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PRÄVENTIVE KONSERVIERUNG
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CONSERVAZIONE PREVENTIVA
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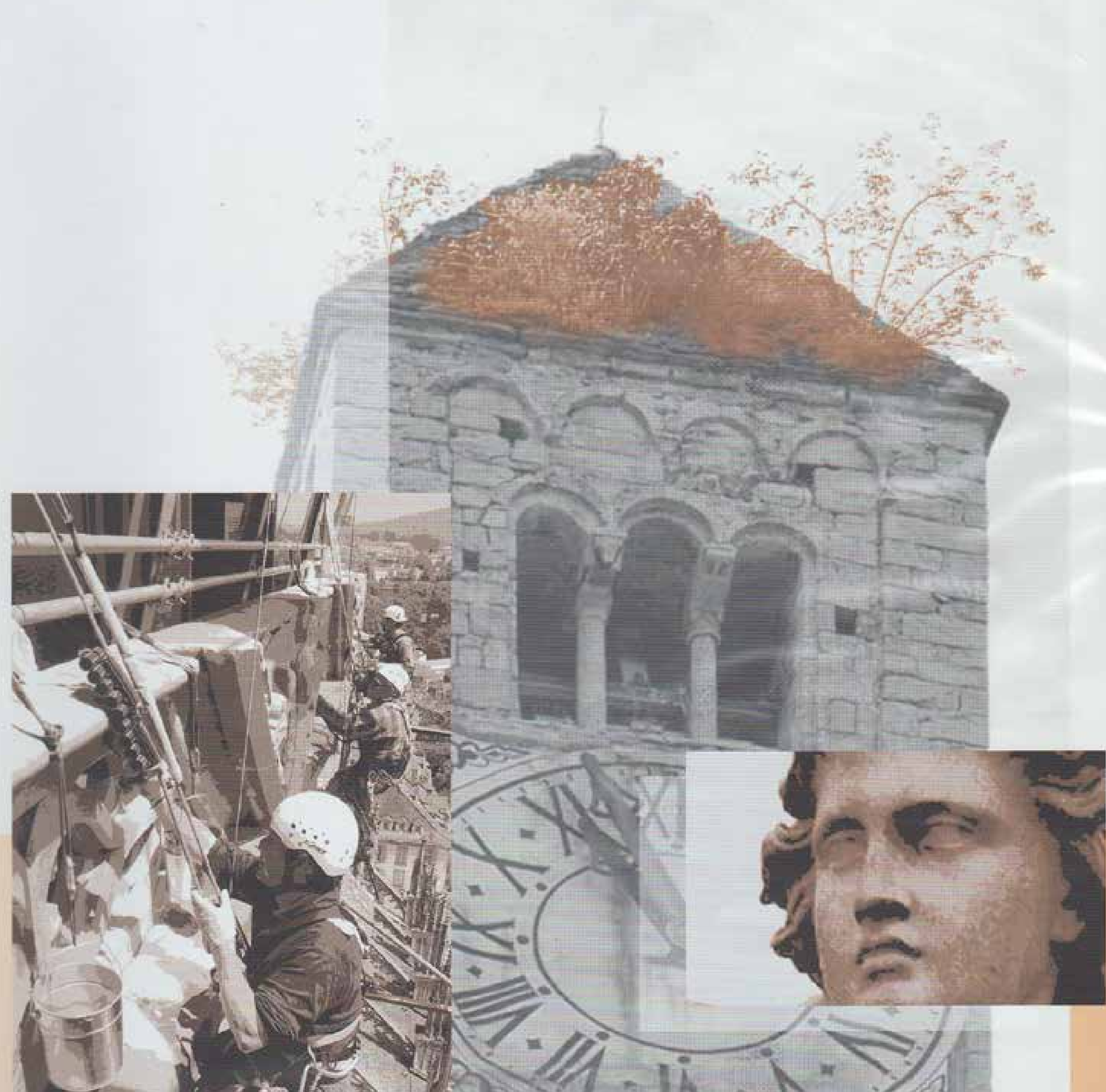
PREVENTIVE CONSERVATION
PRACTICE IN THE FIELD OF BUILT HERITAGE



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PREVENTIVE CONSERVATION OF CHURCHES DURING TUNNEL WORKS IN STOCKHOLM

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Abstract

This year has seen the start of extensive tunnelling work in Stockholm. The tunnelling will take place directly under or very close to five historic churches containing some of Sweden's most valuable architecturally integrated artifacts. Over a period of several years, vibrations from building work will take place directly under or very close to these churches.

In Sweden there is a lack of guidelines specifying how to conduct pre-inspections of historical buildings or architecturally integrated artifacts before any vibration related building work. Due to this a team of conservators developed a customised investigation solution for the integrated artifacts in the churches affected by this project.

The aim of the investigation was to identify risk areas that potentially can be affected by long-term vibration caused from the tunnelling work and future train traffic. Based on the investigation and corresponding risk assessment, preventive solutions were developed.

An important conclusion from this project was that, in addition to a condition survey, it was also important to study the construction of the artefacts and their structural interaction with walls, floors and vaults. This gave an insight into how the artifacts react to vibrations generated by the tunnelling work and thus to the damage risk. The project also showed that long-term preservation of valuable and irreplaceable parts of a historic building affected by vibrations can be best achieved if the preventive solutions are strongly integrated into the project as a whole.

Résumé

Cette année a vu le début d'importants travaux de forage à Stockholm en vue de la création d'une nouvelle ligne de métro urbain. Ces forages auront lieu directement dessous ou à proximité de cinq églises historiques qui contiennent des objets immobiles parmi les plus importants de la Suède. Pendant les années à venir, des vibrations provoquées par ces travaux vont affectées ces églises.

En Suède, il manque des recommandations qui stipulent comment entreprendre des inspections préliminaires des bâtiments historiques ou des objets immobiles en amont des travaux qui risquent de provoquer des vibrations. Suite à ce constat, une équipe de conservateurs-restaurateurs a développé une solution sur mesure pour l'examen des objets immobiles touchés par les travaux de forage.

Le but de l'examen était d'identifier les zones à risque qui peuvent être touché potentiellement par des vibrations persistantes causées non seulement par le travail de forage mais aussi par le trafic ferroviaire futur. Sur la base de ces investigations et sur l'évaluation correspondante des risques, des mesures préventives ont été développées.

Une des conclusions les plus importantes du projet était que, en plus d'un constat d'état, il était aussi important d'étudier les techniques de confection de l'objet et son interaction structurelle avec les murs, les sols et les voûtes. Ces études ont permis de déterminer comment les objets réagiront aux vibrations générées par les travaux de forage et donc d'évaluer le risque de dégâts. Le projet a montré également que la sauvegarde à long terme d'éléments précieux et irremplaçables de bâtiments historiques touchés par des vibrations peut être réalisé d'une manière optimale seulement si des mesures préventives sont intégrées dans le projet dans son ensemble.

Key-words

Preventive conservation, Architectural surfaces, Mural paintings, Stucco, Vibration, Vibration-protection, Vibration–damping, Blasting, Wall paintings, Altar, Plaster, Detachment, Examination, Investigation, Historic churches, Construction

1. Introduction

At the beginning of this year the extensive building work of the 6 km long railway tunnel Citybanan ("the City Line") in Stockholm started. This building work includes the main tunnel as well as service-tunnels and new underground stations. The tunnelling techniques used are blasting in combination with pile driving and sawing. The building work will last approximately 10 years and will take place directly under or very close to five historically important churches in Stockholm.

The churches contain some of Sweden's most historically valuable architecturally integrated artifacts such as altars, pulpits, tombs, mural paintings and stucco. The tunnelling will generate vibration over several years. In some churches the extent of vibrations on the buildings can also increase due to the future train traffic. For several decades now it is generally accepted that vibrations can cause accelerated aging and irreversible damage to historic buildings.[1] In contrast to the approach used during previous tunnelling work in Stockholm, this project was early focused on trying to avoid damage to the historical churches to occur in the first place. [2] The awareness of preventive solutions and risk reduction was from an early stage integrated into the project.

In large infrastructure projects like this, the risk assessment is very often focused on the building as a whole. Potential risks and damage are synonymous with structural damage to the building itself. As a consequence, the entire structure of the churches is examined by experts who are sensitive to these aspects. Vulnerable architectural surfaces and integrated historical art objects are not treated separately.

The City Line project in Stockholm has sought to correct this by deliberately developing a working model, which makes a distinction between the architectural surfaces, historic artifacts, wall paintings and stucco and the building fabric itself.

2. Investigations

2.1 Background

In Sweden building inspections prior to tunnel blasting are carried out on the basis of the Swedish standard SS 460 48 60. The aim of this standard is to establish the responsibility if any damage occurs due to groundwork. This is done by defining the condition of the entire building before for example blasting or pile driving. This standard comprises no special procedure or treatment for historical buildings and art objects. Apart from this standard, there is no other specific framework specifying how to conduct pre-inspections of historical buildings or architectural integrated artifacts before any vibration related building work. In this particular case, there was also no specific cultural property law that defines or recommends an appropriate approach for the architectural surfaces and integrated art objects.

Due to this lack of guidelines, a team of conservators with different specialisations (wood, painting, stone and mural painting) was established within the project. They where given the task of developing a customised investigation solution for the integrated artifacts in the churches affected by this project.

2.2 Objective

The aim of the investigation was to carry out in an early phase - i.e. before any building work starts – an identification of risk areas that potentially can be affected by long-term vibration caused from the tunnelling work and future train traffic. In addition to the condition recording and examination of the material composition, this investigation focused on how the artifacts are integrated with the building. Based on the investigation results preventive conservation solutions were developed for the integrated art objects and architectural surfaces. These solutions should minimize the risk for vibration-induced damage and deterioration for these types of objects of the historical churches concerned.

2.3 Methods

The investigation work was carried out by the conservation-team using scaffolding. The following process and methods were applied:

A. Base maps for survey and monitoring

An overall initial photo documentation was carried out. These photomaps acted as a base map for the following survey of construction and recording of current damage. This enabled visual documentation using photographs with drawings. Selected objects were measured by stereo-photogrammetry.

B. Examination of materials and construction

This part of the investigation aimed at identifying the materials used, the combination of materials and construction techniques of altarpieces, pulpits, tombs, mural paintings and stucco décoration. The method used followed common practice within conservation documentation [3] but special care was taken to make it understandable to the different stakeholders within the project who come from different backgrounds. A clear and simplified visualisation was required. A significant part of the examination was to identify how artifacts connect to walls, floors and roofs and to what extent these bounderies are original or later additions. (Fig. 1). Technical equipment such as endoscopes and portable microscopes were helpful in order to identify the materials and construction techniques. (Fig. 1).

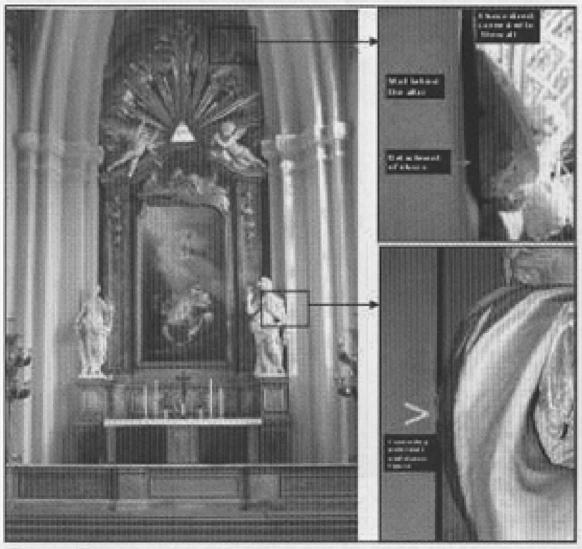

Fig. 1: Examination of the wall-integrated altar in Maria Magdalena church. Zones where the altarpieces have a direct connection to the wall. Photo: A. Henningsson

C. Condition survey

The condition survey was limited to recording mainly structural damage and weakness in the interaction between layers of construction. All existing damage was recorded as well as tendencies to deterioration that could be affected by long-term vibrations.

For plastered vaults and walls, different crack types, areas of cavity and loose plaster or stucco were recorded. The internal conditions of the plastered surfaces were investigated by plaster analysis and in situ measurement by micro drilling resistance.[4]

D. Archive research

As a complement to the examination of condition and construction an archive research was carried out focusing in particular on explanations regarding the causes of the recorded condition. The archive research could also reveal information about changes in the construction and previous restoration treatments, re-design of altars or rearrangement of artifacts in the building.

E. Vibration measurement during test blasting

In one of the churches, a test-blasting program was conducted. The test blasting provided information on how a large alterpiece made of wood and stucco and fixed to a wall receives vibrations caused by blasting. Vibration measurement equipment was installed on different parts of the altarpiece in order to evaluate how this type of vibration was transported and distributed over the altarpiece and the associated building.

3. Risk assessment

The investigation results were used to conduct a basic risk assessment. [5] The risk assessment identifies areas with particular risk for damage due to the tunnelling work and future train traffic.

3.1 Vibrations and consequences on historic architectural surfaces

Vibrations in general affect the rate of deterioration of an historic material.[6] The presumed cumulative effect and risk for detachment of wall paintings and plaster are commonly mentioned in the preservation literature.[7]

In the field of architectural conservation there is a lack of applied research regarding critical vibration velocities and damage on architectural integrated art in historic buildings. It is difficult to evaluate allowable vibration limits and how it affects an historical material. The effect of the vibration depends on a combination of the type of historic material, the pattern of interaction in the building as well as the degree of deterioration. This makes it very difficult to set the appropriate level of vibrations that should not be exceeded. In addition, it is not only the level [8] of the vibrations that defines the risk of vibration-induced damage for a material: the frequency of the waves produced by different vibration sources must also be considered.[9] Due to this a case-by-case assessment for each of the sensitive parts or artifacts in an historic building is required.

3.2 Criteria for risk evaluation in this project

An important consideration in the risk assessment was not only to evaluate the status of the material composition but also to evaluate how the artifacts are constructively integrated within the building. The type of structural bond between the artifacts and the building structure influences to what extent vibrations are expected to affect the artifacts.

3.3 Defined risks areas

The altarpieces were especially singled out as high-risk objects. The fact that they are totally or partly fixed to the floor and surrounding walls makes the transportation of vibration direct. Two of the altars are mainly composed of stucco gilding and paint layers. Materials such as wood, glass or painted canvas are partly recessed in the construction, which makes it a complex system. A notable artifact is the baroque high altarpiece in the Gustaf Vasa church, with a height of 15 meters and composed of painted and gilded wood and stucco elements. As this altarpiece was moved from another church in 1905 some constructive replacements were made and today it is connected to the wall by steel-beams.

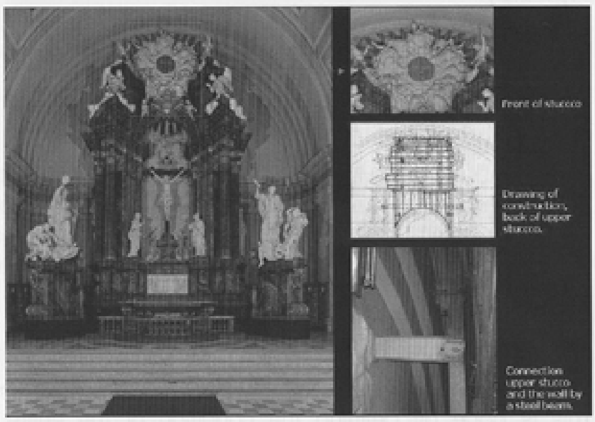

Fig., 2: Part of visualisation of the construction and wall integration of the high altar in Gustav Vasa church. Photo: Fokus GmbH Leipzig / A. Henningsson

Three-dimensional architectural surface details built up of lime or gypsum such as stucco figures and reliefs, integrated tombs, epitaphs, brackets, capitals and rib of vaults are also defined as risk areas. (Figs. 3-4). These elements are partly integrated into vaults and walls depending on the type of construction. Cracks and cavities in plaster, stucco and wall paintings can be aggravated in a vibration-exposed environment and potentially result in detachment.

Fig. 3: The mural paintings and decorated plaster on the rib vaults in Clara church. Photo: A. Henningsson

4. Preventive conservation solutions

Based on the investigation results and risk assessment preventive conservation solutions within in a broad spectrum were developed with the purpose of :

- Reducing the transportation of vibrations to sensitive areas and objects in the building.
- Reducing fatigue and deterioration caused by vibrations from the tunnelling work.
- Avoiding an increase in maintenance due to the building work and the future train traffic.

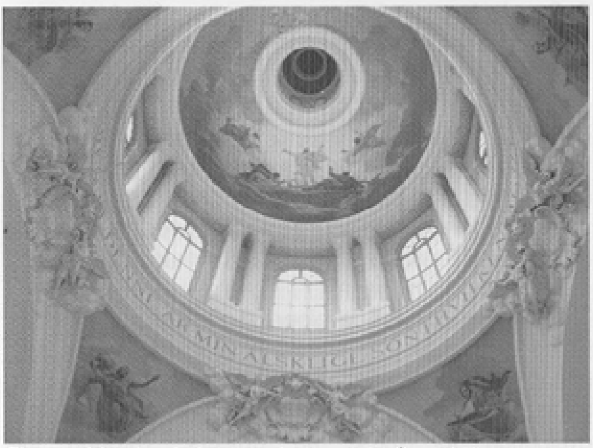

Fig. 4: Mural paintings and stucco in Gustaf Vasa church. Photo: A. Henningsson

4.1 Definitions and deployment

As this project is constituted mainly of stakeholders [10] with little experience in culture heritage preservation, it was important to define clear definitions and distinctions of the preventive conservation solutions. The project adopted the following general definition of preventive conservation: "...preventive conservation is defined as any measure that prevents damage or reduces the potential for it".[11] A further distinction is made between indirect and direct preventive solutions.[12] This distinction made it easier to discuss the actual deployment of the solutions with the different stakeholders and how it affects their area of responsibility.

4.2 Indirect preventive conservation solutions

Indirect preventive conservation solutions in this project are the interventions that improve the immediate environment of the building or its site to prevent damage and deterioration on the architectural surfaces and artifacts. Indirect solutions are for example damping of the rails and the sub grade by isolation pads or modifying the technique of pile driving to reduce vibrations. The level and intensity of blasting is also defined as an indirect solution. The actors of these indirect solutions are mostly non-preservation specialists like blasting experts, tunnelling constructors or railway management boards.

4.3 Direct preventive conservation solutions

The project definition of direct preventive conservation solutions has a remedial character and involves direct action on the artifacts by a conservator. As opposed to "traditional" remedial intervention or treatment, the direct preventive conservation solutions are mainly temporary solutions during the tunnelling work. A direct preventive solution within this project is to create temporary facings over certain risk zones of the artifacts for example stucco or plasters. Further, vibration-damping solutions on artifacts are defined as direct preventive conservation solutions. In the case of the baroque altar in Gustaf Vasa church a reversible construction to damp or interrupt the vibration before they reach the object is being developed.

The actors of the direct preventive solutions are specialized conservators and engineers in the field of preservation.

4.4 Control by monitoring areas

A set of monitoring areas are selected in each church to control the impact of the tunnelling work. For example wall paintings with cavities and cracks were selected. Testing regularly the efficiency of the preventive conservation solutions was also part of this program.

The monitoring is based on the mapping of cracks and cavities, logging of cracks widths as well as fixing points of artifacts in the structure. These parameters will be regularly evaluated and correlated with continuous vibration measurements. (Fig, 5-6). Conservators with adequate specialization are controlling these monitoring areas. In addition an interdisciplinary overall evaluation takes place in the working groups.

Fig. 5: Measuring crack width in stucco using micro-scope. Photo: H. Ekestang

5. Project integration and implementation

5.1 Working groups for deployment

To plan and deploy the proposed preventive conservation solutions a working group for each church was set up. The working group included participants from the Swedish rail administration and of external experts such as a conservators, blasting experts, building engineers and project managers. The aim of this team structure was to address impact on the overall project plan and decide to which extent the recommended preventive solutions shall be implemented and by whom.

5.2 Project experience

Preventive conservation of architectural integrated objects in the field of tunnelling is a new working area. Few hands-on experiences could be applied in this case. The knowledge available is often focused on the preservation of the whole building as a structure and the risk assessed from a structural point of view.

The absence of frameworks that provide guidance in evaluating risks associated with vibrations generated from tunnelling work and how it impacts large-scale architectural artifacts and surfaces made the project more difficult to manage.

What is apparent in this type of project is that regardless of good intentions different stakeholders have different concerns that sometimes can be in conflict. Examples of this are understanding of historic and irreplaceable values, level of prevention, definition of adequate risks, budget constrains and project time lines.

The experience from a conservator's point of view is that an understanding of these valuable and irreplaceable parts of a historic building was reached first by treating the architectural artifacts and surfaces separately from the building as a structural unit. This approach enabled the setting up of the applied investigation model, risk assessment and developed preventive solutions.

Preventive conservation is an interaction of several solutions. Our investigation reveals that a long-term preservation of these integrated artifacts can only be reached if the indirect and direct solutions are interacting. This project had phases where the different stakeholders very often focused on only one solution. The appropriate level of vibrations during the blasting period was often highlighted as a separate solution. The prevention of vibration-induced damage should be treated as an entirety. This involves a combination of appropriate level of vibrations during the blasting, ways to reduce the vibrations or interrupt vibration transportation to the artifacts and in some cases carry out temporary facings.

Often there was a lack of comprehension that preventive conservation measurements also are needed after the tunnelling work is completed, as permanent changes in the environment of some churches will take place due to future train traffic.

Fig, 6: Condition survey by mapping of the stucco altar in Maria Magdalena church. Photo: H. Ekestang

6. Conclusion

In the field of architectural conservation there is a lack of applied research regarding critical vibration velocities and damages on architectural integrated art in historic buildings. In combination with the absence of frameworks in Sweden, that provide guidance in evaluating risks associated with vibrations generated from tunnelling work and how it impacts large scale architectural artifacts and surfaces made the project more difficult to manage.

The City-Line project developed an investigation model, which distinguish the architectural surfaces, historical artifacts, wall paintings and stucco from the building structure. This way of working enabled a proper risks evaluation for these art objects. Through this investigation model, object specific risks could be identified for the architectural integrated artefacts in the churches. This made it possible to integrate preventive conservation solutions in an early phase of the tunnelling project.

As an addition to the general condition survey undertaken this investigation also focused on the construction of the artefacts and their structural interaction with walls, floors and vaults. This was an important element in estimating how sensitive the artifacts and architectural surfaces are to vibrations that move through the building during the blasting. The combination of current condition of artifacts and their exposure to vibration was evaluated when identifying risk areas.

This project shows clearly that long-term preservation of valuable and irreplaceable parts in a historic building affected by vibrations can best be realised if the preventive solutions are strongly interacting in an entirety. An example of this is the combination of appropriate level of vibrations during the blasting, ways to reduce the vibrations or interrupt vibration transportation to the artifacts and in some cases carry out a temporary facing.

For the project implementation of the preventive conservation solutions a basic and distinct terminology was set. The preventive conservation solutions were divided into direct and indirect preventive conservation solutions. This distinction made it easier to discuss the deployment of the solutions with the different stakeholders and how it affects their area of responsibility. The definitions also aimed to make it clear that preventive conservation is an interaction of different solutions and that the responsibility for implementing them might lie with different groups.

NOTES

[1] FIELDEN (2001), p.156,158.

[2] Information about damage on artifacts in the churches of Stockholm during tunnelling work for the subway. Document for Adolf Fredrik church reports that a stucco-relief integrated in the wall was damaged by cracking during tunnelling 1949 in; „Till Kyrkorådet i Adolf Fredriks församling i Stockholm", in document for Adolf Fredriks kyrka (dated 1949-03-30). Statment by achitekt M. Westerberg in in Stockholm City Archives.

[3] KOLLER (1994), p. 7.

[4] In some churches the plaster of the architectural surfaces was characterized by thin section to retrieve information about the type of plaster and the internal structural condition. On monitoring areas the adhesion to different plaster layers and the adhesion to masonry was measured in situ by drilling resistance measurements. Download: http://www.sintechnology.com/html/DRMS_Cordless.html (5. June 2009).

[5] The project applied a basic evaluation based on the results from investigation results in B, C and D in the model. None of the available frameworks for risk assessment in the field of cultural property was possible to apply within this project. JEBERIEN (2007), p.21 ff. The setting of scenario after BROKERHOF et al (2007), p.10 was used in presentation but not systematically in the overall project.

[6] TORRACA (1988) p. 53, 62

[7] MORA, MORA, PHILIPPOT P (1984), p. 209.

[8] Vibration levels are defined in peak particle velocity (PPV) with the unit mm/s.

[9] JÄGER W, RUGE P (2008), p. 4.

[10] Stakeholders of the project are blasting experts, building engineers, blasting company, project managers by national railway commissions and church authority representative.

[11] LEVIN (1992), web-version.

[12] HENNINGSSON (2008), p. 7

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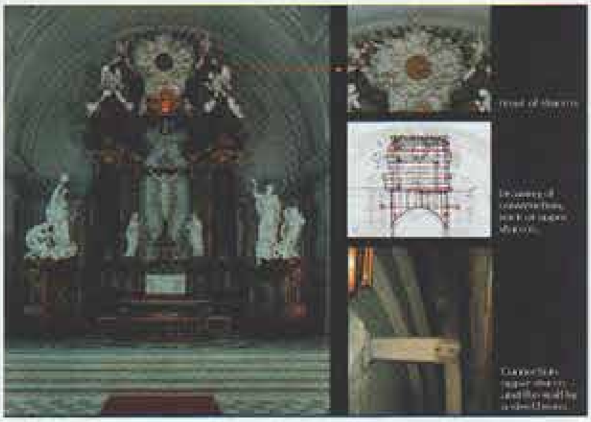
Fig, 1: Examination of the wall-integrated altar in Maria Magdalena church. Zones where the altarpieces have a direct connection to the wall. Photo: A. Henningsson



Fig, 2: Part of visualisation of the construction and wall integration of the high altar in Gustav

Fig, 4: Mural paintings and stucco in Gustaf Vasa church. Photo: A. Henningsson

Fig. 5: Measuring crack width in stucco using microscope. Photo: H. Ekestang

Fig. 6: Condition survey by mapping of the stucco altar in Maria Magdalena church. Photo: H.

DIAGNOSTICA, INTERVENTO E MONITORAGGIO: IL CASO DELL'ORATORIO DI SANTO STEFANO A LENTATE SUL SEVESO (MILANO) *Davide Del Curto, Carlo Manfredi, Gianfranco Pertot, Valeria Pracchi, Elisabetta Rosina, Luca Valisi*

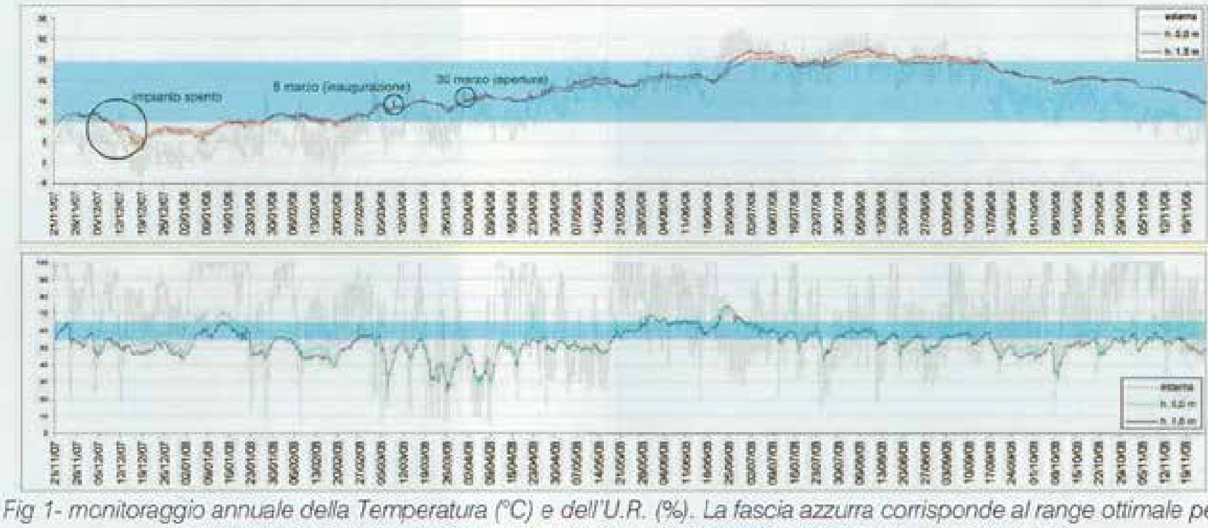


Fig 1- monitoraggio annuale della Temperatura (°C) e dell'U.R. (%). La fascia azzurra corrisponde al range ottimale per la conservazione delle pitture murali e affreschi T=10-24°C, U.R.=55-65. UNI 10829/99

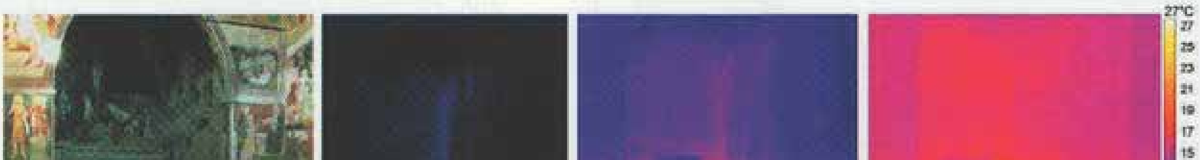


Fig 2 - riscaldamento progressivo delle pareti per effetto dell'impianto Temperierung (range 9-27°C)