Treatment of historic surfaces with water repellent and consolidation products
Choices for intervention

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Dealing with Heritage

Assessment and Conservation

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Barbara Lubelli

4.1 – Introduction

Surface treatment on historic buildings, such as the use of water repellents or consolidation products, can have an irreversible impact on architectural heritage. However, decisions in this field are often taken without enough knowledge of the possible risks of such an intervention on the short and long term. This chapter explains the working principles of water repellent and consolidation products, provides an overview of classes of products and their development over time, and proposes a method to guide the user in the choice whether or not to apply a surface treatment and to select a suitable type of product for a given situation.

4.2 – Historic development of surface treatments

Attempts to preserve monumental surfaces from weathering date back to ancient times when natural products, such as waxes and oils, were used (Cennini, 1859; Secundus, 1962). It was mainly in the 20th century that synthetic chemicals replaced natural products. In the 1950s, inorganic products (e.g. barium hydroxide, alkalisilicates) were progressively substituted by silicon polymers. Nowadays, the trend is towards water-based products (more environmental- and user-friendly than traditional solvent-based products) and nano-structured products (Borsoi, 2017; Sierra-Fernandez et al., 2017). Technical trends in product development are clear and several reviews on this subject can be found in literature (e.g. Lewin, no date; Price, 1996; Doehne and Price, 2011; Siegesmund and Snethlage, 2011b).

The use of surface treatments has not only been influenced by the technical developments, but also by the (inter)national debate on conservation. The charters of Athens (Athens Charter, 1931) and Venice (Venice charter, 1964) recognized the necessity of monument preservation and approved the use of modern techniques, provided that their efficacy had been proven by scientific data and experience. This was seldom the case for surface treatments, the long-term effects of which were unknown in many cases of application. The Venice Charter implicitly introduced reversibility as a requirement for conservation interventions. However, most surface treatments turned out to have irreversible effects. The conflict arising from prescriptions of reversibility and needs of preservation, sometimes by irreversible interventions, has fed the debate on conservation during the 20th century. The development of the concepts of re-treatability and compatibility (Teutonico, 1997) reflects the attempt to overcome the dualism between theory and practice.

With respect to the Dutch situation, it is not fully clear up to which degree the debate on restoration ethics has actually influenced the use of surface treatments in the conservation practice. A research project carried out in the last years of the 1990's, involving Belgium, Italy and the Netherlands, highlighted a gap between theoretical positions and conservation practice and underlined the absence of a clear policy line; the authority in conservation matters often being entrusted to local bodies (Naldini et al., 1998). Nowadays, despite choices regarding surface treatments are left to the local authority, this often refer to a centrally approved position of the national conservation authority, the Cultural Heritage Agency (RCE). The position of the RCE and its predecessors towards the application of surface treatments, and in particular towards water repellents, seems to develop from the cautious approach in the 1960s to enthusiasm in the 1970s. In the 1980s, its position returned to being cautious: RCE publications (Schuit, 1986a, 1986b, 1994; Schuit and Polder, 1992) mention the risks of surface treatments, even though they do not provide criteria for decisions. The theoretical issues related to loss of authenticity of materials due to surface treatments are first mentioned in 1994 (Helm et al., 1994) under the influence of the international debate (Nara document, 1994).

One of the problems emerging from conservation practice is the scarcity of information on the (long-term) effects of the different surface treatments applied to monumental surfaces. Product technical sheets are not informative enough and consequently it is hard to compare different products based only on the data reported by the producers. Product are rebranded and new products are often introduced on the market without sufficient preliminary testing of their (long term) compatibility and durability. Actors involved in conservation are not always fully aware of the effects of treatment on the behaviour of materials. This lack of sufficient knowledge favours the development of extreme, opposite attitudes towards the application of treatments. Nowadays in the Netherlands the application of surface treatments on monumental buildings is generally prohibited, while it is still commonly accepted and applied for building of less historic value. When considering the negative effects some treatments may have in the presence of some specific conditions on the durability of materials, a more conscious approach to the application of surface treatment would be desirable, also for non-listed buildings.

4.3 – Water repellent treatments

Definition

A water repellent treatment consists of the impregnation of a substrate with a product which creates a hydrophobic layer on the treated surface.

Aim

A water repellent treatment aims to prevent or reduce rainwater penetration and thus slow down those damage processes related to the presence of a high moisture content, such as biological growth, frost decay and sulfate attack. Besides, by keeping the surface dry it aims to reduce the soiling of surfaces.

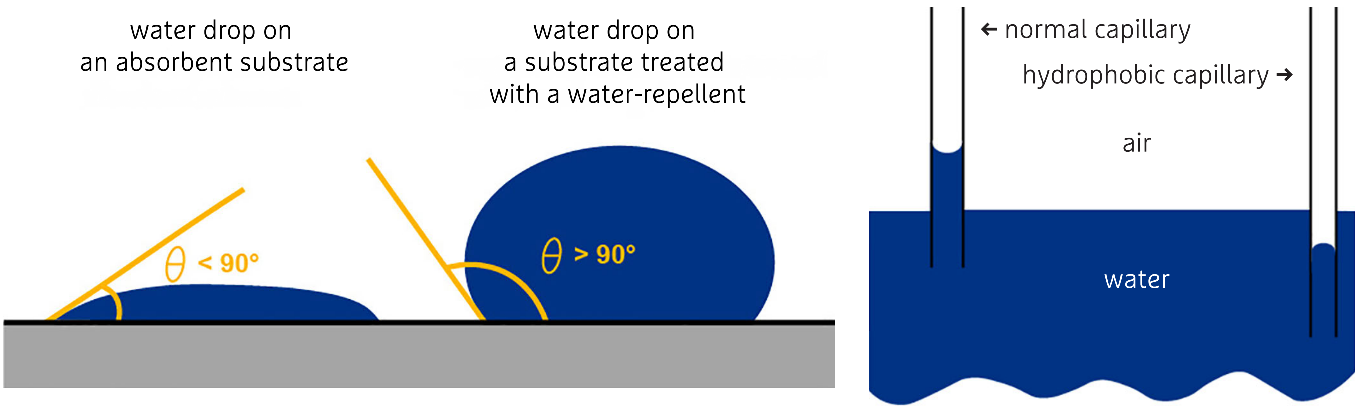
Working principle

A water repellent treatment works by changing the contact angle between water and a building material: normally this contact angle is about 0°; following the application of a water repellent, the contact angle becomes larger than 90° [FIG. 4.1]. Therefore, a material treated with a water repellent cannot absorb water by capillarity [FIG. 4.2].

Because of their effect on capillary transport of liquid water, water repellent treatments significantly modify the drying process of a material. The drying process of an untreated material occurs in two phases:

1. *by liquid transport to the surface:* the surface is wet and the drying front is at the surface;

2. *by water vapour transport:* when the moisture content becomes lower than a certain value (Critical Moisture Content), the surface is dry and the drying front recedes into the material.



FIGS. 4.1/4.2 Behaviour of absorbent (hydrophilic) and water repellent (hydrophobic) materials

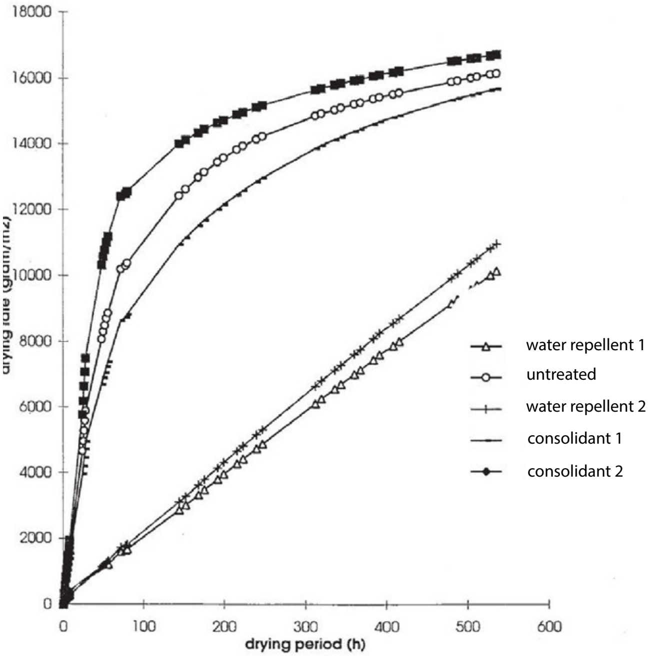


FIG. 4.3 Drying curve of a material: untreated, treated with water repellent treatments and treated with consolidation treatments (adapted from Hees et al., 1998)

Liquid moisture transport is much faster than the water vapour transport; therefore, drying occurs much faster in the first phase than in the second one. This is shown by the two different slopes of the drying curve of an untreated porous material [FIG. 4.3].

A water repellent treatment stops liquid moisture transport, while allowing water vapour transport. Therefore, a material treated with a water repellent will only dry by water vapour transport [FIG. 4.3] with a dramatic decrease of the drying rate as overall result. This may have negative consequences for some damage processes.

4.4 – Consolidation treatments

Definition

A consolidation treatment consists of the impregnation of a material with a product that, penetrating in depth, improves the cohesion of the decayed parts and the adhesion of these to the sound material beneath. The result is an improved resistance to the decay phenomena.

Aims

The main aim of a consolidation treatment is to improve the cohesion of the decayed part of the material and its adhesion to the sound material beneath. It is important to mention that consolidation treatments can be effective when the loss of cohesion occurs in the form of powdering or sanding [FIGS. 4.4/4.5]. A consolidant treatment is not effective in the presence of delamination and can even be harmful.

Working principle

A consolidant treatment works by (partially) filling the pores and the very thin fissures present in a decayed material [FIG. 4.6/4.7]. The (partial) filling of the pores and the recovered cohesion leads to an increase of the mechanical strength.

Consolidation treatments are normally applied in a fluid state in order to facilitate their penetration in the depth of the substrate. The applied fluid may solidify by cooling or, more often, it may set by chemical reaction or by evaporation of the solvent. Generally, a reduction in volume occurs during setting.

FIG. 4.4 Powdering of the stone: a consolidation treatment may be effective in this case / Photo: B. L.ubelli

FIG. 4.5 Powdering of the stone: a consolidation treatment may be effective in this case / Photo: B. L.ubelli

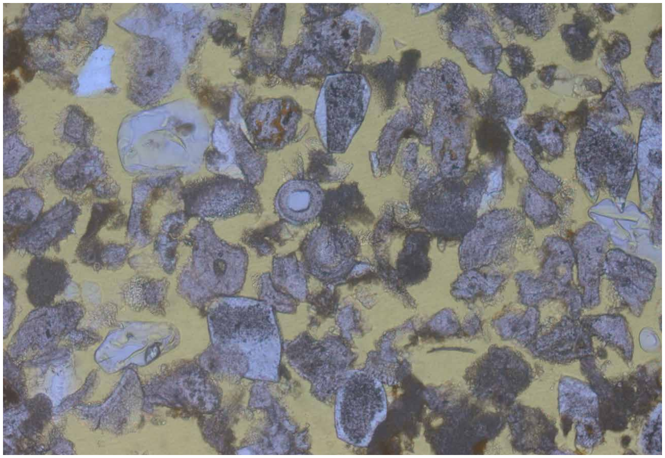


FIG. 4.6 Microphotograph showing deposition of silica gel in sound Euville limestone / Photo T.G. Nijland

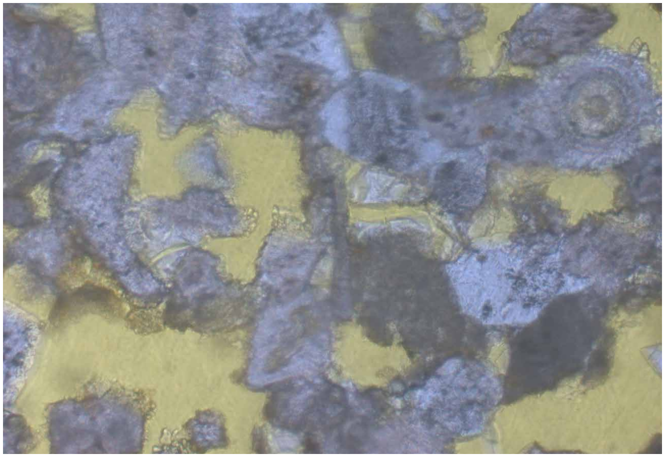


FIG. 4.7 Microphotograph showing deposition of silica gel in sound Euville limestone / Photo T.G. Nijland

The partial filling of the pores has an effect on the absorption and drying behaviour, as both the open porosity and the size of the pores decrease. Typically, the rate of capillary absorption and the total absorption of a material after consolidation is lower than that of the same material prior to consolidation. Similarly, the drying of consolidated material is slower than before treatment; however, liquid moisture transport remains possible. In general, the drying of a material treated with a consolidant is faster than that of the same material treated with a water repellent.

4.5 – Types of products

Water repellent products

The most commonly used water repellent treatments are silicone-based: silanes and siloxanes [TABLE 4.1]. The smallest molecules among silicon compounds are silanes (general formula SinH2n+2). When the molecule comprises several silicon-oxygen bonds, the products are known as siloxane. Mixtures of silane and siloxane are often used. Thanks to their small molecules, silane and siloxane can penetrate the pores of the material (silane can even penetrate the very fine pores of concrete) where they react (polycondensation) to form large molecules and 'attach' to the pore walls of the material.

The main advantages of silane and siloxane products are their deep penetration, their good thermal and oxidative stability and their chemical inertia towards atmospheric agents.

In the last decades, different developments have occurred in this field. Next to liquid products, water repellent products in the form of cream have been developed: generally, these products have a higher percentage of active components and, thanks to their high viscosity which allows for a longer contact time with the substrate, can achieve a deeper penetration depth [FIG. 4.8] (Lubelli and Hees, 2004). Since the years 2000, water repellents in powder form have been introduced to the market, mainly as additives in dry mortar mixes, as e.g. salt accumulating renovation plasters for salt loaded substrates).

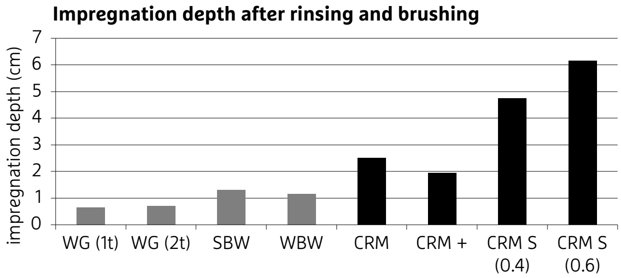


FIG. 4.8 Impregnation depth of different water repellent products applied to a fired-clay brick; liquid products are reported in grey, cream products in black.

TABLE 4.1 Historic development of water repellent silicone products (Lubelli et al., 2012)

YEAR	PRODUCT	SOLVENT	APPLICATION	% ACTIVE COMPONENTS
1960	Silicones	Hydrocarbon	Sandstone	< 5
1970	Oligomeric siloxanes	Hydrocarbon	Natural stone, brick	< 10
1980	Alkoxysilanes	Hydrocarbon	Idem and concrete	10-100
1990	Mixture of oligomeric siloxanes and alkoxysilanes	Hydrocarbon or water (emulsion)	Idem	< 10
2000	Further developments of mentioned mixtures	Idem or in the form of a cream, also in powder form	Idem; also as powder to be added to dry mortar mixes	25-80

4.6 – Consolidation products

Nowadays, the most widely used consolidation products are based on ethyl silicate (tetra-ethoxysilanes or TEOS). Ethyl silicate was originally developed in the 19^{th} century but only commercialized on a larger scale in the field of conservation starting from the 1970s. The composition of TEOS has changed over time (in this case an evolution towards solventless products also has occurred) and nowadays several commercial products are available on the market. The reaction of these products with the substrate occurs as follows: the consolidation product penetrates the material and – when in contact with the water present in the substrate and after silanol formation through hydrolyzation – polymerises through a condensation reaction and forms nanometrical spherical particles of silicagel. The silicagel is responsible for the increase in strength in the consolidated stone (e.g. Zendri et al., 2007; Ferreira Pinto and Delgado Rodrigues, 2004). The main advantages of TEOS-based products are their good impregnation depth and water vapour permeability. Their main limitation is the shrinkage that occurs during the drying phase, which leads to very fine cracks and which may have negative consequences on degradation processes [FIG. 4.9]. Attempts to tackle this problem have been made by introducing elastified, nanostructured and hybrid silanes. Modified products have been also developed in which surfactants (Mosquera et al., 2008), or silane components and/or silica nanoparticles (Kim et al., 2009) are added to influence the sol-gel transition and thus reduce shrinkage.

Another problem of TEOS-based products is their low affinity with calcareous materials, such as mortars and limestones. In fact, as the final product of these reactions is silica-gel, TEOS-based products are most effective on materials containing silica, such as sandstone and bricks (Graziani, Sassoni and Franzoni, 2016). For the consolidation of calcareous materials, modified TEOS products have been developed by the industry.

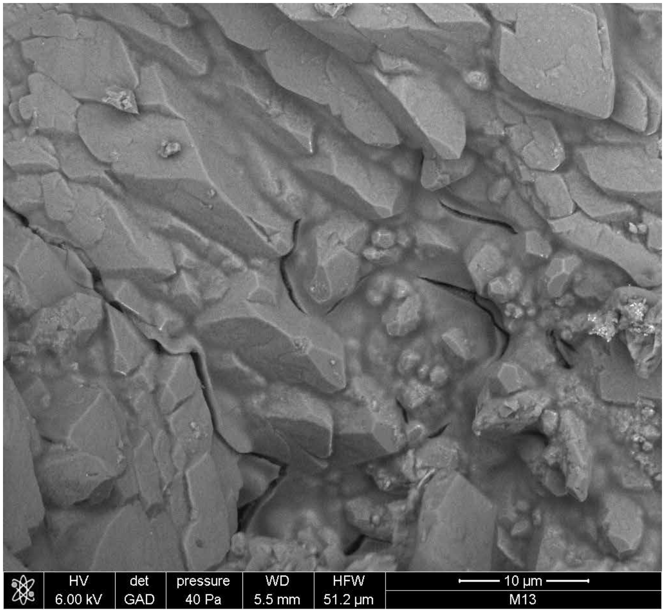


FIG. 4.9 Scanning Electron Microscopy (SEM) image showing shrinkage cracks in TEOS layer deposited in Euville limestone / Photo: TNO

Additionally, different alternatives have been proposed: calcium alkoxides (Natali et al., 2015), nanolimes, (Slížková and Frankeová, 2012; Zornoza-Indart et al., 2012; Chelazzi et al., 2013; Rodriguez-Navarro, Suzuki and Ruiz-Agudo, 2013; Licchelli et al., 2014; Borsoi, 2017; Otero et al., 2018), hydroxyapatite (Sassoni, Naidu and Scherer, 2011; Yang et al., 2012; Sassoni et al., 2013; Franzoni et al., 2015), etc. Most of these alternatives are still at the experimental stage, but nanolimes (i.e. $Ca(OH)_2$ nanoparticles in alcohol) have already been commercialized. However, from a recent literature overview of application of nanolime in practice (Borsoi, 2017), it has become clear that these products are presently more often used for works of art (e.g. fresco, statues) than for application on buildings.

Recent developments

Recently, both in the case of consolidant and water repellent products, research has been focused on the development of nanostructured products. These products contain active particles of nanosize, i.e. of the size of 10-9 µm. Often inorganic components, such as silica (SiO_2), aluminina (Al_2O_3) or copper (Cu), are mixed for example to TEOS or polysiloxane (De Ferri et al., 2011; Ditaranto et al., 2011). The use of nanoparticles aims to improves the properties of the products with respect to traditional treatments (e.g. reduce shrinkage cracks (Mosquera et al., 2008) and/or to provide them with some additional functionalities (e.g. a biocidal effect) (Ditaranto et al., 2011).

4.7 – Decision process

To treat or not to treat?

When deciding on the application of a surface treatment, this choice should consider the specific situation thoroughly. A water repellent treatment might be possibly a solution for stopping rain water penetration. Differently, using a water repellent only for reducing soiling, might be ineffective in the long term and risky. In fact, the beading effect, which reduces the sticking of soiling to the treated surface, disappears after few years, while all the risks related to the application of a water repellent still remain. As surface treatments are generally irreversible, alternative solutions having a higher degree of reversibility should be considered first (Hees et al., 2014) [FIGS. 4.10/4.11].

For a good evaluation of a specific situation, the following aspects should be considered:

- *Effect of the treatment on the value of the object to be treated:* on one hand, due to the application of a surface treatment, the authenticity of the material will be partially but permanently altered; on the other hand, in the absence of alternative solutions, rejecting the application of a treatment may imply the permanent loss of the object due to further material degradation. A compromise between these two extremes can often be found in the choice of a compatible treatment.
- *Presence of moisture and source:* treatment of a surface with a water repellent product can be useful to avoid rain penetration, while it is useless and it can even become dangerous if another moisture source, such as rising damp, leakage etc., is present. In these cases, either the source should be eliminated prior to the application or, when this is not possible, alternative solutions to the application of a water repellent should be considered. A somewhat wet substrate is generally not a contraindication for the application of TEOS-based consolidant products. Inversely, the presence of water can be a contraindication for the application of dispersions such as nanolime or calcium alkoxides in alcohol, as water destabilizes the dispersion, creating the risk of too fast deposition of the particles on the surface and consequent whitening.
- *Presence of salts and source:* the presence of salts in the substrate is a contraindication for the application of not only water repellent (as this favours accumulation of salts at the treated/untreated interface with consequent spalling of the treated layer [FIGS. 4.12/4.13/4.14/4/15] but also of consolidant products (TEOS may retain its water repellent properties in such cases for a long time). Depending on the source of salts and moisture, preliminary desalination of the substrate may offer a solution.

- *Condition of the substrate:* there are situations in which the state of conservation of the substrate constitutes a contraindication to the application of a treatment. For example, in all those cases where it is expected that the water repellent will fail to perform properly, e.g. because of the presence (or risk of development) of cracks (as for example in windmills, due to movement of the structure (Lubelli et al., 2007), it may be better to consider alternative solutions. Consolidant treatments can be applied to recover loss of cohesion (present in the form of powdering, sanding, chalking…) but they are not effective in the case of materials showing layering (in the form of exfoliation, delamination spalling or scaling). In these cases, adhesives and/or micro-grouting need to be used to re-join the layers together.
- *Other factors:* the presence of previous treatments can affect the decision on re-applying a treatment or not. Therefore, it is important to know whether a treatment has been applied in the past. For example, it happens frequently that a wall needs to be re-pointed or that damaged bricks need to be replaced. If the wall has been previously treated with a repellent, the dilemma arises whether the treatment should be re-applied or not after repointing or repair of the masonry. While, on one hand, the repaired, untreated part may favour drying of the masonry (and thus reduce the risk of frost and salt damage), it contributes to increase the absorption of rainwater, leading to a higher moisture content in the wall on the other hand. A recent laboratory experiment carried out on brick walls with different types of repointing mortar has shown that for the studied combinations and length of wet-dry cycles, the faster drying cannot compensate for the increased water absorption. Therefore re-application of a water-repellent is in most cases advised for treated masonry after replacement of the pointing (Nijland et al., 2019).

FIG. 4.10 A paster layer for protection can be an alternative for a waterrepellent treatment / Photo M. van Hunen

FIG. 4.11 A roof protection can be an alternative for a waterrepellent treatment / Photo W.J. Quist

FIGS. 4.12/4.13 Salt accumulation beneath the layer treated with a water repellent (left) and subsequent spalling of the treated part (right) during a laboratory test / Photos: B. Lubelli

FIGS. 4.14/4.15 Spalling due to salt accumulation beneath the treated layer; the water repellent is still effective several years after the application / Photos: M. van Hunen

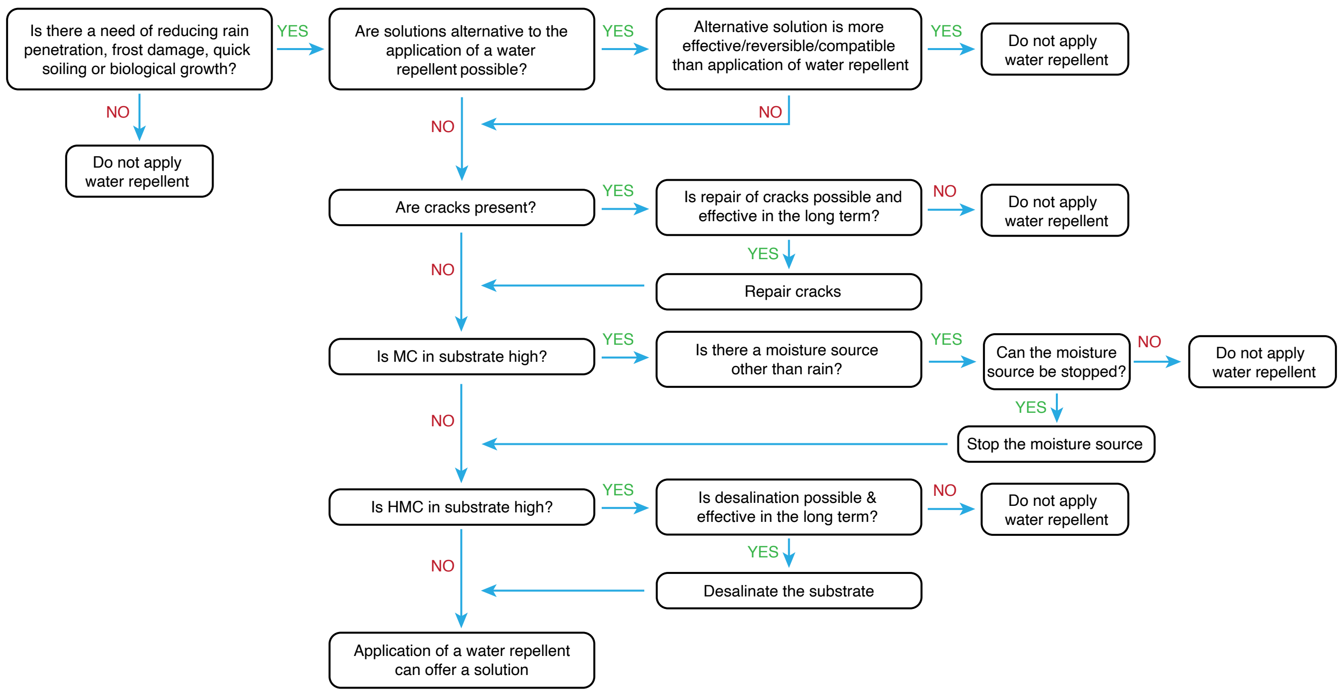


FIG. 4.16 Decision process regarding the application of a water repellent (wr) treatment.
(MC = moisture content; HMC = Hygroscopic Moisture Content, which provides an indicative measure of the presence of hygroscopic salts)

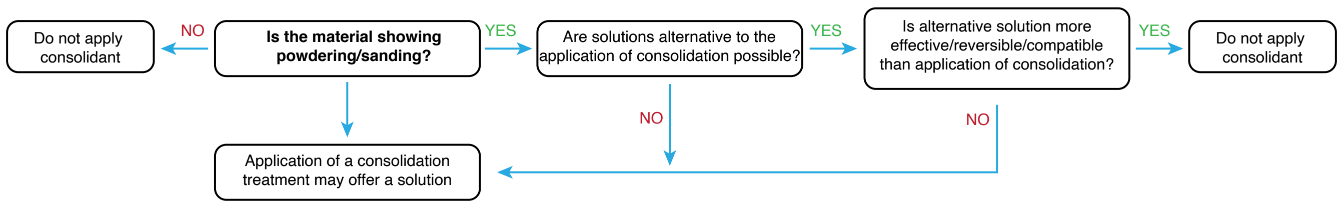


FIG. 4.17 Decision process regarding the application of a consolidation treatment

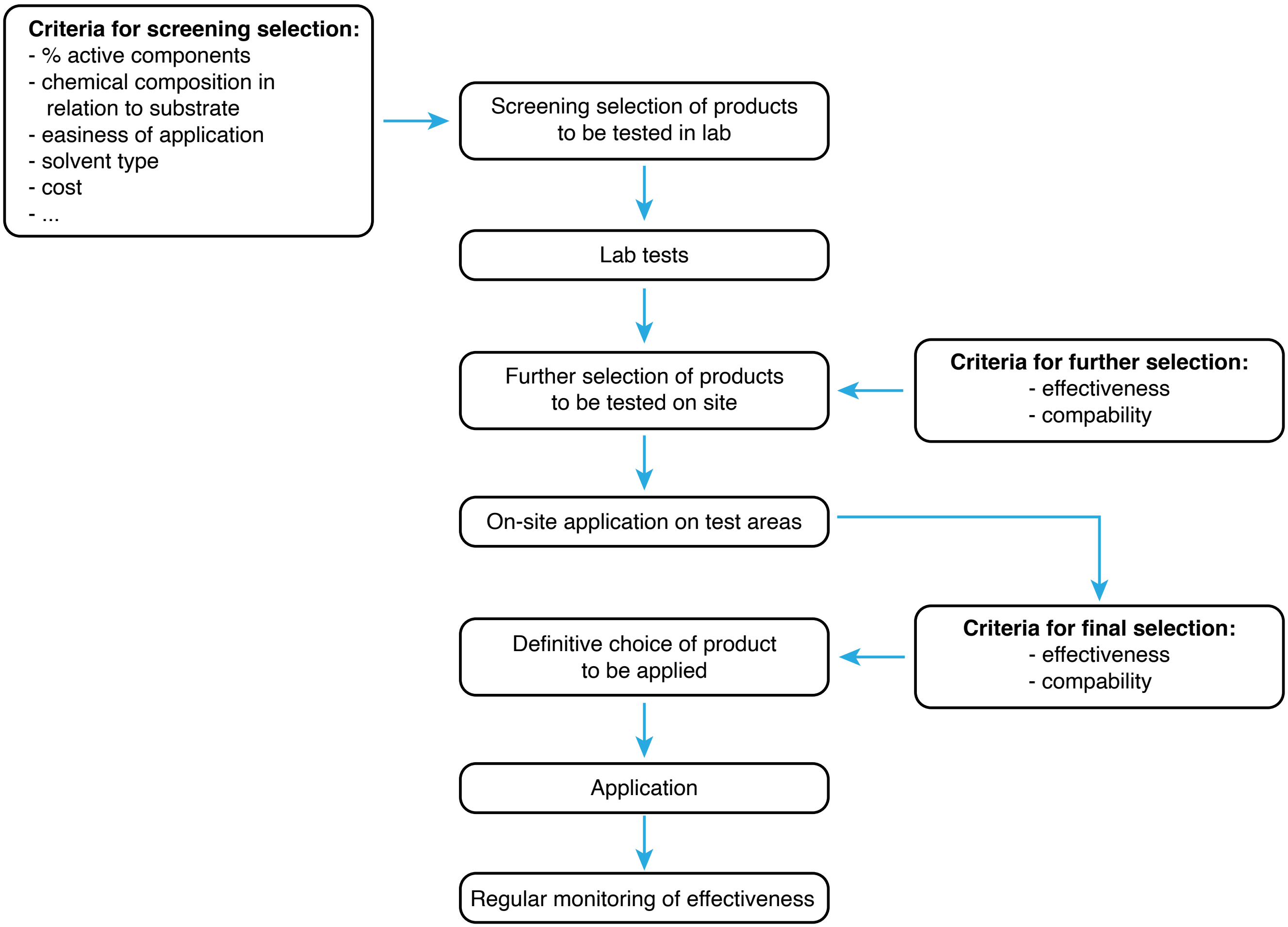


FIG. 4.18 Process for the choice of an effective and compatible surface treatment

How to select a suitable treatment

A first screening selection of a surface treatment product can be based on the information provided by the technical sheets and on the available knowledge of advantages and limitations/ drawbacks of the different classes of products. Properties such as percentages of active components, chemical composition in relation to substrate, ease of application and solvent type can guide a first selection of products to be tested in laboratory.

In a laboratory, the capability of the treatment to fulfil the requirements of effectiveness and compatibility should be assessed. Based on the results from the laboratory investigation, a further selection of few products to be tested on site on small areas can be made. Based on assessment of their compatibility and effectiveness when applied in the on-site conditions (e.g. moisture content of the substrate and environmental conditions may affect the behaviour of a treatment), a definitive selection of a suitable product can be made. This decision process is summarized in [FIG. 4.18]. The requirements of effectiveness and compatibility and how to assess them are discussed in the following sections.

Effectiveness

A water repellent treatment can be considered effective if it is able to stop capillary transport of water through the treated layer. The effectiveness of a water repellent to stop water ingress through the treated surface can be assessed in several ways. A first indication can be obtained by placing some water drops on the treated surface: in the presence of a water repellent a clear beading effect will be visible [FIG. 4.19]. As this beading effect disappears from the surface after some time (the products are degraded by the UV light), it is advised, in the absence of a clear beading effect, to assess the effectiveness a more reliable way. A more precise evaluation of the effectiveness can be obtained by the assessment of the absorption of the treated surface by means of capillary absorption measurement on a sample (in laboratory) or Karsten Tube test (on site or in laboratory) [FIG. 4.20]. The lower the absorption, the more effective the water repellent treatment can be considered. The impregnation depth can be assessed by splitting the treated material perpendicularly to the treated surface and wetting the broken surface. The treated part will be clearly distinguishable as it will remain dry and thus lighter in colour than the untreated part [FIG. 4.21].

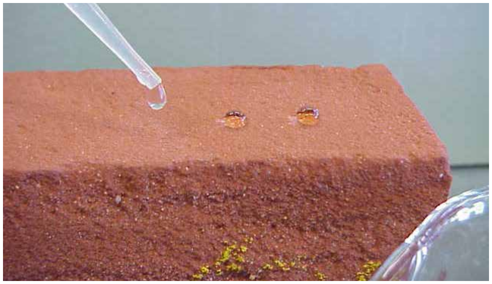


FIG. 4.19 Method for the assessment of effectiveness of water repellent treatment: beading effect / Photo: B. L.ubelli

FIG. 4.20 Karsten Tube test / Photo: R. van Hees

FIG. 4.21 Measurement of the impregnation depth / Photo: B. Lubelli

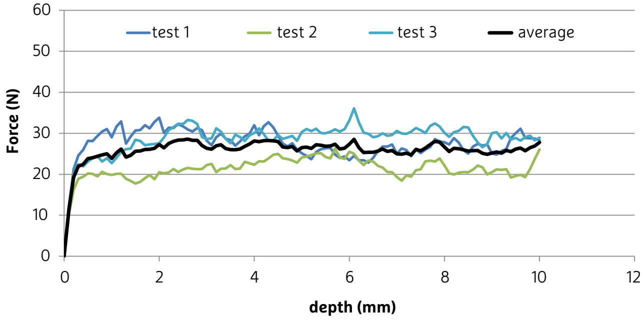


FIG. 4.22 DRMS measurements on sound Lede stone

For consolidation treatments, a recovery of the internal cohesion of the substrate confirms the effectiveness of the treatment. The most direct way to assess the recovered cohesion is by measuring the (tensile) strength of the material before and after treatment (Slížková et al., 2015). These measurements are destructive and can be complex; therefore, alternative methods such as the Drilling Resistance Measurement System (DRMS) are often applied. This test, which can also be applied on-site, consists of drilling a hole in a stone and measuring the penetration force needed as a function of depth (Fratini et al., 2007; Pinto and Rodrigues, 2008). This method can assess the distribution of the product in depth (e.g. Ferreira Pinto and Delgado Rodrigues, 2004; Matteini et al., 2011; Borsoi et al., 2017; Otero et al., 2018). The hardness of the treated surface, assessed before and after treatment, is often reported as a measure of the effectiveness of the consolidation. However, this might not necessarily give a measure of an improved internal cohesion in the material, but be only the result of an increased hardness due to the filling of the pores. Besides, as variations in the hardness of the substrate can be large [FIG. 4.22], a significant number of drilling holes is needed; this can be a problem in the case of measurements on valuable objects. Microscopy techniques (mainly Scanning Electron Microscopy, as optical microscopy cannot reach a sufficient magnification) can provide additional information on the presence and even effectiveness of the treatment, as they make it possible for an expert eye to identify a more or less strong interaction of the particles with the substrate Sometimes, a semi-quantitative method, the Scotch tape test, is used for the evaluation of the effectiveness of the consolidation, both in laboratory and on-site (Drdácký et al., 2012; Ruffolo et al., 2014; Slížková et al. 2015; Daniele et al., 2018; Otero, et al., 2018). This method, standardized in the ASTM D3359 (ASTM, 2017), can be useful to assess an increase of the cohesion at the very surface of a material, but it does not provide information on the effectiveness of consolidation in the depth.

Compatibility

In the specific case of surface treatments, the compatibility of a treatment can be defined as follows: a treatment can be considered compatible if it does not lead to technical (material) or aesthetic damage to the historical materials. At the same time, the treatment as such should be as durable as possible (Balen et al., 2005; Hees et al., 2017). Compatibility includes aesthetic, chemical, physical and mechanical requirements. Some class of requirements, such as aesthetic and chemical requirements, are common to both water repellent and consolidation treatments, some others are specific to one group only.

When considering aesthetical requirements, no visible change of colour (either discoloration or darkening) or change in gloss or in the visible surface structure of the substrate should occur due to the surface treatment. In principle this aspect can be assessed by visual observation [FIG. 4.23]. More detailed information on colour changes can be obtained by means of a colorimeter, following e.g. the standard EN 15886:2010 (CEN, 2010). Besides, the treated surface should not become sticky, as this can cause dust and dirt particle to adhere and lead to soiling of the substrate.

FIG. 4.23 Maastricht limestone 1 day after the application of different consolidation products: product 2 and to a lesser degree product 1, have caused whitening of the surface / Photo: B. L.ubelli

For a good chemical compatibility, harmful chemical reactions between treatment and substrate and between treated substrate and dirt particles, salts, etc. should be avoided. For example, sodium and potassium silicate consolidants, which were commonly used in the past, are nowadays not used anymore because of the risk of formation of soluble salts following their application (Siegesmund and Snethlage, 2011a).

Physical compatibility includes requirements related to thermal and hygric dilation and moisture transport properties. The effect of a surface treatment on the hygric and thermal dilation of the treated materials should be nihil or very limited in order to prevent damages such as spalling of the treated zone. Especially in the case of hydrophobic treatments applied on clay-rich stone, their effects on hygric dilation need to be checked, as it has been shown that they can be relevant (Siegesmund and Snethlage, 2011a). The effect of the treatment on the thermal and hygric dilation can be assessed by comparing the dilation of treated and untreated substrates (for example according to EN 13009:2000 (CEN, 2000)).

Regarding the transport moisture properties, the requirements are different for water repellent and consolidation treatments, as the first are supposed to change some of these properties, whereas the second should do this as little as possible. In the case of water repellent, the water absorption by capillarity at atmospheric pressure (as measured by the capillary absorption test) and a low pressure (as measured by Karsten Tube test) should be reduced as much as possible. At the same time, the treatment should not significantly reduce the water vapour transport: in fact, as this is the only drying mechanism possible in a treated material, reducing it would further delay or inhibit the drying. Snethlage and Sterflinger in (Siegesmund and Snethlage, 2011a) report that the water vapour diffusion resistance should not increase for more than 20% with respect to the untreated substrate. In the case of consolidation treatments, the water transport properties of a treated material should not change too much compared with those of the untreated material: these properties include the capillary water absorption, the water vapour diffusion resistance and the hygroscopic adsorption behaviour.

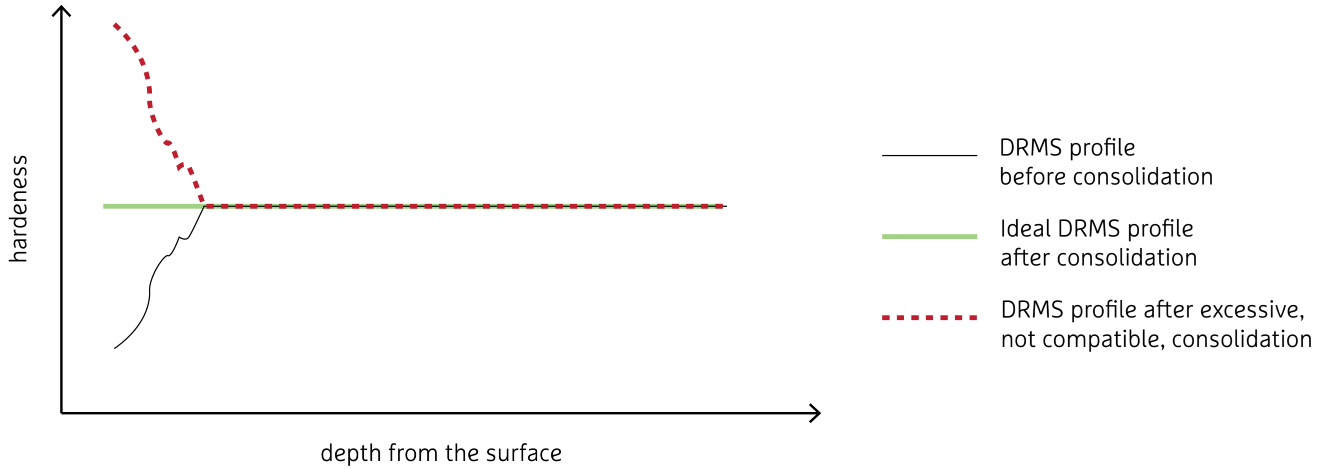


FIG. 4.24 After consolidation the stone should ideally recover its initial hardness (green DRMS profile)

Mechanical compatibility requirements demand that the treated layer has similar mechanical properties to those of the untreated part, i.e. no hard layer should be formed at the surface. This is a risk in the case of consolidation treatments, as these are meant to partially fill the pores and improve the hardness and cohesion of the decayed zone. For a consolidation to be compatible, the 'hardness' of the decayed, treated material should be not much higher than that of the sound material [FIG. 4.24].
A difficulty in assessing the compatibility, and in particularly the mechanical compatibility of consolidation treatment, is presented by the fact that tests are generally carried out on sound specimens, whereas consolidation treatments are supposed to be applied on decayed substrates. This has two main consequences:

- the transport of the treatment into the substrate might be different, as the porosity and pore size of the decayed substrate are generally higher and larger than of those of the sound substrate. This may affect the depth reached by the treatment and its distribution.
- It is hard to define how large the increase in mechanical properties of the treated layer can be in order to avoid damage. Attempts to define these values and the rate at which they should change have been made (Siegesmund and Snethlage, 2011a); however, the validation of these criteria in practice is still pending.

How to assess the presence of a water repellent treatment on-site

Sometimes it can be useful to determine the presence of a water repellent, as this can clarify some damage processes and decay patterns and it can affect the decision whether or not to treat a section of masonry or an object. In the following paragraphs the different steps in the investigation process are described and summarized in a diagram [FIG. 4.25]. A first, simple test to assess the presence of a water repellent is to spray some water on the surface to be tested. If a beading effect is visible, a water repellent treatment is present. As silicone-based water repellents are degraded by UV light over time, the presence of a clear beading effect at the surface suggests that the treatment is relatively recent (few years). The presence of algae may give a water repellent effect. In the case of algae growth on the surface it is therefore suggested to not rely on the beading effect only but to carry out further investigations.

Should the water repellent be some years old, it might have been degraded at the very surface because of the effect of UV light; in this case no beading will occur. It is therefore advised to carry out a Karsten Tube test, also when the beading effect is not visible. The Karsten Tube consists of a graduated glass tube welded at its lower part on a cylinder cell. The tube is filled with water stepwise and the absorption of the masonry measured over time. The water column simulates the pressure exerted by driving rain. The description of the procedure can be found in (Hees, 1998).

In the execution of the test and in the interpretation of the results the following aspects need to be taken into account:

- it is important to consider the absorption expected for an untreated material of the same type as the one to be tested. For example, a very low absorption measured on low porous stone is not necessary a sign of an effective water repellent treatment, but the normal behaviour of the stone. In the case of stones with a very low absorption, the ‘contact sponge method’ (Vandevoorde et al., 2009) may provide more precise and conclusive results than the Karsten Tube test.
- the presence of soiling, occluding the pores of the material at the surface, may result in low absorption also in the absence of a water repellent (see insert Atlantic huis). In such cases, the soiling should be removed as much as possible before performing the test.

If doubts persist, sampling of material and additional tests in laboratory might be necessary.

In a laboratory, the presence and effectiveness of a water repellent can be further checked by measuring the water absorption by capillarity through the treated surface. The advantage with respect to the Karsten Tube test is the possibility of comparing the absorption through the outer (treated) part to that of the inner (untreated) part. Besides, when a core sample is available, the impregnation depth reached by the treatment and the possible variation of its effectiveness in the depth can be checked. The first can be checked by wetting the core: the treated part will not get wet and remain of a lighter colour than the rest of the material [FIG. 4.26]; the second can be checked by observing the shape of water drops at different depths, from spherical to more elliptic.

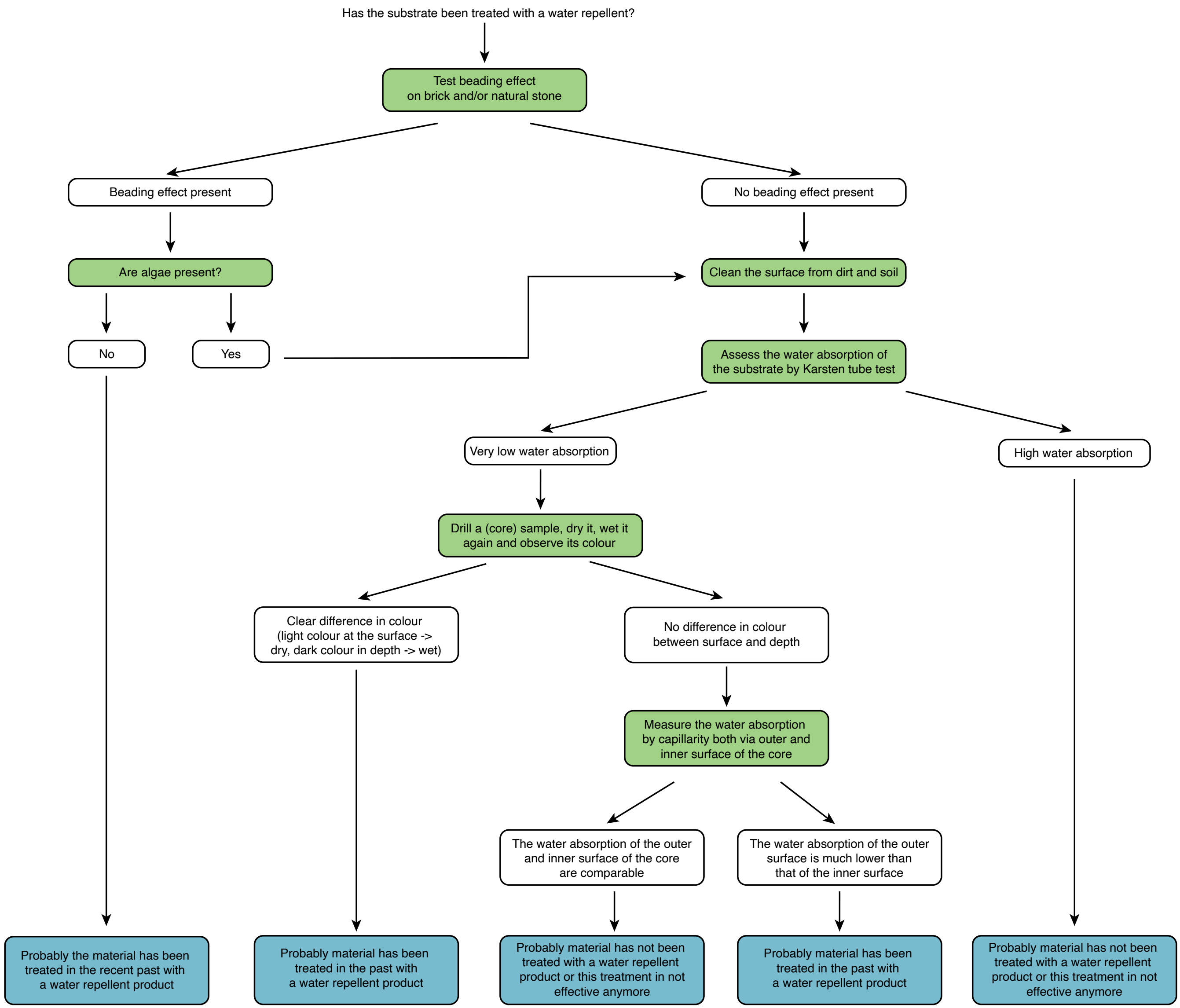


FIG. 4.25 The decision tree presented here shows how to assess the presence of a water repellent treatment

FIG. 4.26 The penetration depth of a water repellent treatment has been assessed by wetting a cross section of the sample with water: the light part corresponds with the treated layer / Photo: B. L.ubelli

Atlantic House in Rotterdam - Decision about the application of a water repellent

The Atlantic House is a monumental building in Rotterdam, the Netherlands, dating back to 1928-1930. It has a concrete structure and brick masonry fillings. In 2008-2009 the building, was renovated and converted to housing. Cleaning of the façades was planned as part of the renovation. Cleaning may lead to an increase of water absorption (as it removes the soiling filling the pores at the surface) and consequently to water infiltration, which in this case could be particularly risky for the corrosion of the reinforced concrete structure. Therefore, the option of applying a water repellent treatment following the cleaning of the façade was considered and the risks of this intervention were evaluated.

Two test areas were prepared: one was only cleaned, the other was cleaned and treated with a water repellent product. The water absorption of the masonry of both test areas was measured by a Karsten Tube test and compared to that of the not-cleaned masonry [FIGS. 4.27/4.28]. Moreover, the presence, amount and type of salts in the masonry were assessed, as salts constitute a contraindication to the application of a water repellent treatment.

The results of the Karsten Tube tests [TABLE 4.2] show that the masonry before cleaning had a very low absorption. Cleaning significantly increased the water absorption; the subsequent treatment with a water repellent was able to reduce the water absorption to nihil. However, the results of the salt analyses showed the presence of a high salt content in the masonry. Based on these results it was advised to reconsider the need for cleaning the masonry.

FIG. 4.27 Execution of the Karsten Tube tests on the masonry not cleaned (left), cleaned (middle) and cleaned and treated with a water repellent (right) / Photos: B. L.ubelli

FIG. 4.28 Salt efflorescence, evidence of the presence of salts in the masonry, further confirmed by chemical analyses / Photo: B. L.ubelli

TABLE 4.2 Water absorption measured by Karsten Tube test - step 1

MATERIAL	**BEFORE CLEANING**				**AFTER CLEANING**		**AFTER CLEANING & APPLICATION OF WATER REPELLENT**	
	brick. soiling	**brick. soiling**	**brick. little soiling**	**brick. little soiling**	**brick**	**brick**	**brick**	**brick**
Method 1								
step 1	v	v	absorbs	absorbs	absorbs	absorbs	v	v
step 2	v	v					v	v
step 3	v	v					v	v
step 4	v	v					v	v
step 5	v	v					v	v
Method 2								
5 min	0.2	0.1	2.4	2.2	Full abs. in 4’46”	0.95	0	0
10 min	0.4	0.2	Full abs. in 9’42”	3.1		1.7	0	0
15 min	0.6	0.3		Full abs. in 13’ 51”		2.45	0	0
WA-K (ml)	0.4	0.2				1.5	0	0

WA-K: water absorption measured by Karsten Tube = absorption after 15 minutes – absorption after 5 minutes; V = no absorption


Rusting iron / W.J. Quist