Cleaning Historic Concrete

A Guide to Techniques and Decision-Making

Guidelines

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Getty
Conservation
Institute

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The Getty Conservation Institute (GCI) works internationally to advance conservation practice in the visual arts—broadly interpreted to include objects, collections, architecture, and sites. The Institute serves the conservation community through scientific research, education and training, field projects, and the dissemination of information. In all its endeavors, the GCI creates and delivers knowledge that contributes to the conservation of the world's cultural heritage.

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Foreword to the English Translation

Cleaning—whether to improve a building's appearance, arrest deterioration, assess conditions, or provide a clean surface for treatment—is often an integral part of any physical conservation project. Although principles relating to the why and how of cleaning are common regarding many building materials, there are specific methods and techniques appropriate to each material's unique characteristics. In addition, each building generates its own response to cleaning depending on its cultural significance and a range of other considerations.

Recognizing that one of the current challenges in the concrete conservation field is the limited availability of specific technical literature to guide practitioners, the Getty Conservation Institute (GCI) has partnered with the Laboratoire de Recherche des Monuments Historiques (LRMH) and the Cercle des Partenaires du Patrimoine (CPP) to make available an English-language translation of the CPP's essential 2009 publication, *Le nettoyage des bétons anciens: Guide des techniques et aide à la decision*. Written by Myriam Bouichou and Elisabeth Marie-Victoire, this was the fourth volume of the series Les cahiers techniques du Cercle des Partenaires du Patrimoine.[1] Based on the CPP's research, the publication was targeted toward stewards and professionals working in the field of conservation of historic sites built in concrete. The LRMH and CPP have been at the forefront of research on conservation and diagnostic techniques for historic concrete since the early 1990s.

This translation, *Cleaning Historic Concrete: A Guide to Techniques and Decision-Making*, has been produced under the auspices of the GCI's Concrete Conservation project, which seeks to improve the conservation of twentieth-century concrete heritage by tackling some of the challenges facing this emerging field through development of scientific research, model field projects, training, and publications. The project is part of the GCI's Conserving Modern Architecture Initiative.

The GCI would like to thank the authors, Myriam Bouichou and Elisabeth Marie-Victoire, for their assistance in publishing this English version of their work.

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1 Other volumes in this series related to concrete conservation include (in French) Elisabeth Marie-Victoire, *Les altérations visibles du béton: Définitions et aide au diagnostic,* Les cahiers techniques du Cercle des Partenaires du Patrimoine, no. 1 (Champs-sur-Marne: Cercle des Partenaires du Patrimoine, 1996).

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- Roland Merling, head of the Building-Structural Works program, Marketing Department, Italcementi Group
- Eric Pallot, chief architect of France's historic monuments
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Isabelle Pallot-Frossard
Former Director, Laboratoire de Recherche des Monuments Historiques, and former Secretary General, Cercle des Partenaires du Patrimoine

Preface

The Cercle des Partenaires du Patrimoine

After more than a century of industrialization and increased agricultural activity, various forms of pollution have changed the environments surrounding historic monuments, accelerating the degradation of the materials used to build them. The materials themselves have also greatly evolved, most notably as a result of the introduction of concrete and reinforced concrete.

In light of the cultural and economic challenges involved in conserving monuments, the development of new research paths has proven essential to identifying the most appropriate methods and products to protect and conserve architectural heritage. The first step has been to identify the types of damage affecting older materials, followed by the study of the behaviors of contemporary materials when subjected to natural aging and the environment. This new research is focused on the study of these materials, their mechanisms of deterioration and their etiology, and the development of new conservation techniques.

With this in mind, in 1992 the Heritage division of France's Ministry of Culture and Communication joined with nine large companies and four public scientific bodies to form an organization in support of the Laboratoire de Recherche des Monuments Historiques (LRMH), creating the Cercle des Partenaires du Patrimoine (CPP). This nonprofit organization (governed by the law of 1901) is structured to mobilize not only financial resources but also scientific and technological expertise, both private and public.

Under a three-year partnership agreement, members of the CPP provide financial support to the research and contribute human and material resources. For each of the research programs approved by the general assembly, a specific scientific committee is formed of LRMH engineers, representatives of the companies involved, and external experts. This ensures multidisciplinary and complementary expertise, necessary for the effectiveness of the research. Finally, public and private partners provide CPP researchers with access to their analytical equipment.

The CPP also responds to calls for projects from both Europe and France (Agence Nationale de la Recherche, Programme National de Recherche sur la Conservation du Patrimoine Culturel, launched by the Ministry of Culture and Communication), which enables it to develop its research activities and broaden its scientific network. Thanks to this financing, the CPP is able to recruit doctoral candidates and young researchers, who in turn receive first-rate experience in the conservation of heritage materials.

Since its formation, the CPP has thus been able to launch and successfully complete twenty-seven French projects and nine European projects, create numerous scientific publications, and publish four technical manuals for use by professionals, architects, regional authorities, and private owners or businesses.

Cleaning Historic Concrete: A Guide to Techniques and Decision-Making is the result of two research programs supported by the Ciments Calcia group, a founder of the CPP and one of its most loyal members. The purpose of this technical manual is to provide a simple decision-making aid to contractors, project managers, and businesses performing conservation. This document will help users adhere to the same conditions of effectiveness in cleaning a familiar material—concrete—that are employed in cleaning more traditional historic materials such as cut stone, brick, and lime plaster.

Isabelle Pallot-Frossard
Former Director, Laboratoire de Recherche des Monuments Historiques, and former Secretary General, Cercle des Partenaires du Patrimoine

INTRODUCTION

Soiling is an issue that affects most concrete buildings. The result of urban or industrial air pollution, it can vary from fine, blackish deposits to significant encrustation. It can also involve various forms of biological growth: moss, lichens, or algae. In both cases, soiling contributes to deteriorating the surface of the concrete and significantly mars the aesthetic appearance of a structure.

The types of surfaces that require cleaning are highly diverse, both in their nature and in their degree of deterioration. In most instances, they are exposed concrete facades created from formwork removal or with an exposed aggregate finish. While some surfaces still bear the imprint of the timber formwork (which should be preserved), others are in advanced states of deterioration. Monuments may also include concrete sculptures or ornamental finishes, which require special attention in order to preserve their sculpted or molded details.

Distinct conditions and issues are encountered when cleaning indoors or outdoors. For interiors, the working conditions are more sensitive, as there may be windows, wall paintings, or furnishings that must be protected and preserved. Outdoor soiling can be extremely hard to treat, and cleaning methods need to be effective without damaging the concrete.

With the aim of facilitating selection of the cleaning techniques best suited to each of these situations, two research programs were carried out by the Cercle des Partenaires du Patrimoine (CPP). The first, completed between 1996 and 2000, focused on cleaning mineral soiling on facades and outdoor sculptures. During this phase, the performance of the most commonly used techniques for cleaning outdoor concrete was compared to that of the gentler methods typically used in stone conservation.

The second program, carried out from 2006 to 2009, focused on cleaning interiors and removing outdoor biological growth. Thirteen techniques were tested at four different sites. How does one evaluate the quality of a cleaning technique, and how is one method chosen over another? To answer these questions, three criteria were used: ease of implementation, effectiveness of cleaning, and impact or secondary effects on the concrete.

This technical manual, the fourth published by the CPP, presents a summary of the results of these two research projects. Section 1 describes in detail the different types of soiling encountered on concrete monuments. Section 2 describes the various techniques used for cleaning concrete. Section 3 reports on the results of tests conducted at three sites in Paris—the Maison du Brésil, the church of Saint-Esprit, and the church of Sainte-Odile—and at a fourth site, the Centre Jeanne Hachette in Ivry-sur-Seine, southeast of Paris. In sections 4 and 5, decision trees and summary sheets describing the testing techniques will assist contractors, conservation practices, and conservators in selecting the best cleaning procedure or procedures to use.

1. TYPES OF SOILING

Soiling on Outdoor Concrete

Two types of soiling are found on concrete outdoors: black soiling and biological growth.

Black Soiling

Black soiling is the result of urban or industrial air pollution.

Soiling depends on the environment (temperature, humidity, and air pollution) and the surface condition of the concrete (roughness and porosity). It also depends on the monument's orientation and architectural characteristics, which will delineate the paths of rainwater runoff and thus the nature and intensity of the soiling. Black soiling develops over several stages. First, a layer of dust appears; then, thin deposits of black grime accumulate until the final stage, when a black crust forms.

Air Pollutants

Pollutants can be categorized into two types: primary pollutants and secondary pollutants.

Primary pollutants include gases such as sulfur dioxide (SO_2), nitrogen oxide (NO_X), and carbon monoxide (CO); volatile organic compounds (VOCs); and solid particles (fly ash, soot, and biogenic particles). These originate from various processes, including volcanism, biomass combustion, salt vaporization on the surface of the ocean, or resuspension of mineral particles by wind erosion. They can also come from natural sources and human activity (industrial fuel combustion, domestic heating, solid waste, vehicle emissions, and wood combustion).

Secondary pollutants are formed by chemical interactions between primary pollutants, leading to the formation of ozone (O_3), peroxyacetyl nitrates (PANs), polycyclic aromatic hydrocarbons (PAHs), aldehydes, ketones, sulfates, and nitrates.

These gas and particle emissions can have major consequences for historic monuments due to their interaction with some materials, sulfation, deposition, accumulation, and cementing of particles.

There are two types of pollutant deposition: dry deposition and wet deposition. Dry deposition is defined as the process of gravitational deposition and transfer of particles and gases from the atmosphere. It occurs when solid or gaseous particles come into contact with a surface and remain there. In wet deposition, interactions take place between airborne gases and particles and water droplets in the atmosphere. These interactions occur in two ways: the leaching of particles through rainwater, and the incorporation of particles into raindrops when they become trapped in the droplets as the droplets are formed in a cloud.

The blackening of facades or sculptures is the result of atmospheric particle deposits (figs. 1, 2). These atmospheric particles may originate from human activities—such as fly ash, soot, or wood particles—or from natural sources—such as sea salt, soil particles, or microorganisms. Fly ash is made up of spherical particles between one and several dozen microns in diameter, originating from carbon and heavy fuel combustion. It can be ferrous, carbonaceous silico-aluminate or sulfurous. Soot deposits are the primary cause of blackening on facades. Soot particles can measure several dozen nanometers when isolated, and in micrometers when assembled in chains or aggregate. They are composed of a carbon core (graphite) surrounded by adsorbed or condensed hydrocarbons and sulfates. These particles are produced by the combustion of light petroleum-based fuels in diesel or gas vehicles, kerosene or natural gas, or coal and plant biomass. Black soiling is mostly due to dry deposition; wet soot deposition is of minor significance.

By reacting with SO_2 in the air, calcite on the surface of the concrete transforms into gypsum in areas sheltered from rain. This gypsum then cements the deposits of atmospheric particles onto the surface. As a result, a layer forms, measuring anywhere from 10 μm to several centimeters in thickness. This is called black crust (fig. 3).

FIGURE 1 Example of thin black soiling in Le Havre, France.

FIGURE 2 Example of thin black soiling in Lyon, France.

FIGURE 3 Example of black crust, Le Havre. This layer is formed when gypsum bonds atmospheric particles onto a concrete surface.

Black crust contains fly ash and soot produced by human activity. These airborne particles provide the surface material with the sulfur and catalyzers (carbon, iron, titanium, etc.) necessary to oxidize the atmospheric SO_2 into SO_3. This process, called sulfation, along with the humidity in the air, leads to the formation of sulfuric acid (H_2SO_4), which in turn combines with Ca^{2+} ions to form gypsum ($CaSO_4$, $2H_2O$). Black crust can also contain the following, depending on local particle pollution:

- inorganic compounds (airborne soil and dust particles),
- organic compounds (airborne plant remains and pollen), and
- biological growth in or on the crust, such as bacteria and fungi.

Development and Location of Black Soiling

Since the end of the twentieth century, new regulations seeking to reduce industrial pollution, sulfur fuel levels, and traffic led to a reduction in SO_2 and an increase in NO_x in urban areas. The concentration of fly ash decreases as soot concentration increases. This coincides with a decrease in the particles' mass and an increase in their total number. Consequently, there are fewer instances of thick, coarse black crust but a higher number of thin, black, smooth, compact deposits. Because this change is a recent one, however, the full impact of this shift in pollutants cannot be assessed until several more decades have passed.

On outdoor monuments, distinct and multiple areas of soiling can generally be observed. Areas that are sheltered from rain are most often subject to black crust. Areas affected by runoff and heavy rain are lighter, while areas closer to automobile pollution are darker. These various deposition and leaching events determine the distribution of soiling on all exterior architectural elements (facades or sculptures).

Biological Growth

Environmental conditions also determine the presence and type of biological growth on structures. These growths can be classified into four major categories: algae, lichens, fungi, and mosses. Algae and lichens are frequently found in the form of blotches of varying color on the facades of concrete monuments.

Algae

Algae includes mostly photosynthetic plants that form a group of highly diverse organisms ranging in size from a few microns to several dozen meters. Unlike other plants, algae are simply organized on a thallus. A thallus is a plant structure without stems, leaves, or roots and is made of more or less differentiated, nonvascular tissue. Algae grow in aquatic or high-humidity environments. Their colonies may be isolated, in groups of cells, or filamentous.

Algae are divided into major groups based on two criteria: coloration and cellular reserves. Green algae (called chlorophytes) and blue algae (cyanophyta), among others, are most commonly found colonizing on historic buildings. For algae, the term *biological degradation* primarily refers to an unsightly effect on the color of the structure.

Generally, three different types of this plant can be identified:

Green algae. Green algae are mostly found on outdoor surfaces (fig. 4); however, they can grow inside buildings if there is sufficient humidity and light. They form bright green drapes or streaks. Outdoors, colonies often prefer north-facing surfaces.[2] These growths are made by green algae such as Chlorococcaceae and *Ulothrix* and blue algae such as *Aphanocapsa*, *Nostoc*, and *Gloeocapsa*.[3]

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2 *Translator's note:* Green algae colonies prefer south-facing surfaces, if the building is located in the Southern Hemisphere.

3 *Translator's note:* Species of biological growth will vary depending on geographic location.

Black algae. Outdoors, growths of black algae will form streaks ranging in color from dark green to black on surfaces oriented toward the west. Indoors, they accumulate into blackish, viscous deposits. These are mainly caused by blue algae.

Red algae. Red algae growth is dominated by the class Chlorophyceae, including the genus *Trentepohlia*, which possesses carotenoid pigments. These organisms show up in the form of small red-orange spots grouped into broad areas, and often colonize substrates exposed to wind and rain (north–northwest, depending on geographic location). Their pigments lead to staining on concrete surfaces, which is difficult to remove even after the algae growth has been eliminated.

Lichens

Lichen is the result of a symbiotic relationship between microscopic fungi and algae. Together, they form a thallus that attaches to the substrate by rootlike structures called rhizines. Based on differences in the appearance of the thallus, lichens can be classified as foliose, crustose, gelatinous, or fruticose.

Lichens are chlorophyllic and can colonize on concrete, forming a "patina" made up of spots or crusts in varying colors (figs. 5, 6).

The growth of lichens is linked to environmental factors such as water, temperature, wind, and sun, as well as to pollution. Lichens are highly sensitive to smoke and SO_2-rich acid rains. Rural atmospheres rich in nitrogen compounds originating from fertilizers or liquid manure stimulate their growth.

Mosses

Mosses are part of the division Bryophyta. They are vegetal organisms that grow in clumps of small, cushion-like formations typically green in color,

FIGURE 4 Green algae growth on an exterior wall at the Centre Jeanne Hachette, Ivry-sur-Seine, France.

FIGURE 5 *Xanthoria parietena* and *Caloplaca* lichens growing on a concrete surface at Karl Marx Stadium, Villejuif, France.

FIGURE 6 Lichens on a concrete sculpture at the church of Sainte-Thérèse d'Elisabethville, Aubergenville, France.

FIGURE 7 Moss on a handrail at Centre Jeanne Hachette.

FIGURE 8 Detail of moss on a handrail at Centre Jeanne Hachette.

composed of stems and leaves that contain chlorophyll but have neither roots nor vessels (figs. 7, 8). Mosses are anchored to the substrate by absorbent, threadlike structures called rhizoids.

They generally inhabit humid areas, forming veritable carpets of green. They grow on trees, rocks, cut stone, and concrete. Highly resistant, they can survive through extended dry periods before being revived by even a small amount of rain.

Other Types of Biological Growth

Other, more evolved plant species such as climbing plants can also be found on concrete structures (fig. 9).

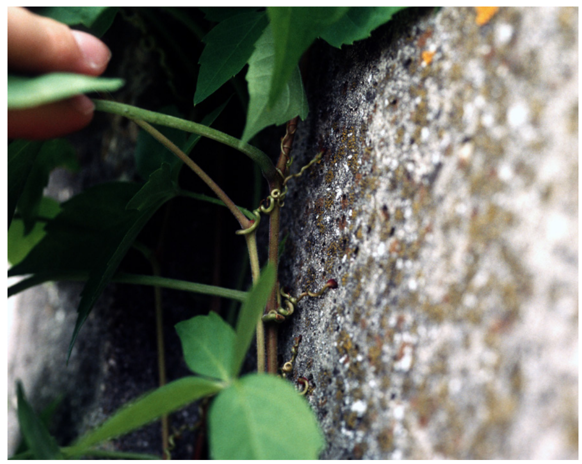


FIGURE 9 Climbing plant anchored in concrete pores on a wall at Karl Marx Stadium.

Algae, lichens, mosses, and other types of biological growth contribute to deterioration of the surfaces on which they colonize by the following means:

- causing water retention;
- producing organic acids;
- forming patinas, as with oxalates; and
- for mosses and lichens, causing mechanical deterioration by anchoring to the surface with their rhizoids.

Furthermore, the accumulation of a photosynthetic biomass is an excellent nutritional base for an entire heterotrophic bacterial flora that potentially contributes to the formation of other organic acids.

Soiling on Indoor Concrete

Soiling found inside monuments mainly consists of fine black deposits left by particle pollution (figs. 10, 11). The principal indoor particle pollutants are asbestos, dust, fine particles produced by tobacco smoke, heating fuel, and candles (i.e., those used in places of worship).

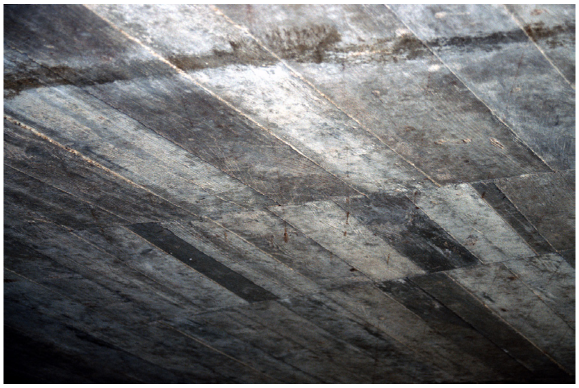


FIGURE 10 Indoor soiling consisting of particle deposits at UNESCO headquarters, Paris.

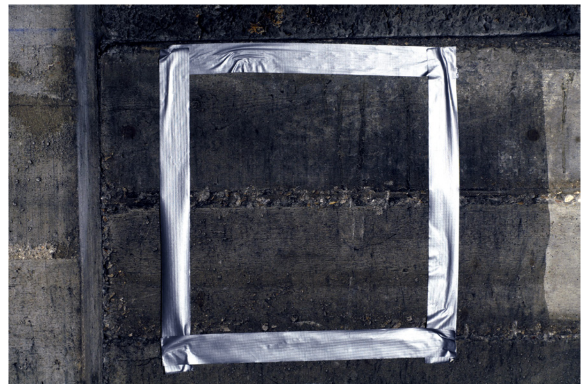


FIGURE 11 Detail of indoor soiling at the church of Saint-Esprit, Paris.

Atmospheric pollution's effect on indoor pollution depends on the building's use, which may have a strong influence on the concentration of gas and particles, as well as on microclimatic conditions (temperature, relative humidity, and air speed) inside the building.

These conditions determine the pattern and speed of particle and gas deposits. When a building is frequented by people, the presence of thermal gradients, vertical instability, and air circulation increases, which stimulates the particle deposition process. The number of visitors also contributes to augmenting particle concentration. Furthermore, because indoor air exchange is fairly low in such buildings, particles can accumulate and ultimately result in higher concentrations indoors than outdoors. Concentrations of harmful gases (SO_2, NO_2) normally are lower inside buildings but increase as more outside air is exchanged.

In the specific case of churches, even if the building is well isolated from atmospheric pollution, indoor pollution from carbonaceous aerosols can sometimes be more significant than atmospheric pollution. Candle burning is a major source of carbonaceous micro-soot particles. Carbon-rich particles can accumulate to form significant soiling. They are also an optimal substance for the incorporation and adsorption of harmful gases such as SO_2 and NO_2.

2. DESCRIPTION OF CLEANING TECHNIQUES

The various cleaning techniques tested during the trial campaigns are grouped into the seven categories listed below. The name of each technique is followed by a number in parentheses that corresponds to the reference number on the data sheets presented in section 5. Two techniques (polyvinyl alcohol-based peelable poultices and chemical cleaning) that are considered inappropriate for use on historic buildings and sculptures have been added to this list for reference but were not included in section 5.

Water-Based Cleaning

Pressurized Water (W1)

This technique consists of projecting a jet of pressurized water onto the surface to be cleaned. The soiling is first softened by the moisture, then eliminated by the pressurized jet. The amount of pressure used and the flow rate selected must be adapted to the condition of the concrete.

Nebulous Spraying (W2)

Nebulous spraying consists of generating a mist of water using spray lines (attached to the upper part of the area to be cleaned) to soften and remove soiling. Spraying should be followed by soft brushing. This technique can produce significant amounts of water runoff.

Water Injection-Extraction System (W3)

Injection-extraction is a cleaning technique that uses cold water in a slight vacuum. The suction (through the suction head) creates a vacuum space when applied to a surface. Water is sprayed at a low pressure, generating a cleaning action by the meeting of air and water, which, when combined with the vacuum action, produces air turbulence that detaches the soiling from the surface. The dirty water that comes in contact with the surface is immediately suctioned back into the vacuum and collected in a tank to be treated or disposed.

Steam with Soft Brushing (W4)

The devices used in this study (wallpaper removers or steam cleaning appliances) were designed for domestic use. Steam is generated by a pressurized heating tank. In the case of steam cleaning appliances, different nozzle types are available, with simple projection or with brushes that create a simultaneous mechanical and steam cleaning action.

Cleaning by Abrasive Blasting

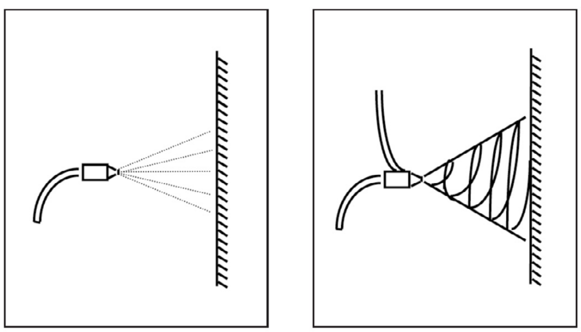
There are many techniques for cleaning by abrasive blasting. They are differentiated by the type of abrasive used and the method of projection.

Direct Abrasive Blasting with Dry Media or Wet Media (A1, A2)

Dry or wet direct abrasive blasting consists of projecting abrasives under pressure onto the surface to be cleaned using a dry or wet method. Specialized blasting machines have been developed for this purpose. This equipment incorporates tanks that can contain different types of powders, rotating nozzles that can blast both wet and dry abrasives, and, as an option, a dust collector.

Vortex Abrasive Blasting (A3)

Vortex blasting involves projecting a spiral vortex of air, water (30 to 60 L/hr), and particles under low pressure (0.5 to 1.5 bars). This method's uniqueness lies in the rotating jet that generates a vortex that moves parallel to the surface to be cleaned (fig. 12).



a) b)

FIGURE 12 Schematic representation of direct cleaning (a) and vortex cleaning (b).

Types of Abrasives

Glass grit. Glass grit is a glass powder. It can be categorized as fine, microfine, or superfine depending on the size of the granulate.

Calcium carbonate. Two types of calcium carbonate particles of varying shape and hardness are available: angular particles from 5 to 500 µm, and rounded particles from 40 to 140 µm. Angular particles are made by crushing amorphous calcium; rounded particles are produced by controlled microcrystalline growth.

Alumina. Alumina, or aluminum oxide, comes in various diameters from 29 to 45 µm. These are the finest abrasive particles used in cleaning.

Other types of blast media include powdered fruit pits, sponges, and dry ice.

Cleaning With Poultices

Rockwool-Based Poultices (P1)

The use of rockwool-based poultices in cleaning consists of the following steps:

1. A network of microporous pipes is installed on the surface to be cleaned.
2. The rockwool is applied by projection to the surface, mixed with a binder to help it adhere to the surface.
3. The poultice is irrigated regularly through the microporous pipes, which are connected to a solenoid valve coupled to an electronic control panel that manages water distribution.
4. Cleaning is completed by using water and a soft brush to remove the soiling, which has been softened by the poultice.

Since this type of poultice will not adhere to ceilings or arches, this technique is reserved for cleaning facades.

Attapulgite Clay-Based Poultices (P2)

This cleaning paste has a base of attapulgite, with various aggregates that change the physical properties of the clay, and an aqueous solution. It may contain more or fewer additives based on the nature and size of the soiling.

The cleaning process consists of applying the paste with a manual or mechanical sprayer, then leaving it to work for anywhere from a few hours to a few days, depending on the degree of soiling. A soft plastic spatula is used to remove the paste. The cleaning must be finished by soft brushing or by using an injection-extraction system to eliminate the remnants of the soiling and the poultice residue.

This highly thixotropic paste can be applied to facades as well as to arches and moldings.

Cleaning With Peelable Poultices

Polyvinyl Alcohol-Based Peelable Poultices

These poultices have a base of polyvinyl alcohol. The technique consists of using a roller, paintbrush, or spray gun to apply the paste, then leaving it to polymerize for 12 to 24 hours, depending on temperature and humidity conditions. The film that forms is then peeled off manually. If it is difficult to peel off (i.e., the film breaks), a second layer may be applied. It is necessary to wait for the second layer to dry before the final peeling. To improve the film's resistance, a layer of cellulose fibers may be used between two layers of paste. These products can be cleaned with water and are recyclable.

Note: *This technique was tested and found inappropriate, as it resulted in loss of original material due to high adhesion to the concrete surface.*

Latex-Based Peelable Poultices and Latex- and Clay-Based Peelable Poultices (PP1, PP2)

These pastes have a base of natural latex (rubber-tree sap stabilized with ammonia solution). They are ready to use and can be applied with a brush or a pump, using a machine specially designed for this purpose. After a polymerization time of at least 24 hours, the highly elastic film that forms is removed manually.

Latex-based poultices are available in different versions, for example, without extra additives or with increased quantities of EDTA (ethylenediaminetetraacetic acid), which is a calcium complex. Some products also contain clay.

Laser Cleaning (L)

Laser cleaning was specifically developed for cleaning black crusts of various types and thickness from stone. As of 2009, the best technology is the ND-YAG pulse laser, which emits light in the infrared spectrum (wavelength 1.064 μm, maximum power 400 mJ, and pulse durations of 8 nsec). The laser produces ionization (or plasma), visible in the form of a bright light, causing part of the soiling to vaporize on the material's surface. At the same time, a microwave of shock is generated, which spreads without damaging the material and ejects the soiling in the form of dustlike particles.

This technique involves no contact with the surface. Elimination of soiling may be gradual, depending on energy and frequency settings.

Chemical Cleaning

Various chemical agents (acids, alkalines, detergents, etc.) may be used depending on the type of soiling to be removed. First, the surface to be cleaned is moistened in order to limit penetration of the chemicals. The chemical agents are then applied in liquid or paste form, followed by thorough rinsing in order to neutralize chemical reactions. Chemical cleaners are most often used on new facades, in particular to eliminate oil stains from formwork removal (which involves the use of strong lye- or potassium-based detergents). However, certain chemical agents are also used for more stubborn stains on older facades. For example, selected acids (hydrofluoric acids, ammonium bifluoride, hydrochloric acid, phosphoric acid, etc.) can remove some very hardened stains more quickly.

Chemical agents may also be used for specific cleaning purposes, such as diluted acids to treat efflorescence or solvents to remove tar stains. This is when they are most effective.

Note: *Chemical agents are rarely used on historic monuments, as they can be too aggressive and may leave harmful residues on surfaces. Thus, they were not tested as part of this study.*

Biocides (B)

Biocides are chemicals that are toxic to microorganisms. There are several types; the most well known are quaternary ammonium salts. These work by adsorption on the cellular surface level and lead to degradation by tension of the cytoplasmic membrane, which causes cell death. This process is shown in figure 13.

Quaternary ammonium is sometimes paired with isothiazolinones (organosulfur molecules that work by inhibiting cellular proteins).

The conditions for biocide application are discussed in the decision tree on biological growth in section 4 of this manual.

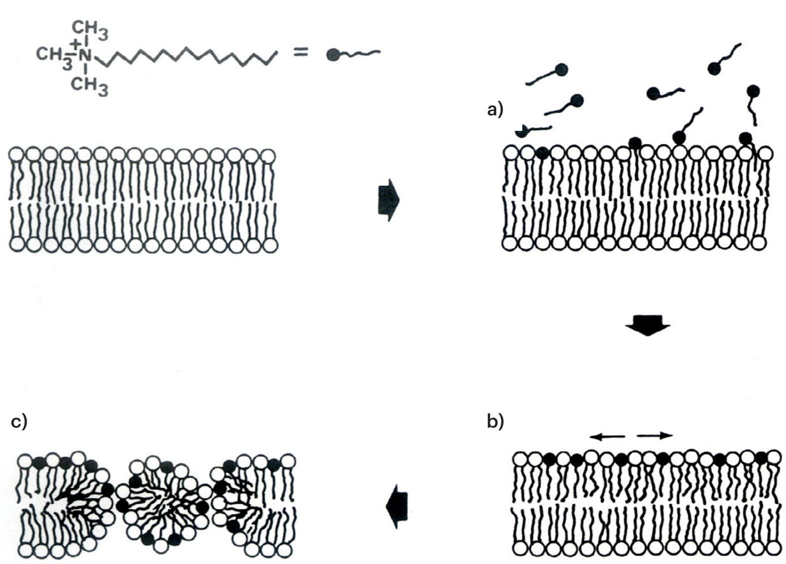


FIGURE 13 Diagram illustrating the interaction of quaternary ammonium on a cell membrane. (a) Intercalation of molecules in the bilayer of the cell membrane. (b) Disturbance caused by the intercalation of molecules preferentially in the external layer of the membrane. The external layer enlarges in comparison to the internal layer. (c) Dislocation of the bilayer lipid structure and formation of mixed micelles. Source: Isomaa 1984, 27.

3. FIELD TRIALS

To optimize the cleaning process for each field trial campaign, the companies that developed or sell the techniques and products tested during the research came to participate in the trials.

Testing On Outdoor Concrete

Black Soiling

Facades: Maison du Brésil, Paris
Constructed from 1957 to 1959 by the Brazilian government on the campus of the Cité Internationale Universitaire de Paris, the Maison du Brésil was designed by French (Swiss-born) architect and city planner Le Corbusier in collaboration with Brazilian architect Lúcio Costa. Conceived as a gathering place for Brazilian students living in Paris, this student housing facility features ninety-six rooms on five stories, as well as a theater, cafeteria, and library (fig. 14).

FIGURE 14 The Maison du Brésil at the Cité Internationale Universitaire, Paris.

The main building rests on exposed board-marked concrete pilotis, with a roof terrace. Its cladding typically consists of exposed aggregate precast concrete panels on the western, northern, and southern facades. The eastern facade is composed of 100 recessed balconies of alternating finishes: rough exposed concrete, exposed aggregate concrete, and brightly painted rough concrete. The eastern wing, which holds the cafeteria, and the western wing, which houses the lobby and theater, each have a rooftop garden.

The entire Maison du Brésil complex was added to the Inventaire Supplémentaire des Monuments Historiques[4] list in 1985.

The main building's pilotis are topped with horizontal bands of exposed board-marked concrete. On the western facade, twelve panels of this concrete, which are slightly sheltered by the balconies, showed relatively fine and homogeneous black soiling, probably the result of automobile pollution given their proximity

4 *Translator's note:* This is a French national cultural heritage designation. "Inscription à l'Inventaire Supplémentaire des Monuments Historiques" confers a level of protection below that of the highest, most restrictive "classement au titre des Monuments Historiques."

to the surrounding road. The timber board markings (alternating vertical and horizontal) used as formwork for these panels remained visible under the soiling.

Each of the companies whose products were used in these trials had access to one panel (1.35 m high × 1.10 to 1.80 m wide) to test each cleaning procedure. The goal was to remove the soiling while preserving the surface of the concrete.

Multiple techniques were used: pressurized water, nebulous spraying, various types of abrasive blasting (wet and dry media, direct blasting, and vortex), rockwool- and attapulgite clay-based poultices, a polyvinyl alcohol-based peelable poultice, and laser cleaning.

While the pressurized water and peelable poultice techniques proved insufficient, all of the other techniques yielded satisfactory results, although the final appearance of the cleaned areas was observed to be variable from white to yellowish (fig. 15). It appeared that the techniques that incorporated water (i.e., poultices or water flow) produced the brightest results (fig. 16). When the cleaned surfaces were observed through an optical microscope, a yellow "coloration" could be seen on the border of the stain that seemed to dissolve with water.

In terms of impact on the concrete's surface, the laser and all of the abrasive blasting techniques, when improperly used, led to alterations (abrasion, even amorphization), which highlighted the indispensability of a qualified operator. Techniques that employed continuous water flow, even in low quantities, had very little effect on the concrete's state of deterioration, but this is only because the concrete was initially sound. In the case of concrete that shows spalling or, in particular, detachment linked to reinforcement corrosion, these techniques, which use large amounts of water and thus may trigger corrosion, should be avoided.

Many of the techniques—including abrasives, poultices, and peelable poultices—also left residue on the concrete's surface, which may have a negative impact on the suitability of the cleaning.

FIGURE 15 Results of cleaning trials by laser (L1, L2, L3, L4) and fine sand abrasive (Q1, Q2) at Maison du Brésil.

FIGURE 16 Results of cleaning with an attapulgite poultice, which yielded a brighter result, at Maison du Brésil.

Sculptures: Church of Saint-Esprit, Paris

Designed by French architect Paul Tournon, who took inspiration from the layout of the Hagia Sophia in Istanbul, the church of Saint-Esprit was built between 1928 and 1934 by the François Hennebique Company (fig. 17); a bell tower was added in 1962. Its facade is clad in brick from Burgundy. Inside, exposed board-marked concrete is decorated with mural paintings and mosaics. With its 33 m high dome and a crypt 33 m long and 27 m across, the church of Saint-Esprit is one of the largest concrete churches in

Paris. It has been included on the Inventaire Supplémentaire des Monuments Historiques list since August 1979.

The church's facade, overlooking rue de la Cannebière, is decorated with twelve bas-reliefs of a very fine cement-based mortar, each representing a month of the year. Created by four different artists (one for each of the four seasons), the sculptures vary in complexity. Nevertheless, because the bas-reliefs are slightly recessed from the facade, all had black soiling that was relatively fine and homogeneous, probably produced by automobile pollution.

For the cleaning trials, each participating company had access to one bas-relief (approximately 1 × 1.7 m) per cleaning procedure. As with the Maison du Brésil, the goal of the tests was to achieve optimal cleaning for each technique while preserving the concrete's surface as much as possible. Eight techniques were tested: pressurized water, nebulous spraying, various types of abrasive blasting (wet and dry media, direct blasting, and vortex), attapulgite clay-based poultice, and laser cleaning.

The tests on these sculptures led to more mixed results, not only because the soiling was thicker but also mainly because of the complexity of the reliefs. Apart from the pressurized water and the attapulgite clay-based poultice methods, which were ineffective, and the nebulous spraying, which failed to eliminate the thicker soiling (figs. 18, 19),

FIGURE 18 Detail of the church of Saint-Esprit bas-relief representing the month of August being cleaned with nebulous spraying.

FIGURE 17 The church of Saint-Esprit, Paris.

FIGURE 19 View of the August bas-relief, showing soiling residue.

FIGURE 20 The bas-relief at the church of Saint-Esprit representing the month of December, prior to fine sand abrasive blasting.

FIGURE 21 The December bas-relief after fine sand abrasive blasting.

the five other techniques produced good cleaning results overall. However, in the grooves of the sculptures, which are more difficult to clean, soiling residue was observed after a wet abrasive technique was used. Laser and dry abrasive blasting—in this case, fine sand (figs. 20, 21)—proved to be the most effective.

In terms of harm to the concrete's surface, the same conclusions may be drawn as those for the facade trials: the skill of the operator is an important factor in achieving optimal cleaning results without damaging the concrete. Because it was not possible to take samples, these conclusions are mainly based on visual observations.

Biological Growth

For the removal of biological growth, an initial series of trials was conducted on the surrounding walls of the Karl Marx Stadium in Villejuif, which were carpeted in thick growth made up of algae and lichens. These trials demonstrated the effectiveness of steam combined with mechanical removal, and of some quaternary ammonium- and sodium hypochlorite-based biocides. However, the steam cleaning technique still needs improvement, and a study of the lasting effects of these cleanings is recommended.

A second series of trials was carried out on the Centre Jeanne Hachette in Ivry-sur-Seine, described below.

Centre Jeanne Hachette, Ivry-sur-Seine

The Centre Jean Hachette, constructed between 1970 and 1983, represents the culmination of French architect Jean Renaudie's theories on urban planning. This multiuse complex features residences, walkways, cultural facilities, and shops. The apartments, all equipped with garden terraces (fig. 22), are arranged in a cascade that fans out around the towers erected by Ivry city architect Renée Gailhoustet. They completely cover the shopping area from their elevated position over the street. All levels can be accessed by the walkways, which form an interconnected network.

FIGURE 22 Garden terraces at Centre Jeanne Hachette.

Prolific biological growth is present across the entire complex, most notably on the majority of the parapets and railings. Two areas were subject to trials:

- a handrail located on the third floor of Centre Jeanne Hachette 2, which showed algae, lichen, and moss growth (nine test surface areas of 40 × 35 cm each); and
- parapets located on the second floor of Centre Jeanne Hachette 1, which mainly showed significant lichen growth (ten test surface areas of 40 × 65 cm each).

Three biocidal solutions were used: a quaternary ammonium-based product; a quaternary ammonium- and isothiazolinone-based product, both of which require dilution; and a ready-to-use quaternary ammonium-based product. The biocides were applied by spraying on three consecutive rain-free days, one application per day, until the surfaces were saturated.

Two months after the treatment, two removal procedures were tested: dry brushing only, and a water injection-extraction system. In addition, a steam treatment, with technical improvements made in comparison to the tests conducted at Karl Marx Stadium (steam jetting), and the injection-extraction technique were each tested alone without preapplication of biocide.

None of the three biocides allowed for instant removal, unlike steaming and water injection-extraction.

Three months after removal, the best results were achieved with steam cleaning (figs. 23, 24). Though this method takes longer to apply, the results were surfaces clear of all growth.

Water injection-extraction alone yielded satisfactory results but proved less effective than steaming. With biocides, using dry soft brushing to remove dead growth proved unsatisfactory, as it did not remove the remains of the black thalluses and lichens that were present on the concrete's surface (fig. 25). Injection-extraction in addition to biocides produced a highly satisfactory result. The biocide containing both quaternary ammonium and isothiazolinone performed better than products with only quaternary ammonium, which all performed equally.

A year and a half later, the surfaces cleaned with injection-extraction alone showed regrowth in crevice areas, and remnants of black thalluses and lichens were still present on the surface of the areas treated with biocide and soft brushing.

In terms of impact on the concrete, chlorine levels were tested on samples of ground concrete. No chlorine pollution was detected.

FIGURE 23 Results of steam cleaning trial at Centre Jeanne Hachette.

FIGURE 24 Control area for cleaning trials.

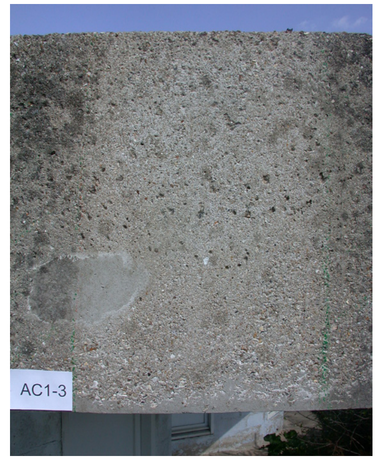


FIGURE 25 Results of cleaning trial using ready-to-use biocide product followed by brushing.

Testing On Indoor Concrete

Black Soiling

Board-Marked Concrete Finish: Church of Saint-Esprit, Paris

The interior of the church of Saint-Esprit is exposed concrete with visible traces from the formwork (fig. 26). The church walls are covered with fine black unhardened deposits from the incomplete burning of candle wax.

FIGURE 26 Interior of the church of Saint-Esprit.

Tests were conducted on the gallery level, on surface areas of 40 cm^2. Three types of latex-based peelable poultices were applied: with ammonia solution, without ammonia solution, and with varying concentrations of EDTA. The water injection-extraction system was also tested using two spray pressure levels (2 and 20 bars).

A few issues arose when testing the latex-based peelable poultices. All were applied using a brush, but some of the products were too liquid, causing drips; others were too viscous and therefore difficult to apply—for example, they could not reach into all of the irregularities on the concrete's surface. The duration of polymerization varied from one to eight days. Some of the products adhered too firmly to the surface, whereas other products

FIGURE 27 Area of interior gallery at the church of Saint-Esprit, showing satisfactory results after cleaning by latex-based peelable poultice.

FIGURE 28 Area of gallery, showing insufficient results after cleaning by latex-based peelable poultice.

FIGURE 29 Area cleaned using water injection-extraction, which produced the most effective results.

did not adhere enough. Moreover, the products' effectiveness varied from satisfactory to insufficient (figs. 27, 28).

Finally, some of the latex-based peelable poultices had damaging effects on the concrete. For instance, some pulled away significant amounts of material when removed. Observation through a binocular magnifier as well as a scanning electron microscope combined with elemental analyses (energy dispersive spectroscopy) showed, for certain products, the presence of latex, crystallization, and salt residues in addition to sodium contamination.

The water injection-extraction system proved very easy to use and did not cause any environmental impacts. In terms of effectiveness, it is also the method that produced the best results (fig. 29). The cleaned areas were homogeneous, and no difference was observed between the two spray pressure levels tested.

Bush-Hammered Concrete Finish: Church of Sainte-Odile, Paris

Designed by French architect Jacques Barge and constructed beginning in 1935 on the commission of Monsignor Edmond Loutil, the church of Sainte-Odile is a key example of sacred art in 1930s Paris. Inspired by Roman architecture, the church has one of the highest bell towers in Paris (fig. 30). Its facade is composed of brick and bush-hammered concrete with a pink sandstone base. The interior is pink bush-hammered concrete made of pink granite aggregate and red marble powder, and is richly decorated with sculptures, windows of *pâte de verre* and cement mortar, ironwork, and enamel and gold-plated pieces (fig. 31). Both the church and its facade, on rue du Presbytère, have been listed on the Inventaire Supplémentaire des Monuments Historiques since 2001.

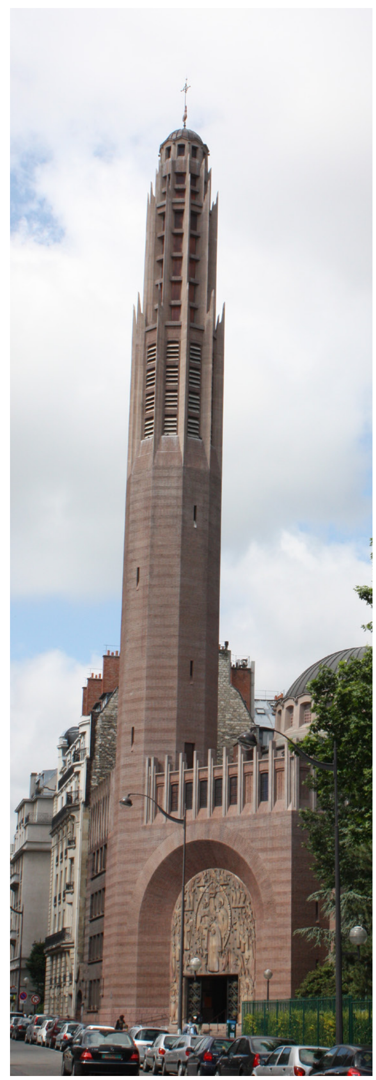


FIGURE 30 Exterior of the church of Sainte-Odile, Paris.

Cleaning tests were conducted around the organ on the gallery level, on surface areas of 40 × 40 cm. The surface of the concrete was very coarse, with fine unhardened soiling, probably related to a combination of incomplete combustion of candle wax and the building's heating system.

Three types of latex-based peelable poultices were tested: with ammonia solution, without ammonia solution, and with varying concentrations of EDTA. Again, the water injection-extraction system was employed, using two spray pressure levels (2 and 20 bars) and, for this trial, a latex- and clay-based peelable poultice.

In terms of execution, no difficulties were encountered during application or peeling. Though the latex- and clay-based peelable poultice was more adherent, it was not difficult to peel. The water injection-extraction system also proved easy to use and gave the best results in terms of effectiveness of cleaning. As at Saint-Esprit, the cleaned areas were homogeneous, and no difference was observed between the two pressures tested. The various peelable poultices resulted in satisfactory cleaning, though less homogeneous than with injection-extraction.

FIGURE 31 Interior of the church of Sainte-Odile.

The latex- and clay-based product gave good results (fig. 32). Products with higher concentrations of EDTA did not produce more satisfactory results than the others. Finally, a difference in color was observed between the results obtained with the peelable poultices and those obtained with injection-extraction: the concrete cleaned with injection-extraction was much more pink (fig. 33).

FIGURE 32 Area cleaned with latex- and clay-based peelable poultice, which yielded good results at the church of Sainte-Odile.

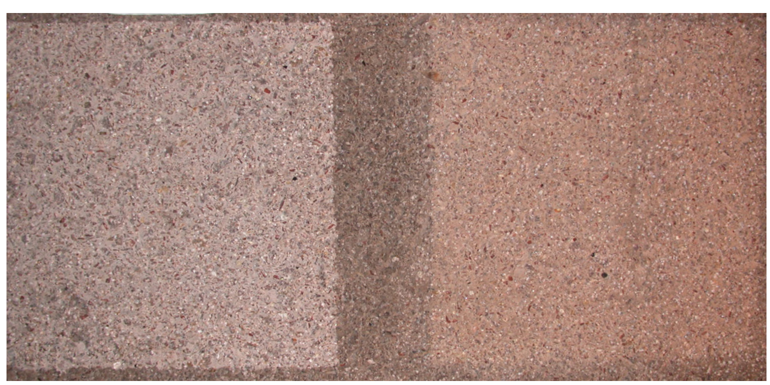


FIGURE 33 Area cleaned with peelable poultice (left), and area cleaned with water injection-extraction showing a pink color compared to other areas (right).

Due to the pulverized surface of the bush-hammered concrete, all the techniques used caused numerous small particles of binders and aggregate to come loose.

Conclusions

Together, these cleaning trials were able to establish the influence of surface and surrounding conditions on the efficacy of each cleaning technique.

Outdoors, it was determined that, in general, some techniques that proved effective in cleaning the facades were not well suited to cleaning sculptures. The techniques that worked best on exteriors were not suitable for cleaning interiors.

Conditions for implementing the techniques proved important, as inappropriate use may cause damage to the concrete surface and/or produce unsatisfactory results. The skills and experience of the person applying the products are critical to successful cleaning.

Finally, it is strongly advised to trial the techniques on test areas before commencing the cleaning project. This will provide a model or benchmark for the work and assist in developing the parameters of use for each technique and product eventually selected.

4. HOW TO CLEAN HISTORIC CONCRETE

Detailed Examination

Examining in detail the surfaces to be cleaned is an essential first step. This must be done by qualified practitioners and should include the following, as shown in the flowchart in figure 34:

1. locating the surfaces that must be cleaned on the structure (outdoor or indoor, wall base or bell tower);
2. determining the area of the surface to be cleaned (1 m^2 or 1000 m^2);
3. specifying the type of surface that must be cleaned: facade or sculpture, simple or complex reliefs;
4. determining the nature and characteristics of the soiling (black soiling, biological growth, etc.); and
5. assessing the substrate's state of deterioration (sound or friable).

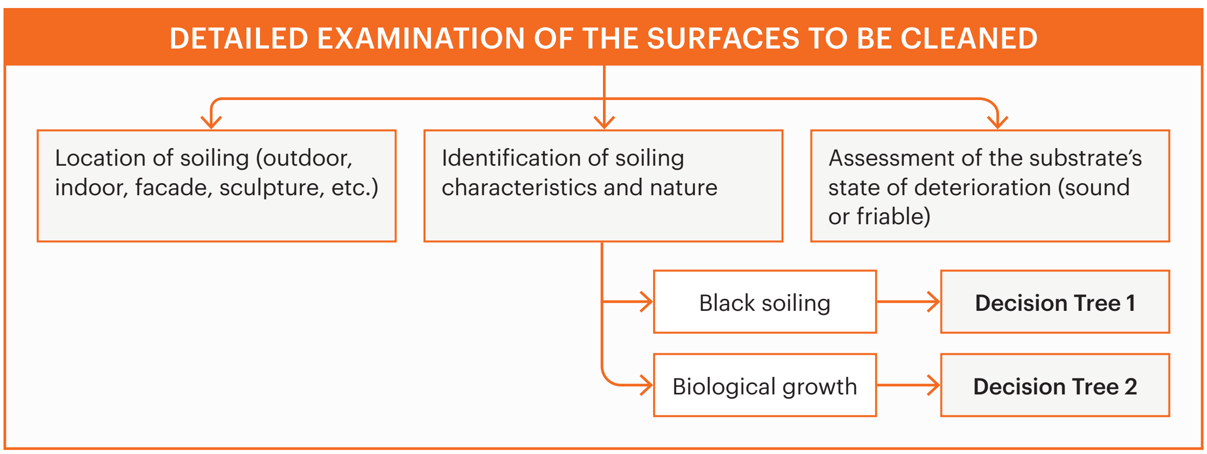


FIGURE 34 Flowchart of the process for evaluating surfaces to be cleaned.

Cleaning Black Soiling

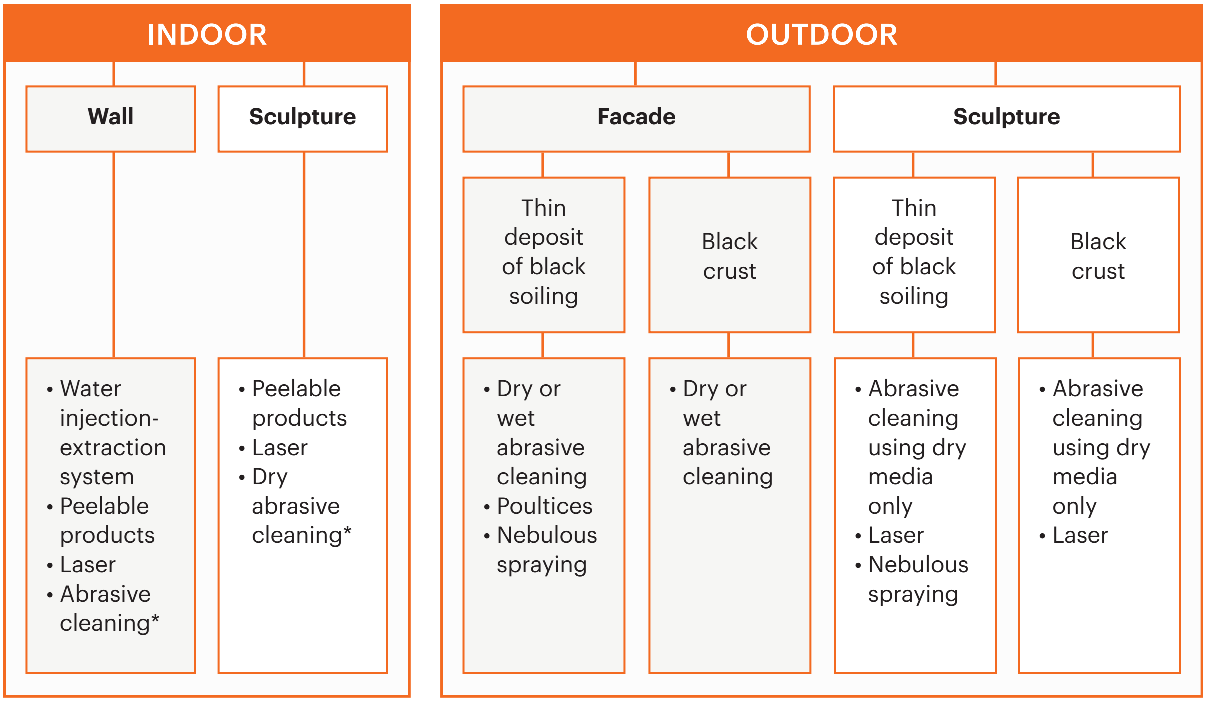
Selection Procedure

Selection Criteria

Selection should be made based on the following five criteria (fig. 35):

1. type of soiling (thin deposits, thick deposits, etc.),
2. type of surface that must be cleaned (facade or sculpture, simple or complex reliefs),
3. the concrete's state of deterioration,
4. work site conditions (indoor or outdoor, accessibility, etc.), and
5. budget.

Decision Tree No. 1



*If it is possible to contain the abrasives.

FIGURE 35 Flowchart of the process for selecting the cleaning technique for black soiling.

Notes

Exposed rebar. The presence of exposed rebar does not affect the selection of cleaning techniques.

Abrasive blasting. If the areas to be cleaned feature a complex relief, using the wet abrasive blasting method is not recommended, as it will not reach into the deepest recessed areas. However, in urban areas, if the relief is not too complex, the wet method should be used in order to limit the formation of clouds of abrasives. If the cleaning operation is not being done as part of a larger conservation project that requires scaffolding to be installed, the dry method may be suitable in urban areas as long as the abrasives can be contained—for example, with a booth that is sealed to the facade.

Peelable products. Some peelable products currently on the market have a base of natural latex stabilized with ammonia solution. Ammonia fumes (which may be aggressive for materials such as copper and aluminum) are released during application and drying. Precautions should be taken to ventilate the area and protect sensitive materials from contact. Operators should use appropriate personal protective equipment as required by local work safety regulations, such as gloves, goggles, and respirators.

Laser. The laser is especially well suited to cleaning sculptures (particularly for badly damaged surfaces) but can be costly for cleaning large areas. It also requires specific work site safety equipment (protective glasses and light containment).

Execution Procedure

Execution involves five steps, as indicated in figure 36:

STEP 1	PRESELECTION	Select several potentially appropriate cleaning techniques.
STEP 2	PRELIMINARY TESTS	Trial each of the preselected techniques in situ.
STEP 3	FINAL SELECTION	Select the most appropriate technique(s).
STEP 4	CONTROL AREA	Cleaning contractor undertakes a control area in situ to be preserved for the duration of the work.
STEP 5	WORK SITE	Work should observe local safety and environmental regulations appropriate to the cleaning technique chosen.

FIGURE 36 Flowchart of the execution procedure for cleaning black soiling.

1. Preselection

There is rarely a single solution for each site. Thus, it is recommended that several suitable techniques are trialed.

2. Preliminary Tests

These tests involve implementing the preselected techniques on areas that are identical in terms of the concrete's soiling and state of deterioration. This is done in order to identify the techniques that are most effective and that have the least impact on the substrate. (Sometimes a simple visual observation will suffice, but closer observation of fragments under a binocular magnifier or other equipment may be necessary. A budget should be provided for preliminary tests.)

3. Final Selection

Based on the results of the preliminary tests, the technique(s) best suited in terms of effectiveness (criteria to be determined with the client) and harmlessness should be selected.

4. Control Area

One of the first steps to be completed on-site is having the contracted cleaning company create control areas approved by both the client and the company. These areas will serve as references during the cleaning operation and should be preserved for the duration of the work.

5. Work Site

In urban settings, users should plan for abrasive containment and reprocessing (for abrasive cleaning methods) as well as water recovery (for techniques that require large amounts of water). If the laser method is used, special protections must also be arranged.

Cleaning Biological Growth

Selection Procedure

Selection Criteria

Selection should be made based on the following four criteria (fig. 37):

1. identification of type of biological growth,
2. the concrete's state of deterioration,
3. work site conditions (indoor or outdoor, accessibility, etc.), and
4. budget.

Decision Tree No. 2: Biological Growth (Algae, Lichens, Fungi, and Mosses)

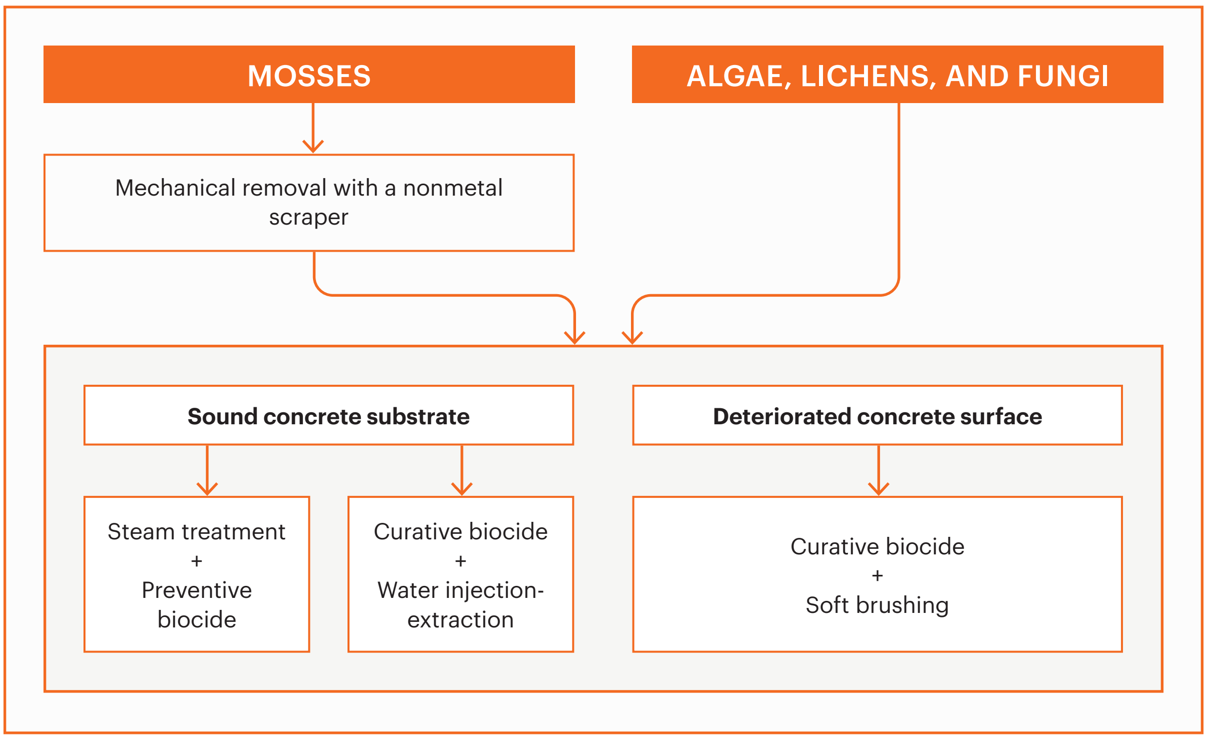


FIGURE 37 Flowchart of the process for selecting the cleaning technique for biological growth.

Execution Procedure

Execution involves two steps, as indicated in figure 38:

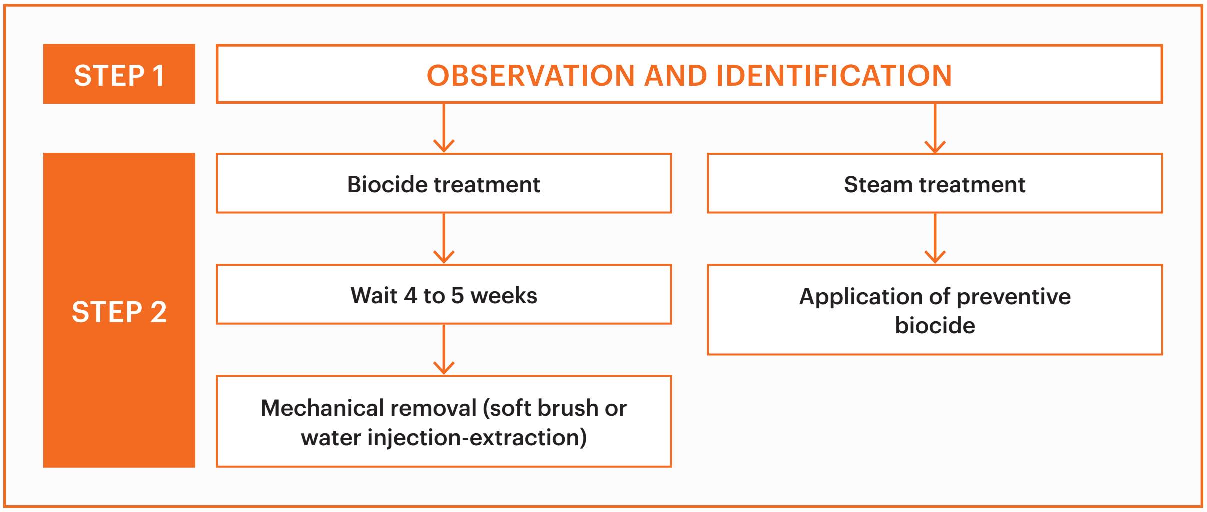


FIGURE 38 Flowchart of the execution procedure for cleaning biological growth.

1. Identification

Biological growth may be identified in a general way (since the biocides used to remove them are multipurpose), but this must be done by a specialist.

2. Execution

Outdoor biocide treatments must be done in dry weather to avoid dilution of the biocides by rainwater. Frost periods should also be avoided, since most products are water-based.

Some products will have an immediate effect (particularly sodium hypochlorite-based disinfectants). In general, they are ready to use and are applied by spraying but must always be neutralized very quickly with water. They have no preventive effect. Other products are slower to work but longer lasting since they don't have to be rinsed. Thus, they have both corrective and preventive effects. Commercially available products are usually quaternary ammonium-based.

The execution procedure is as follows:

- Apply the biocide by spraying or brushing for two or three days at a rate of one application per day.
- Leave the product to work for at least four to five weeks.
- Ensure that the growth is well dried before removing it with soft brushing; if it is not dry, reapply the treatment.

Notes on Biocides

- All of these products are generally concentrated and should be diluted with water according to the suppliers' instructions.
- Periodic maintenance spraying is recommended in order to avoid any regrowth (frequency to be assessed based on environmental contamination conditions).

- Sodium hypochlorite-based products are a source of chlorine ions, which may be damaging to the concrete's reinforcement.
- When a water repellent is applied after a quaternary ammonium-based product is used, the material must always be rinsed before application of the repellent in order to avoid inhibiting its effectiveness. The surface-active properties of the biocides were found to be incompatible with the hydrophobic properties of the water repellent.
- Quaternary ammonium-based products do not destroy rooted plants, but precautions should be taken to protect fragile plants and foliage.
- Water from cleaning work must never be allowed to run off into ponds and septic tanks.

5. TECHNIQUE DATA SHEETS

Note on all techniques:

Safety and environmental regulations vary according to location and must be followed in all cases. Operators should use appropriate personal protective equipment as required by local work safety regulations.

Identification

- Cleaning type: Cleaning with water
- Principle: Wet-method cleaning with pressurized water
- Application: Outdoor

FIGURE 39 Pressurized water cleaning in progress.

Equipment

Equipment	Space requirement
Compressor	~ 1 m^3
Spraying system	Almost negligible

Infrastructure requirement: Water and electricity

Settings (for field tests)

	Nozzle			Pressure
	Projection	**Size**	**Nozzle-to-surface distance**	**Compressor**
Facade	Direct	1 cm	5–10 cm	200 bars
Sculpture	Direct	1.4 cm	20 cm	120 bars

Facade: Thin black homogeneous soiling on flat board-marked concrete.
Sculpture: Thin black homogeneous soiling on complex bas-reliefs.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Facade[1]	10–30 minutes	A few minutes
Sculpture[2]	10–30 minutes	20 minutes

[1]Dimensions of treated area: ~ 1.5 m^2.
[2]Dimensions of treated area: ~ 1.7 m^2.

Pros

- Fast cleaning.

Cons

- Cleaning was insufficient both on facades and on sculptures.
- Possibility of abrasion if the operating settings are ill-adapted (nozzle-to-surface distance too short, pressure too high, or operator lingering too long on the same area).

Recommendations

- Requires a qualified operator.
- Plan for water collection and disposal at the end of the cleaning project.
- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

NEBULOUS SPRAYING

W2

Identification

- Cleaning type: Cleaning with water
- Principle: Nebulous spraying
- Application: Outdoor

FIGURE 40 Nebulous spraying in progress.

Equipment

Equipment	Space requirement
Irrigation system	Almost negligible

Infrastructure requirement: Water and electricity

Settings (for field tests)

	Nozzle	Water flow
Facade	Standard garden hose	Running water
Sculpture	Standard garden hose	Running water

Facade: Thin black homogeneous soiling on flat board-marked concrete.
Sculpture: Thin black homogeneous soiling on complex bas-reliefs.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Facade[1]	10–30 minutes	4 hours
Sculpture[2]	10–30 minutes	3 hours

[1]Dimensions of treated area: ~ 2.5 m^2.
[2]Dimensions of treated area: ~ 1.7 m^2.

Pros

- Technique is easy to use.
- Effective cleaning on facades if the soiling is not very encrusted.

Cons

- Requires additional soft brushing.
- On sculptures, the recessed areas are generally left uncleaned, and if the soiling layer is too thick or hardened, it is only partially removed.
- Requires a water source for the duration of treatment and significant soaking of the treated surface.

Recommendations

- Plan for water collection and disposal at the end of the cleaning project.
- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

Identification

- Cleaning type: Cleaning with water
- Principle: Injection-extraction system
- Application: Indoor/outdoor

Equipment

Equipment	Space requirement
Entire system	~ 1 m^3
Spraying system	Almost negligible

Infrastructure requirement: Water and electricity

Settings (for field tests)

	Pressure	Head size
Facade	2 bars	Medium (15 cm long)
Interior finish	2 or 20 bars	Medium (15 cm long)

Facade: Varied biological growth on flat surfaces.
Interior finish: Thin black homogeneous soiling on flat board-marked concrete and on rough surfaces with visible aggregate.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Facade[1]	10–30 minutes	A few minutes
Interior finish[2]	10–30 minutes	A few minutes

[1]Dimensions of treated area: ~ 0.3 m^2.
[2]Dimensions of treated area: ~ 0.2 m^2.

FIGURE 41 Water injection-extraction system equipment.

FIGURE 42 Water injection-extraction cleaning in progress.

Pros

- No environmental pollution; water is contained.
- No chemical products.

Cons

- On complex reliefs, a vacuum was hardly achieved under suction, and water is not contained.

Recommendations

- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

STEAM WITH SOFT BRUSHING W4

Identification

- Cleaning type: Cleaning with water
- Principle: Simultaneous steaming and soft brushing
- Application: Outdoor

FIGURE 43 Simultaneous steaming and soft brushing.

Equipment

Equipment	Space requirement
Entire system	~ 1 m^3
Spraying system	Almost negligible

Infrastructure requirement: Water and electricity

Settings (for field tests)

	Pressure	Head size
Facade 1	Unknown	Large square section, wallpaper remover
Handrail and facade 2	3.75 bars	Small rounded nozzle (2 cm diameter), average length (15 cm long)

Facades 1 and 2 and handrail: Varied biological growth on flat surfaces.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Facade 1[1]	10–30 minutes	A few minutes
Handrail and facade 2[1]	10–30 minutes	A few minutes

[1]Dimensions of treated area: ~ 0.3 m^2.

Pros

- No chemical products.

Cons

- Longer cleaning time.
- Work site safety precautions for use of steam should be taken.

Recommendations

- Requires a qualified operator.
- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

DIRECT ABRASIVE BLASTING WITH DRY MEDIA — A1

Identification

- Cleaning type: Abrasive blasting
- Media: Dry
- Projection: Direct
- Application: Outdoor

FIGURE 44 Direct abrasive blasting with dry media (alumina powder).

Equipment

Equipment	Space requirement
Compressor	~ 1 m^3
Spraying system	Almost negligible
Blast suit	Almost negligible
Booth	20 m^2

Infrastructure requirement: Electricity and water supply for the booth

Settings (for field tests)

	Abrasive			Nozzle			
	Type	Shape	Size	Projection	Size	Nozzle-to-surface distance	Pressure
Facade	Calcite	Spherical	120–240 µm	Direct	10 mm	30–40 cm	2 bars
	Glass grit	Sharp edges	50–100 µm	Direct	8 mm	30–40 cm	2 bars
	Alumina	Sharp edges	45 µm	Direct	2 mm	10 cm	2 bars
	Alumina	Sharp edges	29 µm	Direct	2 mm	15 cm	1 bar
Sculpture	Calcite	Spherical	120–240 µm	Direct	10 mm	30–40 cm	3.5–4 bars
	Glass grit	Sharp edges	50–100 µm	Direct	4.5 mm	15 cm	2–2.5 bars
	Archifine[1] no. 8	Sharp edges	0–100 µm	Direct	2.5 mm	5–10 cm	0.9–1 bar
	Aluminum	Sharp edges	45 µm	Direct	2.5 mm	5–10 cm	0.9–1 bar
	Archifine no. 7	Sharp edges	30–150 µm	Direct	2.5 mm	5–10 cm	2 bars

[1]*Translator's note:* Archifine is a commercial name for alumina silicate.

Facade: Thin black homogeneous soiling on flat board-marked concrete.
Sculpture: Thin black homogeneous soiling on complex bas-reliefs.

Duration (for field tests)

Surface cleaned	Abrasive type	Installation time	Cleaning time
Facade[2]	Calcite/glass grit	10–30 minutes	A few minutes
	Alumina/Archifine	10–30 minutes	10–30 minutes
Sculpture[3]	Calcite/glass grit	10–30 minutes	1 hour
	Alumina/Archifine	10–30 minutes	1.5–2 hours

[2]Dimensions of treated area: ~ 1.5 m^2. [3]Dimensions of treated area: ~ 1.7 m^2.

Pros

- Fast, effective cleaning on facades and sculptures with calcite and glass grit.
- Fine abrasives: highly effective but slow technique, reserved more for precision cleaning and sculptures cleaning.
- Possibility of containing abrasives in a booth.

Cons

- Risk of abrasion of the concrete surface if the operating settings are ill-adapted.
- Abrasive residue observed on cleaned surfaces under a microscope.
- Requires protective gear for the operator (blast suit).
- Stirs up large clouds of abrasives (requires containment and reprocessing on-site).

Recommendations

- Requires a qualified operator.
- Plan for abrasive containment and disposal at the end of the cleaning project.
- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

DIRECT ABRASIVE BLASTING WITH WET MEDIA — A2

Identification

- Cleaning type: Abrasive blasting
- Media: Wet
- Projection: Direct
- Application: Outdoor

FIGURE 45 Direct abrasive blasting with wet media (calcite powder).

Equipment

Equipment	Space requirement
Compressor	~ 1 m^3
Spraying system	Almost negligible

Infrastructure requirement: Water and electricity

Settings (for field tests)

	Abrasive			Nozzle			
	Type	**Shape**	**Size**	**Projection**	**Size**	**Nozzle-to-surface distance**	**Pressure**
Facade	Calcite	Spherical	120–240 µm	Direct	10 mm	30–40 cm	2 bars
Sculpture	Calcite	Spherical	120–240 µm	Direct	10 mm	30–40 cm	3.5–4 bars

Facade: Thin black homogeneous soiling on flat board-marked concrete.
Sculpture: Thin black homogeneous soiling on complex bas-reliefs.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Facade[1]	10–30 minutes	A few minutes
Sculpture[2]	10–30 minutes	1 hour

[1]Dimensions of treated area: ~ 1.5 m^2.
[2]Dimensions of treated area: ~ 1.7 m^2.

Pros

- Fast, effective cleaning on facades.

Cons

- On more complex reliefs, difficulty cleaning in the recessed areas due to the formation of a paste (of abrasives and water) that fills the recessed areas.
- Risk of abrasion of the concrete surface if the operating settings are ill-adapted.
- Abrasive residue observed on cleaned surfaces under a microscope.
- Minor containment of abrasives with the wet method (requires containment and reprocessing on-site).
- Requires protective gear for the operator (blast suit).

Recommendations

- Requires a qualified operator.
- Plan for abrasive containment and disposal at the end of the cleaning project.
- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

VORTEX ABRASIVE BLASTING A3

Identification

- Cleaning type: Abrasive blasting
- Media: Dry and wet
- Projection: Vortex
- Application: Outdoor

FIGURE 46 Vortex abrasive blasting with wet media (calcite powder).

Equipment

Equipment	Space requirement
Compressor	~ 1 m^3
Spraying system	Almost negligible

Infrastructure requirement: Water (depends if using wet or dry media) and electricity

Settings (for field tests)

	Abrasive				Nozzle				
	Media	Type	Shape	Size	Projection	Size	Nozzle-to-surface distance	Pressure	Pressure at the surface
Facade	Wet and dry	Dolomite	Sharp edges	60–70% at 60–80 µm	Vortex	Unknown	~ 30 cm	2 bars	400 g
Sculpture	Dry	Calcite	Sharp edges	70% at 60–80 µm	Vortex	9 mm	~ 30 cm	1–1.5 bars	Unknown

Facade: Thin black homogeneous soiling on flat board-marked concrete.
Sculpture: Thin black homogeneous soiling on complex bas-reliefs.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Facade[1]	10–30 minutes	A few minutes
Sculpture[2]	10–30 minutes	30 minutes

[1]Dimensions of treated area: ~ 1.5 m^2.
[2]Dimensions of treated area: ~ 1.7 m^2.

Pros

- Fast, effective cleaning on facades and sculptures with dry media; with wet media, only effective on facades.

Cons

- Risk of abrasion of the concrete surface if the operating settings are ill-adapted.
- Abrasive residue observed on cleaned surfaces under a microscope.
- Requires protective gear for the operator (blast suit).
- Stirs up large clouds of abrasives with dry media, minor containment with wet media (requires containment and reprocessing on-site).

Recommendations

- Requires a qualified operator.
- Plan for abrasive containment and disposal at the end of the cleaning project.
- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

ROCKWOOL-BASED POULTICES

P1

Identification

- Cleaning type: Cleaning with poultice
- Principle: Cleaning by applying a rockwool-based poultice
- Application: Outdoor

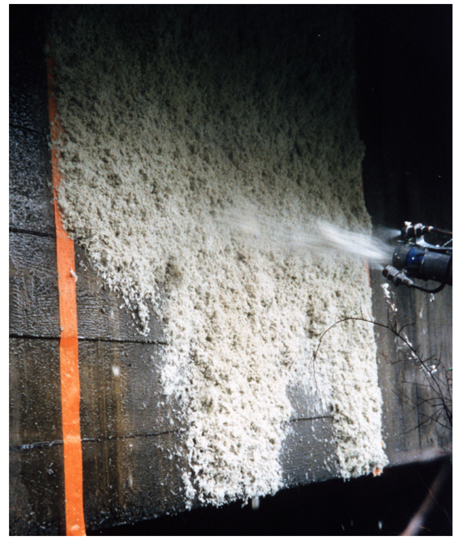


FIGURE 47 Spraying a rockwool-based poultice.

Equipment

Equipment	Space requirement
Compressor	~ 1 m^3
Spraying system	Almost negligible
Irrigation system	~ 0.05 m^3
Remote interrogation system	~ 0.05 m^3

Infrastructure requirement: Water and electricity

Settings (for field tests)

	Poultice type	Water flow
Facade	Rockwool	17 L/day

Facade: Thin black homogeneous soiling on flat board-marked concrete.

Duration (for field tests)

Installation time[1]	Cleaning time[1]
½ day	8 days

[1]Dimensions of treated area: ~ 2.5 m^2.

Pros

- Effective but slow cleaning on facades.

Cons

- Requires additional soft brushing.
- Technique is ill-suited to highly complex reliefs.
- Poultice residue observed on cleaned surfaces under a microscope.
- Dispersion of rockwool while poultice is being sprayed.
- Requires a water source for the duration of treatment (the solenoid valve and remote control system can be battery-powered).
- Limited adherence to soffits.

Recommendations

- Plan for recovery and disposal of poultices at the end of the cleaning project.
- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

ATTAPULGITE CLAY-BASED POULTICES

Identification

- Cleaning type: Cleaning with poultice
- Principle: Cleaning by applying an attapulgite clay-based poultice
- Application: Indoor/outdoor

FIGURE 48 Application of an attapulgite clay-based paste.

Equipment

Equipment	Space requirement
Compressor (or manual application)	~ 1 m^3
Spraying system (or manual application)	Almost negligible
Injection-extraction system	~ 0.05 m^3

Infrastructure requirement: Electricity and water supply necessary for the injection-extraction system

Settings (for field tests)

	Poultice type
Interior finish	Attapulgite (+ aggregate + additives)[1]
Facade	Attapulgite (+ aggregate + additives)[1]
Sculpture	Attapulgite (+ aggregate + additives)[1]

[1]With possible addition of EDTA at 12.5g/kg of paste.

Interior finish: Thin black homogeneous soiling (probably from candle burning) on flat board-marked concrete.
Facade: Thin black homogeneous soiling on flat board-marked concrete.
Sculpture: Outdoor; thin black homogeneous soiling on complex bas-reliefs.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Interior finish[2]	A few minutes (application by hand; 5 m^2/hr for spraying)	48 hours
Facade[3]	10–30 minutes (application by hand)	48 hours
Sculpture[4]	10–30 minutes	48 hours

[2]Dimensions of treated area: ~ 0.2 m^2.
[3]Dimensions of treated area: ~ 2.5 m^2.
[4]Dimensions of treated area: ~ 1.7 m^2.

Pros

- Negligible use of water.
- Good adherence, even on soffits.

Cons

- Additional soft brushing and/or an injection-extraction is required.
- On facades, the paste alone is not as effective. Overall results improved by the addition of EDTA.
- Only the paste containing EDTA was tested on sculpture. Cleaning was insufficient.
- Poultice residue observed on cleaned surfaces under a microscope.

Recommendations

- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

Identification

- Cleaning type: Peelable poultice
- Products: Latex-based paste
- Application: Indoor

Equipment

Equipment	Space requirement
Brush or trowel	Almost negligible
Spraying system	Almost negligible

Infrastructure requirement: Electricity, no water supply needed

Settings (for field tests)

	Peelable poultice type	Application
Interior finish 1	Natural latex-based[1]	With brush, trowel, or spray machine
Interior finish 2	Natural latex-based[1]	With brush or trowel

[1]Several versions are currently available, both with and without EDTA added in different proportions.

Interior finish 1: Thin black homogeneous soiling (probably from candle burning) on flat board-marked concrete.
Interior finish 2: Thin black homogeneous soiling (probably from candle burning and outside air pollution) on rough surfaces with visible aggregate.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Interior finish 1[2]	10–30 minutes	24 hours to 8 days
Interior finish 2[2]	10–30 minutes	24–48 hours

[2]Dimensions of treated area: ~ 0.2 m^2.

FIGURE 49 Application of a latex-based paste.

FIGURE 50 Peeling the latex film off the surface.

Pros

- Technique is easy to use and effective.
- Film is both strong and highly elastic, and easy to peel.
- Technique does not require special site conditions (the building can still function as usual).

Cons

- Requires preliminary tests in order to determine which version of the product is best suited (preference given to products without EDTA).
- May peel off portions of the concrete skin.
- May cause salt crystallization on the concrete.
- Some product residue observed on cleaned surfaces to the naked eye.
- Ammonia fumes must be monitored.

Recommendations

- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.
- Use the same spray system (to control film thickness) and the same product throughout the project.

Identification

- Cleaning type: Peelable poultice
- Products: Latex- and clay-based paste
- Application: Indoor

Equipment

Equipment	Space requirement
Brush or trowel	Almost negligible
Spraying system	Almost negligible

Infrastructure requirement: Electricity, no water supply needed

Settings (for field tests)

	Peelable poultice type	Application
Interior finish	Natural latex- and clay-based	With trowel

Interior finish: Thin black homogeneous soiling (probably from candle burning) on rough surfaces with visible aggregate.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Interior finish[1]	10–30 minutes	48 hours

[1]Dimensions of treated area: ~ 0.2 m^2.

FIGURE 51 Application of latex- and clay-based paste.

FIGURE 52 Peeling the latex- and clay-based film off the surface.

Pros

- Technique is easy to use and effective.
- Film is both strong and highly elastic, and easy to peel.
- Technique does not require special site conditions (the building can still function normally).

Cons

- Requires preliminary tests in order to determine which version of the product is best suited.
- May peel off portions of the concrete skin.
- Some product residue observed on cleaned surfaces to the naked eye.
- Ammonia fumes must be monitored.

Recommendations

- Do preliminary tests on control areas that can serve as references during the cleaning operation.
- Use the same spray system (to control film thickness) and the same product throughout the project to achieve consistent cleaning.

Identification

- Cleaning type: Laser
- Principle: Cleaning by photonic descaling
- Application: Indoor/outdoor

FIGURE 53 Laser cleaning in progress.

Equipment

Equipment	Space requirement
Laser	~ 0.25 m3
Generator	~ 1 m3

Infrastructure requirement: Electricity, no water supply needed

Settings (for field tests)

	Area	λ	Energy	Humidification	Spot	Nozzle-to-surface distance
Facade[1]	1	1064 nm	400 mJ	Yes	7–8 mm	15 cm
	2	1064 nm	400 mJ	No	7–8 mm	15 cm
	3	1064 nm	200 mJ	No	7–8 mm	15 cm
	4	1064 nm	400 mJ	Yes	7–8 mm	80 cm
Sculpture[2]		1064 nm	—	Yes	14 mm	40 cm

[1]Laser focal length: 80 (cm) 400 mJ max on emerging.
[2]Laser focal length: 80 (cm) 1 J max on emerging + arm (prototype of laser for large surface).

Facade: Thin black homogeneous soiling on flat board-marked concrete.
Sculpture: Thin black homogeneous soiling on complex bas-reliefs.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Facade[3]	1 hour 30 minutes	A few hours
Sculpture[4]	A few hours	4 hours 30 minutes

[3]Dimensions of treated area: ~ 0.08 m^2.
[4]Dimensions of treated area: ~ 1.7 m^2.

Pros

- Highly effective cleaning but requires preliminary tests in order to determine optimal conditions for cleaning.

Cons

- Cleaning is slow with the traditional device normally used for conserving sculptures, but is shortened significantly with the large-surface laser prototype.
- Requires protective equipment for the treated area (tarps) and for the operator (safety glasses).

Recommendations

- Requires a qualified operator.
- Conduct preliminary tests on control areas that can serve as references during the cleaning operation.

QUATERNARY AMMONIUM-BASED BIOCIDES

Identification

- Cleaning type: Biocide
- Principle: Spraying biocide
- Application: Outdoor biological growth

FIGURE 54 Spraying a biocide.

Equipment

Equipment	Space requirement
Spray bottle	Almost negligible
Spraying system	Almost negligible

Infrastructure requirement: Water, electricity supply needed if using spraying system

Settings (for field tests)

	Biocide type	Application	Removal
Handrail and facade 1	Quaternary ammonium and isothiazolinone	Manual spraying	Manual brushing or injection-extraction
Facade 2	Quaternary ammonium, sodium hypochlorite	Manual spraying	Manual brushing

Handrail: Lichens, mosses, algae.
Facades 1 and 2: Lichens, algae.

Duration (for field tests)

Surface cleaned	Installation time	Cleaning time
Handrail and facade 1[1]	10–30 minutes	5 minutes plus 5 weeks waiting time before removal
Facade 2[1]	10–30 minutes	5 minutes plus 5 weeks waiting time before removal

[1]Dimensions of treated area: ~ 0.2 m^2.

Pros

- Technique is easy to use; effectiveness varies depending on product used.

Cons

- Requires two operations: application of biocide, followed by removal of biological remains after 4 to 5 weeks.

Recommendations

- See decision tree no. 2 and procedure.
- Outdoor treatments must be done in dry weather.
- Apply the biocide by spraying or brushing for 2 or 3 days (without rain) at a rate of one application per day.
- Leave the product to work for at least 4 to 5 weeks.
- Ensure that the growth is well dried before removing it with soft brushing or water injection-extraction; if it is not dry, reapply the treatment.
- Rinse the treated surfaces with water before waterproofing.

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