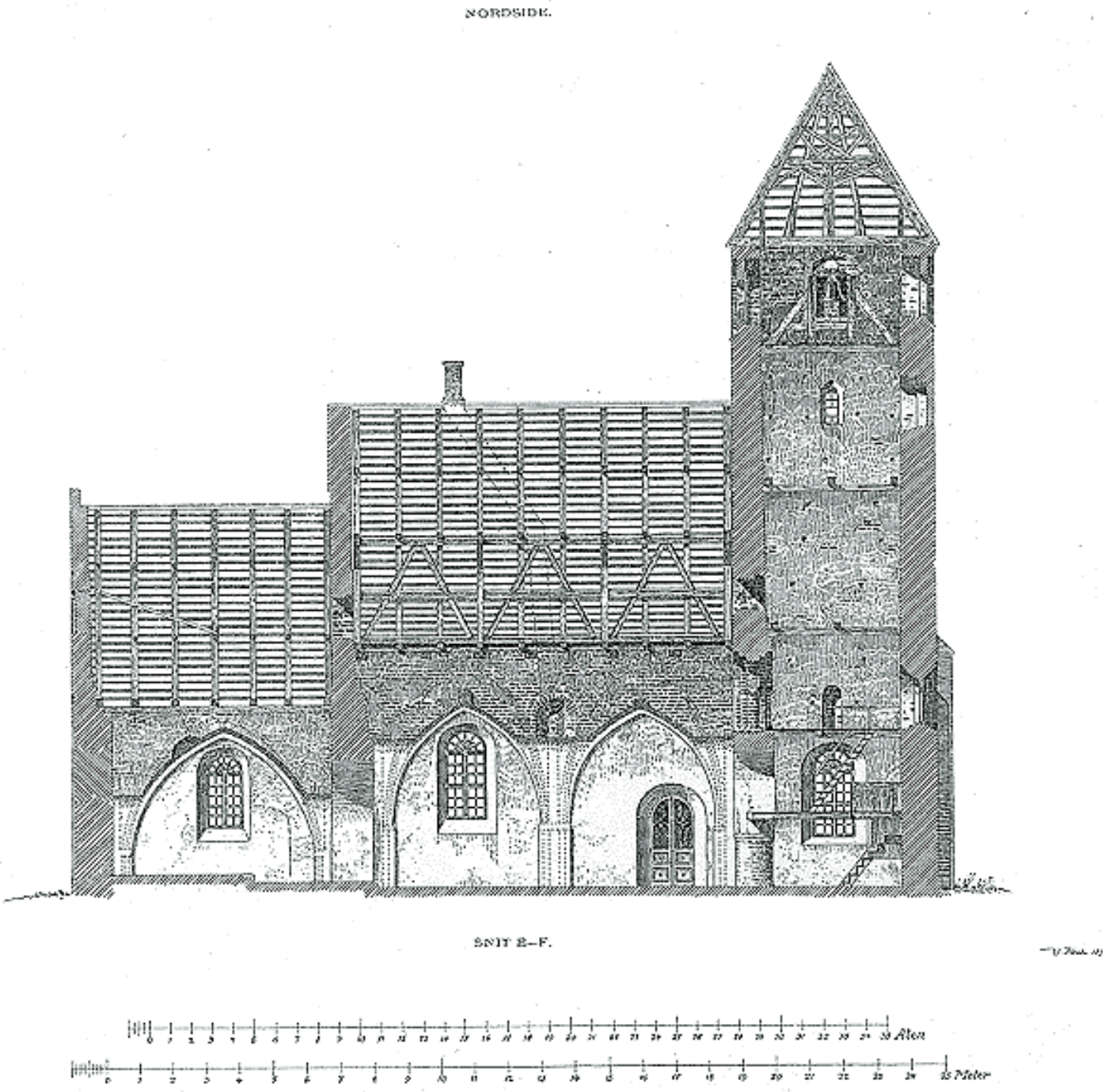
The north side of Tirsted Church



Raphael Project

The re-restoration of the wall paintings in 1929

A photograph of the south-east part of the chancel from 1917 shows what poor condition the wall paintings were in a mere 25 years after their uncovering and restoration. The damage is clearly connected to problems with moisture in the plaster layer. Numerous light and dark-coloured stains had formed on the surface of the plaster. The damage generally follows the joints of the underlying bricks, and therefore can be assumed to be a result of the transport of water-soluble salts through the joint mortar. The stains forming on the interior surface were probably also a result of the presence of various salt ions, which were transported in the porous substrate.

In 1927 the wall paintings restorer employed by the National Museum, Egmont Lind, inspected the paintings on the chancel walls, the condition of which he described as “mildly stated – horrible”. He concluded that the salt damage was caused by the radiators that were heating the interior. The first re-restoration began the 15th of February 1929 and continued over four months, ending the 9th of July. It was mostly carried out by Egmont Lind, with the participation of Eigil Rothe to a lesser degree.

Lind does not reveal details of the treatment, stating only that the scenes were dusted off, and impregnated with Carlsberg Preparation (an as of yet unidentified concoction prepared by the Carlsberg Brewery for the treatment of wall paintings in Denmark). He was, however, quite critical of Kornerup’s reconstructions, which he considered to be based “to a high degree on free fantasy.” Other reconstructions were “carried out with little connection to a medieval painting style.” Kornerup’s report from 1929 concentrates on the artistic changes he made to the painting so that would more closely resemble a Gothic painting. The difference in the painting styles of Kornerup and Lind can be seen on a fragment where Lind’s reconstruction was partially removed to reveal the reconstruction of Kornerup underneath.
Another example of changes made in the reconstructed areas can be seen on the kneeling figure of Gideon, depicted as a knight in armour, which was partially destroyed by the insertion of a window in the south wall after the vaults were built.

We can only see about half of the figure on Kornerup’s watercolour from 1876. The part that is visible is documented as dark lines on a light background, and a photograph from 1917 shows that this is the way Kornerup reconstructed this figure. However, Lind chose to repaint the figure, changing the armour to black, and making the outlines white. On the same scene, the sleeping figure of Esai is seen with the Tree of Jesse growing out of his chest. Lind not only moved the sprouting branch from the right side of the chest to the middle, but he also added many new branches and flowers. In addition, Lind changed the beard and hair on the sleeping figure, and many other details, such as the clouds depicting heaven, and the water falling from the sky. In effect, Lind’s additions were more often than not a result of his fantasy, despite the fact that this was his strongest criticism against Kornerup’s restoration.

An interesting detail affecting both Kornerup's and Lind's restoration reflects the prevailing moral attitudes at the end of the 19th and beginning of the 20th centuries. In the scene depicting the meeting of Mary and Elisabeth, both of the pregnant women were painting with an opening in their stomachs showing the tiny figures of Christ the Child and St. John the Baptist. The display of such corporal details was unacceptable when Kornerup uncovered the paintings, and the wombs on both figures were covered over with gypsum and their dresses were painted on top. Lind removed the gypsum despite the fact that "the exposition of the embryos strongly shocked the moral opinion of the priest and some of the members of the parochial church council."

Lind does not go into details about the technical problems during the restoration in 1929, but he does remark that the drain around the church was in miserable condition, and that the moisture in walls greatly interfered with the work. The fact that he did go ahead with the restoration work on the paintings despite the unresolved problems with rising damp was something he would come to regret. Even before his work was finished he saw moisture stains forming on areas of the painting not affected earlier. (Though he states that the damage was mostly occurring outside of the figurative scenes). Two years later the paintings were so damaged by the moisture that a complaint was lodged by the church deanery, who, supported by the professional opinion of a local mason, regarded the results of Lind's restoration as unsatisfactory. Lind returned to the church in 1931 to inspect the situation.

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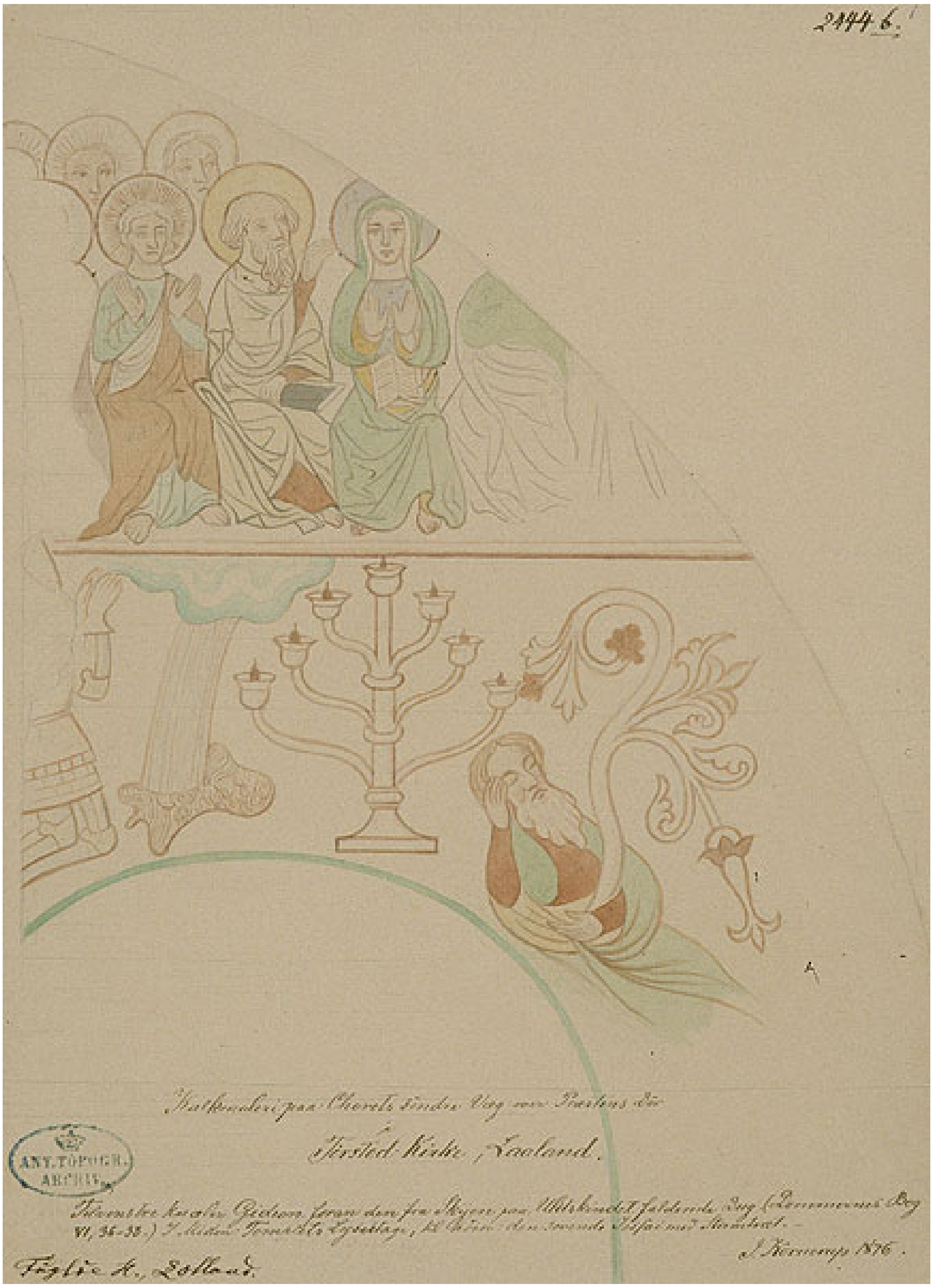

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Tirsted Kirke, Laaland.
ANT. TOPOGR. ARCHIV.
J. Kornerup 1876.


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The situation after the re-restoration in 1931

In the beginning of 1931 the National Museum received a complaint from Tirsted Church counsel, concerned about the rapidly deteriorating condition of the wall paintings that Egmont Lind and Eigil Rothe had restored two years earlier. The critique centred on the opinion of the church deanery, who recruited a local mason to support their theory that the restoration in 1929 was carried out in the wrong period of the year (it took place in the later winter and spring months), and therefore the result of the work was unsatisfactory. Lind's rebuttal of this accusation constitutes very interesting reading. It demonstrates how little at that time was understood of the mechanisms and conditions governing moisture distribution and salt crystallisation.

Lind was aware of the horrible state of the drain around the foundation of the church in 1929. He even noted that water was standing in the cellar under the chancel, but he proceeded nevertheless with the restoration of the wall paintings. Therefore, it is difficult to understand his excuse two years later "...neither the now deceased Conservator Eigil Rothe nor I could know at the time the restoration took place that the walls would suffer to such a degree from moisture.....Had the church council informed Conservator Rothe or me of the true condition of the drain, then the work would have obviously not been started until the circumstances were improved." Lind defends the choice of the cold months as the prime time for such a restoration to take place. In fact, according to him, thanks to the fact that the winter of 1929 was very severe, and the heating was turned on often and on full power, this was the very reason that the treatment could take place at all, as the interior walls were able to dry out to a degree that permitted the impregnation of the scenes where the damage was most severe.

Lind also expresses his satisfaction with the results of the impregnation with the Carlsberg Preparation on the scenes that were selected for this treatment, stating that all expectations were exceeded. He attributed the appearance two years later of moisture stains on the scenes that were not impregnated in 1929 (the ones in better condition at that time) to the fact that they did not receive the same protection as the more deteriorated scenes. It is obvious that he was not aware that the impregnation itself could have been the reason for the alarming state of the adjacent scenes. It is very likely that moisture was prevented from moving through the impregnated areas, and as a result began to pass through the non-treated, and therefore, more porous areas of the painting. When the heat was turned on in the winter of 1929/30 salts started to crystallise in the previously well preserved scenes.

The impregnation of certain areas with the Carlsberg Preparation, however, was not the only reason for the appearance of salts in the adjacent areas. Lind and Rothe retained most of the mortar repairs that were carried out during Kornerup's restoration in 1891-2. There where Lind found Kornerup's reconstructions unacceptable, he simply washed off the paint layer, and reused the same surface for his own reconstructions. The mortar that was used for these repairs was very hard and had a smooth and closed surface (something that can be very clearly seen on photographs taken with raking light). It was, therefore, easier for the salts to migrate to the surrounding original areas that were more porous.

In February of 1931 a new drain was installed around the chancel, and Lind went to the church in April to inspect the condition of the walls. He states that a noticeable improvement had taken place, and that the walls seem to be drier. He also suggests that the gutters on the south and north walls of the chancel be replaced, noting that the present gutters were too narrow and difficult to clean because they were mounted too deeply under the eaves of the roof. He imagined that a strong downpour would cause the rainwater to flow over and down the facade of the church, contributing to the moisture problems caused by rising damp. In conclusion, he suggests that a re-restoration of the paintings be delayed for about 2 years, so that the changes in the interior climate could be monitored.
The paintings, however, were not treated in two years. When Lind returned to Tirsted church in 1940, the situation was tragic.

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The re-restoration of the wall paintings in 1940

Egmont Lind returned to Tirsted church carried out the third restoration of the wall paintings in October and November 1940. No photographs exist prior to the treatment, but Lind's colourful prose, full of personal comments describes the awful situation. "The plaster has lost its adhesion in countless places, and the cracked bulges are barely holding onto the wall; other places have already fallen off. In the places where the injection syringes had been mounted, or there where parts of the paintings were detached in order to treat the substrate, one could see that the surface of the bricks was so deteriorated that it formed a layer of powder, the thickness of which varied from a few millimetres to about a centimetre."
Lind remarks that the scenes that were not impregnated in 1929 because of their good condition were now in such poor condition that there was almost nothing left of them. He attributes this to the lack of impregnation, and not to the fact that the untreated areas were more porous than the treated ones, which led to a migration of the moisture and salts to the untreated scenes. Only two scenes on the south wall, Esther and Ahasverus and the Pentecost scene are described by Lind to be in good condition. Because he considers the deterioration of the paintings to be inevitable, ending in the total loss of the entire decoration, Lind suggests that, at least, the Esther and Ahasverus scene could be detached in the near future. "(The church community) has accepted the fact that the day will come when the rendering (and paintings) must be knocked off the wall...Whether a new rendering should be applied, or whether the red bricks should be displayed is a discussion in itself – the latter would probably be the most beautiful. In the meanwhile, the church can start to collect funds to pay for a couple of stained glass windows in the east wall, or a granite or brick altar to replace the existing altar, which, one must say, is a foul piece of carpentry, so that (this way) the pain over the loss of the wall paintings will quickly wear off."

The re-restoration of the paintings in 1940 centred mostly on the consolidation of the plaster (possibly with polyvinyl acetate), the execution of some new plaster repairs, and a renewal of some of the reconstructed portions of the painting. These reconstructions were not necessarily a repetition of the areas supplemented in the previous restoration by Kornerup, or even a repetition of Lind's own reconstructions from 1929. The changes in the iconographic details can be traced on archive photographs. For example, Kornerup reconstructed the lower portion of the Cain and Abel scene, painting some irregularly-shaped stones in 1892. In the course of the first re-restoration in 1929, Lind changed the stones to a series of wavy lines. In 1940 Lind redid this portion of the scene, changing the lines back into stones. However, he did not use Kornerup's stones as a model. A close inspection of the decorative border under the scene also shows that it was redone by Lind.

An interesting and sadly humorous detail is included in Lind's report describing the situation in 1940. The areas of the painting that had lifted off the substrate were deteriorating at an alarming rate. "....Indeed (these areas) are falling to the floor in the form of small flakes and grains of dust, and sometimes even on the priest, when he is sitting in his chair in the south-east corner of the chancel. For years, Saturday after Saturday, the sexton has swept up the particles and served them – if I may cite him – to his hens. It cut my heart, when this was reported to me, to think where the lower third of the figure of the Prophet Habakuks has ended."

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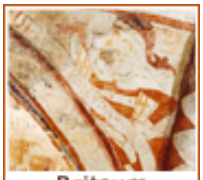
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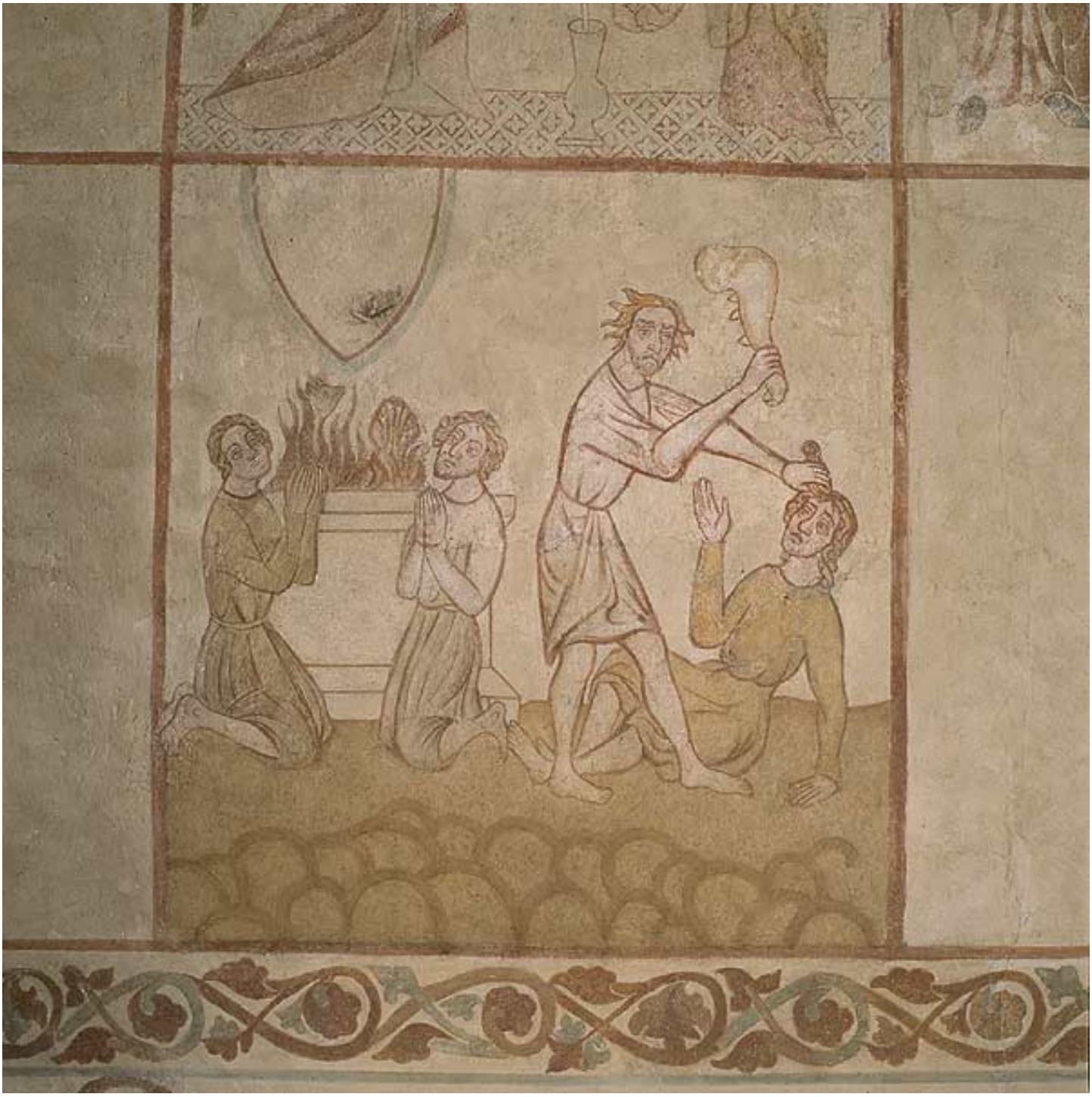

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Inspection of the paintings in 1943

Egmont Lind returned to Tirsted in 1943 to inspect the condition of the wall paintings that he had re-restored three years earlier. Although he had not expected the treatment to have lasted long, he was pleased to note that there was no new deterioration visible on many of the scenes. However, there were problems with the scenes on the upper register on the south wall, where chunks of plaster were falling to the floor.

In 1944 two stained glass windows were mounted in the east wall. Lind remarks in his report that he will visit the church the next time he will be in the neighbourhood to see if the wall paintings work well together with the stained glass windows. Should it be necessary, he adds, one could re-restore some of the scenes (meaning strengthen the colours) in order to improve the aesthetic balance in the decoration of the interior. Fortunately, this never took place.

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The re-restoration of the wall paintings in 1964-65

A very short report written by Egmont Lind describes the third re-restoration of the paintings in the chancel, which took place over the course of three months in the winter of 1964-65. The work was carried out by Robert Smalley, a wall paintings restorer from Great Britain, who was hired in 1963 by the Department of Conservation at the National Museum of Denmark.

Lind describes the work as routine re-restoration: cleaning, mortar repairs, retouching, applying a new layer of toned limewash to the areas where the pictorial content was missing from the scene. He also states that the scene in the south-east corner depicting Daniel in the Lions Den is lost, and that no reconstruction was made. However, some small fragments must have been preserved, because during the next re-restoration taking place in 1972, Smalley described the difficulties during the consolidation of the deteriorated paint layer, mentioning, among others, the scene with Daniel in the Lions Den.

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The consolidation of the wall paintings in 1972

The fourth treatment of the wall paintings in the chancel was confined to the south-east corner, where three scenes were in extremely poor condition. Geoffrey Pearce assisted Robert Smalley in an attempt to re-fix the flaking plaster and paint layer, and to prevent further spontaneous detachment. This was done as a last resort prior to detaching the scenes in this area and transferring them to substitute supports.

Smalley described the difficulties he encountered during the treatment of the deteriorated paintings in his report, stating that their condition was so fragile that “Alone the opening of the church door was enough for large areas to fall off the wall.” He holds the impregnation of the paintings with the Carlsberg Preparation in 1929 responsible for the poor condition of the paintings in this area. According to Smalley, the detachment of the plaster was caused by the large amount of moisture in the wall, which pushed the plaster and paint layer off because it could not pass through the impregnated surface. In addition, the concentration of moisture in the lower wall was extremely high due to the hard and dense rendering on which the painted drapery was reconstructed under the figurative scenes in 1929.

It was not possible to apply a temporary protective facing to the deteriorated surface. After several experiments with different glues (the types of glue are not identified) successful adhesion was achieved with a mixture of polyvinyl acetate emulsion and lime putty, which was applied after wetting the surface of the painting with limewater. The grout was then applied with a brush by repeatedly touching the edge of the flaking area, whereby the adhesive was sucked under the loose portion reattaching it to the substrate.

Unfortunately, the effects of this treatment were not long-standing. It was deemed necessary to detach the scenes in the south-east corner one year later.

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Raphael Project

The detachment of three scenes in 1973-74

A photograph taken in 1973 of the south-east corner of the chancel clearly shows the poor condition of the wall paintings prior to their detachment in the last months of that year. The damage was concentrated in the areas where the original rendering was still intact. Not much was left of the scene depicting Jonas and the Whale and Samson Bearing the Gate of Gaza. The lower half of the scene was a complete reconstruction executed by Egmont Lind in 1929 on the same hard and smooth plaster Kornerup used for his reconstruction (Lind removed Kornerup's reconstruction but re-used the plaster).

The upper half was restored by Kornerup, and re-restored twice by Lind, and small details were altered every time the painting was treated. The three scenes were not retouched before they were detached, and afterwards the surviving lines were enhanced by overpainting, but the lost details, such as the hair and the features on the face, or the leaves on the trees were not reconstructed. The deterioration of the pictorial content can be traced on a series of photographs spanning 76 years: 1917; 1929; 1940; 1973; 1974




The surface treatment of the paint layer prior to the application of the facing consisted of spraying with a commercial fixative (more specific information was not provided). Cotton gauze was cut in squares measuring 20 x 20 cm and glued to the surface with animal glue. Four layers were applied. Afterwards, each scene was cut along its borders, and then each was detached from the wall separately. All the rendering that detached together with the paint layer was then removed from the back by grinding it away with a Carborundum stone. A backing layer of titanium dioxide and polyvinyl acetate emulsion was spread on the back, after which a lining of cotton gauze was glued with polyvinyl acetate emulsion. Thus treated, the detached pieces were then glued with polyvinyl acetate emulsion directly to a oil-impregnated chipboard, and the facing was removed with warm water. The back of the plates were protected against moisture by a layer of aluminium foil, which was glued on. The edges of the plates on the scenes adjacent to each other were provided with tongue and groove fittings, so that the three scenes (and a piece of the decorative frieze) could be mounted together to form a continuous surface. The transfers were screwed back in their original locations with raw plugs and brass screws (through the front of the painting), with no space left for air circulation behind the plates. Finally, the heads of the screws and the joints between the plates were covered with putty (content not recorded) and retouched.

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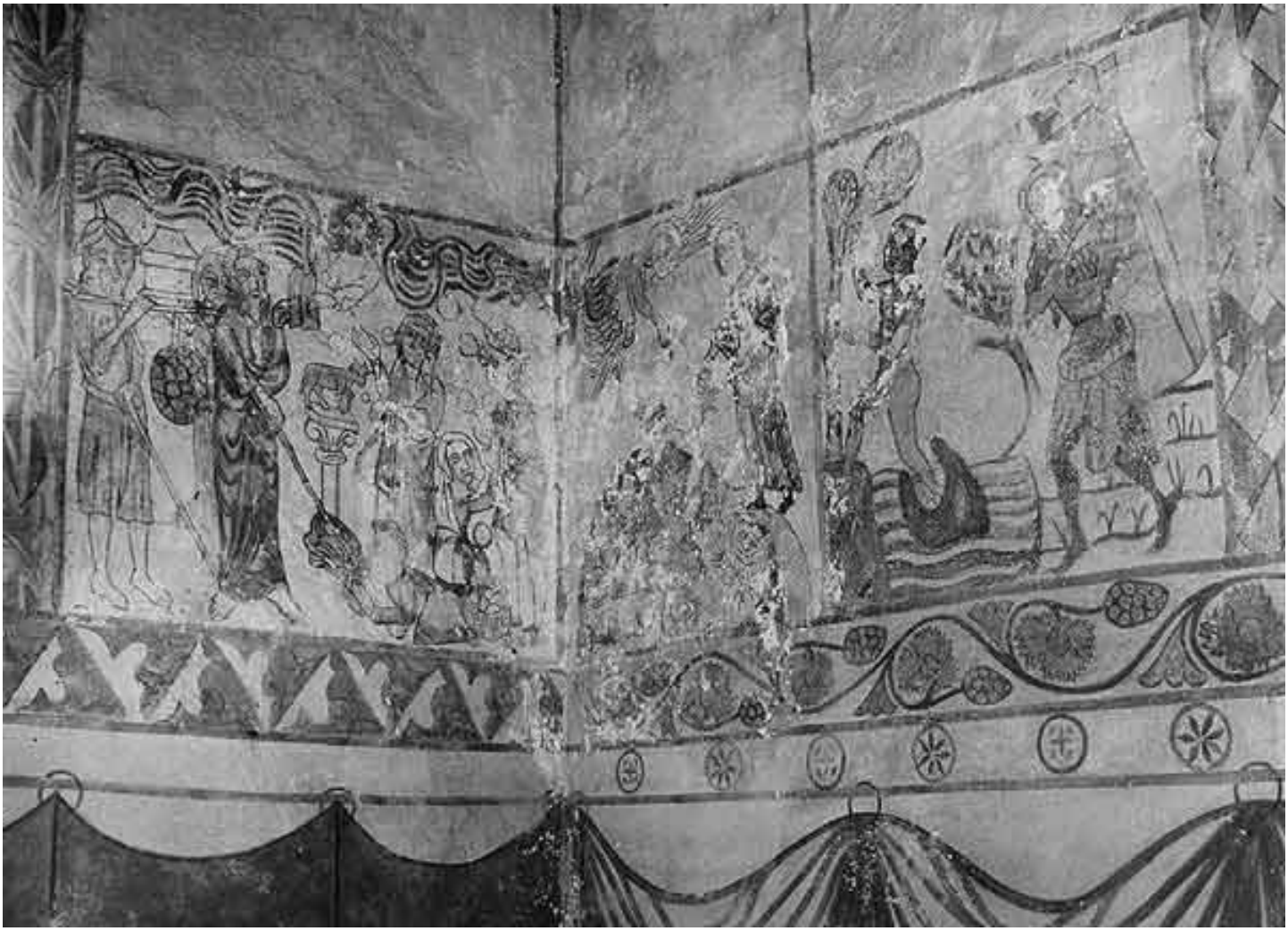
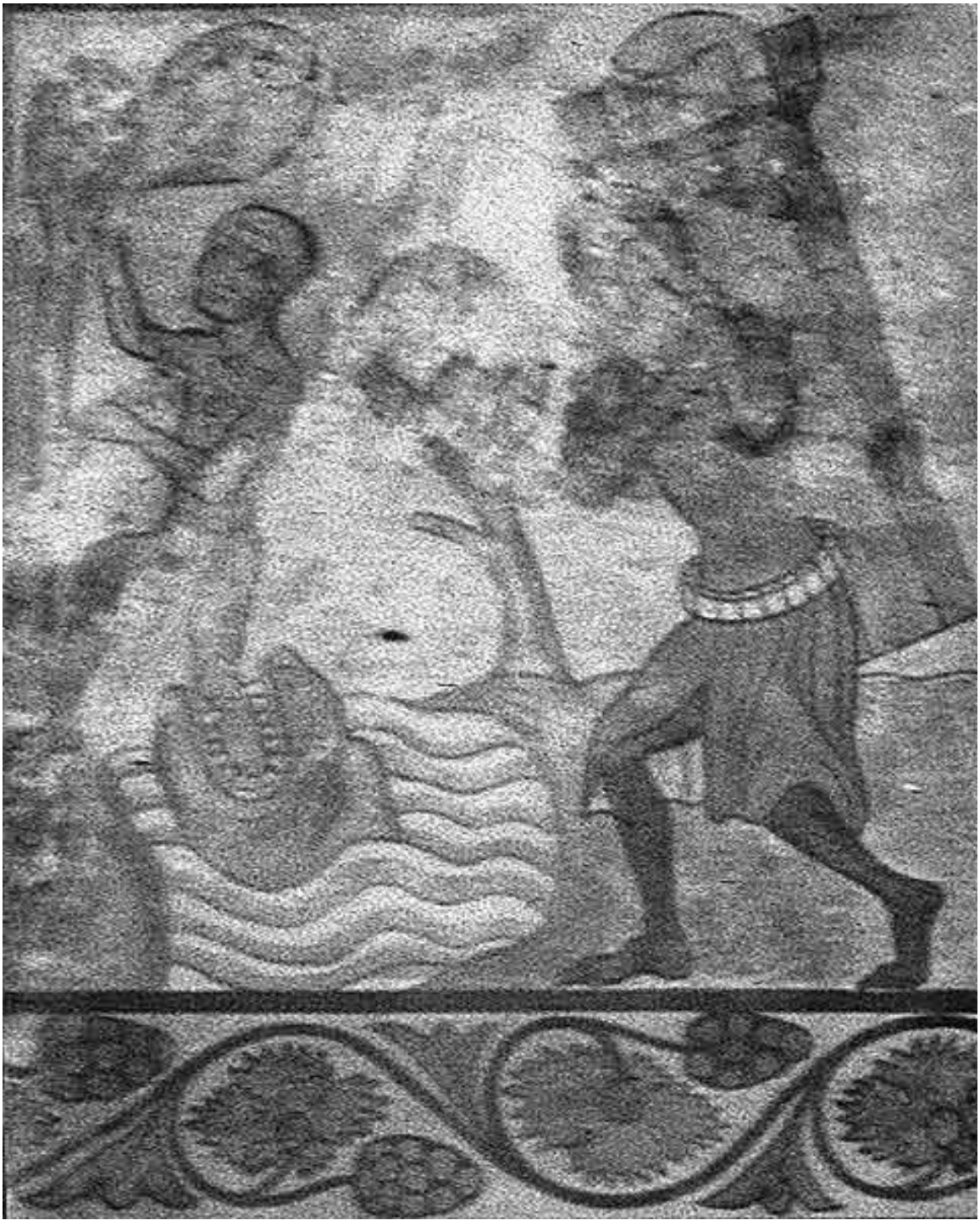
Königslutter


Tirsted


Britsum





Raphael Project

The consolidation of selected scenes in 1982

The deterioration of the three upper scenes on the south wall, which was first noted by Lind in 1943, was extremely pronounced in 1982, after a period of 6 weeks in the early spring, when a new organ was built in the church. During this time the heating was kept at 18-20º C. The fall in the relative humidity accelerated the damaged caused by salt crystallisation. After an inspection of the condition of the paintings in May, a decision was made, similar to the one taken 10 years earlier regarding the three scenes in the south-east corner. An attempt was to be made to consolidate the deteriorated plaster and the flaking areas of the painting in the hope that this would be sufficient in order to keep the painting in situ and prevent a detachment and transfer. This was carried out by Kirsten Trampedach and Mette Kristine Jensen in November.

A commercially available fixative in a spray can, Krystal Fixatif (manufacturer and content not identified) was used to consolidate the deteriorated plaster. The flaking areas were fixed with polyvinyl acetate emulsion or a grout consisting of slaked lime, crushed limestone, and limewater.

The upper register, where the three damaged scenes are located, is painted in a zone spanning from ca four to five metres over the level of the floor The explanation given for the presence of salt damages so high on the wall followed the generally accepted theory at that time that the migration of moisture in the walls primarily took place in a vertical movement, rising up through the substrate by capillary force. As usual, the blame was placed on the poorly functioning drain around the chancel. Although it might seem unusual that this explanation was accepted in this situation, no attempt was made at that time to discover another source to account for the presence of moisture so high on the wall.
A new drain was placed around the chancel in 1984, but the deterioration by salt damage was not arrested on the upper three scenes. In the beginning of 1985 the condition of the paintings was so poor that a decision was made to detach them.

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Raphael Project

The detachment of three scenes in 1985

Salts continued to crystallise in the upper part of the south wall after the consolidation of the paint layer on three scenes in 1982. In 1985 it was considered necessary to detach what was remaining of the paint layer. Before this took place, however, a closer look was taken of the facade and the corbel. The inspection revealed sufficient damage in the roof tiles and cracks in the tuck-pointing for rainwater to penetrate into the wall from above. It was first then that the explanation was put forth that the damage on the upper scenes was caused by the horizontal movement of moisture in the wall, i.e. from the facade to the inner surface, as opposed solely to rising damp from the foundation. The cement mortar used during the tuck-pointing of the facade in 1892 was apparently too rigid to absorb the slight movements of the wall, resulting in the formation of tiny cracks. The situation probably was additionally aggravated by frost damage (the cement tuck pointing was removed in 1990).

The detachment of the upper three scenes took place in May in 1985, and was carried out by Kirsten Trampedach and Mogens Larsen. Each scene was detached separately. Prior to the application of the facing the surface was sprayed with fixative (Winsor Newton in a spray can). The facing consisted of one layer of Japanese tissue and two layers of cotton gauze, which were applied with animal glue. When the facing was dry, the borders of each scene were cut and the paint layer was pulled off the wall. Some of the plaster, especially from the masonry joints, was lifted off together with the paint layer. The detached fragments were then stored for five years at the Department of Conservation at the National Museum. In this period they were not mounted on a working stretcher, but only loosely fastened along the edges of the facing to a chipboard. The insufficient humidity in the storage room contributed to further damage, as the facing shrunk and detached itself from the paint layer in several places.

The treatment of the detached pieces was taken up again in 1988, and the transfers were completed by Isabelle Brajer. By that time the hygroscopic facing adhesive had caused deformations of the surface, and, as no counter-mould was made of the uneven surface prior to detachment, the original surface configuration was not able to be replicated. The detached pieces were therefore strip-lined and stretched on a working stretcher so that the treatment of the reverse side could be carried out. After the plaster was filed off the back, it was impregnated twice with a diluted acrylic emulsion (Billy's, prod. in Sweden). The back was then lined with three layers of cotton gauze, which was applied with a mixture consisting of Acronal 290 D (acrylic emulsion), Cascol PVA emulsion, titanium dioxide and barium sulphate. This backing was 5 mm thick, and functioned as an intervention layer. The facing was then removed by first swelling the animal glue with a large amount of cold water. The glue then lost its adhesive properties, and the Japanese tissue and gauze could be removed together with most of the glue without dissolving it. The surface of the painting was then cleaned thoroughly with water and steam.

The paintings were mounted on 1/2 inch thick, prefabricated Fiberglas/epoxy honeycomb plates (prod. by Ciba Geigy) with epoxy glue. An epoxy paste was used to fill the open cells along the sides of the support. Four openings were made on the back of each transfer by lifting off the outer surface of the fibreglass. An aluminium plate with a corresponding opening was glued with epoxy over the holes to strengthen these areas. Four hooks were screwed into the wall for each of the transfers. The position of the hooks corresponded to the holes on the back of the transfer, and the three scenes were mounted on the wall in their original locations by placing the holes over the hooks.

A common situation for all six transfers is that they were all mounted directly to the wall without leaving a space for air circulation behind the plates. Had this been done, it would have created an even more pronounced difference in the vertical plane of the transfers and the surrounding scenes that were not detached. Another striking feature is the contrast of the flat surface of the transfers in comparison to the original uneven rendering.

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The re-restoration of two scenes in 1994

New problems with salt crystallisation appeared within five years after the transfers were hung in the upper register on the south wall. The surface of the wall blocked by the plates did not allow the transpiration of moisture, so instead, the salts crystallised around the transfers. A similar situation was occurring on the lower transfers hanging in the south-east corner of the chancel.

Ironically, the transfers were producing the same effect as the Carlsberg Preparation, which was used on selected scenes 65 years earlier. And it is disturbing to think that not much was achieved despite the progress in the education of conservators in this period.

A mitigating circumstance in Tirsted Church, however, was the fact that after the re-restoration of the decoration in 1940, none of the treatments encompassed the entire decoration, but constituted, instead, a series of patch-up jobs limited to a selected number of scenes. Unfortunately, the same approach continued in the spring of 1994, when two scenes in the middle register on the south wall were re-restored, one of which was located directly below one of the transfers in the upper register. The treatment was limited to two weeks and was carried out by Isabelle Brajer.

Again, the purpose of the treatment was to prevent the execution of additional detachments. Because the effect of new salt crystallisation was discerned in the original plaster around the various plaster repairs that stemmed from the previous treatments, an attempt was made to prolong the life of the two scenes on the wall by removing all of the older plaster repairs. They were replaced by a weaker mortar made with slaked lime and sand, the surface of which was cut with a spatula to create an open and toothed surface with a larger area in order to facilitate the transport of moisture and salts.

The new repairs were covered with limewash, which was toned to match the warm-coloured background of the paintings, and retouching was carried to the level of the colour strength of the surviving paint layer surrounding the lacuna. In effect, however, the newest plaster repairs were supposed to function as sacrificial layers, which would hopefully attract moisture migrations and salt crystallisation. This was a temporary solution, because it was now becoming more and more apparent that a major re-restoration of the entire decoration in the chancel was inevitable. But despite this prospect looming in the close future, the attitude in 1994 was that of let's-see-if-this-helps-a-bit. This attitude was a result of several factors, one of which was the feeling of guilt and compassion on the part of the conservators towards the small rural church community in Tirsted, who were repeatedly being subjected to treatment after treatment and bearing the financial burden for all the work carried out inside the church, as well as the frequent repairs of the drain outside. Already nine years earlier Kirsten Trampedach was sensitive to the situation: "As the paintings on the south wall, despite repeated conservation treatments, were not able to be preserved, it would be reasonable

if part or all of the work would be carried out without charge (the National Museum would cover its own cost); the church's expenses in connection with the preservation (of the paintings) have already been extensive, without having achieved a satisfactory result." Another factor playing a role was the feeling of procrastination, because the idea of transferring all of the remaining scenes on the south and the east wall was already slowly being conceived at this time.

The treatment of the two scenes in 1994 was, therefore, a patchy solution. In 1997 the church community council expressed their dissatisfaction with the visible deterioration of the paintings, especially on one of the two scenes treated three years earlier – the popular Pentecost scene, the fading of which has been documented: Kornerup's watercolour from 1891; 1917 ; 1930 ; 1940 ; 1994. In September of 1997 Isabelle Brajer returned to the church to make a work plan and estimate for a comprehensive treatment of the entire decoration.

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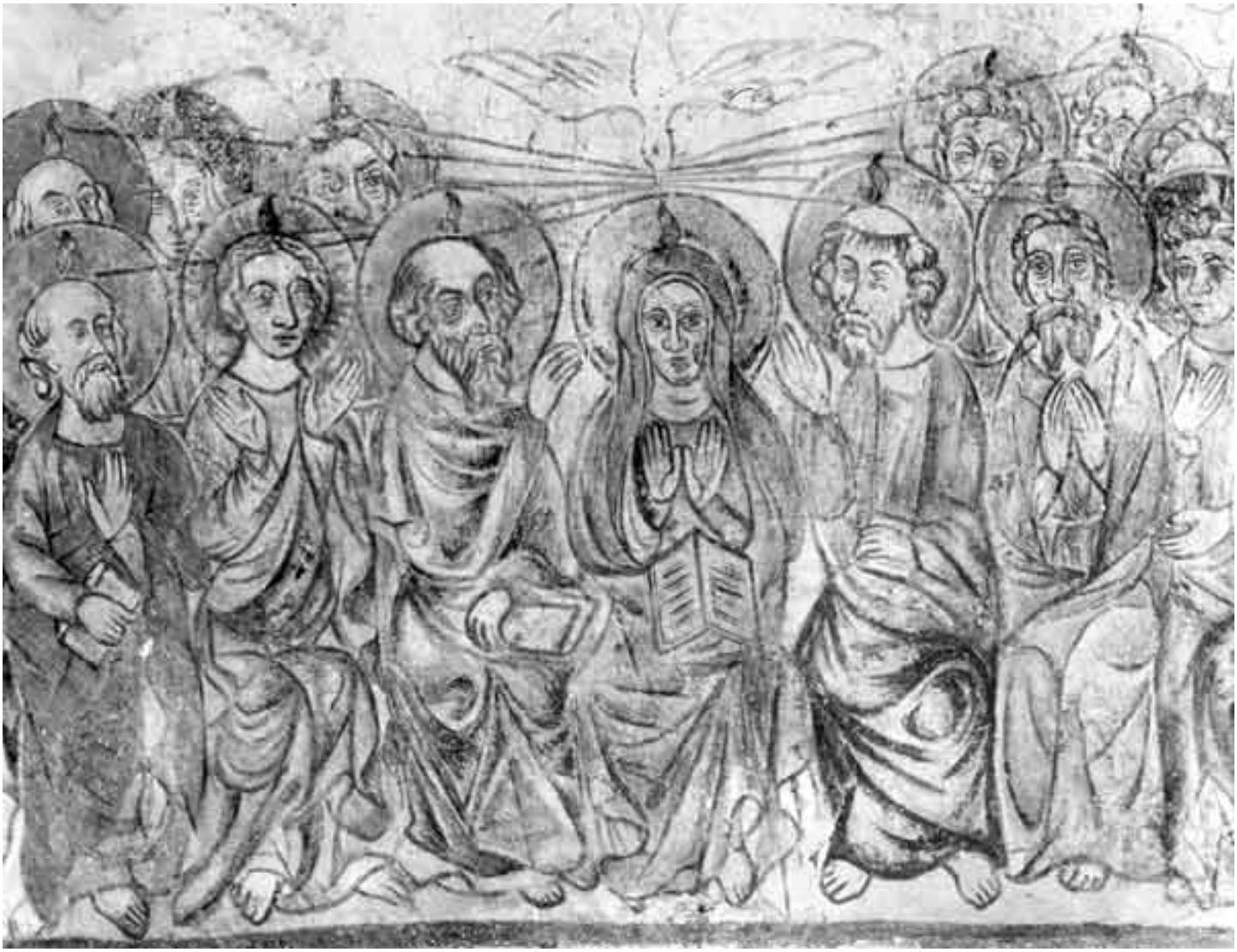

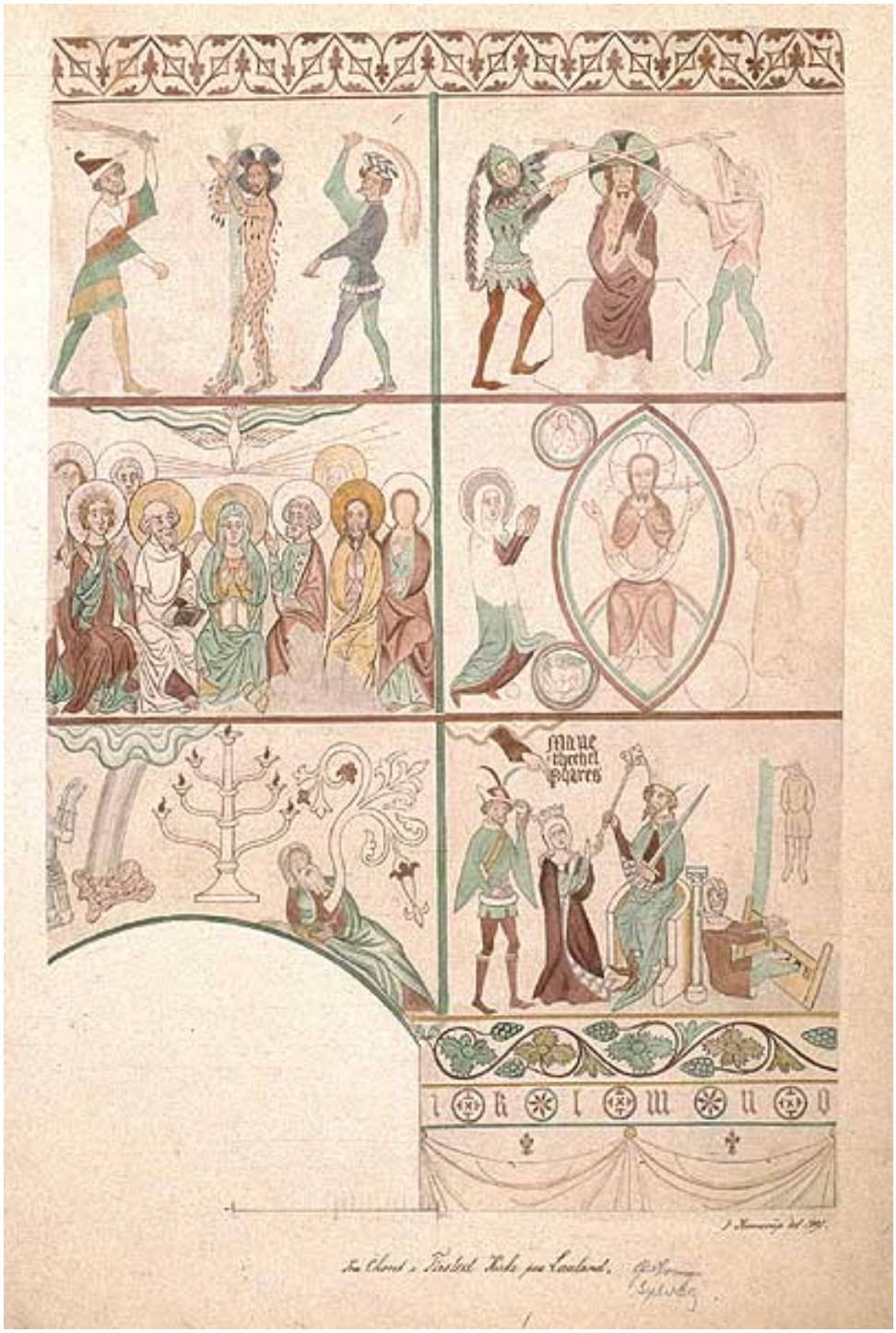
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Raphael Project

The formulation of a plan for the re-restoration of the wall paintings in 1997

By 1997 the church community was tired of all the problems they were having with the wall paintings. Since the uncovering and restoration of the decoration in 1892 the paintings had been treated eight times. It was unfortunate that the paintings happen to surround the altar, because each time work had to be done, a scaffolding had to be built, and the conservators' presence created major disturbance in the church. Therefore, when a plan for the re-restoration of the entire decoration was formulated in September 1997 the church council (especially the priest) wanted a guarantee that a final solution could be found, and they pressed for the detachment of the remaining paintings. The curator from the National Museum, Henrik Græbe, approved the idea.

One must keep in mind, that despite the fact that the drain was tested and was supposed to be functioning at that time, water was standing in the cellar beneath the chancel after every heavy rainfall. Early church records mention the existence of a spring that played a part in the local rituals on St. Hans' Day (midsummer night). It could be possible that this spring was now located under the chancel, and under certain conditions it penetrated into the cellar of the church. At the same time, the presence of the salt dome under the church was a source for concern. The ground water was so contaminated with sodium chloride that all the wells in the village were sealed, and water was piped in from about 12 km away. With this seemingly inexhaustible source of moisture and salts the situation looked hopeless, and it appeared that detachment was the only solution.

Isabelle Brajer was asked to formulate the restoration plan. Not all the scenes were in such poor condition that it was necessary to detach them. The west wall of the chancel was an inner wall, and although the scenes here were strongly overpainted, and there were some large cracks, the rendering was sound. The same pertained to the western half of the north wall. The initial restoration plan called for the detachment of the remaining four scenes on the south wall, four scenes on the east wall, and two scenes on the east end of the north wall. This time, however, a counter-mould was to be made of the entire wall, so that a new support could be built that replicated the original unevenness of the rendering. This required the removal of the very smooth and hard plaster repairs, the surface of which was higher than the level of the original wall in many areas. In order to provide a more suitable surface on which the counter-mould could be made, new plaster repairs were to be made that followed the surface configuration. The new support was to be constructed of fibreglass and epoxy, and it was to form a false wall on which the detached scenes would be mounted in the correct positions. The already transferred scenes were to be removed from their flat supports, and then mounted together with the other scenes on the new support, so that there would be no difference in the level between the empty fields and the painted fields. The transition from the false wall to the original wall in the middle of the north wall (only the east half was to be detached) was to be disguised with a plaster repair that bridged the height difference between the two surfaces. It was estimated that this ambitious plan would require the work of two conservators for one year, and that they would be supplemented by a larger team on occasion. During this time a temporary wall was to be built, separating the chancel from the nave, and a temporary altar was erected so that church services could continue while the work was being done.

The church petitioned the diocese for help in raising the substantial funds required for this project. In January 1999 the work was ready to begin.

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Raphael Project

The most recent re-restoration in 1999-2000

The fourth total re-restoration of the wall paintings in the chancel began in January 1999, with Isabelle Brajer and Lise Thillemann (from the National Museum's Department of Conservation) composing the core team of conservators. Simultaneously with the re-restoration project, a separate research project was initiated in Tirsted Church by Poul Klenz Larsen, a building engineer who was the Department of Conservation's specialist in climate, moisture and salt problems. The data he collected pertaining to the measurement of moisture in the walls had a very important bearing on the restoration plan.

The restoration work began with a thorough examination and documentation of the wall paintings. At this stage the condition of the paintings and observations pertaining to the painting technique were mapped. The paintings were photographed in normal, raking and UV light. In addition, clear polyethylene foil was fastened to the wall in order to make tracings of the figurative scenes and the decorative borders.

A few weeks after the work started, while the examination and documentation phase was still being carried out, the conservators started having doubts about the correctness of the initial plan involving the detachment all the paintings on the south and east walls, as well as part of the north wall. This plan was based on the belief that there was uncontrollable rising damp taking place in the walls. Poul Klenz Larsen's measurements, however, showed that, despite the water in the cellar of the church, the significant movement of moisture in the walls was not taking place in a vertical plane, but in a horizontal plane, even at the height of 1 meter over the floor level.

The Italian specialist in the transfer of wall paintings, Sabino Giovanonni, was asked to come and give his opinion. He arrived in February, and thought that it was not necessary to detach more scenes. He thought that the deterioration could be stabilised by treatment with barium hydroxide or calcium oxalate. Ivo Hammer, the Austrian wall paintings conservator, who visited the church in March was also of the opinion that it was not necessary to detach more paintings. Having first-hand experience with salt-contaminated paintings, he strongly recommended salt extraction compresses.

A new plan for the treatment of the paintings was made, which involved salt extraction. Paper-pulp compresses, however, would only extract salts from the superficial layers. It was necessary, therefore, to alter the climate in the room in order to ensure that salts in the deeper layers would not migrate to the surface. Therefore, the installation of a new heating system was necessary for the new plan to be a success.

The work started with the removal of the old plaster repairs, which were both physically and aesthetically damaging to the surrounding areas, and the cleaning of the decoration. A limited amount of consolidation of the plaster and paint layer was necessary. New plaster repairs were carried out with a lime and sand mortar that followed the configuration of the uneven surface. This was followed by a salt reduction of the salt-contaminated areas where the original rendering still existed (the west wall and the west part of the north wall, where no salt damage was visible, were not treated). The various phases in the treatment program were documented by mapping .

There was much discussion pertaining to the aesthetic completion of the decoration. In the end, it was decided to restore the pictorial content in the areas where the earlier reconstructions had been removed together with the old repairs. However, this was done with a monochromatic red line. The transferred scenes were not re-hung on the south and east walls. This decision was primarily taken due to fear of provoking the recurring salt damage in the most salt-infested area of the wall. Instead, the pictorial content was reconstructed with a red line on new plaster, and the transfers were hung on the west wall in the tower. Retouching of the small lacunae within the figurative scenes was carried our with a hatching technique. The decorative borders below and above the scenes, and around the windows were reconstructed in full colour, the intensity of which matched the pale colours of the scenes .

It was unfortunate that a large part of the history of the wall paintings was removed in the course of the recent re-restoration. However, it is clearer to see today, what a large portion of the surviving decoration was reconstructed.

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Moisture measurements in the wall

Troxler measurements

A series of measurements were made in order to determine the moisture load in the wall structure. The first were made with a Troxler neutron probe. This instrument determines the moisture content in the wall to the depth of 25 cm. The results of the measurements are qualitative, as a higher value corresponds to a higher moisture content, but does not provide information about the actual amount of moisture. This method can, therefore, be useful to identify sources of moisture, or enclosed areas of higher moisture concentration. Troxler measurements in Tirsted were carried out within a quadratic grid with divisions every half metre.

The measurements show that the exterior wall is basically dry, with the exception of the lowest metre, where values correspond to high moisture content. The wall is less moist in the area where the chancel wall meets the nave, and also in the niche created by the bricked up entrance. This can be explained by the fact that these areas are less exposed to rain than the other areas at ground level. The slightly higher values higher up on the facade, west of the window, mark the area where a window was bricked up during the renovation of the building in 1891-92. The moisture here can probably be contributed to the difference in the porosity of the materials used to brick up the window and the surrounding original material. However, a similar difference was not detected in the interior in this area. The scaffolding interfered with measurements in the interior, and therefore values were not obtained from all the areas in the lower part of the wall. There where the wall was measured, however, it proved to be dry.

No elevated values were obtained on the lower parts of the inner wall in the area of the cellar, where flooding was regularly reported in connection with heavy rainfall (for example, 30 cm of water was present in the cellar for a period of 14 days in February 1999). A pump installed in the cellar prevents the elevation of the flood waters, keeping it at two meters below ground level. An inspection of the gutters and drains has shown them to be functioning properly.

Wooden plugs

In order to measure the moisture content across the entire section of the wall nine sensors were embedded at three different heights (30 cm, 200 cm, and 400 cm over floor level) and three depths (15 cm, 55 cm, and 95 cm from the inner surface) on the south wall. The sensors consisted of beech wood plugs containing two electrodes. The level of electrical resistance indicated the moisture content in the area being measured. This was based on the supposition that the wood would take up moisture from the wall and remain in equilibrium with the wall's moisture. This allowed for the calculation of the relative humidity at a particular depth. The sensors' range is 50 – 98% RH, which corresponds to the hygroscopic level at which bricks and plaster transport moisture in the form of vapour. It was, therefore, possible to register whether the wall was in equilibrium with the surroundings, or whether moisture was spreading from below, from the inner or outer surfaces, or from above. The sensors were also provided with thermo-sensitive elements, which allowed for the adjustment of the measurements after temperature fluctuations.

The sensors collected data in the period between May 1999 and February 2000. During this time all nine sensors, regardless of their placement and time of the year, displayed constant values above 98% RH, which was outside the sensors' range. The conclusion was that the massive wall was permanently out of balance with its surroundings, and that there had to be an external source contributing moisture. Although it was not possible to determine the direction from which the moisture was entering, the source was thought to be rain falling on the facade.

Gypsum blocks

A new set of measuring sites were chosen in order to determine whether rising damp had any influence on the moisture balance in the wall. New sensors were embedded at three heights (30 cm, 100 cm, and 200 cm over floor level) and three depths (15 cm, 55 cm, 95 cm). They consisted of gypsum blocks with electrodes embedded in them. The measurements were based on the same principle as with the wooden plugs, and also contained thermo-elements. This time, however, the sensors' range was 98 – 100% RH, which corresponds to the level at which bricks and plaster transport moisture in the form of liquid.

The final results of these measurements are not ready, however, provisional results indicate that there is no difference in the moisture content at the three heights. Nor could a difference in the moisture content of the inner and outer wall be determined, with the exception of the lowest measuring site closest to the outer wall. The higher value here was not a result of rising damp, but the fact that rainwater at this level fell on the narrow horizontal edge of a plinth encompassing the lower facade of the chancel. Therefore, these provisional results indicate that the movement of moisture primarily takes place in a horizontal direction, from the facade to the inner surface. This could probably explain the relatively even distribution of salts in the plaster at the inner surface.

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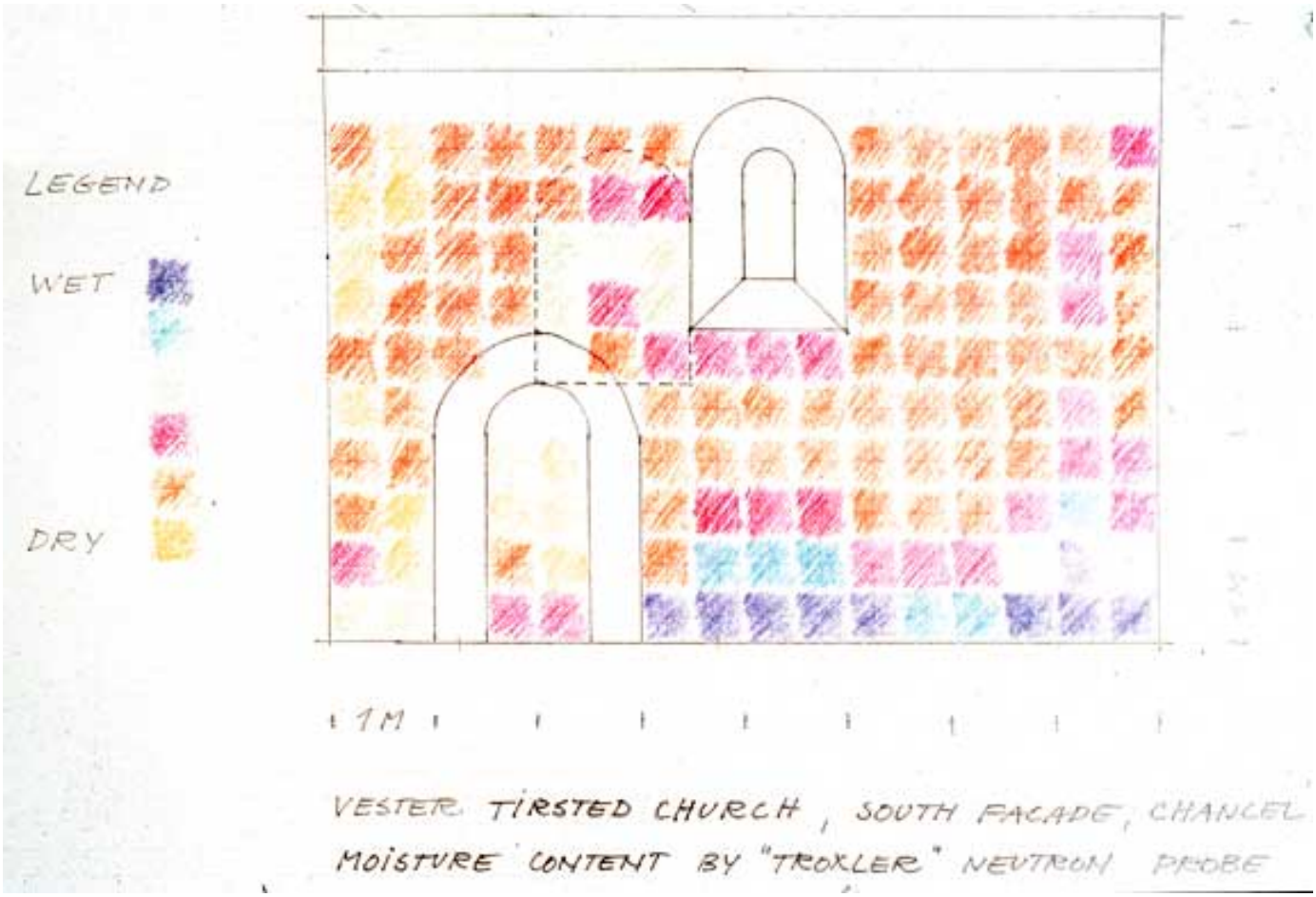
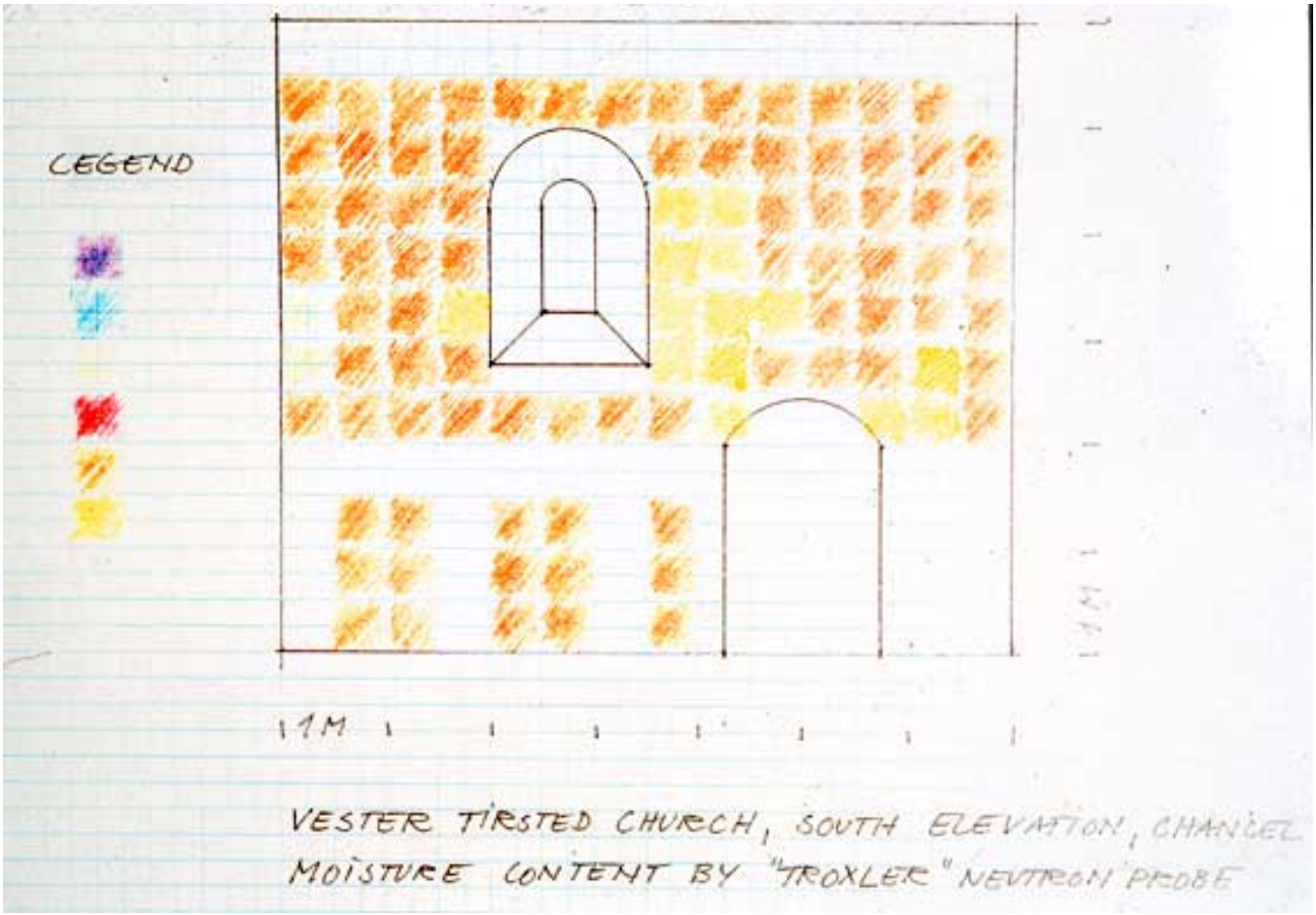
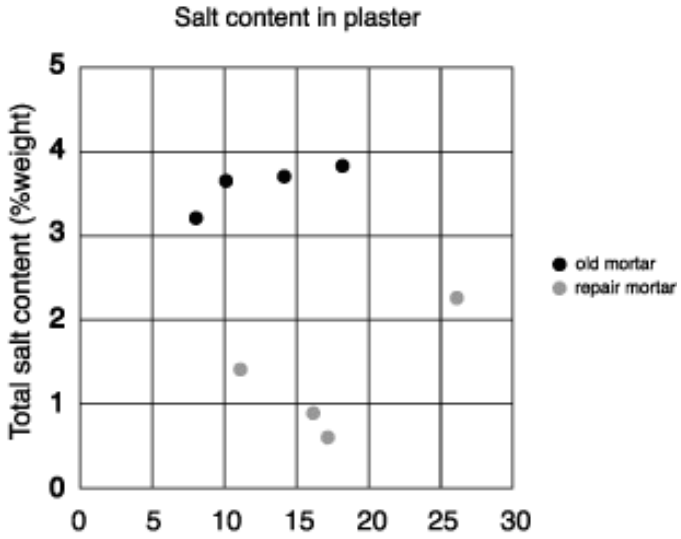
Moisture measurements in the wall



Moisture measurements in the wall

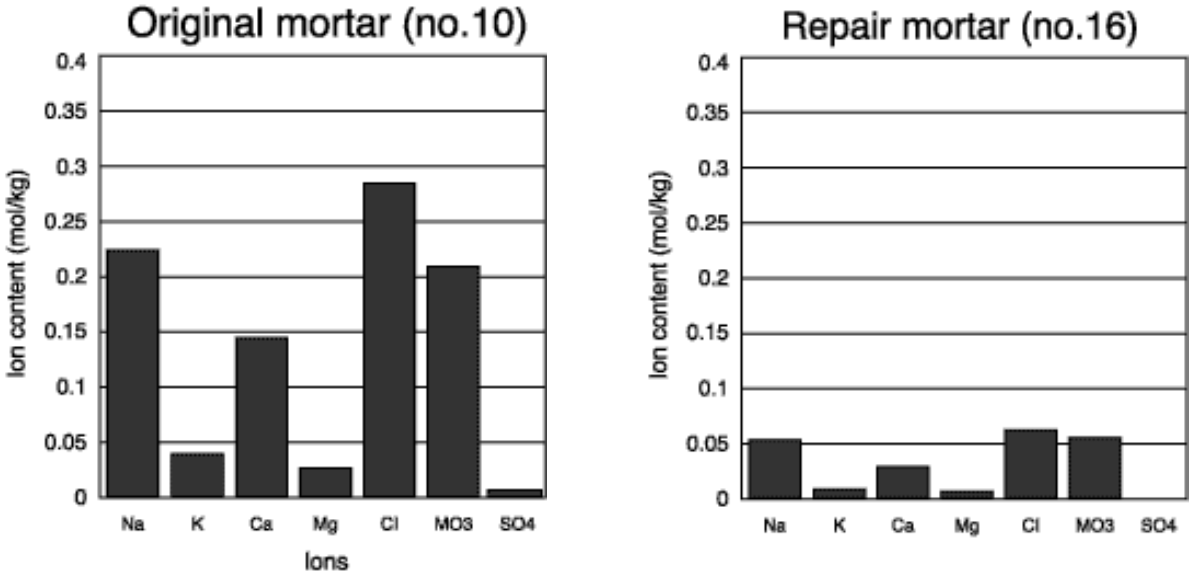


Salt analysis of the wall paintings

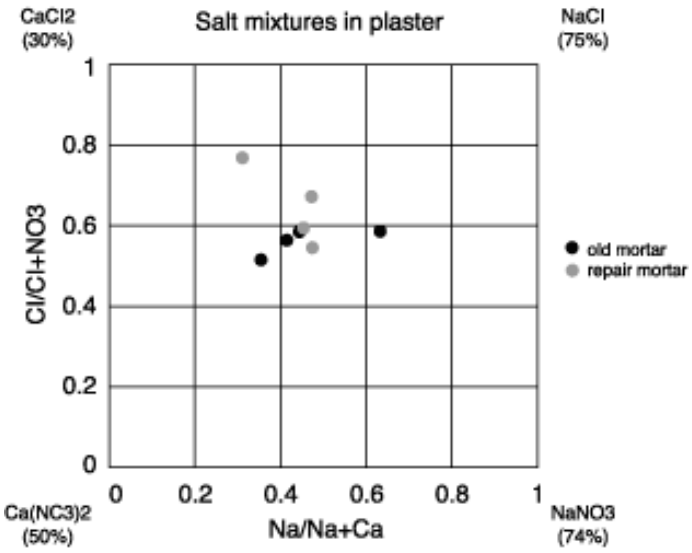


The salt analysis was carried out by Poul Klenz Larsen at the Department of Conservation Laboratory. The analysis showed that the rendering on which the paintings were executed had a total salt content (by weight) between 3-4%. Even the plaster repairs from the earlier treatments were contaminated by salt, though on the average, around 1%, which proved that the salt damage had occurred over a longer period of time.

The high content of salt identified in all of the samples taken from various locations and heights indicated that the salt contamination was distributed rather evenly on the entire inner surface of the chancel's walls. It was therefore unlikely that it had occurred as a result of a local disturbance or an individual historic event. The analysis confirmed the impression that the deterioration of the wall paintings was occurring because of salt crystallisation in and on the surface of the plaster.



Sodium, calcium, chloride and nitrate ions are dominant, while the content of potassium and magnesium is small. This situation applies both to the original rendering as well as to the repair plaster. This indicates that the salts had spread from the older parts of the plaster, or from the masonry into the repairs. Furthermore, the homogeneity of the ion composition in the original rendering and the repair plaster demonstrates that no new ions were introduced with the repairs, for example alkaline components from cement.



The ions that were identified can combine to form four different salts: NaCl, $NaNO_3$, $CaCl_2$ and $Ca(NO_3)_2$. (It is noteworthy, that no gypsum was found). The mixture of these salts can have salt crystallisation points between 75-30% RH. Therefore, the crystallisation of the salts could be prevented by maintaining a constant environment in the interior at ca 80% RH.

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Heating and interior climate

The climate inside Tirsted Church was measured both before, during and after the restoration project. The church is not heated in the summer, and the temperature hovers around 16ºC. The humidity in this period is around 70-80% RH, which corresponds to a moisture content of ca 12g/m^3. This is roughly the same climate as outdoors, and, therefore no serious moisture problems occur during the summer months. In the winter, however, the church is periodically heated to 18-20ºC (until 1999 two cast iron radiators were placed along the north and south walls in the chancel), resulting in a fall in humidity to 40% RH or lower.

One could assume that such a drop in the humidity would have a strongly drying effect on the interior surfaces of the walls in the church. The oscillations in the relative humidity, however, were not as pronounced as expected. This was because every heating session introduced moisture into the air, which could be seen by a 1-2 g increase in the absolute humidity per cubic meter of air. This phenomenon is well known from almost all the other churches in Denmark that are periodically heated. Some of the newly introduced moisture can be contributed by the congregation, who exhale an average of 20 g moisture per hour per person. But most of the moisture is given off by the building's interior surfaces via the so-called buffer effect. This is explained by the fact that a rise in the temperature provokes the evaporation of the water inherent in the porous materials in the structure, such as brick, lime and wood. In such a situation the thick walls of the church function as humidifiers that contribute moisture to the interior with every heating period. It is due to this repetitive pumping effect that, over a longer period of time, a high concentration of salts are found in the inner layer of plaster.

Such heating and associated drying out is particularly damaging for wall paintings that are contaminated by salts, due to the salts' varied interaction with the humidity in the air dependant on the time of the year. In the summer, when the RH is high, the salts dissolve when they absorb moisture from the air. In the winter, moisture is given off when the RH drops, resulting in the crystallisation of the salts. It is therefore important to keep the temperature, and the accompanying reduction of moisture in the wall, to a minimum. In addition, the period for heating should be as short as possible, because the effects of drying are progressively worse the longer the heat is on. Furthermore, air circulation also has an influence on salt efflorescence. In stationary air salt efflorescence takes place on the surface, causing much less damage to the wall paintings. Air currents, on the other hand, cause the evaporation to take place deeper under the surface, and salt crystallisation under the paint layer result in flaking and exfoliation.

New salt damage on the wall paintings in Tirsted could be prevented by not heating in the winter. Proof of this was seen in the period when the restoration project took place, when the chancel was isolated from the nave. There were, therefore, times when there was no heat in the chancel, as opposed to the nave, where the heating continued in the periodic pattern as always. The relative humidity in the chancel was constant at 80% both in the summer and in the winter. By keeping air currents adjacent to the wall to a minimum salt efflorescence could be prevented. However, it was unrealistic to expect that the church community would accept the omission of heat in the church after the project was over. Just as unacceptable would be the creation of a protective micro-climate by erecting a glass or Plexiglas wall in front of the paintings.

In an attempt to prevent new salt problems from appearing in the near future, a decision was made to exchange the old convector heating system installed in 1929 with a new system based on radiating heat. Flat heating panels were installed in the wooden ceiling between the beams. Heat from the panels radiates directly down on the area in front of the altar, whereas the surfaces of the walls do not get heated at all. There are also plans to install radiant-heat panels under the pews in the nave. There is not much experience with radiant heating systems in Denmark, and, the experience gained from Tirsted church will hopefully contribute to solving similar problems in other churches.

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Tirsted


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Discussion pertaining to the aesthetic completion of the decoration

When the paintings were uncovered and restored in 1892, Prof. J. Kornerup argued for the preservation of the fragments because he said that it was possible to recreate the compositional scheme, even though some of the fields would stand empty. He recreated the decorative scrollwork that divided the walls into areas, and drew the lines that framed the individual scenes. In addition, he completed some of the figurative scenes, reconstructing up to 50% of some of the scenes. These reconstructions were substantially altered in the course of the many re-restorations that were carried out over the next century. Due to the fact that they were executed on very hard and smooth plaster, which was detrimental to the paintings, they had to be removed, and so most of the historical reconstructions were destroyed in the course of the most recent treatment. And since about 50% of the decoration was reconstructed, the removal of these areas had a serious impact on the presentation of the paintings.

Therefore, a decision had to be taken whether to reinstate the reconstructed portions, and if so, which version should be re-established – the last, which was there when the most recent re-restoration was initiated, or the first, which might have been closer to the original. The problem was compounded by the fact that the complete photographic documentation of the earlier stages did not exist, just selected areas. And it was made even more complicated by the fact that some details were uncovered during the most recent treatment, which made it impossible to recreate the last version. The scene depicting the Tower of Babel is a fitting example. The entire scene, unfortunately, is not visible on Kornerup's watercolour from 1876, because the drawing was executed before the vault was removed.

The first photograph of the scene is from 1917, and it shows three figures – two standing men, and only the upper half of a third man in the lower right side of the scene. Kornerup extended the torso of the third figure to the left, but did not reconstruct the legs. Egmont Lind, taking up Kornerup's hint that this was not a standing figure, reconstructed the lower half in 1940, drawing the legs in a manner that suggested that the figure was falling down the hill. However, during the re-restoration in 1999, it was discovered that the limewash layers were never removed from this area, and the damaged, but still visible, legs of the figure were found directly in line with the torso, indicating that this was a standing figure.

Also discussed was the possibility to preserve the surviving fragments as they were, as isolated fragments presented on a neutral background of limewashed mortar, without carrying out any reconstructions. But this was not done for two reasons: firstly, the paintings in Tirsted are iconographically significant in Denmark, and the decoration was well known, and (what is also very important) very well liked by the church community. Secondly, six of the scenes had been detached earlier, and were transferred to flat rectangular plates. The strongly overpainted transfers had darkened and were aesthetically very different than the non-transferred scenes. There was doubt if the dark geometric forms could be visually united with the pale irregularly-shaped surviving fragments on the wall.

These transfers were also a cause for concern for another reason. Previously, they were screwed directly to the wall, and, as a result, salt efflorescence appeared in the adjacent scenes because moisture was unable to pass through the plates. Although the new heating system was supposed to prevent further salt crystallisation, it was decided not to risk having the salt damage reappear a few years after the major restoration. So, it instead of re-hanging them in the chancel, they were mounted on the west wall in the tower where there was no moisture damage. In place of the transfers, a monochromatic line was used to reconstruct the pictorial content on the wall, using the dominant colour in the decoration, red.

The previously reconstructed areas within the scenes were also completed in a similar manner. When there was doubt how to draw a line, the oldest documentation (either watercolour drawing or photograph) was chosen as the model. It can be discussed, whether it was correct to include the watercolour drawings as models for the reconstructed areas. Although Kornerup's draughtsmanship and power of observation are admirable, a comparison of the photographs taken of the decoration shortly after it was restored by him shows that he did not record all of the details correctly, and a certain amount of interpretation can be seen on some of them, especially the scene with Mary and Elisabeth.

It was also decided that the smaller lacunae within the figurative scenes should be retouched in order to enhance the legibility of the pictorial content. As always, decisions pertaining to the aesthetic presentation of wall paintings in a church are very subjective. However, taking all the circumstances into consideration, the primary motive behind the solution chosen for Tirsted was the possibility to conveying the fact that much of the decoration was not original, while, at the same time, retaining the pictorial content.

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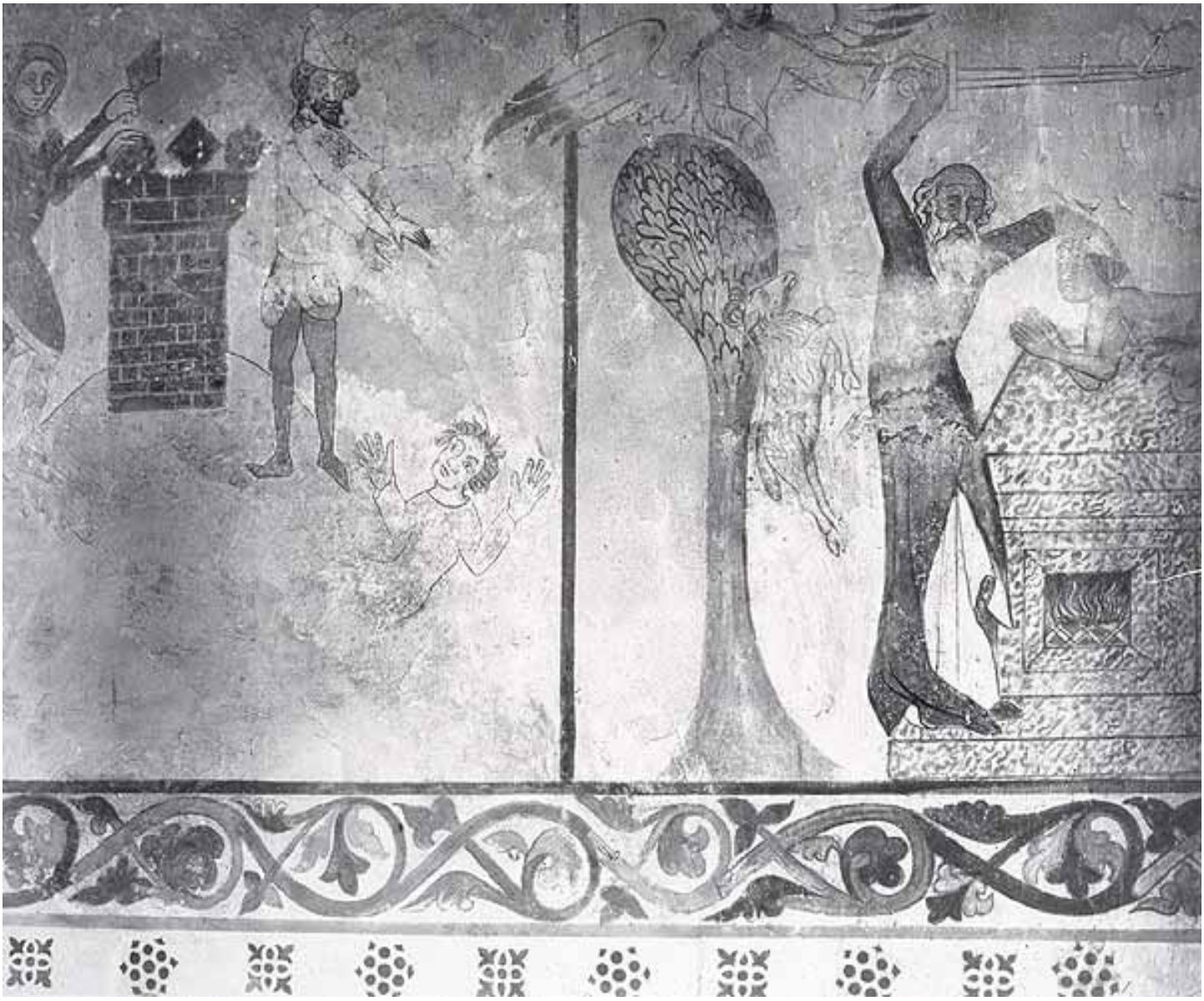


Jomfru Maria besøger Elisabeth. Lucas I Cap. 41-42
Kalkmaleri i Tirstrup Kirke.
J.K. 1892.

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Retouching of the wall paintings in 1999/2000

After carrying out the plaster repairs and salt reduction treatment two types of aesthetic disturbances were prominent in the decoration. The first were the large areas, sometimes covering many square meters, where it was decided that the missing pictorial content would be reconstructed with a simple red line so that the iconographic content of the decoration would not be reduced. The second were the countless tiny repairs, often no larger than a thumbnail, as well as the small and medium-sized repairs that were located within the surviving scenes.

These lacunas in the paint layer not only created visual unrest, but also made it difficult to perceive some of the figures. The plaster repairs were prepared with a limewash layer that matched the general tone of the background. This formed the ground layer for the retouching, which was carried out with watercolours using a hatching technique.

This technique was considered appropriate in this case due to the original textured surface, which was created by the crossing tracks of the bristles of the brush used to apply the limewash. Furthermore, by keeping the network formed by the cross-hatching lines open, it was easy to maintain a light and airy appearance of the retouched areas, which matched the worn appearance of the original paint layer.

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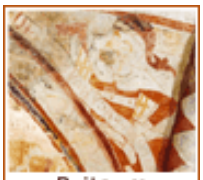
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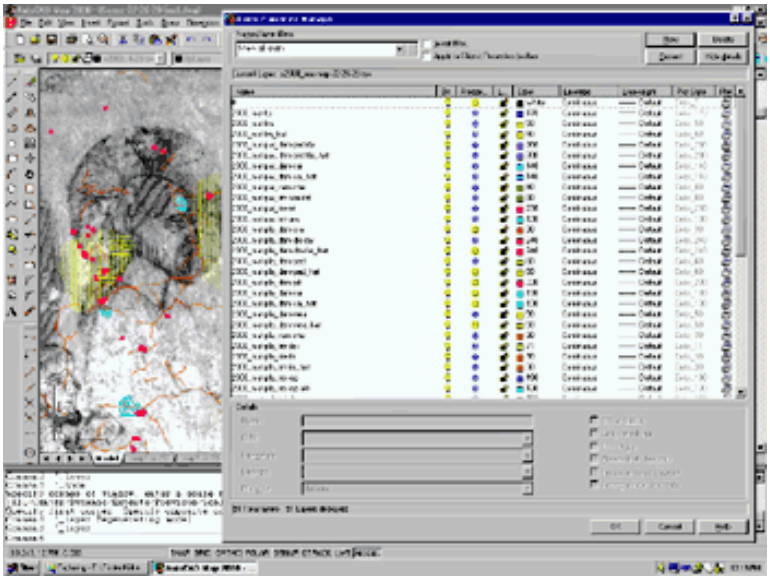
Graphic Documentation

Until Denmark's participation in the Raphael-project graphic documentation was normally carried out manually, on acetate overlays on black and white photographs, or directly on photographs. The design of the map and the symbols chosen to depict various phenomena varied from case to case, as there was no standard methodology regarding graphic documentation.

A more structured system, as the one developed in the course of the Raphael-project, was implemented for the first time in Denmark during the re-restoration project taking place in Tirsted Church in 1999-2000. Various graphic maps were created following the rules explained in the Introduction to the Structure, using Auto CAD 2000 software. According to the new system, all information about a particular painting (in Tirsted the painting was divided into scenes) is first systematically gathered in separate files. This allows for the creation of an infinite number of thematic maps that can visualise whatever combination of phenomena is thought to be interesting in a particular case.

In the case of Tirsted Church emphasis was put on three areas: 1) the creation of maps containing information about the painting technique, i.e. marking the presence of physical signs that give evidence to how the painting were created; 2) the documentation of the condition of the paintings at the start of the re-restoration; 3) documentation of the conservation and restoration procedures carried out in the course of the re-restoration. Due to restricted time and resources only five scenes were chosen for the implementation of the new system (the remaining 19 scenes were documented manually). Three of the chosen scenes are on the east wall: Jesus entering Jerusalem, The Crucifixion, and Moses and the Copper Snake. The remaining two scenes are on the south wall: Gideon and the Golden Fleece/ Tree of Jesse, and Esther and King Ahasverus.



Layer structure in Auto Cad 2000.In this setting the layers that are lit (in the "freeze" column) present mapped information about damage in the plaster layer.

Mapping of the painting technique (Map1)
Mapping of the condition (Map 2 and Map 3)
Mapping of the treatments (Map 4 and Map 5)

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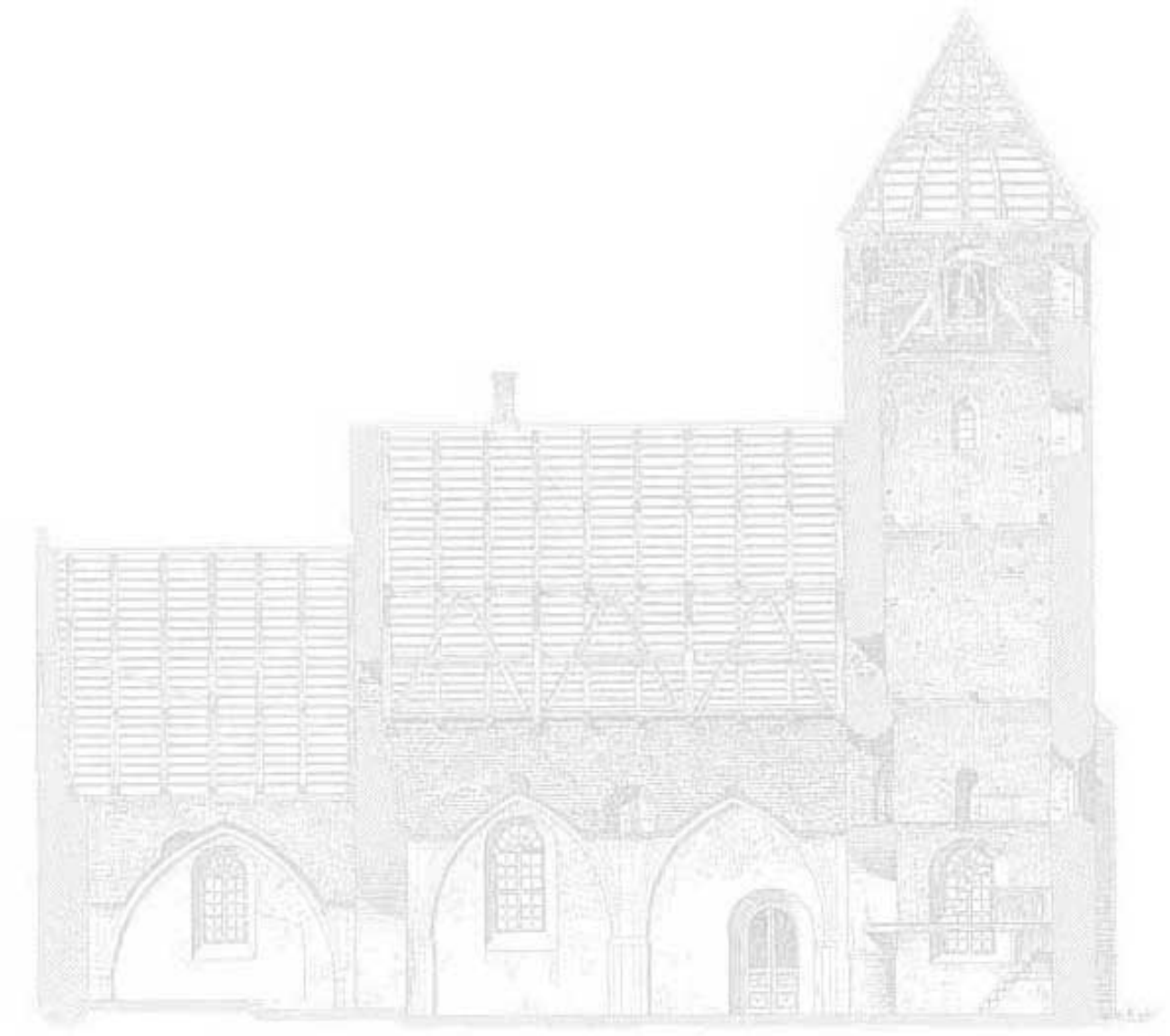

Raphael Project

The uncovering of the Gothic wall paintings

Jakob Kornerup came to Tirsted Church for the first time in 1859. Around this time wall paintings in the vast majority of the medieval churches were still hidden under a crust of limewash. Such was also the case in Tirsted, where the interior was sealed in white. Limewash covered the walls and the two quadripartite vaults that rose seven metres over the floor of the nave. Beyond the chancel wall's arched opening a lower vault filled the easternmost bay of the church, the chancel. Here, the walls as well as the webs and ribs of the vault were also covered with limewash. Kornerup felt that the probability of finding a hidden painted treasure in this church was great. Whether he actually knocked some of the limewash off the walls during his first investigations is unknown. But it is very probable that he crawled up over the vaults and saw fragments of paintings on the walls that belonged to the period before the vaults were erected in the interior of the church.

We do know that Kornerup returned to Tirsted in 1876 because the first few of the many watercolour drawings that he executed of the paintings in Tirsted are from that year. The curve of the vault still concealed the upper areas of the partially uncovered scenes, but enough details were revealed to initiate a discussion about dismantling the vaults. The decision to remove the vaults in the church was finally taken in 1890, and this was carried out in the summer of 1891.

The removal of the vault revealed the areas that were hidden by the brick structure in the chancel (nothing survived after the removal of the two vaults in the nave). The original decorative scheme in its entirety came to light after the remaining whitewash was knocked off the wall with a sharp-edged hammer.

The wall paintings, however, were seriously damaged. Originally, a series of 45 scenes were painted in rectangular fields that were arranged in two or three registers on the walls. The window splays in the four windows had also been decorated. A drapery was painted on the lower part of the walls. When the vaults were constructed in the second half of the 15th century the original narrow and high-sitting windows in the chancel were bricked-up, and portions of the wall on the north and south side were knocked out to make place for larger windows placed centrally under the arch of the wall rib.

Several scenes were destroyed in the process. But despite the fragmentary condition of the decoration (only 34 of the scenes were extant in 1891) it was clear that the iconographic content of the uncovered paintings was of substantial importance, as attested by Kornerup's watercolours made after he restored the paintings, and by the earliest photographs from 1917.

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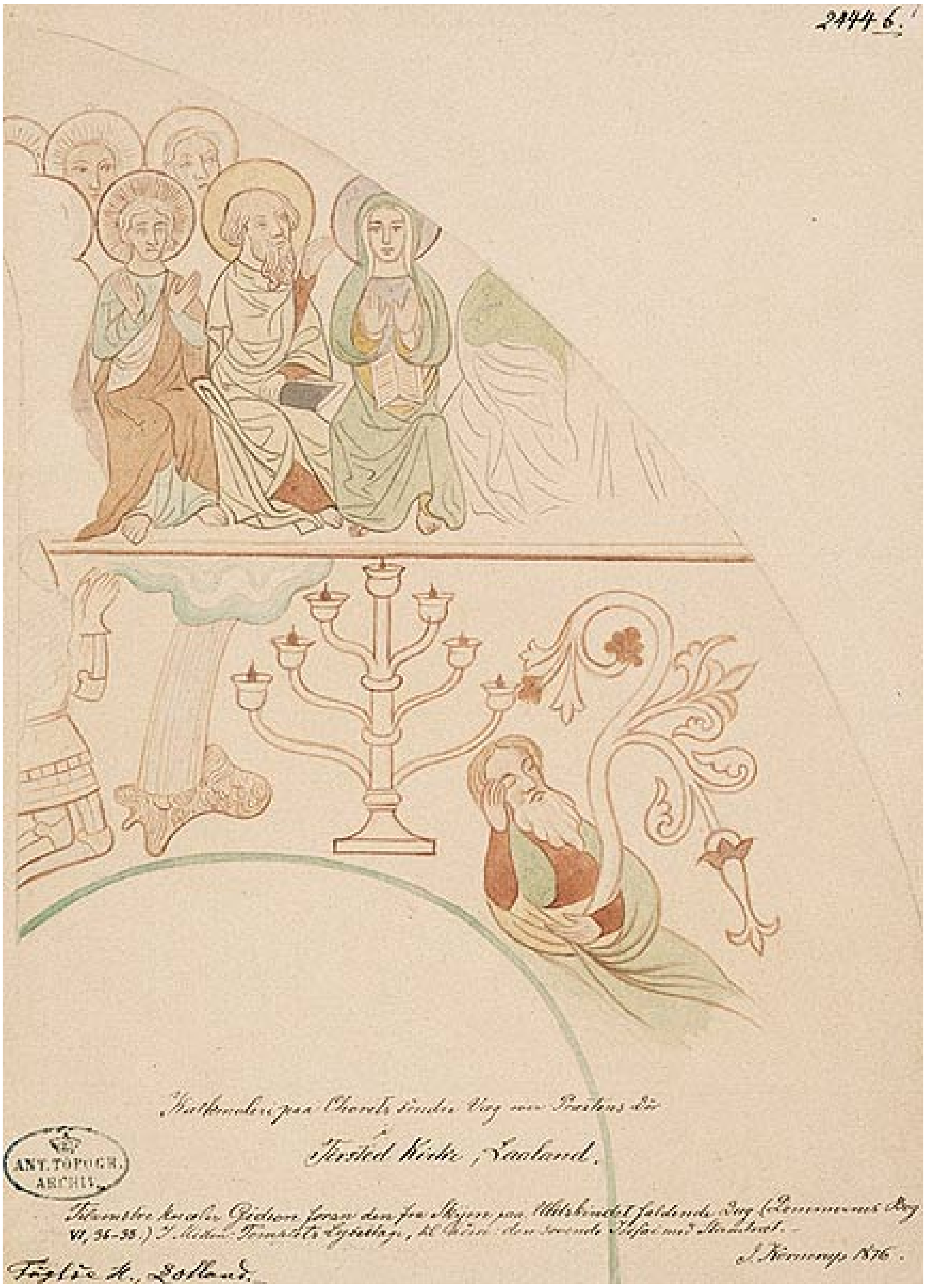
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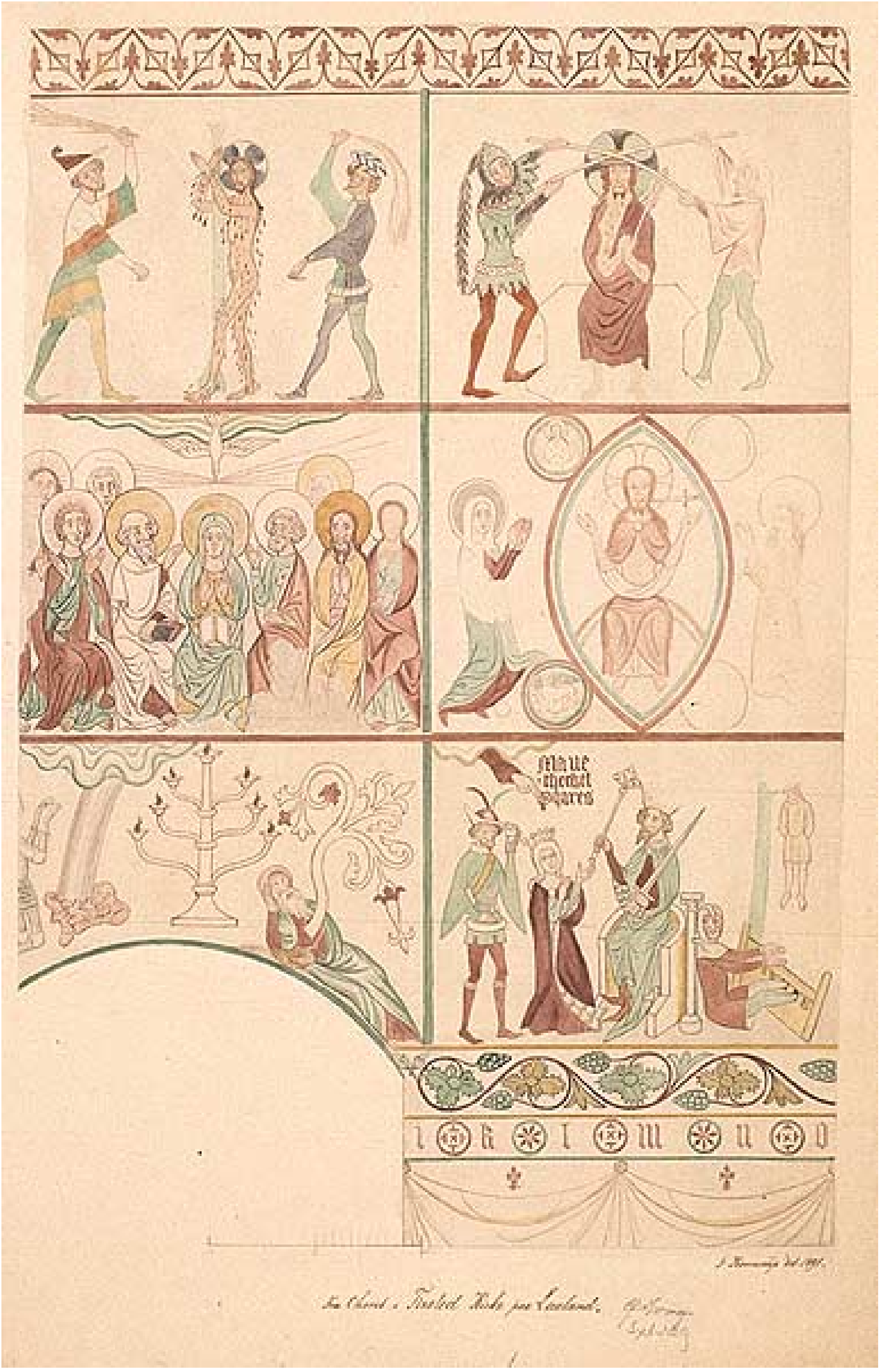

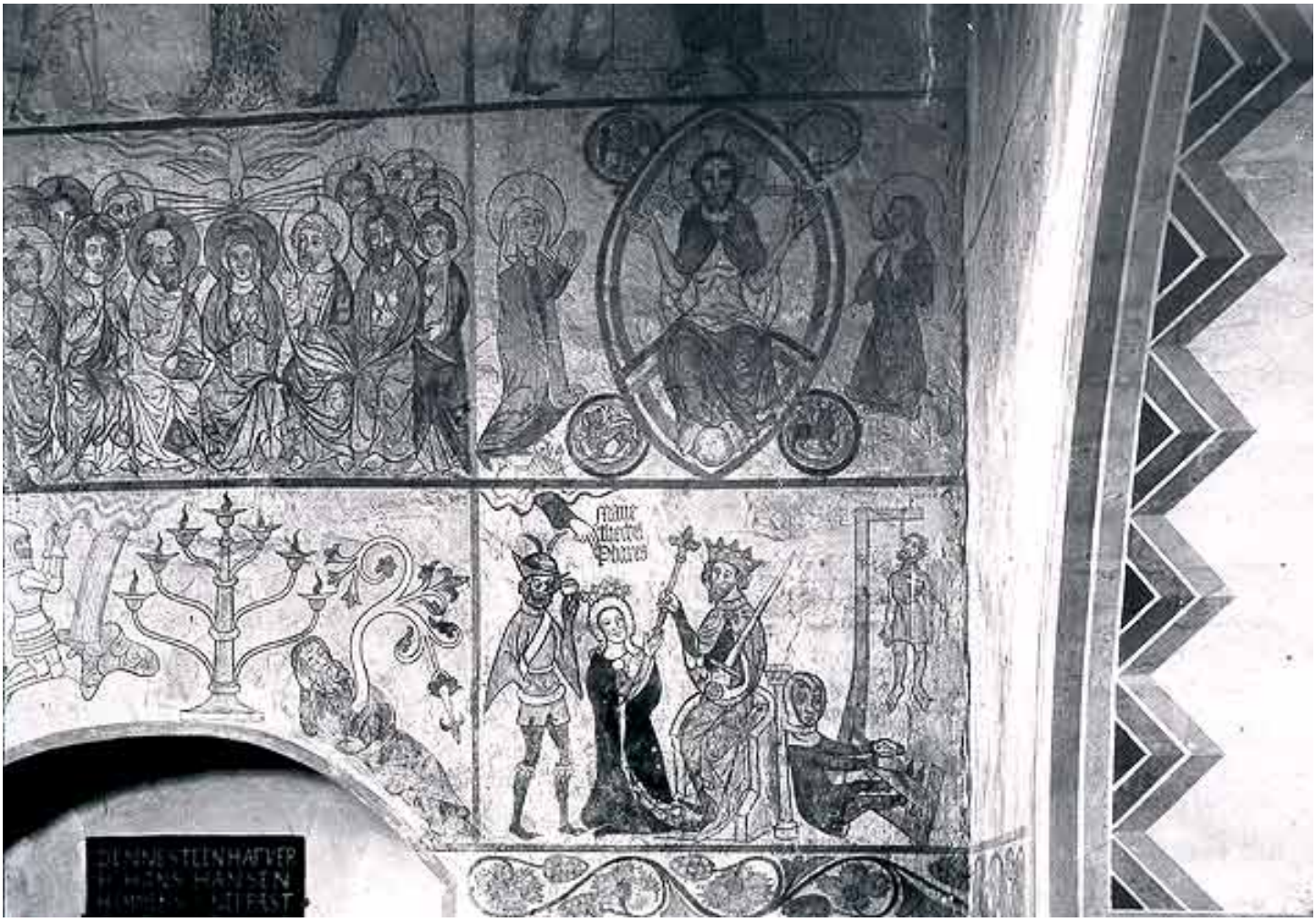

Raphael Project

The painting technique of the Gothic wall paintings

The paintings in the chancel were executed on a thin layer of plaster, which was applied to the brick wall. The thickness of the rendering varies from 1 – 10 mm, with the exception of certain areas, especially on top of the joints of the masonry, where it can be up to 30 mm thick. The plaster has a very characteristic uneven and rough surface, creating a layer of pronounced plasticity. The mortar was applied in portions having no connection to the composition of the painting, in fact, it could have been applied long before the paintings were executed. The edges of the portions of plaster, which slightly overlap the previously applied portions, are visible (in raking light) in many areas of the painting.

A layer of creme-coloured limewash was applied to the plaster with a coarse brush. The limewash was spread very quickly over surface leaving trails of brushstrokes in various directions, attesting to a haphazard application. The limewash constitutes the ground layer for the painting, but it is also visible over large portions of the painting in the form of a background.

The paintings were executed al secco, after the limewash was dry. The decoration was started with a preliminary drawing make with a light red colour. The painting was then built up in layers, with shadows and contours added in the final stages. Today, only small fragments of the painting have survived, which can attest to its original strength.

The majority of what is seen today belongs to the first stages of the painting process.

Fine lines incised in the ground layer have been found on almost all of the faces. Two parallel lines mark the bridge of the nose, and two lines define the eyebrows. These lines are so fine they cannot be seen from the level of the floor. They seem to have been executed as part of the drawing process, possibly as an aid indicating the placement of the features on the face. The lines are not present on the few faces where the final paint layers have survived, and a close inspection of these areas concluded that the scratched lines seem to be present under the paint layer.

The red colour, ranging from pale or medium strength iron oxides to an intense violet caput mortuum, dominates the decoration today. Green has also been used, both in the ornaments and the garments of the figures. Two different shades of green are seen, but only the pale green – identified as basic copper chloride – belongs to the original painting. The darker and stronger green colour is an oxide of chromium, which was used in the restoration of the paintings. Yellow ochre was used in the scrollwork and within the scenes. These three colours – red, green and yellow – formed the main chromatic scheme of the decoration.

However, other colours were also used, albeit to a lesser degree. Some areas of the painting were outlined with black contours, on others a strong red oxide was used. The black spots on the cheeks of a figure are a result of decomposition of minium – a lead red. A similar effect is seen on the Crucifixion scene, were the blood painted with red lead is now black.

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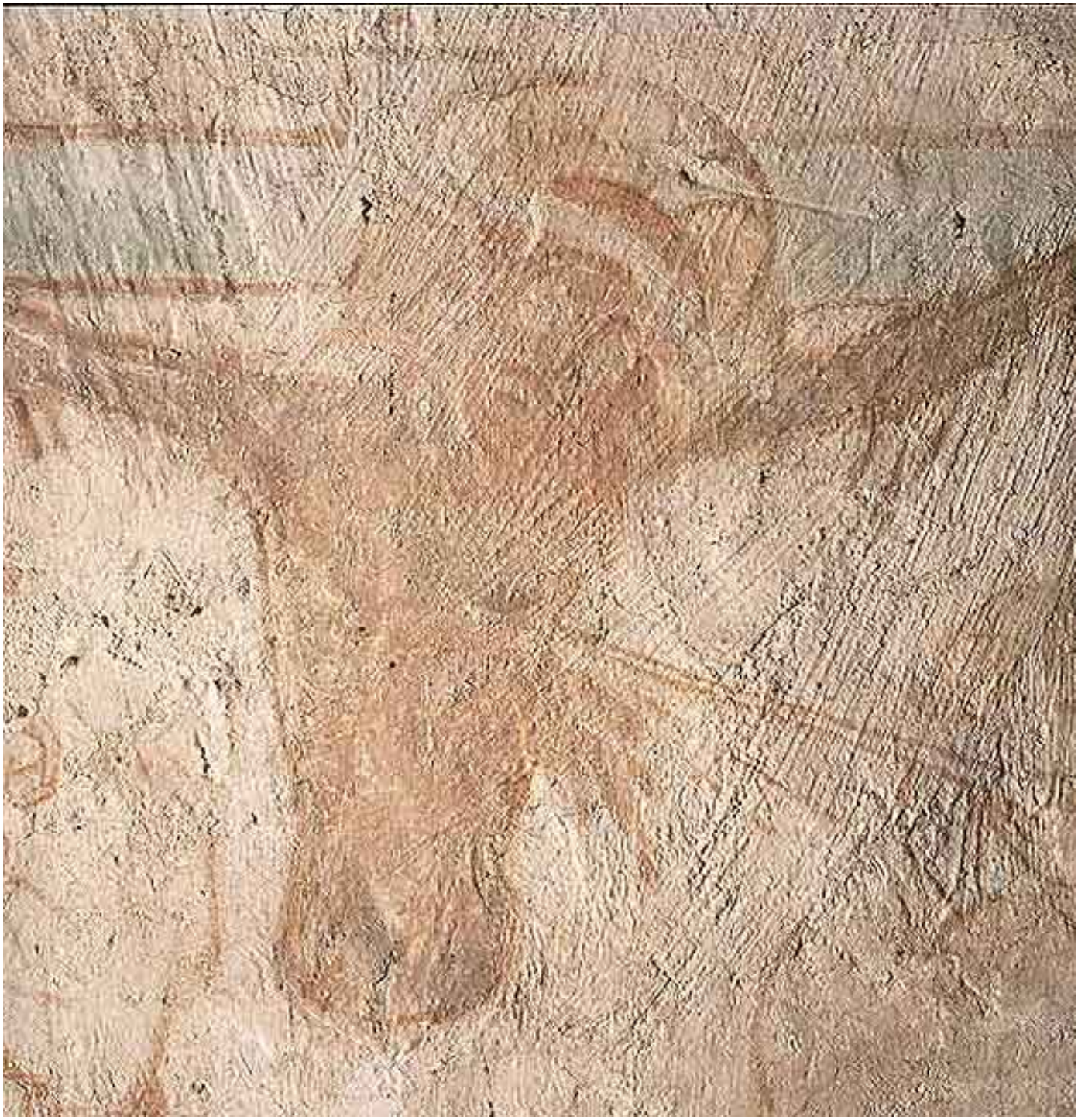

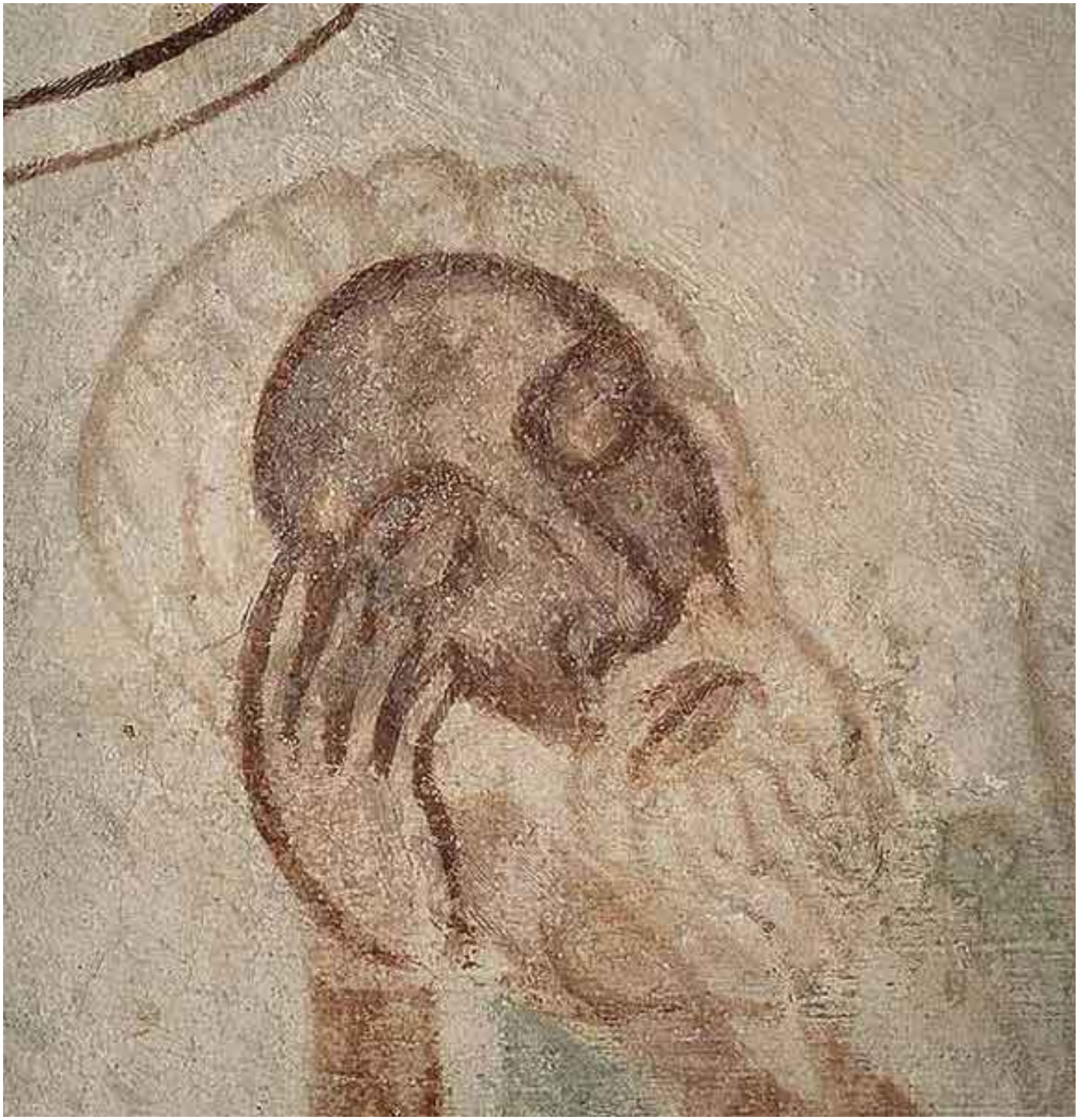

Raphael Project

The restoration of the wall paintings in 1892

After the vault was removed in the chancel, and the remaining limewash was knocked off the walls in July of 1891, the question of how to restore the uncovered fragments of the wall paintings was raised. Kornerup did not conceal before the Directory Board of the National Museum the fact that the decoration was fragmentary, and that the condition of the scenes varied from very well preserved to almost illegible. Of the original 45 scenes, only 26 could be restored. Another 5 scenes were so incomplete, that a reconstruction of the missing portions was impossible, and they were preserved in their fragmentary state. The remaining fields had to stand empty, as no trace of a paint layer was found on them. Nevertheless, Kornerup agitated for preservation of the decoration, emphasising its historical and antiquarian values. He hoped the Directory Board would agree with him, and called attention to the fact that very few wall paintings from this period were found.

It is interesting to note how the attitudes toward preservation of fragmentary paintings has evolved from that time. Kornerup argues that the decoration should not be destroyed and presents a proposal for its presentation – an aesthetic plan that has basically survived throughout the numerous treatments in the past century, and was prolonged in its essence during the most recent restoration in 1999-2000. However, it is doubtful whether such an aesthetic presentation would be proposed today had these fragmentary paintings been uncovered in our time. It seems that the decision to preserve the paintings in the chancel was dependant on the possibility to replicate the general composition of the painting, even though it was impossible to complete the decorative scheme in its entirety. In contrast, aesthetic presentations of fragmentary wall paintings in the present period generally emphasise the archaeological aspect of the isolated original fragments, without even attempting to reconstruct the general design or layout of the composition, not to mention details within the figurative scenes.

Kornerup's plan was founded in a careful study of the various decorative scrollwork, which defined the borders and provided colourful accents to the composition above and below the scenes, as well as around the windows. In addition, the painted drapery and stencilled decoration on the lower part of the wall was reconstructed, providing a visual anchor to the composition. All this, he said, could be replicated with complete confidence, as enough original fragments survived to prevent any falsification. With this backdrop provided for the figurative scenes, the red lines framing the individual fields could be reconstructed, and the missing portions of the figures could be partially reconstructed on the basis of his observation of deteriorated original areas that did not survive the uncovering. (Anything that was adhering poorly to the masonry, or decomposed by salts was probably knocked off the wall). Nothing, however, could be done about the 3 scenes that were destroyed when new windows were built in connection with the erection of the vaults, as well as several other scenes where not much, if anything, was found of the original paint layer. Here the framed fields would be empty. Kornerup sums up his arguments for his aesthetic plan: "At first glance one will understand that time has etched away a part of this old work of art, and, providing that one has any interest for our ecclesiastical antiquities, one can be glad that so much has survived."

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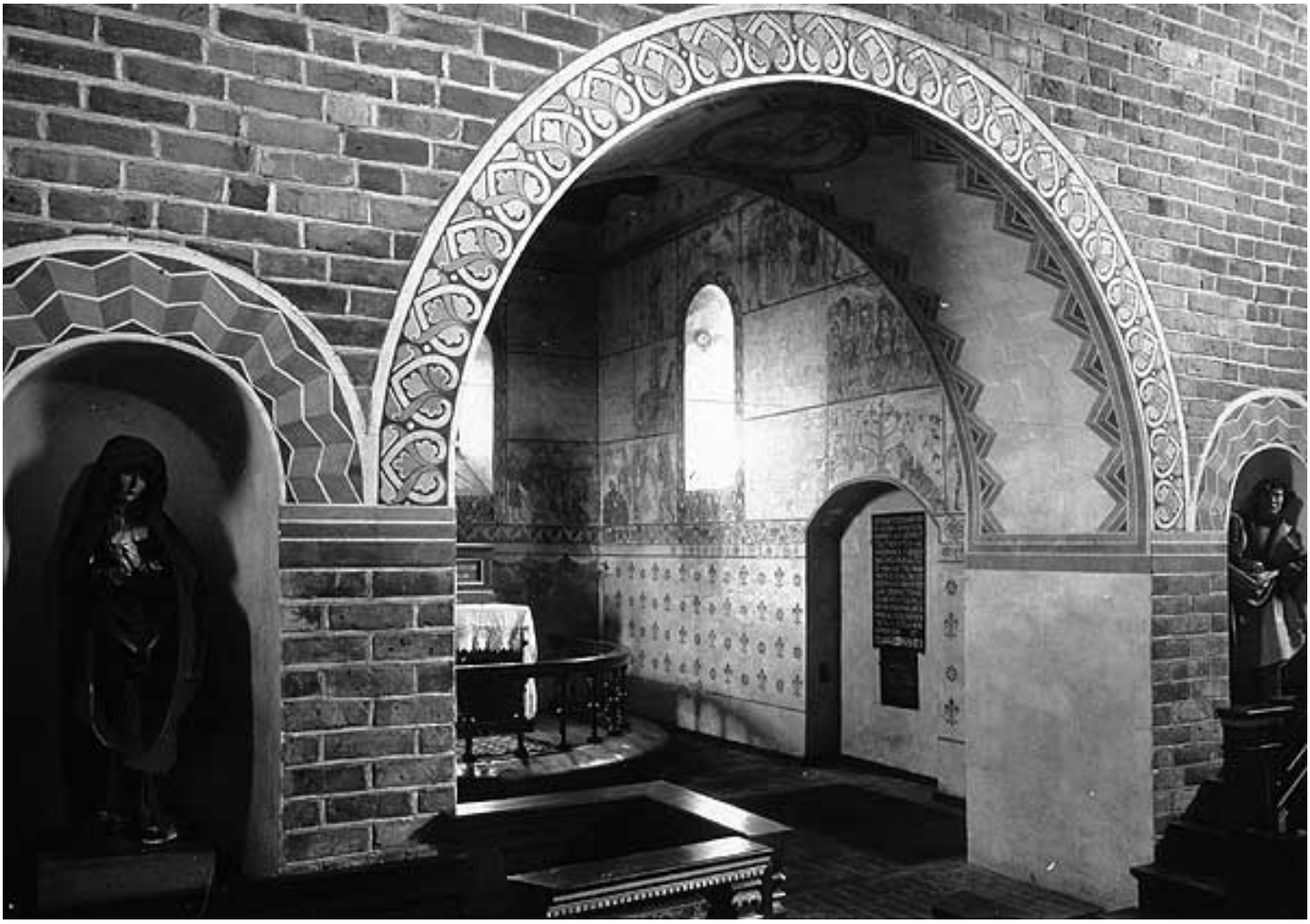
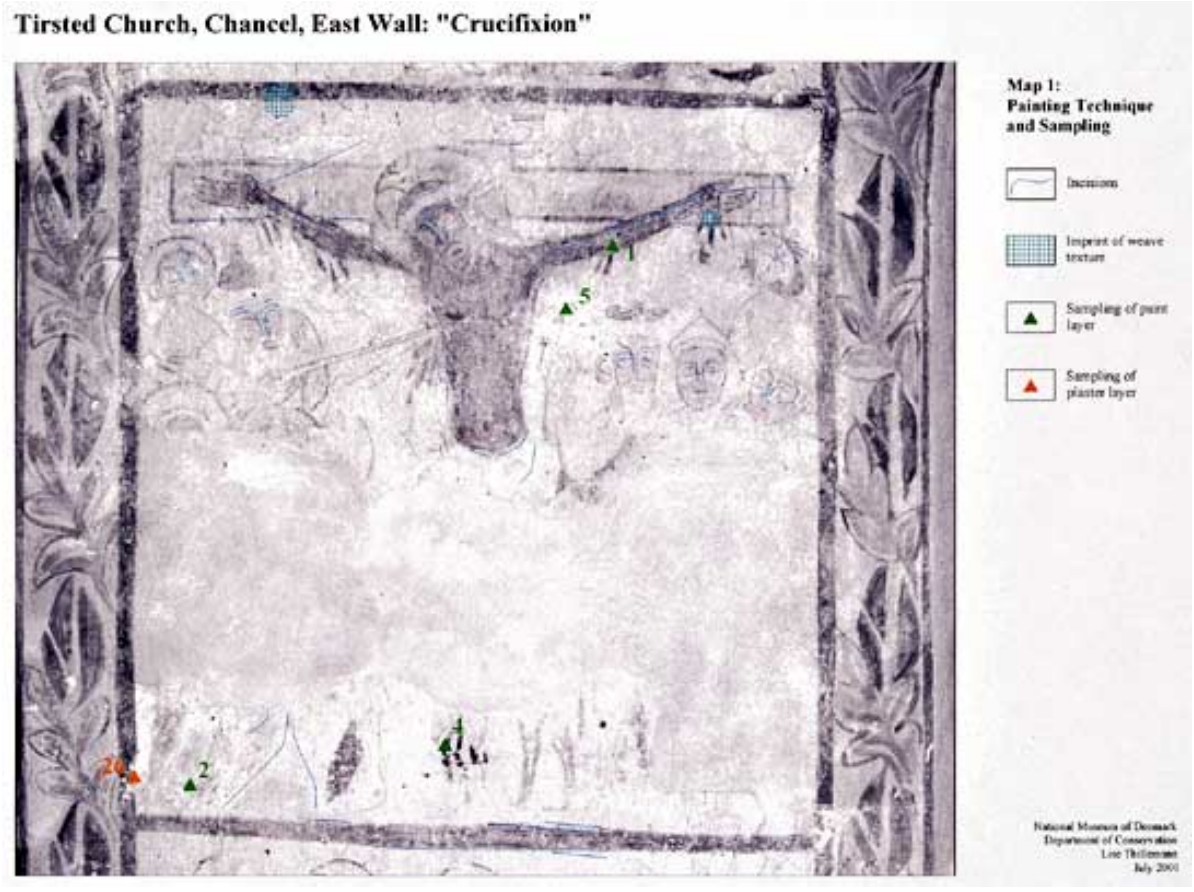


Mapping of Painting Technique

The two main phenomena contributing to the information of how the paintings were created were: 1) The location of plaster joints (in this case butt joints), which clearly show that the plaster was applied to the brick wall independently of the composition of the painting. The painting could have been executed shortly after the application of the plaster, but the way the plaster was applied demonstrates that the painting in Tirsted is not a fresco painting. Following the structure rules, the name of the file for this phenomenon was named: 2000-_pai-pla. [The year the information was gathered (2000) precedes the category name (painting technique), which is followed by the group name (plaster borders)].
2) Numerous incisions, especially in the faces of the figures, demonstrate how this phenomenon was used as an aid in the construction of the painting. The file containing this information: 2000_pai-inc [2000_painting technique-incisions].
Also documented are small areas with imprinted texture of material. The connection of this phenomenon with the painting technique is as of yet unclear, and could be the random imprint of material from the clothes of the masons or painters. The file is named: 2000_pai-tex-oth , [2000_painting technique-texture-other].
Included on the maps documenting painting technique in Tirsted Church is the location of sampling points, where minute parts of the plaster or paint layer were extracted for analysis. File names for the samples of plaster analysed chemically: 2000_sam_che-pla; for paint layer analysis: 2000_sam_che-pai.
An example of a map registering the painting technique is seen on Figure 1.



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Mapping of the Condition

Mapping of the condition (Map 2 and Map 3)
Information pertaining to the state of the scenes was placed into two separate maps, one depicting the condition of the plaster (Map 2), and the other depicting the condition of the paint layer (Map 3).
Map 2 (condition of the plaster – Figure 1) included the following phenomena:
- cracks in the plaster layer (2000_mat-pla_dam-cra) [2000_material-plaster_damage phenomenon-cracks]
- pits and craters formed in the plaster by the expansion of particular substances in the plaster, such as small pieces of unslaked lime, or pieces of crushed brick that were mixed into the plaster (2000_mat-pla-_dam-pit)[2000_material-plaster_damage phenomenon-pitting]
- areas where the adhesion of the plaster to the substrate was poor (2000_mat-pla_dam-pad-cav) [2000_material-plaster_damage phenomenon-poor adhesion-cavity]
- areas where plaster repairs from previous interventions were located. This was included in the damage phenomenon in Tirsted Church because of the damaging effect of the repairs, which necessitated their removal (pre1999_mat-pla_tre-rep) [pre1999_material-plaster_treatment-repairs]
- areas where the surface was damaged mechanically, usually during the uncovering of the painting (2000_mat-pla_dam-wea) [2000_material-plaster_damage phenomenon-wearing]
- areas where the plaster was deteriorated due to salt efflorescence (2000_mat-pla_dam-sal) [2000_material-plaster_damage phenomenon-salts]
- areas where the original appearance of the plaster was altered due to surface consolidation (impregnation) carried out in previous interventions (pre1999_mat-pla_tre-con-res) [pre1999_material-plaster_treatment-consolidation-synthetic resin]
- areas where iron spikes were driven into the plaster (2000_mat-for) [2000_material-foreign]
- areas where the brick directly under the plaster layer was totally disintegrated (2000_material-sub-brick_dam-pco) [2000_material-substrate-brick_damage phenomenon-poor cohesion]

Phenomena documented on Map 3 (condition of the paint layer – Figure 2) included:
- areas where the paint layer was lost or removed in previous interventions (2000_mat-pai_dam-rem) [2000_materials-paint layer_damage phenomenon-removed original] (Lacunas are normally not mapped in the system developed in the course of the Raphael-project because then denote non-existing material – lacunas are not listed among the damage phenomena. In the case of Tirsted this non-existing material was assigned a graphic symbol, nevertheless, in order to graphically depict how much of the paint layer was not original, and was replaced

by repairs and reconstructions in previous interventions. The more correct way to depict the same phenomenon would be to show a map with the location of the original paint layer with the file name: 2000_mat-pai).
- areas where the paint layer was flaking (2000_mat-pai_dam-pad-fla) [2000_material-paint layer_damage phenomenon-poor adhesion-flaking]
- areas where the paint layer was damaged by salt efflorescence (2000_mat-pai_dam-sal) [2000_material-paint layer_damage phenomenon-salts]
- areas where the paint layer was obscured by limewash (residual limewash from the time when the paintings were covered) that was never totally removed in previous interventions (2000_mat-lim) [2000_material-limewash]
- Areas where the paint layer was overpainted in previous interventions (pre1999_mat-pai_tre-ove) [pre1999_material-paint layer_treatment-overpainting]

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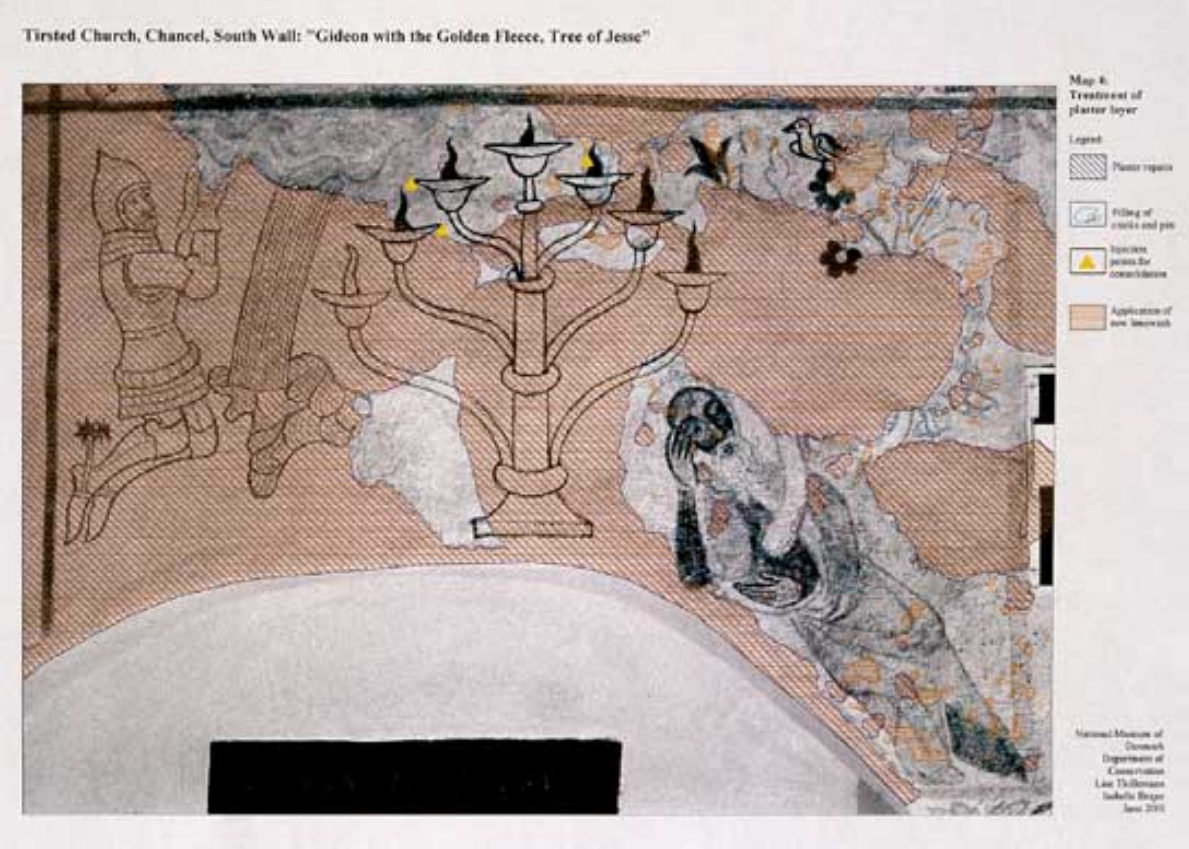
Mapping of the Treatments

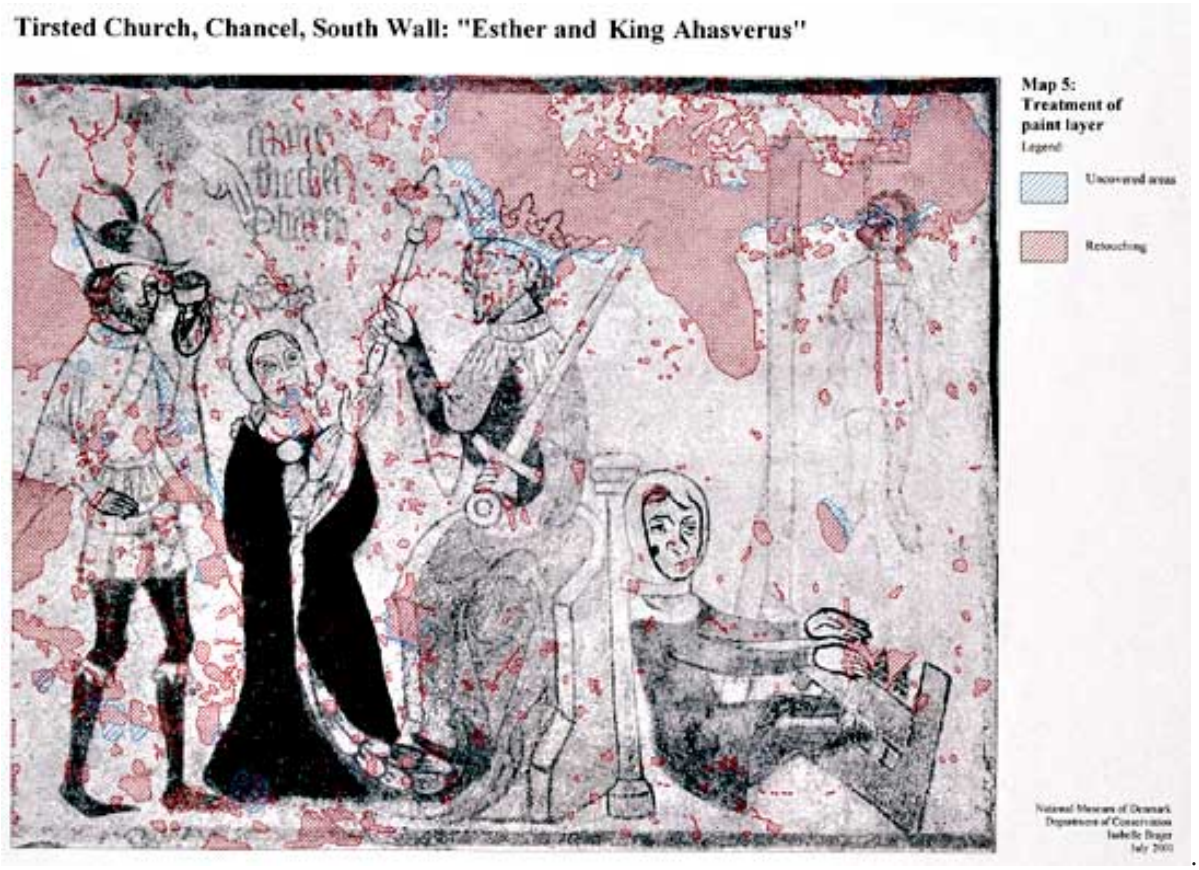
In a similar way as the condition of the painting was divided into phenomena pertaining to the plaster separate from phenomena pertaining to the plaster, the treatments carried out in the course of the re-restoration were also divided on two maps – one for the plaster layer (Map 4), and another for the paint layer (Map 5). Only a selected amount of phenomena was mapped, because certain treatments pertained to both layers, and were carried out on the entire surface, which caused difficulty in the visualisation. One must remember that graphic documentation is a supplement to the written description of the treatment.

Information presented on Map 4 (treatment of the plaster layer – Figure 1) included:
- the location of new plaster repairs (2000_mat-pla_tre-rep) [2000_material-plaster_treatment-plaster repairs]
- areas where small holes and cracks were filled with lime paste (2000_mat-pla_tre-rep-oth) [2000_material-plaster_treatment-repairs-other types]
- points of entry, where injections were made to consolidate poorly adhering plaster (2000_mat-pla_tre-con-lim) [2000_materials-plaster_treatment-consolidation-lime-based materials]
- areas where new limewash was applied (2000_mat-pla_tre-lim) [2000_material-plaster_treatment-limewashing]



Treatment of the paint layer was presented on Map5 (Figure 2):
- areas where the residual limewash was removed (2000_mat-pai_tre-unc) [2000_material-paint layer_treatment-uncovering]
- areas where the paint layer was consolidated with caboxy-methyl cellulose (2000_material-paint layer_tre-con-cel) [2000_material-paint layer_treatment-consolidation-cellulose based material
- areas that were retouched (2000_mat-pai_tre-ret) [2000_material-paint layer_treatment-retouching]
- areas where the pictorial content was reconstructed on a new plaster layer (2000_mat-pai_tre-rec) [2000_material-paint layer_reconstruction]

Tirsted Church, Chancel, South Wall: "Esther and King Ahasverus"



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BRITSUM CHURCH

Introduction to medieval wall-paintings
in the Dutch Reformed church at Britsum
(The Netherlands, province of Friesland).

Building-historical research

Iconographical program

Stylistic and iconographical relations

The paintings and their dating

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Introduction

Between March 1998 and December 1999 decorative and figurative mural and vaultal paintings were exposed and restored in the Dutch Reformed church at Britsum. To that moment they had been hidden beneath many layers of white limewash. These paintings, dating from the sixties of the 13th century, are of great art historical importance. They belong to the oldest medieval wall-paintings known in the Netherlands. However, the paintings not only are of a very high international quality, they also have a unique iconographical programme. Therefore, they are of great importance. The discovery of the paintings and the deciphering of the representations led to great national and international interest and appreciation. Naturally, it is of the greatest importance to preserve these valuable paintings for the future.
The paintings in Britsum are part of an international researchproject of the European Community (Raphael-project).
The most important aim of this project is the analysis, protection and
preservation of medieval wallpaintings in Germany, Denmark and the Netherlands.

On this site you can find short information about the building historical research, about the iconographical programme (the representations and their programmatic connections), about the stylistic and iconographical relations, about the dating of the paintings and about the painting technique and conservation treatment.
There is a survey of literature for those who want to have more information about the church and the wall paintings.

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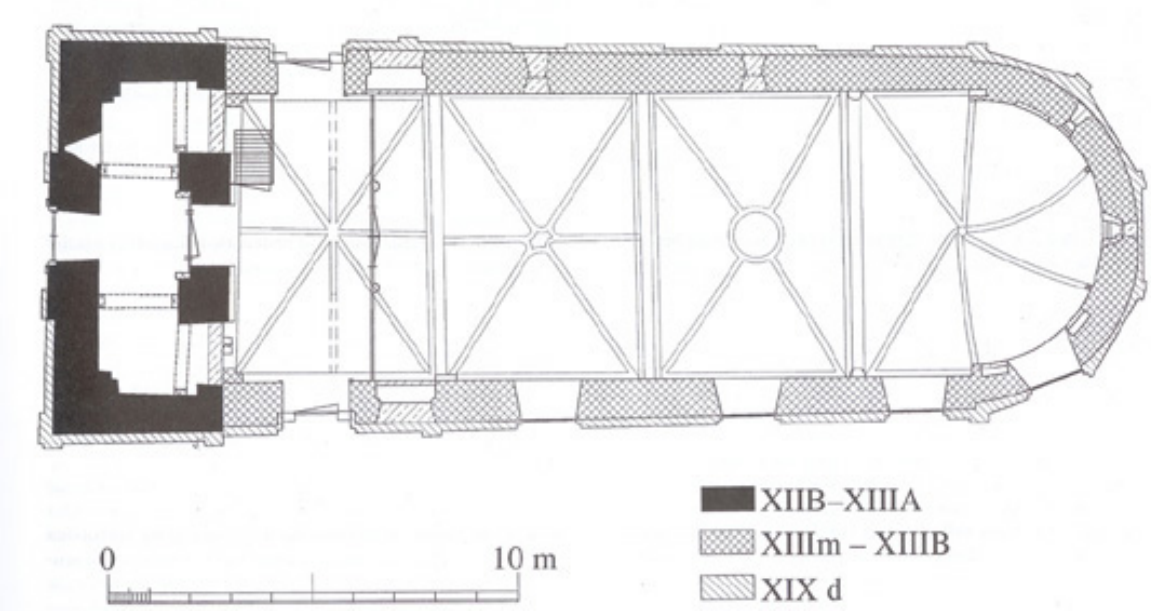
Building historical research

The church is of the so-called ‘hall-church’ type with a single nave without aisles, as customary for Frisian village churches. On the west there is a ‘reduced western block’, consisting of a tower with flanking adjacent spaces provided with a floor, dating from the period 1180-1190. It is a very early example of brick architecture with romanesque details. The ribless dome vaults of the ground floor were built somewhat later, in the 13th century. The greater part of the superstructure of the tower was renovated in the 17th and 18th centuries.
The present nave was preceded by an older (possibly tuff) hall-nave. The present hall-nave, built of brick, and the choir with the semi-circular apse, is vaulted with early romanesque-gothic domes with sturdy round ribs. It is quite likely that the hall nave and choir were executed between 1240 and 1250 and the vaulting around 1260 at the latest. Because of the construction of this vaulted nave the original circular-arched openings in the eastern front of the western block had to be closed.
In the 15th century large pointed-arch windows were built into the southern wall of the nave and the southern part of the apse.
After smaller renovations in the 17th and 18th centuries a fundamental operation took place in 1875, when the church was on the outside covered by an entirely new neo-gothic wall in smooth red brick with accents in yellow stone.
The present exterior of the tower and the western block, both with plastered details, date from 1895.

Interior before the discovering of the paintings

Interior during the restoration activities



Groundplan

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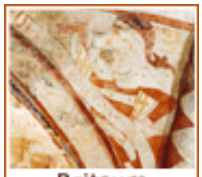
Britsum

Iconographical program

The most important wall paintings are to be found in the chancel of the church, in the zone directly below the vaults. They are applied in pairs on an arch panel. They represent a passion cycle: the Last Supper (vanished), Christ's prayer on the Mount of Olives, the Betrayal of Judas, the Crowning with Thorns and the Whipping (Flagellation). The cycle probably ended with the now vanished representations of the Crucifixion and the Descent from the Cross or the Sepulture of Christ. All these paintings are very damaged.
More is preserved of the Old-Testament figures in the spandrels of the arch panels: Abraham, Isaäc. Jacob, Mozes, Aäron, Salomon with a viola, David with a harp, Jonathan, Absalom with a vielle and finally Saul.
There are inscriptions around these figures: ABRAHAm PATER (=father Abraham), isaAC FILIus ABRAHE (=Isaäc son of Abraham), Jacob PATeRACHA (=patriarch Jacob), MOYSES LEGYS (=Mozes of the Law), AARON FACUNDUS (=Aäron the fluent), SALOMON Rex (=King Salamon), King David with his harp, JonaTHAS DUX (=Jonathan the commander), ABSOLOM FILIus David (=Absolom son of David) and SAUL.
Above the head of Jesus Christ in the representation of the Crowning with Thorns is an inscription with the word NAZARENus (=Jesus of Nazareth).

The Old Testament figures are probably typologically connected with the passion scenes.
The only vaultal painting is to be found on the eastern-most panel of the vault of the nave. It represents the Holy Mary with a crown on her head. Her son, the child Jesus, sits in her lap. Mary is handing a round object, probably an apple, to her son. This representation symbolizes the new Eve (the Virgin Mary as a second Eve), the Incarnation (Christ as a fruit from the womb of Mary) and the Redemption (Christ as the fruit of the cross). The apple possibly also represents the imperial-apple, an attribute for Mary as Queen of Heaven. Mary and Jesus Christ are surrounded by a mandorla.
There are only a few remnants on the wall of the nave: a red consecration cross, fragments of a female saint and part of an angel.
Decorative paintings are found on the ribs of the vault, the transverse arches and around the figurative representations. They consist of geometric patterns and some "candelabra".

Drawing (4A) and photograph (4B) : Isaac

Drawing (5A) and photograph (5B): the Betrayal of Judas; Mozes

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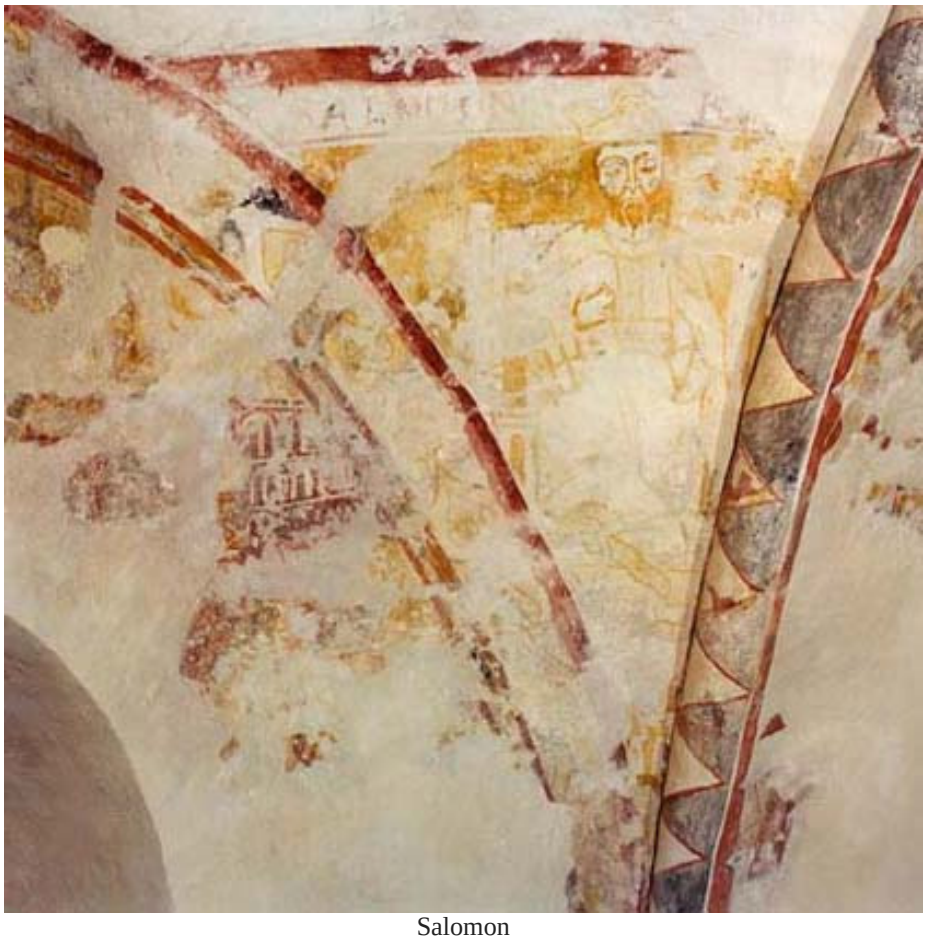
Drawing (6A) and photograph (6B): the Crowning with Thorns; Aäron and Salomon

The Crowning with Thorns



Salomon

King David with the harp.

Virgin Mary with her Child.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Stylistic and iconographical relations

Stylistic parallels for the figure of Mary with her Child are to be found in the moderate "Zackenstil" (zigzag-style), current in Lower Saxony and the area of Cologne in the forties of the 13th century.
There is a clear similarity with book-painting in Aachen from about 1240 and stained-glass in Cologne from about 1250 in the other figures of the paintings in the choir. There is a very great similarity between the head of King Salomon in Britsum and the head of Charles the Great on a tapestry in Halberstadt (Lower Saxony), dating from the first half of the 13th century.
The special iconographic quality of the musical instruments represented seems to point to the influence of English Psalter illustrations, notably the Tree of Jesse, where from the late 12th century onwards the ancestors of Christ are sometimes represented playing musical instruments.
The decorative paintings have parallels in other churches in the northern provinces of Friesland and Groningen. Furthermore, there are similarities with Byzantine ornaments, which can be found in the Westphalian churches in the period 1180-1250 and in the churches of Lower Saxony (e.g. the ceiling-paintings of the church of St. Michael in Hildesheim).
The whole iconographical program with the figures from the Old-Testament in combination with the scenes from the Passion of Christ are absolutely unique, without parallels in other churches, neither in the Netherlands nor in Germany or Denmark.
All the stylistic similarities, the very special program and the very high quality of the paintings make it clear that the paintings in Britsum are of an international importance.

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The paintings and their dating

The stylistic characteristics of the figures (zigzag-style), the similarities with paintings in Aachen, Cologne and Lower Saxony (from the second quarter and the middle of the 13th century), in combination with the dating of the vaulting of the church in Britsum (about 1260), make the dating of the wall paintings in Britsum around 1260 acceptable to be.
Also, the similarity of the decorative paintings to those in the Westphalian churches indicate a date after the middle of the 13th century.
The fact that the Crowning with Thorns and the Whipping on the eastern wall of the choir form the focus of the cycle is unique. There is a prominent presence of Jews as enemies of Jesus and the new Christian faith. The Jews are easily recognized by their funnel-shaped head covering. In this way it is possible that the paintings at Britsum in this way are a reflection of the enthusiastic activities of Frisian Crusaders in 1248-1250.

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The painting technique

A rough plaster layer is applied to the masonry, the so-called arriccio. The material used is shell-lime, and then small fragments of shells give the plaster its rough texture. The thickness of this plaster varies locally, ranging from approximately one centimetre to only a few millimetres.
On top of this arriccio lies a finer plaster layer, the intonaco. This plaster layer was covered by a thick limewash, which was applied freely with a ± 10 cm wide brush. The material must have been rather fluid when it was applied as testified by the air bubbles and drips on the surface.
In this wet limewash a few incisions were applied. Some of these have to do with the architectural decorations, the meaning of others is still unclear. In a few places traces of an underdrawing in charcoal were found.
The decorative painting is executed in several colours, and the paint was applied while the limewash layer must have been still wet. Due to this technique, the paint adheres very well to the ground layers, as the limewash around and the paint layer dried together to create one layer. This so-called 'Kalkmalerei' technique is the northern version of the fresco technique.
In Britsum, the outlines of the image are painted in very thin orange-pink lines. After this, the painter continued with yellow and red. The figures and decorations are painted in thin fluent lines, the form of the lines and planes are a bit rugged.
The painting is finished with a more detailed paint layer in black, as if a contour drawing was applied on top of the already dried painting. This paint layer has only survived in just a few spots because it was applied on a dried surface, the adhesion with the underground was poor. The black colour follows the outlines of the figures and gives depth to the geometric decorations of the wall-arch. The recently uncovered wall painting in its present form shows the preliminary painting without the details that were applied in the second, finishing paint layer.
It is uncertain when the original decorations were covered with a limewash for the first time. After this, the wall paintings disappeared under countless white paint layers. It was not until the early nineties of the twentieth century before they were rediscovered.

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The conservation treatment

From March 1998 till December 1999 the wall paintings were uncovered from a thick cover of limewash layers. Hanna Visser and Helmut Hut carried out the uncovering and consecutive conservation treatments.
The uncovering was carried out in two phases. First, the loose limewash layers were removed by taping the surface with a small hammer. Secondly, the residual limewash and mortar were carefully removed with a scalpel. At the same time, the loose pieces of the painting were consolidated, as the adhesion between the arriccio and intonaco in some cases was poor. Due to a chemical bonding of the painting with the underlying layer, the preliminary paint layer forms one layer with the limewash, and it seemed to be in good condition. The black contours survived hardly anywhere, but when these areas were uncovered, they showed a discoloration, due to chemical changes in the material itself, which has disappeared.
The consolidation of loose intonaco was done by injecting of a synthetic consolidant underneath the loose parts of the painting. Depending on the thickness and depth of the voids under the limelayer, the consolidant was injected through little needle-holes, or sometimes through small holes of approximately 4 mm, which were drilled into the plaster.
After consolidation, the uneven surface marked with a lot of holes and cracks was filled. The filling material was a fine mortar of slaked lime mixed with a little bit of pigment. The fillings were applied by brush and spatula. The last phase in the conservation treatment was the retouching of the fillings. This was carried out with a fine cross-hatching technique with a colour that suited the surrounding colours.

Photograph 11: Mozes, partly uncovered, with a thick package of lime wash layers around.

Photograph 12: the Crowning with Thorns and the damage of the wall around (before restoration).

Read more

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Examination of the paintings in UV light

The re-restoration campaign in 1999/2000 was initiated with an examination of the paintings in normal light (dispersed and raking), and in UV light. Different types of fluorescence were observed in UV lighting. However, it is difficult to interpret these observations. Fluorescence observed on wall paintings in UV light is often dependant on the particular physical and chemical circumstances, which can vary from case to case. Experience in Denmark has shown that, for example, fluorescence of a salt-contaminated surface can give a different impression on wall paintings from various locations, even though the painting technique was similar in each case. To date no standard for the fluorescence of different materials found in wall paintings has been established. Therefore, examinations with UV light often raise more questions than they answer and should be combined with chemical analysis. Even then, it is often difficult to form a complete picture, because in the tiny amount of material that is sampled it is often difficult to identify the presence of proteinaceous material from degraded original binding media. And the more often the given decoration was treated in the past, the more muddled the picture becomes.

Only one of the seven samples sent to laboratory (Department of Conservation at the National Museum) for chemical analysis was positive for the presence of organic binding medium. This site, however, did not display any fluorescence in UV light. Visual examination determined that the sample belonged to an overpainting from an earlier restoration. There were many areas where a faint pink fluorescence was observed. Many of these areas were located on the faces and hands of the figures, but similar fluorescence was also seen on other parts of the scenes, such as the clothing. Organic binding media, however, was not found in any of the samples taken from these areas.

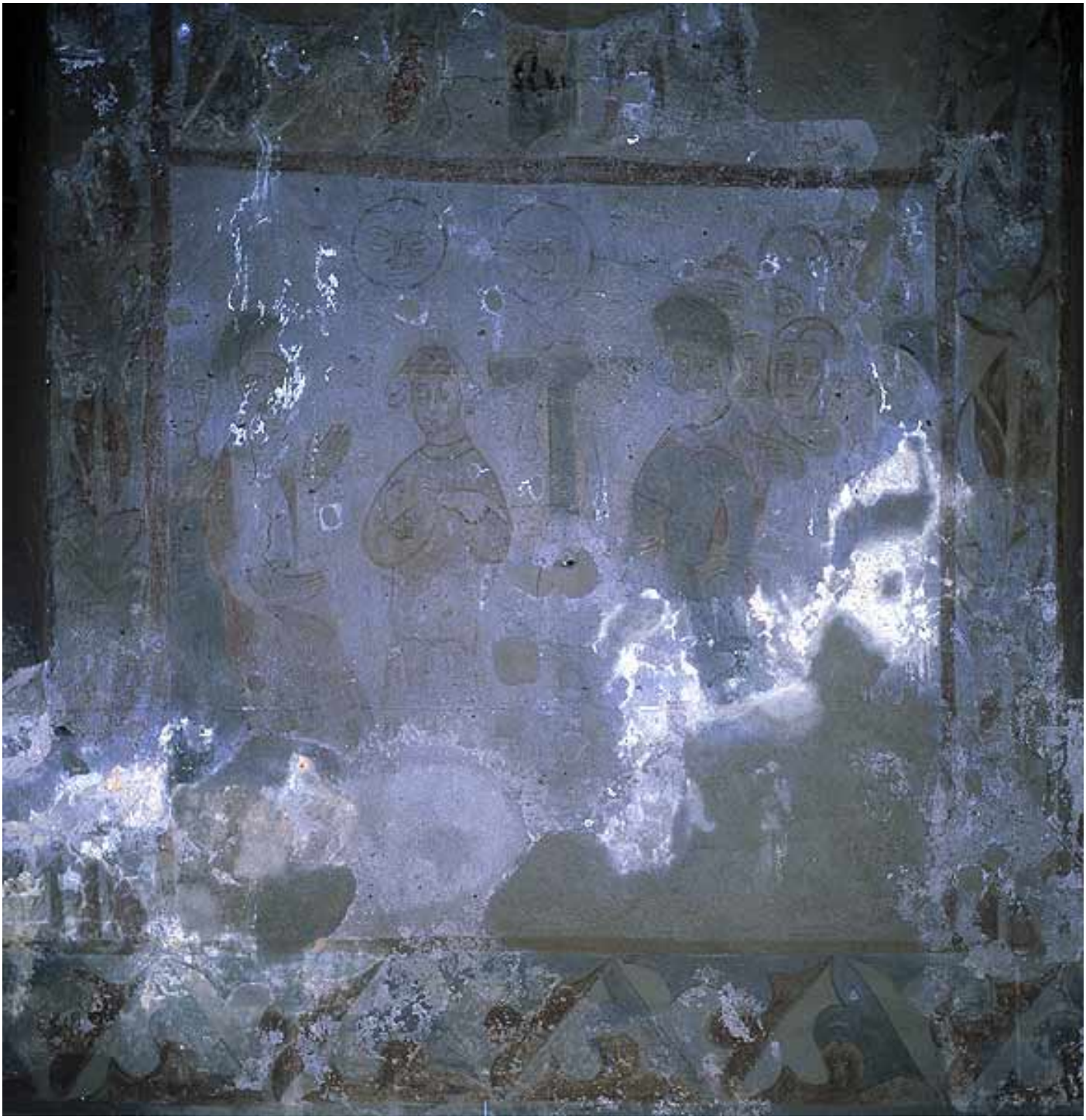
Mortar repairs were clearly visible in UV lighting. Various shades of dark blue marked repairs from the different historical restorations. It seemed that the lesser degree of carbonation (more recent repairs) was represented by a deeper blue colour. An accumulation of salt efflorescence around the mortar repairs (visible as white fluorescence) demonstrates the non-porous character of the mortar used in the earlier periods. White fluorescence also marks areas where polyvinyl acetate used as a consolidating medium dripped down the surface of the painting.

A wide band of white fluorescence on the upper scene on the east wall shows the height of the vaulting that was erected around 1500. The fluorescence is probably the result of a denser presence of carbonates in this area, as mortar used in the construction of the vault was in direct contact with the painting in this area.

Examination of the transferred scenes in UV lighting also gave interesting results. Very strong mustard-coloured fluorescence was observed on the older transfers mounted on chipboards. Although it is difficult to pinpoint the source of this phenomenon, it is probably connected either to the polyvinyl acetate used in the backing, but also seems to stem from the heavy retouching on the front of the transfer. White fluorescence on the older transfers is probably a result of the large amount of salts that were transferred together with the paint layer, and demonstrates that these were not removed when water was applied to the front when washing the facing off the transfer. Also seen were patches of darker blue, denoting areas were mortar repairs were carried out in earlier periods.

The newer transfers mounted on honeycomb plates did not display the strong yellow fluorescence visible on the older transfers, despite the fact that polyvinyl acetate was also used here. It was, however, mixed with other glues and fillers, which might explain the totally different result. The lacunas in the paint layer did not display any fluorescence, appearing dark blue. White fluorescence was also visible, though to a lesser degree than on the older transfers, as were the medium blue spots marking the presence of mortar repairs from earlier periods.

Read more



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Cleaning and fixing of the surface

The superficial dust was removed from the surface of the paintings by brushing it off lightly with a soft brush. Thereafter, a more thorough cleaning was carried out with gomma pane. This cleaning dough was made by dissolving 65 g copper sulphate in 400 ml boiling water, 20 g sodium carbonate was then added, and finally 800 g wheat flour. The dough was kneaded thoroughly, wrapped in several layers of wet cotton fabric alternating with aluminium foil (in order to retain moisture when baking), and then it was baked for 90 minutes at 175ºC. Gomma pane could very easily be shaped so that it could be pressed into small crevices in order to clean the uneven surface. The more fragile areas of the painting could be cleaned by carefully rolling the dough over the surface and lifting off the dust in this manner. The blank scenes where only a toned limewash was found were cleaned with Wishab - Hart (Akachemie) sponges.

In several areas it was not possible to clean the surface because of the poor condition of the paint layer, which was partially detached from the ground layer. These flaking areas were fixed by initially stabilising with a Tylose MH300 (methyl hydroxyethyl cellulose) mixture in water and ethanol (1:30:20), applied through a Japanese tissue. Thus stabilised, the flakes could be fixed by injecting Primal AC33 diluted in water (8:3).

There was also a moderate amount of polyvinyl acetate on the surface of the painting and in the cracks and crevices in the areas where the painting was consolidated in one of the previous re-restorations. The glue was swelled with cotton wool compresses using acetone, and then removed with scalpels. However, it was not possible to remove the glue deeply lodged many of the cracks.

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Plaster repairs carried out in 1999/2000

Prior to the most recent re-restoration of the decoration in Tirsted Church about 50% of the surface in the chancel was covered by plaster repairs from earlier restorations. All of these repairs had smooth surfaces, and although no cement was found in them, they were much harder than the surrounding original plaster. Although the salt analysis of the various plasters showed that the repairs were also contaminated by salts, the content was small compared to the amount of salts found in the original plaster. The scientific data was corroborated by visual examination in normal and UV light, where it was clear that the salt damage was concentrated in the areas of the original plaster directly adjacent to the hard plaster from the repairs. This phenomenon was due to the fact that the migration of salts is easier in the more porous structure of the original plaster.

Despite the fact that the majority of the reconstructions from earlier treatments would be destroyed with the removal of all the smooth and hard repairs, this was decided in order to create a more homogenous interior surface. (All reconstructed areas were traced on plastic foil before they were hammered down). Some of the scenes lost 50% of their content. But the south wall presented the most drastic situation: when all of the scenes that were transferred to chipboards or honeycomb plates were removed, only a little portion of the surface, where four scenes were located in the south-west side, remained on the wall .

Although this decision was taken primarily due to the moisture and salt problems, the execution of new plaster repairs also gave an opportunity to improve the aesthetic presentation of these surfaces. The original rendering was not smooth at all, and all of the flat repairs were, therefore, visually incompatible with the undulating surface. The new repair mortar consisted of one part six-year slaked lime putty and 3 parts fine sand (grain size: 0.0 – 2.0 mm). One part powdered quartz was added to every 12 parts mortar. Although the addition of such fine material rendered the mortar slightly less porous, it improved the plasticity and workability of the mortar enabling the recreation of the original surface texture in the repair.

The mortar was applied in an excess quantity, and after it had set (30 min. to several hours depending on the area of the repair) the surface was cut with a spatula and sculpted to imitate the relief of the original rendering. The areas which appeared too grainy were pressed down, but not polished with the trowel. Finally, lines were incised in the repairs in order to imitate the texture of the brushstrokes in the lime ground layer. The incisions, of course, only gave an approximation of the visual effect of the brushwork, as they created an impression in the plaster, whereas the brushwork created a relief. Nevertheless, viewed at a distance, this effect recreated the textural liveliness of the original surface.

The final surface treatment of the plaster repairs consisted of the application of several layers of limewash, which formed the ground on which the reconstructions and retouching could be carried out. The initial limewash contained an aggregate (1 part powdered quartz for every 2 parts lime putty, mixed with 12 parts water) in order to even out the graininess of the repairs. This was followed by two coats of limewash, and, finally, a layer of pigmented limewash, which was toned to match the warm-coloured original limewash.

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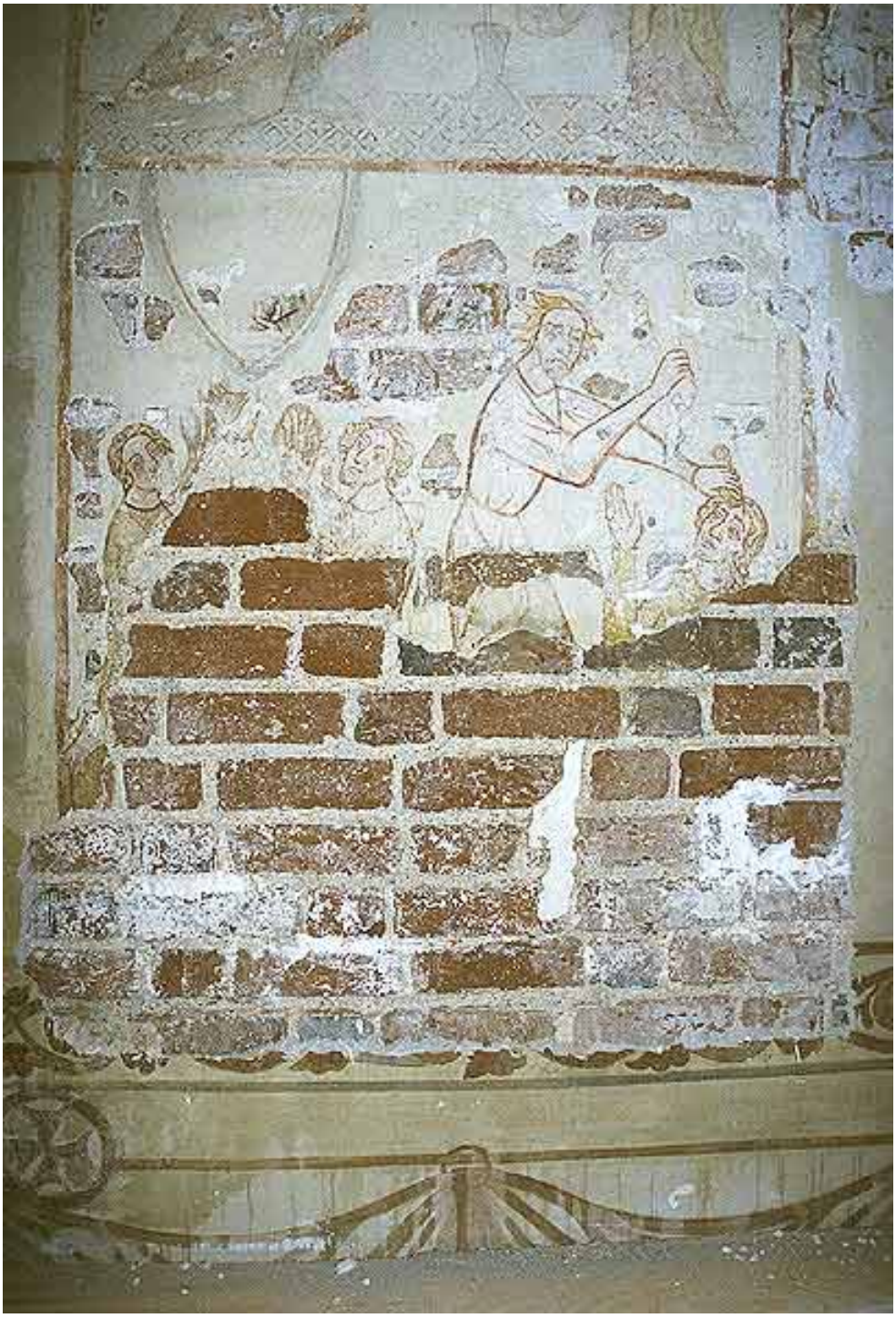

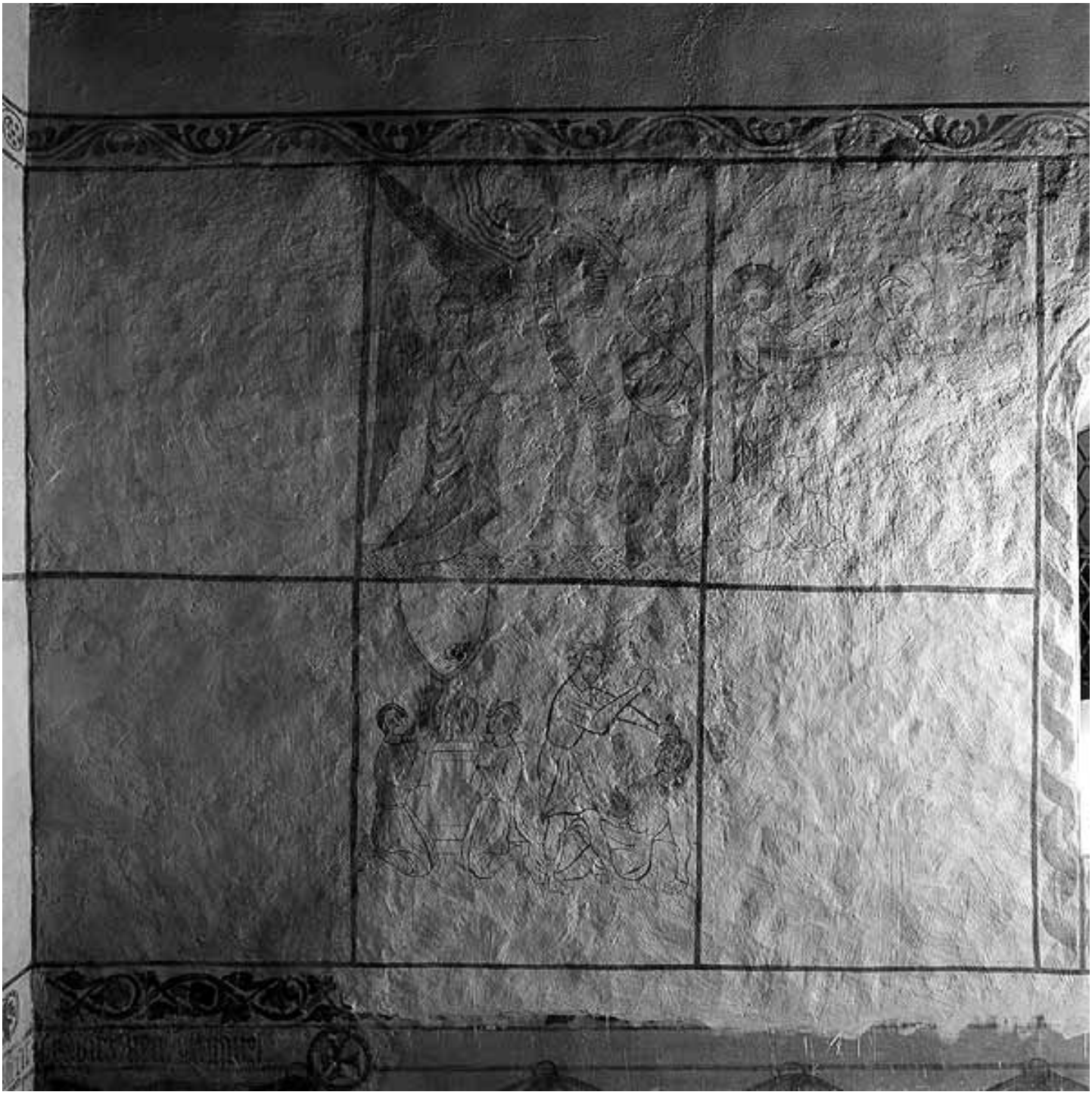

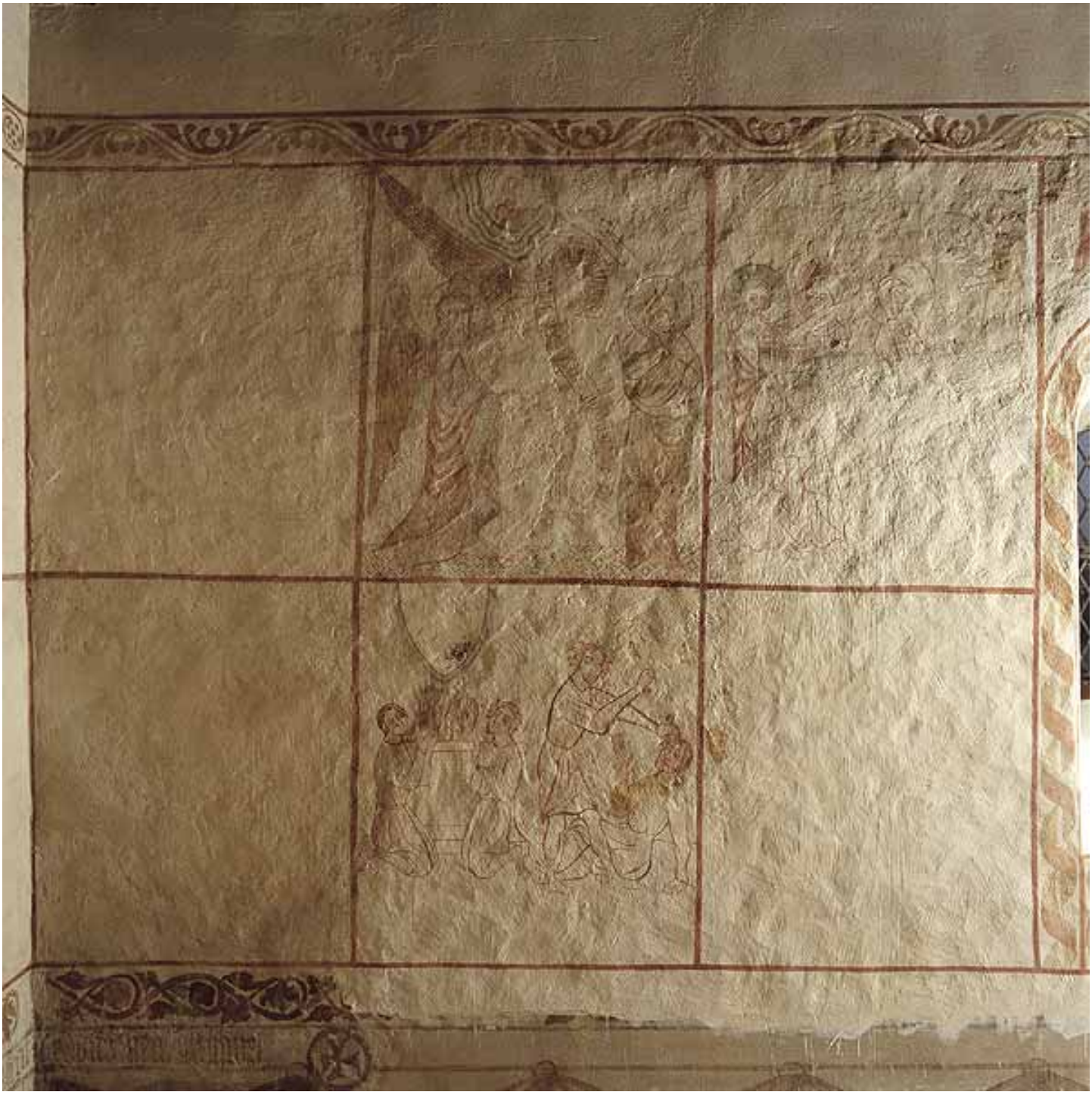

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The salt reduction of the wall paintings in 1999

The salt reduction was carried out with paper pulp (Arbocel BWW 40) and demineralised water.
The principle behind salt reduction with multiple compresses is that water from the compress enters into the pores of the paint layer and rendering directly below it, and dissolves the salts. The salt solution then migrates to the surface as the compress starts to dry, and is removed together with the compress. Direct contact between the paint layer and the paper pulp is prevented by a thin layer of tissue, which is fastened to the wall with water before applying the compress.

The compresses in Tirsted were applied two months after all the plaster repairs were made. Tests showed that this was necessary because the compresses did not adhere well to the wall when the surface was uneven due to the presence of a high amount of lacunas in the rendering after the removal of the plaster repairs. The compress had the consistency of porridge, and was applied by hand by patting it on the wall and spreading it into an even layer, about 5 mm thick.

For every 5 kg of paper pulp, 27 - 28 litres of demineralised water were used. A portion of this size could cover the area of about 4 square metres. The compress was not allowed to dry out completely before it was removed, in order to prevent shrinkage and risk of detachment of the paint layer. The tissue separating the paint layer from the compress facilitated its removal. Otherwise bits of paper pulp would be lodged in the tiny pits and holes in the surface.

Before the removal of the compress the area on which it was spread was divided into squares. For example, the treated area on the east wall between the windows was divided into 96 squares (20 x 20 cm): 6 columns, identified as a – f, and 16 rows, the numbers of which progressed up from the bottom of the compress (nearest the floor). The paper pulp and tissue content of each square was placed in a separate plastic bag and sent to the Department of Conservation's Laboratory for analysis of salt content. This procedure was repeated for each of the five desalination cycles.(The fourth desalination was not successful because the compress dried too quickly and lost its contact to the wall before it was removed.)

Some of the areas showed a declining salt content with each desalination cycle. Others showed a strong extraction in the first cycle, and then a low extraction that was quite similar for the following four cycles. The analysis also showed that the compress collected from areas where the new plaster repairs were located also contained salts, albeit to a much lesser degree than the original rendering. This could be explained by several reasons: the moisture from the repair mortar was enough to dissolve salts in the brick substrate, and these salts migrated into the repair as it was drying; the amount of liquid in the compress was high enough to saturate the pores of the repair and dissolve salts in the underlying substrate; the salts migrated into the repair plaster from the adjacent salt-contaminated original rendering. Or, finally, the ions registered in these areas originate from the uncarbonatated calcium hydroxide in the relatively fresh plaster repairs.

The amount of extracted material was greatest in the first compress, reaching up to 75 g/m2 (3 g/square) in a few areas (the average content of the first compress was 2 g/square). However, this did not necessarily mean that these areas were more salt-contaminated than others, but this could be attributed to the fact that it was easier to extract salts in these areas. Or, the readings were documenting other water-soluble contaminants, as found, for example in the yellow-stained area on the lower part of the east wall (upper photo) (laboratory test could not identify the components of this organic material (could this be the elusive Carlsberg Preparation?).

Although the overall results of the salt reduction were very positive, the treatment was not without negative side effects. Despite the fact that the demineralised water used in the compresses was boiled, and a fungicide was used (25 g Thymol dissolved in a small amount of water and alcohol was added to 75 l of water that was used to make one batch of compress material containing 17 kg paper pulp), serious microbial activity was observed both on the areas under the compress (middel photo) as well as next to the compress (lower photo). The micro-organisms consisted mostly of small round spots, ranging from light grey, through purple and black. Fortunately, it was relatively easy to remove them with 32% hydrogen peroxide, which had no bad effect on the paint layer. The appearance of the micro-organisms was undoubtedly connected to the warm and moist climate in the room when the desalination was taking place (May – October 1999), and it was not introduced with the compress. It is very probable that spores were existing on the surface of the painting. The microbial growth did not reappear after it was washed off, and has not be detected since the re-restoration was completed in August 2000.

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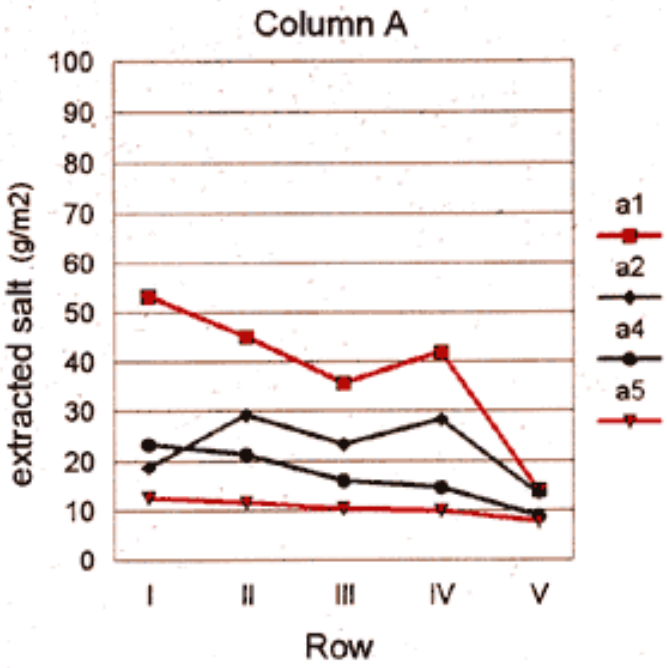
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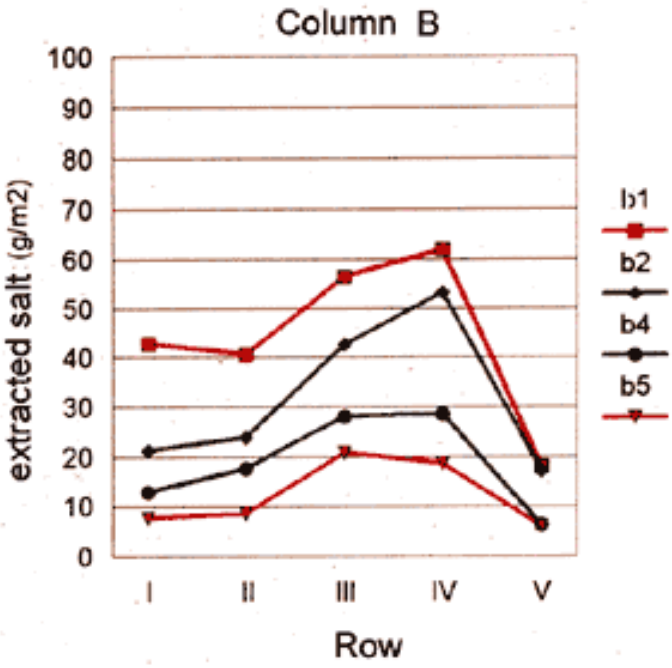
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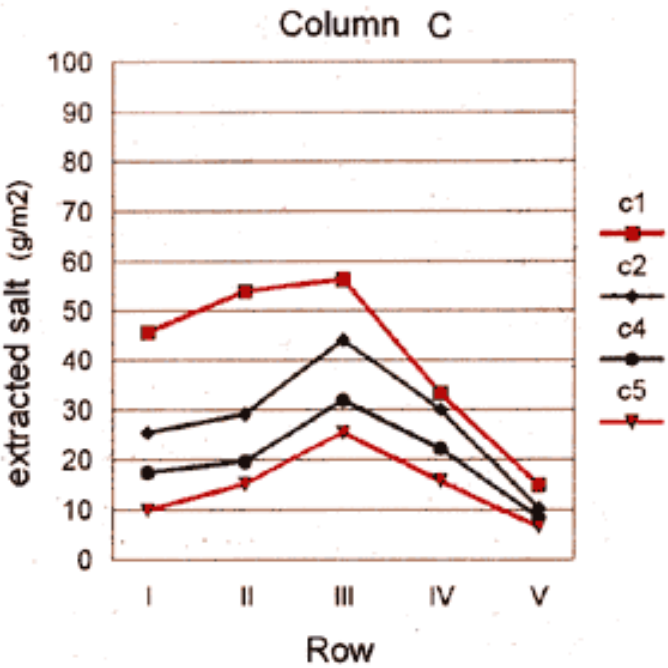
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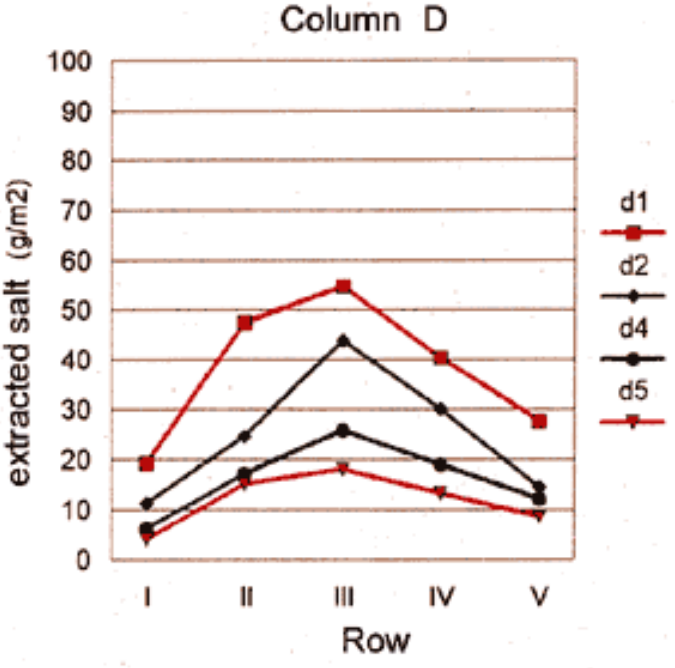
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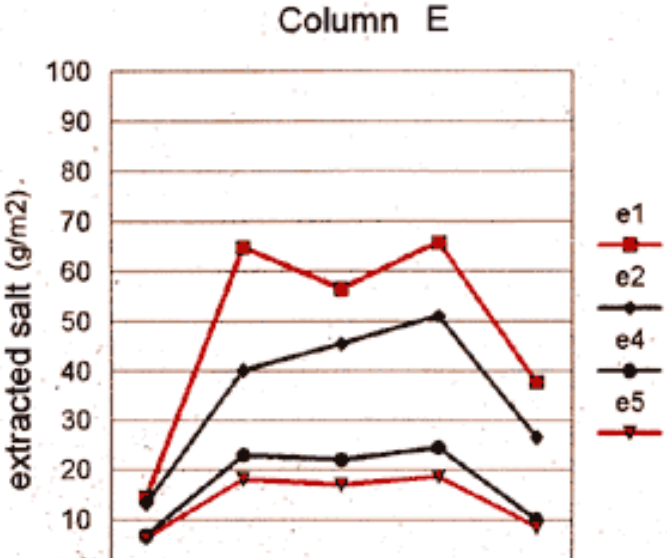
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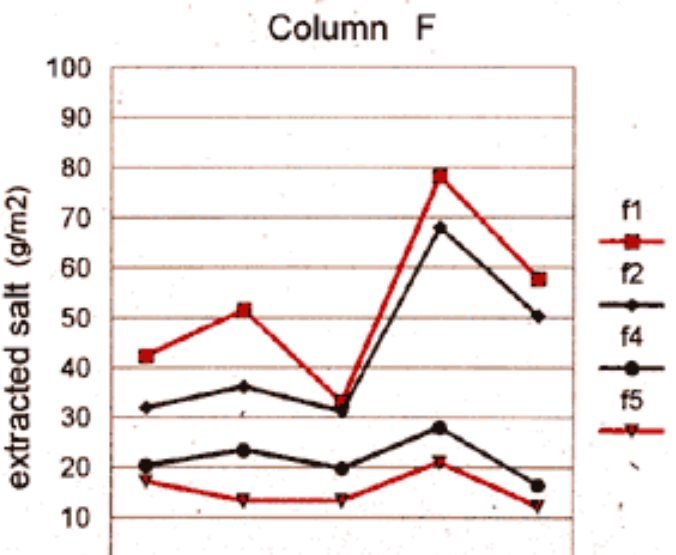
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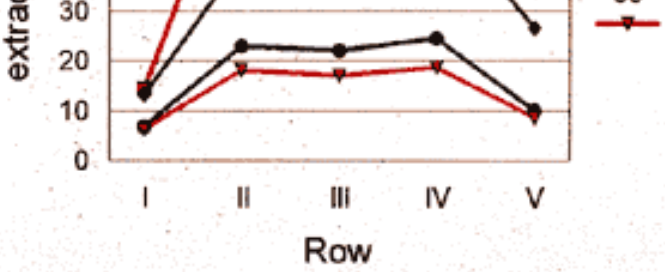
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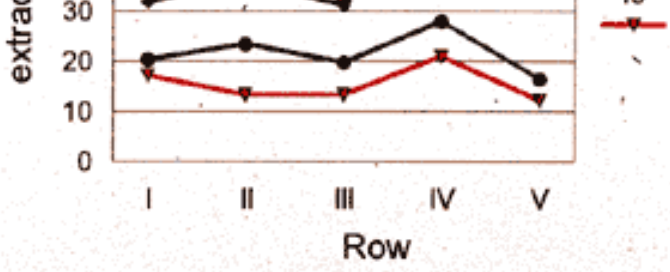
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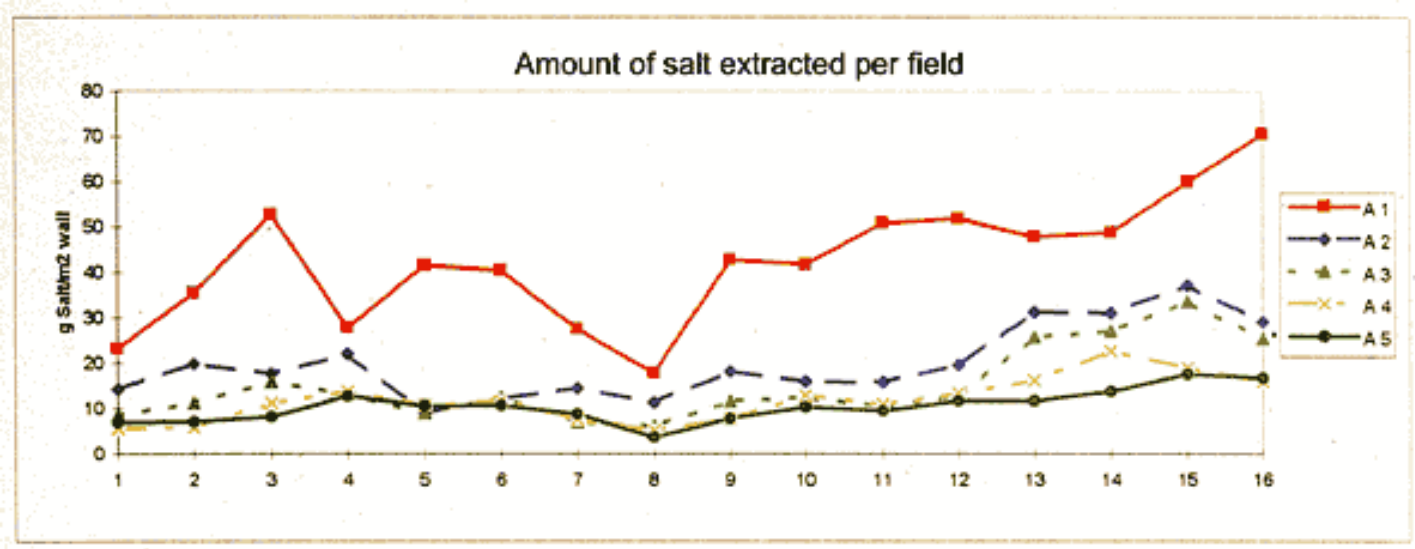
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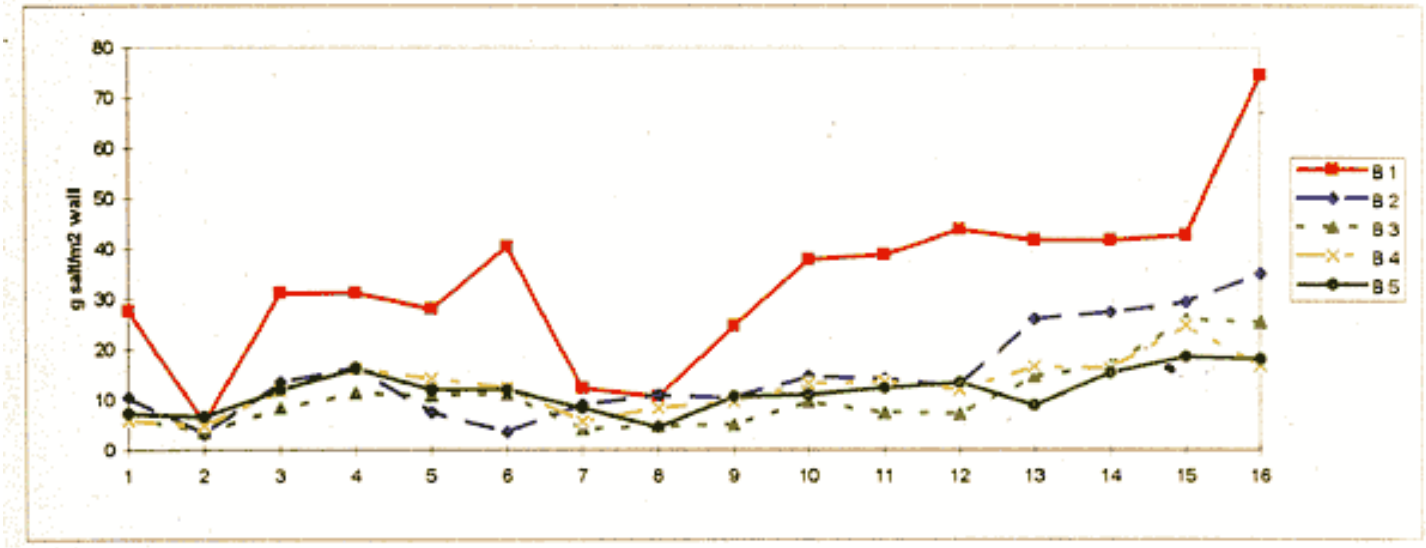
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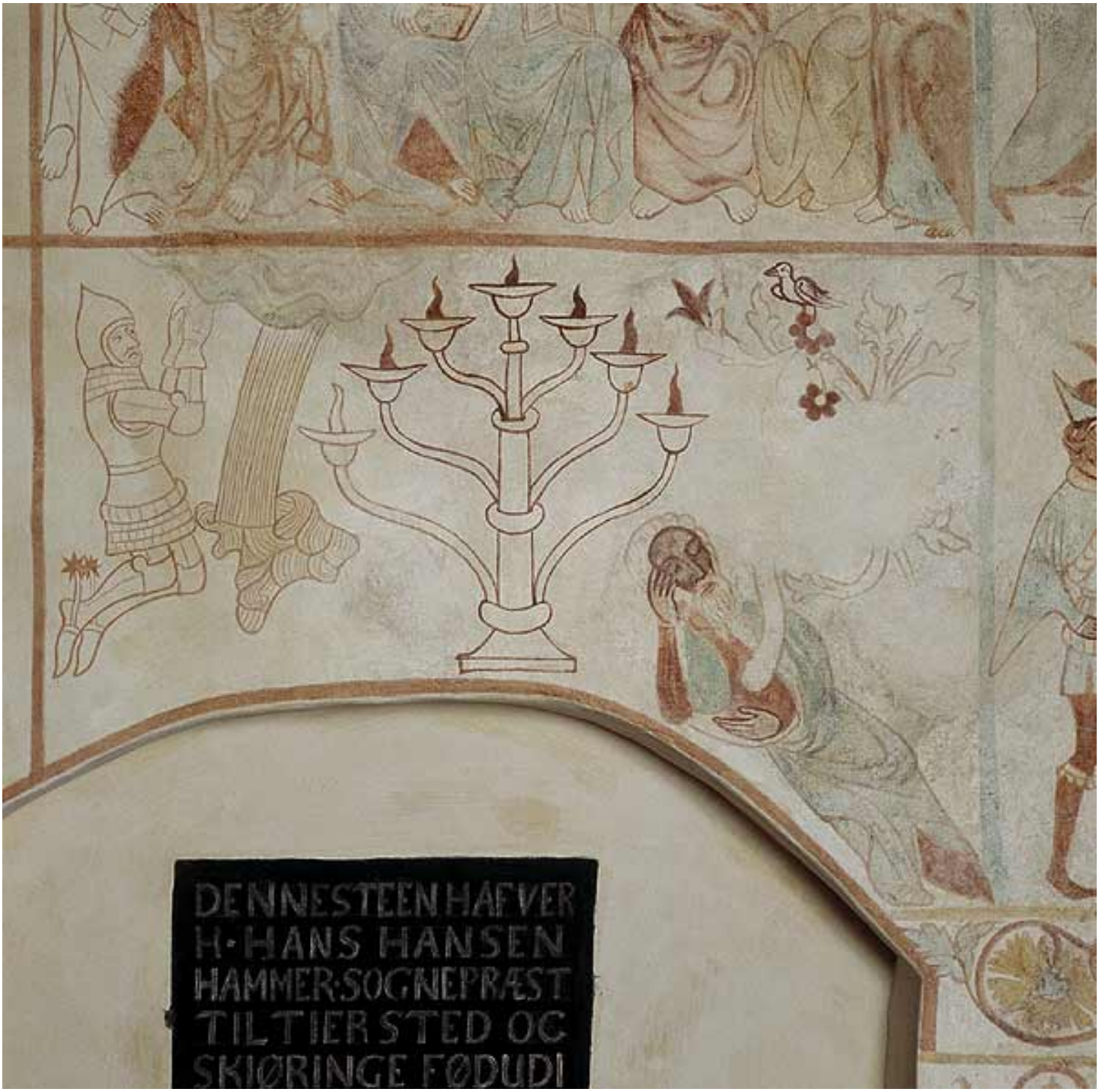
DENNESTEENHAFVER
H·HANS HANSEN
HAMMER·SOGNEPRÆST
TILTIERSTED OG
SKIØRINGE FØDUDI

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Introduction

The collegiate church of Königslutter is a cultural monument of particular importance for Lower Saxony (Germany). Begun in 1135 as burial place of Emperor Lothar of Supplingenburg, the spacious design, the rich architectural sculpture and the stonework of superior workmanship claim imperialistic dignity, being comparable with the cathedral church in Speyer.

Important documents of the times are the medieval wallpaintings, too, which have been preserved in the apse, on the pillars and in the western part of the interior. In the 19th century, August von Essenwein (director of the German National Museum at Nuremberg) prepared an appropriate programme of interior decoration based on medieval reports. He created an overall work of art which turned the interior into a processional way. It reaches its objective in the Maiestas Domini in the apse. The decoration was carried out between 1887 and 1894 by the Braunschweig court painter and decorator Adolf Quensen.

Germany, Königslutter, Stiftskirche, view from the south.

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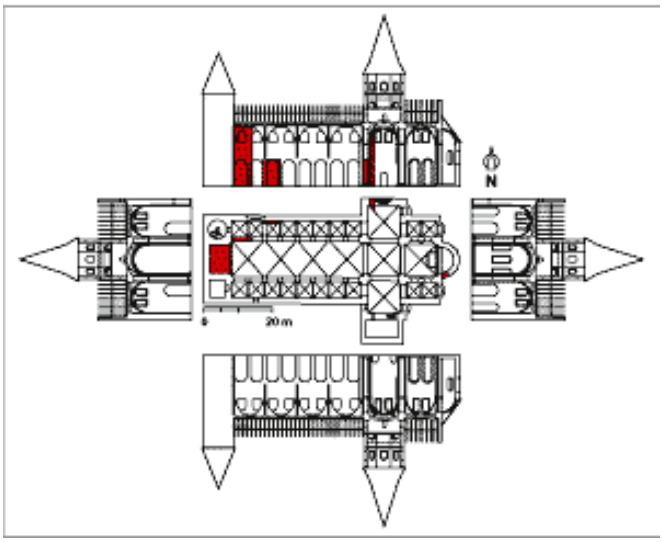
Time table

13th century	Paintings in the choir (spacious rests have been preserved behind historicist wallpaintings).
ca. 1470	The interior is decorated with wall paintings. Below the western
ca. 1510	choir Annunciation and Tree of Jesse are preserved.
1694/95	Restoration after caving in of the vaults of the nave.
1835	The interior is completely restored.
1887-94	Interior decoration based on spacious medieval rests by August von Essenwein and Adolf Quensen.
1953-56	Reduction of the paintings on walls and pillars of the nave; polychromie of pulpit and choir is removed.
1974/78	Spacious securing of the walls by injections; structural protections.
Since 1995	Test restorations and investigations on wallpaintings and exterior of the building.Preparation of a comprehensive maintenance plan.

In a systematic series of measures with regard to the complex mechanisms of damage the wall paintings and their environmental influences have been examined.



Germany, Königslutter, Stiftskirche.
The areas of the actual treatment (2000, later extended) are marked red.

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Historicist wallpaintings

Arcival researches and documentation

The compilation of all historical documents pertaining to the church was analyzed with respect to information about the physical state of the building. This helps in combination with the data base „Stiftskirche Königslutter" to provide a rapid synopsis of the building's construction. All measures undertaken between 1974 and 1978 during the renovation work to improve the static strength of the building were of major importance because of possible effects on the wallpaintings. In this respect, the archives of the building contractors responsible for the securing work yielded a great deal of detailed information: In order to brace the monument, a complex system of steel anchors combined with grouting had been necessary.
It was then possible to prepare plans and drawings containing all the available information and use these to determine areas for further investigation.

Environmental influences

The history of industrial development in the environs of the church of Königslutter is outlined in terms of the emission of substance which may have influenced the deterioration of the wallpaintings. These causes of damage are related to climatic data in order to estimate emission models for damaging substance like sulphates, nitrates, organic compounds and concentrations of dust as a transport medium. It emerged that the Königslutter region had been one of the most polluted in Lower Saxony during the last century as a result of lignite mining and subsequent industries. According to measurements taken in the vicinty of the church, the highest emmission rates occur when there is a south-easterly wind, with sulphur dioxide rates exceeding 400µg/ Hm^3, and corresponding maxima of $H\ NO_2$, Fluorine, Chlorine, Phenole, Pyrite dust, zinc, lead and other components.

Mapping

The successful completion of mapping not only permitted a description of the entire range of damage and of the restoration work but simultaneously provided an indispensable manual for the subsequent interdisciplinary team. It therefore represents not only important basic material for actual anamnesis, diagnosis and treatment work, but can also be regarded as a fundamental „snapshot" allowing important insights for the ensuing work stages. This ranges from monitoring as part of planned maintenance measures through to quality control of future restoration work.

Painting technique

In the course of surveying the damage, investigations were carried out on the painting technique and creative process of the interior decorations. The painting technique of the historicist paintings differs between wall and vault: while the vault of the transept and the side choirs were painted with destemper, the wall areas and the hierarchically more significant choir vault were decorated using an emulsion technique. The paintings were created with the help of technical aids such as templates, punched tracings, etc.. In the flattened cupola and in the window zone of the main apse, it was possible to provide evidence for an apparently medieval plaster (13th century) over approximately 3/4 of the surface, the original painting of which was uncovered by Essenwein and painted over relatively faithfully by Quensen.

Germany, Königslutter, Stiftskirche, apse.
The representation of the Maiestas Domini is based on paintings of the 13th century.

UV fluorescense

To determine earlier painting work and other painting phenomena, investigations were also carried out with UV fluorescence on the flattened cupola of the main apse and in the choir. While some additional insights into the technique of historicist painting were attained, an earlier, possibly medieval painting beneath the leaf frieze of the north pillar of the apse was discovered in addition to the Romanesque painting of the flattened cupola apse.

Stratigrafic and chemical researches

In order to analyse the painting techniques and to characterize the organic fixatives on each point of sampling the following investigations have been carried out: cross-section analysis with chemical recognition of the painting materials, photographic color documentation under microscope both of the visible and the U.V. fluorescece image, dying tests on the cross-sections in order to map specific substance or class of substance (i.e. gypsum, proteins, etc.), microanalytical tests on subfragments for the recognition of class of binders, fixatives etc., FT-IR analyses for the characteriziation of both organic and inorganic components (also after solvent extraction if necessary), SEM and EDS analysis on cross sections of samples for specific problems.

Microbiological examinations

The results of the microbiological examinations of the wallpaintings demonstrate the dependency of microbial contamination and its destructive activity on interior atmosphere and nutrient-related parameters. Furthermore, it was possible to demonstrate interdependencies between the microbial populations of the air within the church and the biogenic infection of the wallpaintings. This phenomena should be investigated in more detail, especially because of its importance for the evaluation of the efficiency of protection and conservation measures.

Water vapour permeability

The water vapour permeability has been measured according to DIN-EN 1062 using 12 drill-core samples. The water vapour permeability of wall surfaces which had been treated with acrylic resin around 1970 is significantly reduced (sd between 0,5 and 1 m) in comparison with the non-treated parts (i.e. the surfaces of the vaults showing sd <0,2 m). However, the reduced permeability of the treated wall surface is regarded as unfavourable but physically acceptable with respect to the present state as well as the present utilization of the building.

Risks by cement and salts

There are two imminent risks for the wallpaintings:
1. The approximately 300 tons of cement injected in 1974 into walls and vaults contain an enormous reservoir of water as well as $H\,Ca^{2+}$ Hk $^{+}H\,SO_4^{2-}$ ions.
2. There is a conspicuous concentration of gypsum and potassium nitrate within and below the painting layers. The origin of these dangerous substance and their distribution and concentration in various materials is discussed within the team. The potential of the two sources of danger for the future is difficult to assess. It is even more difficult to eliminate.

Condition of the masonry

In order to correlate the damage suffered by the wallpaintings to that of the wall, a quick mapping of the state of the joints on the eastern structure of the church was carried out. This yielded the result that numerous joints had begun to crack or were already open. The water taken in via the faulty joints, which may well be partially responsible for damage to the wallpaintings, was also substantiated by taking measurements (Karsten test tube).

Climatological conditions of the interior

For the overall investigation into the damage to the wallpaintings it was necessary to examine the interior environment in order to determine any negative effects inappropriate atmospheric conditions might be having on existing structures – in particular on the precious wallpaintings. These findings are then used to help make decisions on the creation of an interior environment which will preserve the substance and the designing of an appropriate heating system and means of regulation. In addition, the results of investigations on the interior atmosphere are used to prepare more comprehensive plans for the restoration measures that are required to eliminate moisture and salt damage.

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Recent findings referring to the medieval wallpaintings

Anneli Ellesat and Ivo Hammer

Numerous studies conducted at the Kaiserdom collegiate church in Königslutter in the past years and during the Raphael Project have secured extensive findings of medieval painting fragments.

There are visible fragments of medieval paintings in the lower storey of the westwork. Fragments of various periods have been preserved on the walls and vault and were deliberately not overpainted by Essenwein in the 19th century. The conservation of these different periods of painting is largely due to the fact that this area had been walled in and used as a boiler-room for a long time. With the removal of said wall at the formeret in 1886 the lower storey of the westwork was re-integrated into the interior building.

The oldest established painting consists of two medaillons framed by a foliage frieze that show the busts of different persons. Judging by certain stylistic characteristics this painting has been dated back to ca. 1230. It is a lime painting (secco) whose preliminary drawing (red ochre) was done in the fresco technique. Yellow (yellow ochre?) and green (malachite?) layers of paint have been preserved. Cuts and punctures point to the use of dividers for constructing the medaillons.

Another painting stage shows a „damask pattern": a large leaf design outlined in white and partially in black on a red background. The original leaf painting is lost and only remains as a negative form. Rose-coloured veins that originally showed in the leaves can largely be seen under UV-light today. The painting (background and preliminary drawing) was done as a fresco on white limewash and then completed in secco technique. Cuts indicate the laying out of the foliage. At this stage the medaillons were not overpainted but remained visible. This „damask pattern" was apparently a part of the original painting on the western formeret front wall and the window reveal at the west wall. Presumably dating from the same period the unplastered window reveals show painted ashlars alternating in red and white with joints outlined in black (lime painting). This painting, barely visible and only preserved to a small extent today, has been dated back to the first half of the 15th century, more precisely to the time when the main building received its vault: between 1431 and 1460.

Clearly visible is a painting depicting the Tree of Jesse which covers up the entire barrel vault and with regard to stylistic characteristics can be dated back to around 1510. Framed with green foliage, outlined and hatched in black with large blue and yellow blossoms, busts of various ancestors of Christ can be seen along with an image of the Madonna with Christ. At the southern part of the vault saints are depicted: instantly recognizable, holding his head in one arm, is St. Dionysius; the other is a female saint. A haloed Madonna is depicted at the northern as well as the southern half of the vault. The painting was done in secco technique on limewash. Pigments detected include red and yellow ochre, malachite and azurite. Lead pigments were probably used as well as parts of the painting are blackened. At the western formeret front wall and the western half of the formeret reveal there is more foliage, presumably vine foliage originally complemented with reddish-brown fruit. A depiction of the Annunciation on the west wall and an ashlar painting on the window reveal alternating in red, grey and yellow with white joints outlined in black are other examples of this painting period whose overall state has to be called fragmentary.

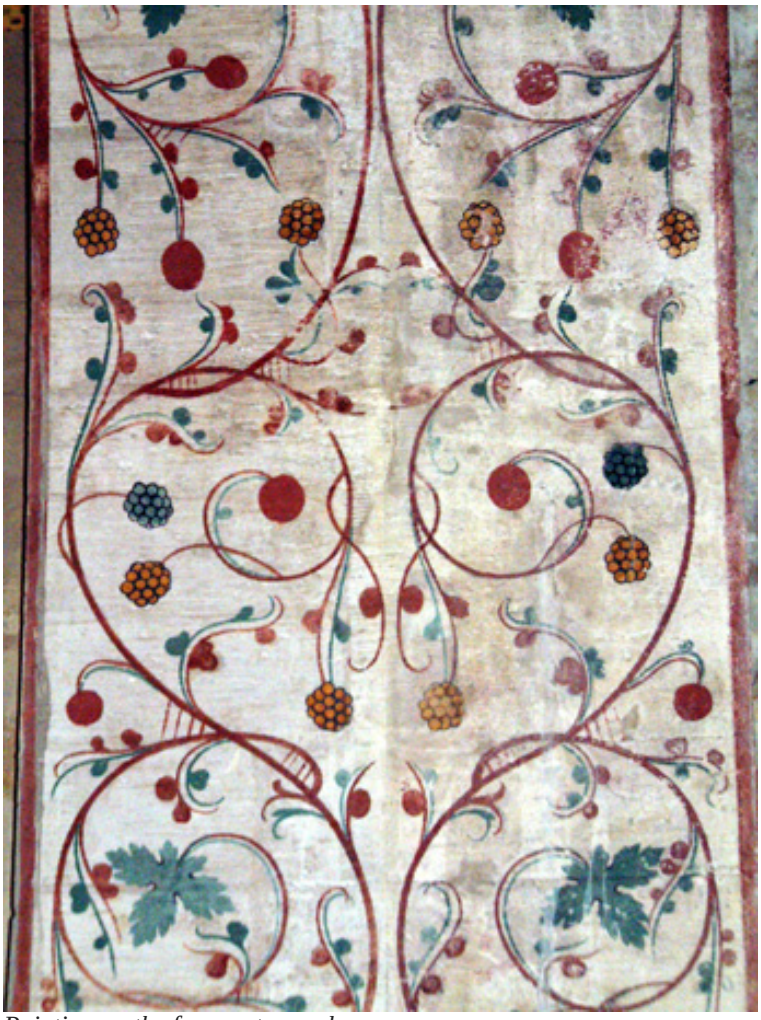
The middle part of the vault is dominated by the painting of the Tree of Jesse.

Detail of the Tree of Jesse: haloed Madonna

Detail of the Tree of Jesse.

Detail of the Tree of Jesse.

Another painting preserved at the formeret reveal is a floral design created after 1887, possibly complementing the older painting from the 16th century. This lime painting depicts stylized red and green foliage with ochre-coloured fruit.



Painting on the formeret reveal.

In the main building the following older painting fragments could be found:
At the painted window ashlars of the clerestory and the ashlars of the arcade in the western vault bay remnants of red (Carput mortuum) marbled streaks could be found which can be dated back to the time when the vault of the main building was erected.

Uncovered marbled streaks on the ashlars of the western clerestory window.
Foto: K. Heiling.

Fragments showing saints with painted pedestals and canopies (around 1500) were uncovered in the 19th century on two pillars of the nave. These paintings show red/black outlines which have been heavily traced and overpainted. Parts of the garment reveal green pigments. The same date can probably be assigned to the remnants of a red foliage design on white lime wash which are located on the north wall of the northern lateral nave, as well as to fragments of a red foliage painting which were found on the vault web of the lateral naves. The ribs and formerets were likely painted in a corresponding red. Floral motifs in red and green could be found on the keystones of the lateral nave vaults.

Uncovered foliage painting in the vault of the nothern lateral nave. Foto: K. Heiling.

Pillar showing the fragmentary painting of a saint.

In the main building fragments of a grey ashlar painting with black outlines (17th century?) could be found on the square stones of the western arcade. Correspondingly the ribs and formerets in the lateral naves show numerous grey and black (blackened pigments?) painting fragments.

Uncovered fragments on the arcade.
The grey ashlar painting with black joints was applied directly onto the stone.
The other black joints, on a red background, are part of the painting by Quensen.
Foto: K. Heiling.

The ashlar painting on the lower wall regions, created by Essenwein in the 19th century which can still be seen in the eastern part of the Kaiserdom, recreates an older ashlar painting in form and colour. Not dated exactly as yet this older painting was uncovered in the course of Essenwein's actions and incorporated into his conception. Fragments from this period could be found on the south wall of the southern transept and lateral nave as well as on the north wall near the lion portal.


At the edges of the uncovered area fragments of an older ashlar painting can be found.

In the course of the examinations different computer-based techniques have been developed for a long-term monitoring process, for continuous observation and documentation of the damage-related parameters being identified.

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ANNOTATIONS

Project studies conducted by students of the Fachhochschule Hildesheim/Holzminden/ Göttingen (FH HHG) (University of Applied Sciences and Arts), Studiengang Restaurierung (Conservation course), Studienrichtung Architekturoberfläche und Wandmalerei (Architectural Surface and Wall Painting):

- 1995/96: Examination and documentation of the wall painting of the westwork under the direction of Prof. Oskar Emmenegger and Prof. Dr. Ivo Hammer with assistance by Dipl. Rest. Kerstin Klein (NLD).

- October 1998: Examination and documentation of the wall painting of the westwork under the direction of Prof. Dr. Ivo Hammer. Additionally an emergency consolidation was done on the paintings in the barrel vault in November 1998.

- April-October 2001: Further examination and documentation of wall painting in the main building under the direction of Prof. Dr. Ivo Hammer with assistance by restorer Lothar Hoffmann, Dipl.Rest. Christel Chionye-Ejim, Dipl.Rest. Heike Leukfeld, and Dipl.Rest. Anneli Ellesat.

- August-Oktober 2001: Complementing examination and documentation of wall painting in the main building by Dipl.Rest Anneli Ellesat, Hildesheim, and restorer Klaus Thönes, Worpswede.

- Preliminary paper on the project Oktober 1998, Ivo Hammer 1998.

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- Paper Jutta Hansch, winter term 1999/2000, project Königslutter, examination of samples.

- Project paper Katharina Heiling and Roland Sommer, October 1998.

- Paper Katharina Heiling und Katja Jäger detailing the findings in April-June 2001, unfinished.

- Paper (Vordiplom) Katja Mühle detailing the findings in the course of the project April-June 2001, unfinished.

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Mapping system of the Niedersächsisches Landesamt für Denkmalpflege
Standards for manuel and digital graphic documentation

Introduction

The most frequently used visual documentation medium for conservation condition recording and analysis continues to be manual mapping, and this has been generally accepted. There is no longer discussion on the aims and objectives of using manual maps before and while working: overall view maps and detailed maps have become an essential part of standard conservation reports.

Even the 'new' issue of whether restoration should in general be documented manually or digitally using computerized techniques is largely academic. There are contrasting points of view on this: some think that documentation will fall behind if modern technology is not applied and that conservators will miss the boat with regard to up-to-date communication methods and analysis. Others see that using a computer for restoration documentation implies considerably more time and money to achieve results of good, or even merely acceptable, quality. Experience shows that it is more difficult to establish usable categories for phenomenon mapping and to select typical object-specific phenomena than it is to choose tools to graphically represent them. It will be interesting to follow further developments in this field.

Germany, Königslutter, Stiftskirche. Historicist wallpaintings in the northern transept.
The conservator-team is working ***in situ.***

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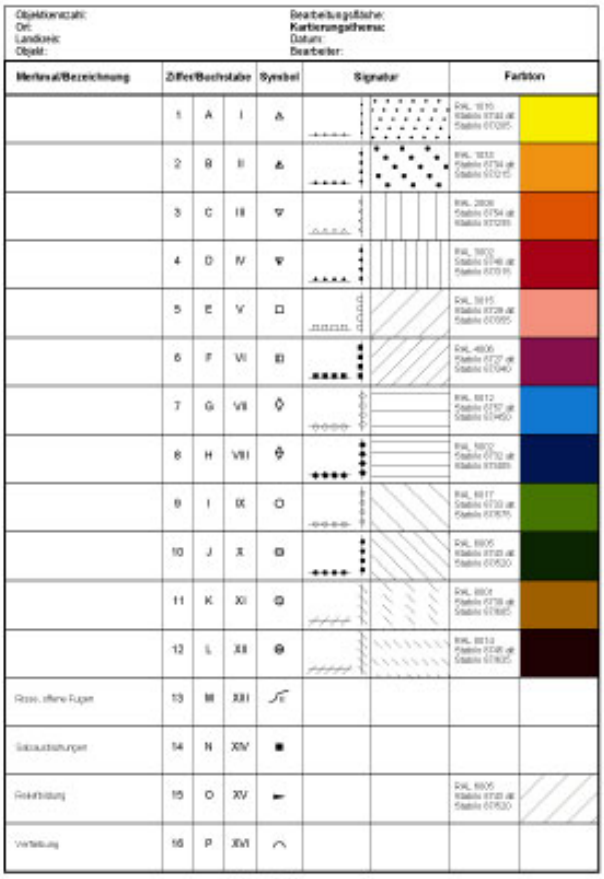
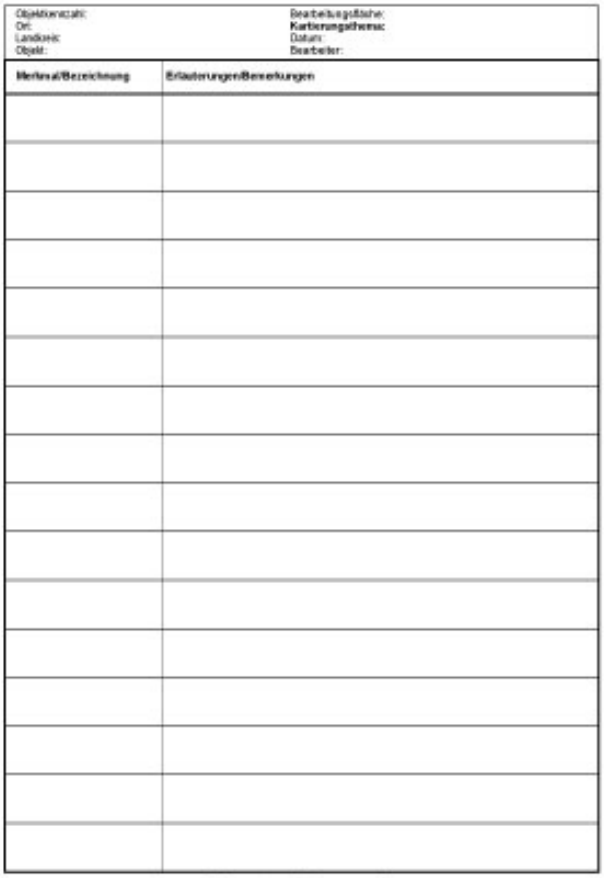
The NLD Manual Mapping System

Since the early 1990s, a standardized mapping system has been in use for condition recording in the restoration department of the *Niedersächsisches Landesamt für Denkmalpflege* (NLD) [Lower Saxonian State Conservation Office] (e.g. VDI, 1987; Eickelberg, Herppich and Zallmanzig, 1990). The goal was and is to achieve nation-wide standardization of representational symbology (symbols, line signatures, hatchings, tints, etc.). Since then, the set of standard sheets developed for this system have been used for manual mapping. So in that kind of way this mapping system was one part of the last condition recordings of Königslutter church since 1995.



A 4 forms for manual and digital mapping according to VDI 3798, additional sheet 3. These basic documents are available as CAD and graphics templates. They can be duplicated by printing or copying the documents. An example of a blank legend form constituting the „table of contents" of one mapping category. In this case 12 legends with their respective graphic representation are possible.



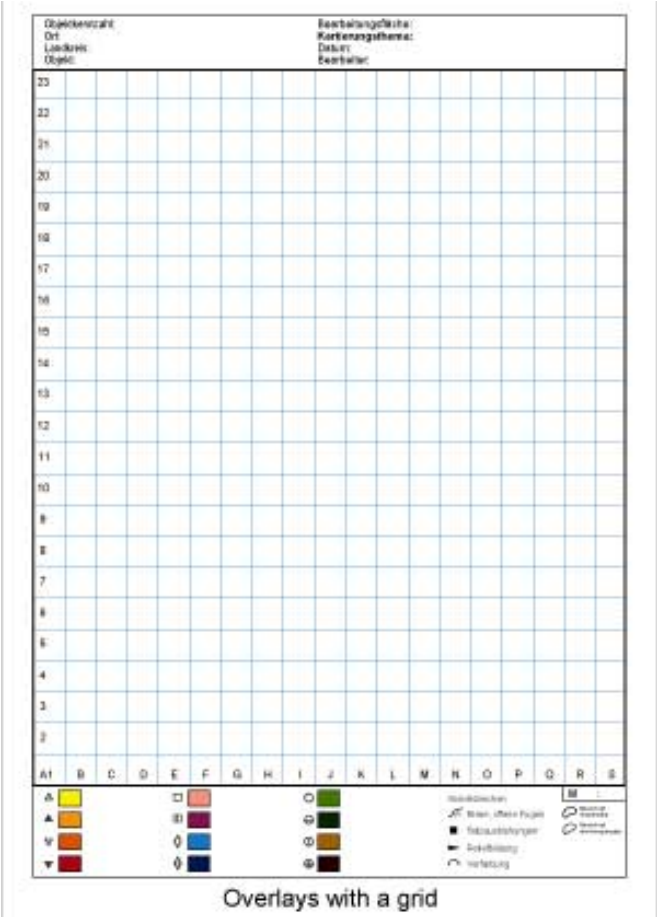
Sheet of Remarks

Sheet for remarks used for manual annotations of observations made during mapping. This form relates to the blank legend.

Overlays

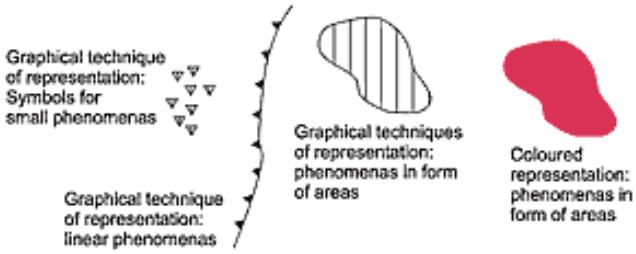
The mapping form (overlay). The middle area shows the base map of the apse of Königslutter church in Germany. For manual mapping only monochrome copies are made, including black&white symbols or hatchings. The digital version (here represented) is using colour; if necessary the base map can be retrieved together with the overlay for quantitive mapping. Foto:

Deutsches Bergbau-Museum Bochum



Overlays with a grid

Phenomena/Name	Number/Letter		Symbol	Signature	Colour
New mechanic defect	4	D	IV	▽	RAL 3002 Stabilo 8748 old Stabilo 67/315



Detail of the blank legends (row four). The definition of phenomena pertaining to one category is done horizontally. During manual mapping on one single mapping form (overlay), both monochrome and coloured representation tools can be used. Although different representation tools are used to record the same phenomenon, the assignment to a phenomenon (in this case new losses) will always be possible by referring to the legend.

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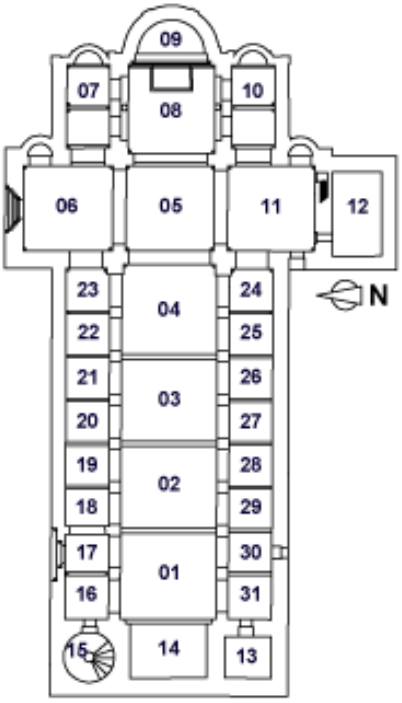
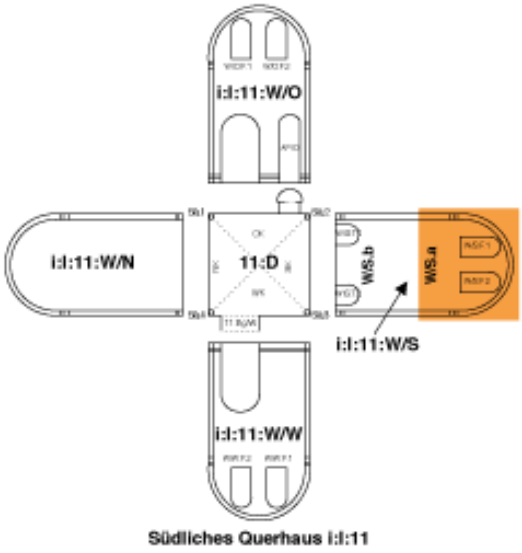
Preparation of a manual mapping campaign

In order to be successful and to obtain as much information as possible, careful planning is recommended before starting mapping *in situ*. It is often impossible to obtain missing material and supplies at short notice, once the project has started.

The subdivision of larger objects into sectors or areas, i.e. the creation of an orientation system, also provides a grid for the systematic production of photographic documentation. Thus, each overlapping photograph can automatically become a base map for manual recording.



Germany, Königslutter, Stiftskirche. Ground-plan of the orientation system. To every bay a code-number is assigned.



Germany, Königslutter, Stiftskirche. Detailed example for the orientation system. This grafik shows the code-numbers of the southern transept (room number 11). Ground-plan combined with wall-areas.

1	2	3	4	5

INNEN	**Innenraum** **i**	**Geschoßebenen** **I** Erdgeschoß **II** Dachgeschoß	**Unterteilung der Geschoßebene** **Erdgeschoß** **R01 - R04** Mittelschiff **R05** Vierung **R06** Nördliches Querhaus **R07** Nördliche Seitenapside **R08** Chor **R09** Apsis Chor **R10** Südliche Seitenapside **R11** Südliches Querhaus **R12** Sakristei **R13** Heizungsraum Westbau **R14** Mittlerer Raum Westbau **R15** Treppenhaus **R16 - R23** Seitenschifff Nord **R24 - R31** Seitenschiff Süd **Dachgeschoß** noch nicht festgelegt	**Raumumschließende Bauteile** **W/N** Wand/Nord **W/O** Wand/Ost **W/S** Wand/Süd **W/W** Wand/West **W/N.a - ?** Wandabschnitte **W/O.a - ?** Wandabschnitte **W/S.a - ?** Wandabschnitte **W/W.a - ?** Wandabschnitte **D** Gewölbe (Decke) **D.NK** Gewölbe Nordkappe **D.OK** Gewölbe Ostkappe **D.SK** Gewölbe Südkappe **D.WK** Gewölbe Westkappe **Details/Gliederungselemente** **Bg/N** Bogen/Nord **Bg/O** Bogen/Ost **Bg/S** Bogen/Süd **Bg/W** Bogen/West **Sä.Nr** Säule mit Nr. **Pf.Nr** Pfeiler mit Nr.	**Wandöffnungen** **F.Nr** Fenster mit Nr. **T.Nr** Tür /Durchgang mit Nr.	**Freitext** Laibung Rahmung Mitte

Germany, Königslutter, Stiftskirche. Code-number list for the orientation system. Every column 1.- 5. are a special part of the code number.

- The total cost of the operation largely depends on the mapping method, and some questions need to be answered at the outset:

- Is it really necessary to use coloured mapping methods?

- Is it possible to achieve the same result by using monochrome mapping methods, or can coloured and B&W graphic techniques be mixed?

- How many copies of the documentation are expected to be needed, and how will this affect reproduction costs?

When using the NLD system, careful adherence to the following points should allow all documents to be complete and ready for archiving after mapping (Behrens and Klein, 1996).

NLD Mapping System – Recording Tools
It is important to order the material for the overlays (polyester transparencies for photocopying onto) in good time. In Germany there are delivery periods of up to three weeks. For calculating the number of overlays required, one transparency is usually required per photograph and category of mapping. If more than one person is participating in the campaign and will cover the same areas, it is necessary to multiply the number of overlays by the number of people involved.

Materials for manual mapping. Base map and overlay are fixed congruently using a drawing board. The corners of the photographic base map are copied as reference marks on all overlays.

Each person will require a minimum set of drawing tools, including a fine, hard black-lead pencil; eraser; pencil sharpener; A4 drawing board; and an appropriate selection of standard coloured pencils for the phenomena likely to be encountered. The use of Schwan *Stabilo* pencils is specified in the NLD mapping system, based on the RAL (German Institute for Quality Assurance and Labelling) colour palette. Pencils must be ordered separately, because a complete set of the selected colours is not available, and it is important to have the coloured pencils available in good time.

NLD Mapping System – Supporting Documents
The following preparations are necessary before starting work on site:

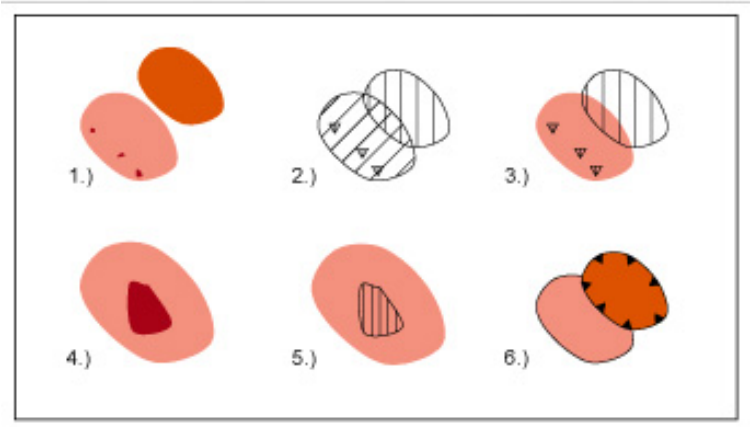
- Fix the photographic base maps onto the A4 drawing boards, ready for the superimposition of the transparent mapping overlay.

- On the basis of preliminary information from the site, define the mapping categories and establish a so-called ‘blank’ legend; it is also useful to test the chosen colouring and graphic techniques prior to going on site.

- Copy the complete set of mapping forms (at least one for each category) onto polyester transparencies, using a monochrome photocopier.

- Copy the blank legend and the remarks sheet onto paper using a monochrome photocopier (the complete set is required, one for each category).

- Pre-sort and pack all documentation materials (e.g. in cardboard boxes or in ring binders) so that all materials are handy *in situ.*



Representation techniques for the mapping system according to VDI 3798, additional sheet 3:

1.) Coloured mapping; 2.) Monochrome mapping; 3.) Combination of 1+2; 4.) Phenomena are on one level; 5.) Phenomena are on two levels; 6.) Framing of area phenomena; dashed line = area is impossible to delimit.

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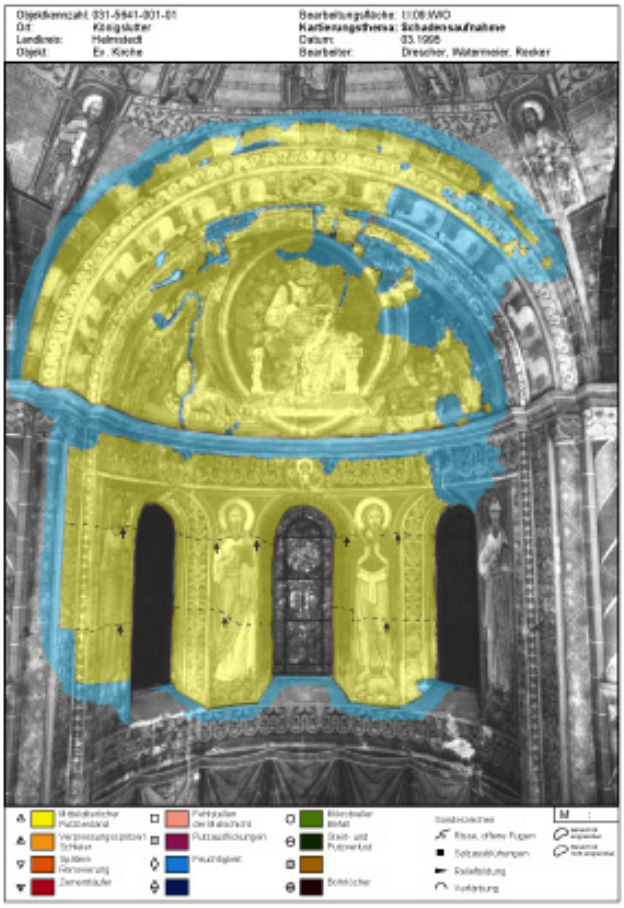
How to carry out mapping

The first step is to check rules and procedures previously developed, both on site and in the office. If several people are to work together, it is better to make a trial map. It is important that all agree on the definition of and graphic representation for each phenomenon to be recorded. If definitions remain unclear or are interpreted differently within the team, the maps will be arbitrary and not comparable, making future evaluation and analysis difficult and probably inaccurate.

*Germany, Königslutter, Stiftskirche. Historicist wallpaintings in the northern transept. The conservator-team is working **in situ.***

Using the photographic base map as a reference, phenomena are directly recorded onto the transparent polyester overlay, onto which the mapping form was copied. Usually, the third standard form is used, which includes a legend and a heading for clear identification. How many overlays per category of mapping are used is a decision that lies with the operator. Contrary to other types of clear overlays (acetates, etc.), the matt finish of polyester transparencies designed for technical drafting allows the use of various drawing utensils, including coloured pencils, drafting lead holders, etc. Moreover, polyester transparencies are very durable, dimensionally stable and can be archived for a long time.

Germany, Königslutter, Stiftskirche, apse. Manual mapping – photographic base map with mapped phenomena on superimposed mapping sheet (overlay = third standard form). The yellow area shows the original plaster. Foto: Deutsches Bergbau-Museum Bochum.



In order to save space, single pre-printed overlays (i.e. mapping forms) contain only an abbreviated version of the blank legend, which gives a complete list of all the representation tools such as symbols, hatching and tints. The 12 legend boxes at the bottom of each mapping form are grouped in the same sequence as the blank legend.

Conclusions regarding manual mapping

Systematically structured manual mapping provides visual information on the current condition of an object. It is the first non-destructive examination method that provides a representation of the object, thus making a considerable contribution to condition assessment.

The low cost of form sheet reproduction is significant. Forms can be used directly for hand-written-notes and for the presentation of mapping results. In general, people who have their first experience with graphic documentation through manual mapping are those best qualified for future digital mapping. The most important aspect in data collection should be to reduce information to its essential elements.
After years of testing, the base as a part of the NLD mapping system was published in January 1999 as an addition to the VDI Norm 3798, Sheet 3 for graphic documentation in condition recording. (VDI, 1999).

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Digital mapping

In the beginning was the line drawing, and it was good. The first conservation maps were carried out using normal blueprints of the building plans produced by architects. In the field of visual documentation in the NLD restoration department, these documents and others were prepared to provide support for all phases of a project, or modified, especially with regard to architecture, to visualize hypothetical reconstructions or re-integrations. The first encounter with Personal Computers (PCs) at the beginning of the 1990s immediately made people want to try to make drawings using this auxiliary medium, in order to rationalize work procedures and to avoid having to start again from the beginning when modifications had to be included.

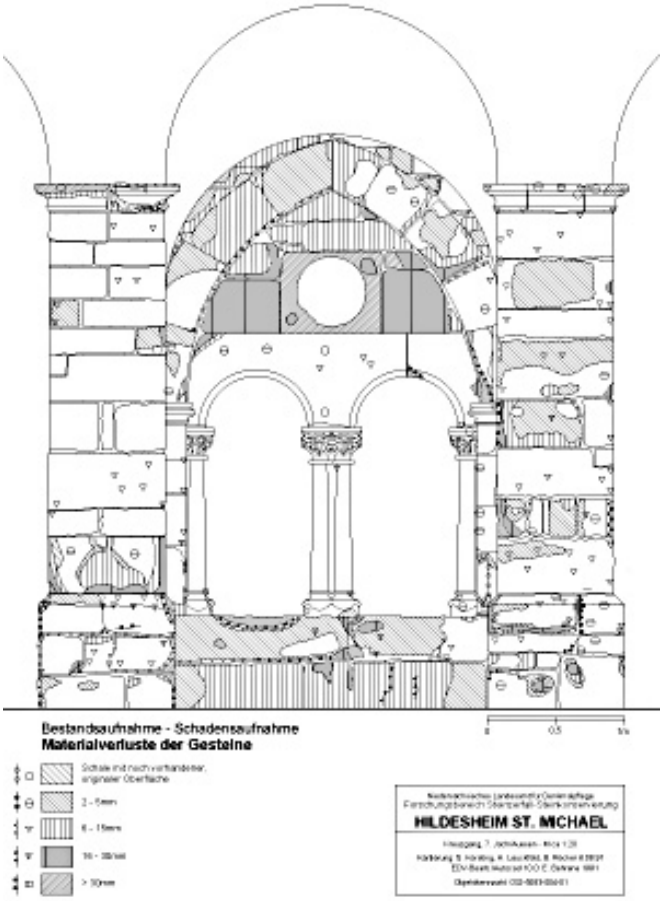
Germany, Stadland-Rodenkirchen, Protestant church, altarpiece, left stringboard. The quality of this line drawing produced via CAD meets the standards of a manually produced drawing.

First steps – mapping using CAD

In NLD, the first digital mapping exercise to be carried out with CAD used AutoCAD. The project was the 7th bay of the cloister in St Michael's Church, Hildesheim, Germany, and had good results, but was also disappointing. Computer programs must be learnt, mastered and

constantly used to maintain familiarity. At the same time, data entry takes as long as drawing by hand, and technical constraints appear due to PC software and hardware limitations.

Why use CAD? It was developed as a program for architects, engineers and designers for drawing presentations in two and three dimensions according to coordinates. However, using a CAD program allows the use of the graphic representational symbols of the NLD mapping system (points, lines, hatching) available as drawing tools, with the exception of tinting (Beck and Behrens 1993) and to connect CAD-files with database information for future statistical evaluation. The integrated layer management is useful for systematic and separate data filing. Inputs can be made via digitizer, keyboard or mouse, and hardcopy outputs up to A0 size can be made using printers or plotters.



Germany, Hildesheim, Protestant church of St Michael, cloister, 7th bay east wall outside. CAD mapping of lost stone material carried out in 1991 according to the system of the Working Group Condition recording (Bestandsaufnahme) of the former BMFT Research Project - Deterioration and Conservation of Natural Stone (Steinzerfall-Steinkonservierung) - relevant VDI 3798, additional sheet 3.

CAD workstation with A1 digitizer for introducing large maps.

Unfortunately, the use of hatching results in very large data files, and large formats create problems with regard to input and output. For this reason, the amount of data should be minimized right from the beginning by concentrating on essentials.

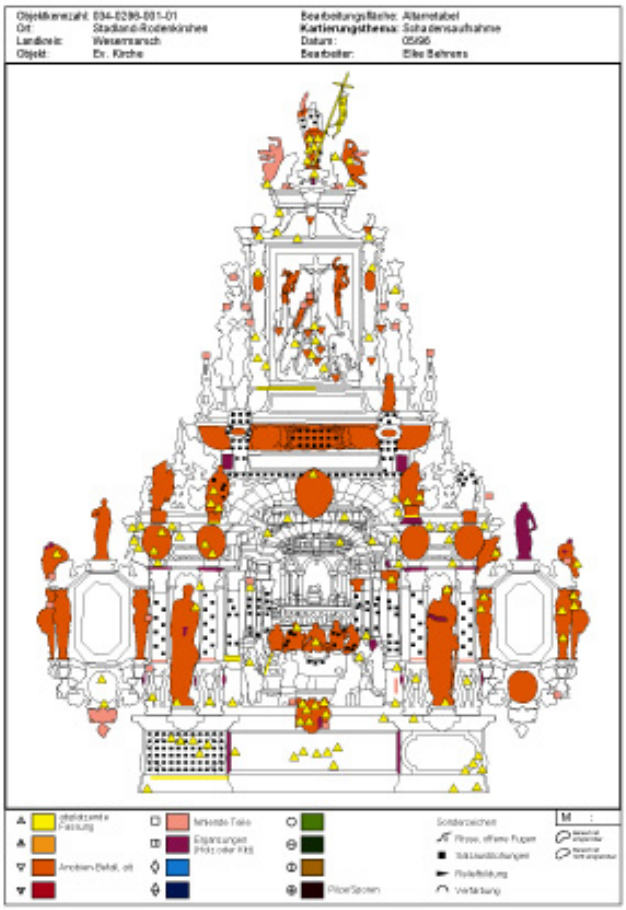
Consequences for daily work

Within the *Wandmalereischäden* [wall-painting damage] Research Project financed by the German Federal Ministry for Research and Technology (BMFT) (Anon., 1994) and organized in co-operation with the NLD, forms reduced to A4 size were developed for manual and computer-aided recording (Beck and Behrens 1993).

For the first time, these forms were produced using CAD, and then graphics software. Then as now, in digital mapping using a PC, the subdivision of objects into referenced areas allows for faster data processing. Manual and digital recording were therefore developed in parallel, with the aim of producing a standardized approach.

A limitation of computer-aided systems is the fact that during work on an object, it is impossible to enter all existing documents into the PC because it would require too much effort. For example, the large amount of time required to scan, process and print photographs (even in smaller formats,

such as A4) should not be underestimated. It depends on resolution and file format of the image data and can be easily calculated. As a consequence, computer-aided documentation is currently restricted to selected cultural objects (mural painting, stone conservation, etc.) (Behrens and Stadlbauer), although computer graphics increasingly are being applied for presentation purposes and for the visualization of summary results.



Germany, Stadland-Rodenkirchen, Protestant church, altarpiece. This graphic record gives a general view of all mapped phenomena relating to the condition of the altar. For a more detailed analysis, it is necessary to study the original documents.

The introduction of sophisticated computer-based documentation has required the creation of a new – almost independent – area of responsibility, that of the documentation specialist, with a new type of expertise and use of a computer workstation dedicated exclusively to conservation documentation. Due to incredibly fast development in PC technology, from the MS-DOS operating system underlying Windows 3.11 to Windows 95/98/Me, and Windows NT 4.0/2000, documentation experts require constant updating of skills, and newcomers have to invest a lot of time in acquiring the necessary specialized skills. A thorough knowledge of computer technology, documentation techniques and heritage conservation is indispensable. This is why at present only a few freelance restoration companies in Germany produce complete documentation using PCs. Normally, only word processing and spreadsheets functions are used. This will perhaps change in the future!

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Basic conditions and preparations

At present, it is impossible to fulfil the dream of having ‘easy-to-handle’ PC-based mapping software for restorers off-the-shelf because a combination of different program components is used in visual or graphic documentation. The most important programs are CAD, graphic, scanning, image processing, word processing, spreadsheet and desktop publishing.

It is important to observe the following points:

- Available financial resources constrain equipment specification.

- In image and graphic data applications, the requirements for hardware and software are higher than for simpler office applications.

- Scanners, digital cameras and digitizers are necessary for input; colour printers and special photographic paper (very expensive) are needed for high-quality output in hard copy.

- Larger data files require larger memory resources and powerful back-up systems.

- Data exchange with outside partners requires compatibility, best achievable through use of standard software.

- Data management includes constantly updating software and old files for compatibility with new program versions (this can sometimes results in loss of format).

- Preparation of templates (e.g. mapping forms) as so-called prototype files.

- Development of orientation systems and signatures for data management.

- Production of base maps, as either drawing files or scanned images, that can be imported to complete style sheets.

How to carry out digital mapping

The preliminary considerations in conceptualizing a digital mapping operation are identical with those needed for manual mapping, namely compiling and testing of categories and their legends. In order to convert the NLD mapping system representation techniques into digital format, a program with the following software options is required:

- Image data filing with open scale.

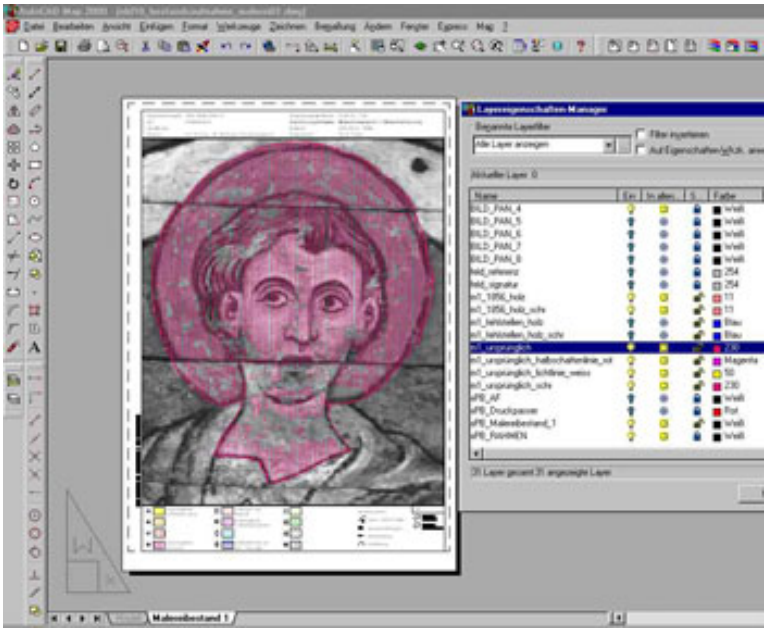
- Text information filing with formatting options.

- Drawing tools for entering points, lines, geometrical forms, symbols, hatching and coloured areas (opaque and transparent) with all formatting options.

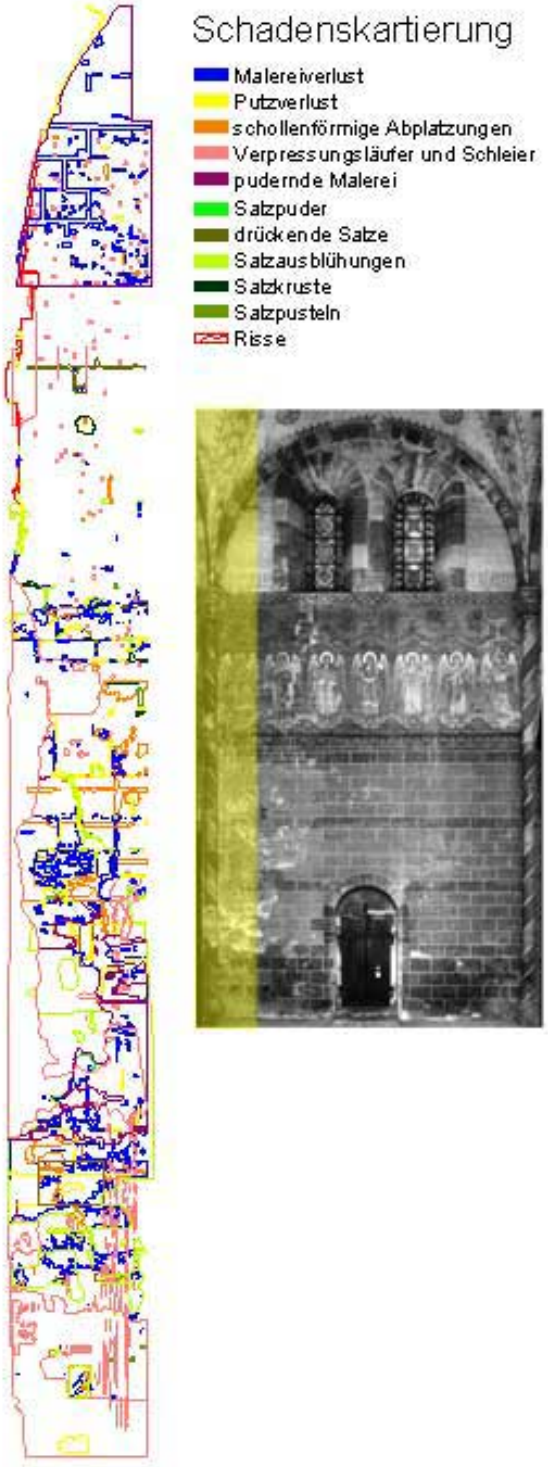
- Layers for phenomenon-oriented filing.

- Connection to databases for future statistical evaluation.
-
Connection to Geographical Information Systems (GIS).

Some of these components are a standard part of graphics programs such as Micrografx Designer, Macromedia Freehand, Adobe Illustrator or CorelDraw, while some of them are found in image processing programs, such as Adobe PhotoShop and CAD programs (e.g. AutoCAD Map or Microstation). Only the most popular programs are mentioned here.



Germany, Protestant church of St. Michael, Romanesque ceiling. CAD-mapping on the base of a rectified black&white image. The layer concept was developed on the basis of the mapping system according to VDI 3798, additional sheet 3. Foto: Deutsches Bergbau-Museum Bochum



Germany, Königslutter Stiftskirche. Medieval wall painting in the lower storey of the westwork, detail of the tree of jesse. CAD-mapping (poor adhesion: cavity/void) of damage phenomena on the base of a rectified color image. Foto: Deutsches Bergbau-Museum Bochum

Germany, Königslutter, Stiftskirche. Historicist wallpaintings in the northern transept. CAD-mapping of damage phenomena on the base of a rectified black&white image. Test conservation area on the north wall (1998) is marked in yellow. (Deutsches Bergbau-Museum Bochum, Ochsenfarth Restaurierungen Paderborn)

Of course, the best method is to carry out mapping directly on the PC. In this case, monochrome (usually) rectified image data are used as base maps. These can be zoomed-in to make details visible on the screen. The contours of area phenomena in different size are marked by a closed outline and the enclosed area is coloured or hatched. In opposite of manuel mapping, for point phenomena a set of symbols are used. Mapping is done layer by layer, according to the categories. Printouts are used for visual control of the work and for archiving.

Combination of manual and digital mapping
If the mapping is done directly using a PC, manually produced documents can be integrated subsequently without problems. The scanning of manually produced overlays, followed perhaps by vectorization of the produced bitmap data, could be considered a good alternative to direct recording.

It is recommended that monochrome representation tools be used. People who know what coloured-original overlays look like can imagine what it would mean to scan them. Depending on the preliminary settings, the scan is often similar to a coloured photocopy. If, in the heat of the moment, the conservator has applied colours irregularly or too thinly, scanners as well as colour photocopiers interpret these as patterns and produce inaccuracies, i.e. parts are missing. A scanned image can at best have the same standard of quality as its original, and so it often becomes necessary to edit the images afterwards by retouching or correcting colours. This costs time and money.

Here are some ideas for economizing efforts:

- Scan the mapping photographs in reproduction size with a 200 to 300 dpi resolution and save them in .TIF, .EPS or .JPG format (the most used formats for image data).

- Make provisional original maps on clear overlays, using only B&W graphic signs with drafting leadholders or fine-line permanent markers monochrome mapping). Such maps are temporary products and not appropriate for archiving.

- Carry out a monochrome (B&W only) scan of these overlays – not greyscale – as interpretation of two colours results in a smaller data file size.

- Depending on the program, import, save and redraw the image data, because several image files superimposed in one file obscure each other. In AutoCAD, such scanned files are imported as bitmap (.BMP) files, formatted transparently and treated like a line drawing by changing the colours. It is possible to import and superimpose several sets of image data (Behrens 1998).

- It is true that PhotoShop allows transparent layers to be produced, and thus several image files to be connected, but, unfortunately, as a pure bitmap program it has no vector-oriented drawing tools and every new layer produces more data. The size of one PhotoShop file can expand rapidly, and this is a great disadvantage.

Before starting mapping, it is really important to know whether the manual maps are to be processed digitally afterwards (indirect recording). What is described here is just one methodology. A professional PC user could probably conceive of other methods such vectorizing.

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Conclusion on digital mapping

A series of trials with different standard software suites operating under Microsoft Windows has brought us directly back to AutoCAD, especially as since Version 14 one can include image data. Practical experience with CAD data has shown good results with regard to long-term compatibility of document files without data losses because CAD programs are for professional applications where files must be accessible for long periods, even though software versions change (Behrens 1998).

Using CAD programs is a first, solid step for those who want to work with the PC in a forward-looking way today. In the future, a possible procedure when using GIS software would be to link rectified image data (raster files) and CAD data (vectorized files) with database information systems. Nevertheless, it is still perfectly okay for people to use, for example, standard, medium-priced graphics programs because these produce excellent documents for presentation (Behrens, 2000).

Using standard programs on a PC improves people's skills and is good practice for coping with potential problems, such as program bugs, driver problems and data losses that unfortunately cannot be avoided. Someone who wishes to concentrate on digital documentation must make this decision on their own.

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Outlook

Digital methods have not yet reached maturity. It is necessary to test and critically evaluate them on the basis of innovative research projects. Someone who is acquainted with environmental conditions on worksites will probably be negative toward mapping being carried out on the scaffolding straight into a PC. It is obvious that heat, cold, dust and vibration have undesirable effects on sensitive devices such as computers, monitors and printers.

The development of complex information systems (Beck, Temme and Rademacher, 1996) requires a team of experts in different fields, and considerable financial resources. In this case one goal of the Raphael-project since 1999 is, on the base of further experiences in documentation systems, to develop a common practise-oriented new Mapping Structure and Glossary for Wallpaintings especially for using the AutoCAD program.

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