Conservation of natural stone

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Dealing with Heritage

Assessment and Conservation

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Wido Quist

2.1 – Introduction

Natural stone has been used in many historical structures all over the world. Pieces of stone taken directly from nature - whether or not worked - were used for a wide range of objects many centuries ago already. Old stone constructions such as Stonehenge near Salisbury in England, the Parthenon on the Acropolis in Athens, the Borobodur on Java, but also the many medieval cathedrals in France appeal to everyone's imagination. It was mostly such traditional monuments that brought John Ruskin and Eugène Viollet-le-Duc to their opposing views on conservation and restoration. The principle of minimum intervention, described in the Burra Charter (1999) as doing as much as necessary and as little as possible echoes through many national and international charters and other policy documents. It is widely supported, but in the case of natural stone conservation, this principle does not provide an unambiguous direction.

The conservation of natural stone is in a specialist discipline where execution technique, art history, (building) technical and geological research need each other. Bringing these different disciplines together years ago was one of the reasons for initiating the Flemish-Dutch Natural Stone Days. In the seven editions that have already been organised, knowledge was brought together, which remained mainly in the various domains, each with its own channels for knowledge development.

Determining the type of stone, together with the determination of the damage and the cause of the damage, is important in the first instance in the conservation of natural stone. Then comes the dilemma of whether or not to intervene, possibly followed by the choice of a particular conservation technique. In this chapter these aspects will be dealt with successively using the diagram in [FIG. 2.1].

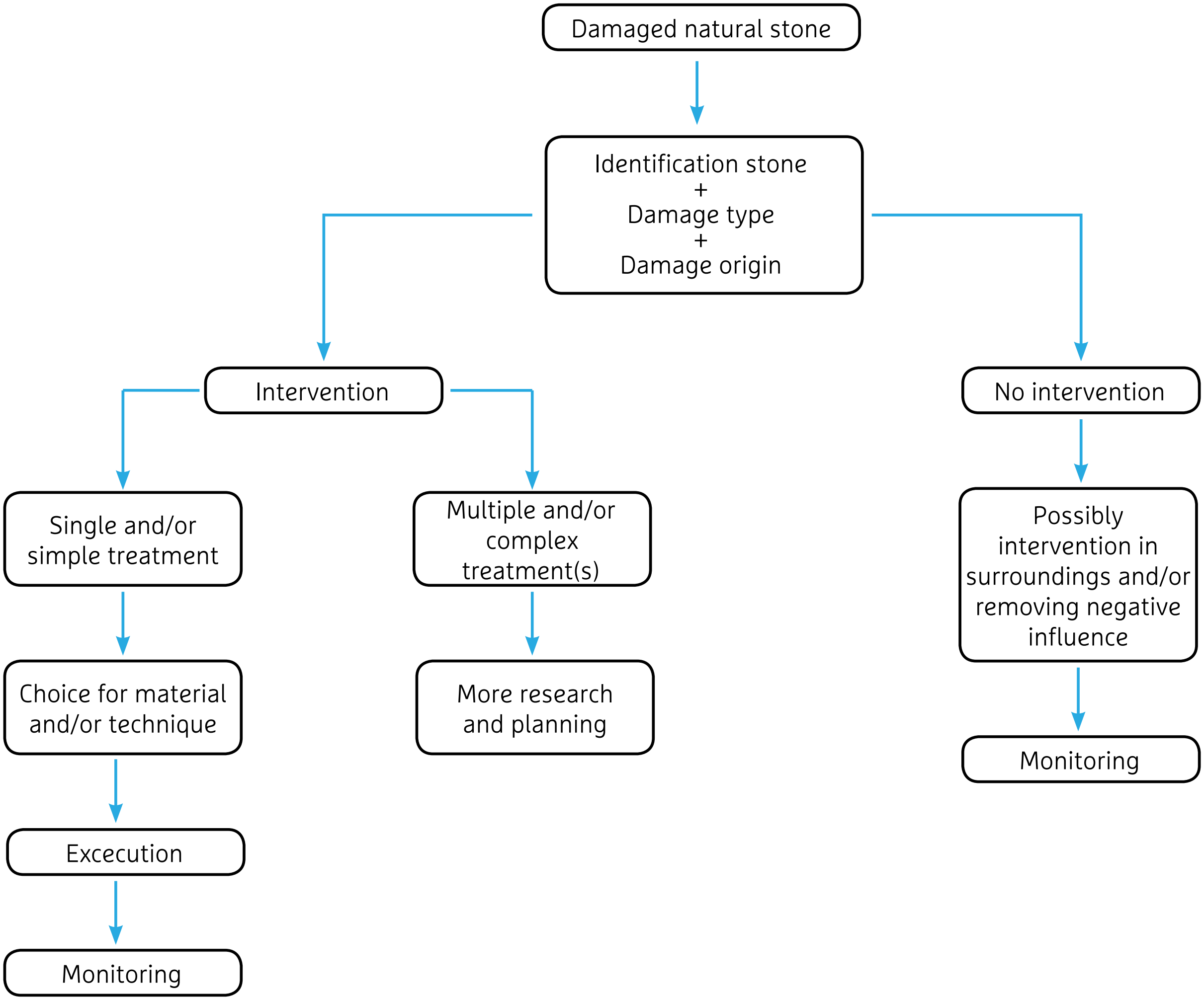


FIG. 2.1 Schematic representation of the maintenance of natural stone

2.2 – Identification of natural stone

Based on its properties the geological context of stone can be determined. And with this context as a basis, stone types and even varieties can be distinguished and identified. Determination has a threefold relevance:

- a historical relevance (where did the stone come from);
- a technical relevance (can the observed signs of ageing be explained by the type, type and origin of the stone);
- relevance to the selection of conservation techniques and materials.

In general, there are two ways to identify stone types: through historical research or through petrographic investigation. Most often a combination is used, depending on the available sources, the complexity and the importance of identifying the stone type. Studying the mineralogical composition, any fossils or inclusions present and structure and texture of a stone in order to identify stone (rocks) is called petrography. This can be done macroscopically or microscopically. Petrographic identification of stone types always starts from references: to what extent does the investigated stone correspond to another, already identified stone. Based on similar characteristics, the type of the unknown stone can then also be determined.

To determine stone types, a (often regional) frame of reference is needed. For areas rich in natural stone without many historical trade connections this will be a relatively simple and unambiguous frame of reference. But, for countries or regions without their own natural stone deposits and with many trade connections, this is a complex matter because of the great variety of natural stone types that may be found there. The Netherlands has always been dependent on supplies of natural stone from abroad (with the exception of the south of the Province of Limburg). Much of the natural stone used in Dutch monuments comes from present-day Belgium, France or Germany. Therefore, there is no local geological reference possible. However, in many cases a first estimation can be made of the expected types of stone used in older buildings in a certain region because the transport of natural stone took place over natural waterways until the mid-nineteenth century. The choice for a material was in the past mainly related to transport opportunities and geopolitical relations with the surrounding areas [FIG. 2.2]. From the second half of the nineteenth century, stone was increasingly transported by train and a large number of new quarries were opened, so there was hardly any connectedness between the location of application and the origin of stone types (Dusar & Nijland, 2012).

FIG. 2.2 Areas of origin of natural stone types used in historic buildings in the Netherlands with their direction of distribution (base map: openstreetmap)

Identification on the basis of historic research

Building archaeological research attempts to determine the construction history of a monument on the basis of its current condition in combination with archival sources. Construction phases, materials used and techniques applied are studied prior to many restorations to create a historical picture as a basis for conservation. The interest in historic buildings, research into them and their preservation started to spread in Europe during the nineteenth century (see Jokilehto, 1986; Jokilehto, 2002; & Denslagen, 1987). The development of knowledge about historic building materials runs parallel to this.

The question of the identification of natural stone, especially with a view to choosing a substitute type of stone, already arose at the beginning of the organized preservation of built heritage in the Netherlands (Quist, 2011), when a start was made in 1903 on describing the Nederlandsche Monumenten van Geschiedenis en Kunst (Dutch historical and artistic monuments). The knowledge about the origin of natural stone developed rapidly and the Rijkscommissie voor de Monumentenzorg (National Commission for the Preservation of Historic Monuments) and the associated Rijksbureau (National Office for the Preservation of Historic Monuments) were established in 1918. A major contribution to this knowledge production was made by mining engineer A.L.W.E. van der Veen, construction supervisor J.A.L. Bom and the State Sculptors N. van der Schaft and A. Slinger (Quist, 2011; Quist & Nijland, 2013). Overviews of the historical context of natural stone used in the construction of historic buildings are described for the Dutch situation in Slinger (1980/1982), Janse & De Vries (1991), Dubelaar, Nijland & Tolboom (ed. 2007/2012) and Quist & Tolboom (ed. 2017). Many stone elements used in Dutch historic buildings can be identified with the help of these sources. In addition to these general informants, archival sources can provide specific information about the origin of natural stone at an object. Accounts, travel reports and supervisor's reports sometimes provide concrete information about the purchase and processing of natural stone, for example. In addition, from the esearch into the persons involved in the building or restoration processes can also be deduced which types of stone may have been used.

Petrographic identification

Identification of stone with the naked eye, possibly assisted by a handheld magnifying glass, is often implicitly based on the historical context. In the Netherlands, it is unlikely that a piece of Lede stone will be used in Groningen in the sixteenth-century or a piece of Bentheim sandstone in the fourteenth-century in Maastricht, for example. Visual observation mainly focuses on block size, part, location, colour and texture, finish and weathering. All of this is related to the researcher's frame of reference. Databases with photographs of stone surfaces or collections with samples can be very helpful in this form of identification (see, for example, https://lithotheek.monumentenkennis.nl). In the case of microscopic identification, a thin-section is made which then is studied using an optical microscope under polarized light [FIG. 2.3]. For this purpose, a piece of stone (typically 2 x 3 or 3 x 5 cm) is cut and dried, polished and glued on a glass plate. Subsequently, the specimen is ground and polished again down to a thickness of 30 µm. Finally, it is covered by a thin glass plate. Prior to grinding and polishing, the sample may be vacuum impregnated by a coloured resin to make it easier to detect voids, pores, cracks, etc., though this is not necessary. Petrographic analysis of thin-sections is most known from geology, but has since its invention in the 19th century been applied to all kinds of (stone-like materials) including cements, ceramics, etc.. In addition to identifying the stone, petrographic analysis can also assist in identifying damage mechanisms, e.g. the influence of air pollution on calcareous materials (see e.g. Nijland & Larbi, 2010).

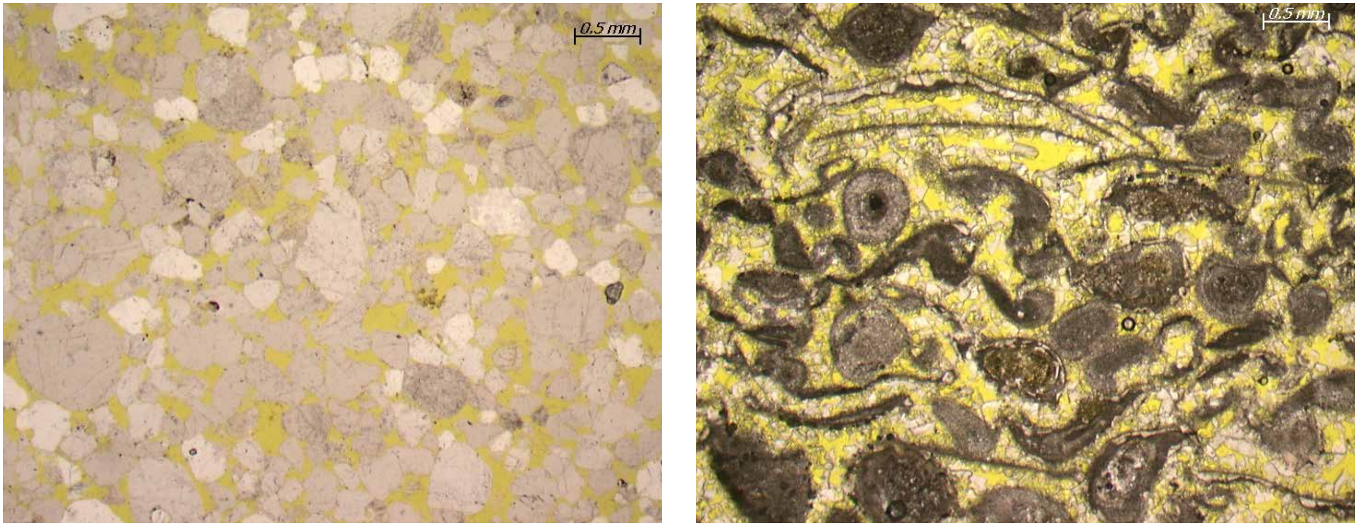


FIG. 2.3 Thin-section of Bentheim sandstone (left, TNO-00445) and Morley limestone (right, TNO-0364). The yellow in both grinding plates is the synthetic resin that has run into the (open) pores during impregnation. In the image of Bentheimer sandstone, the grey/white quarz grains are clearly visible, whereas in the image of Morley limestone various fossil and oolithes remains are visible / Photos: T. G. Nijland, TNO

2.3 – Most important stone types in Dutch monumental buildings

The number of stone types (rocks) is almost infinite. Overviews can be made with the most important types that were used during a certain period for each region or country. [TABLE 2.1] lists the important species which appear as building or sculpture stones on the exterior of historic buildings in the Netherlands in 2020. Most are sedimentary rocks: sandstones and limestones. In addition, there are a number of stone types of volcanic origin on our monuments. To provide an overview, some other types of stone have also been added to the table, such as the metamorphic slate found on many historic roofs and quartzite - known for example from floors from the Reconstruction era - and the Carrara marble used on various statues, memorials and in interiors.

From the almost inexhaustible list of polished decorative limestones, only two examples are put in the table as an illustration (see for instance Quist 2020 for the great diversity of polished limestone in various natural stone collections). In the table, a distinction is made between the stones that were traditionally used before 1850 (but also still after that) and the stones that were mainly used after that time for new buildings and as replacement stones in restorations.

TABLE 2.1 Important construction and sculpting stone types in Dutch monuments

		IN COMMON USAGE BEFORE 1850	APPLIED AFTER 1850 AND AS RESTORATION MATERIAL
Sedimentary rock	*Sandstone*	Bentheim Sandstone (D) Obernkirchen Sandstone (D) Baumbergen Sandstone (D)	Udelfangen Sandstone (D/L) Rackowicze Sandstone (PL)
	Limestone	Lede or Balegem Stone (B) Gobertange (B) Blue Belgian Limestone (B) Maastricht limestone (NL) Kunrade limestone (NL)	Euville limestone (FR) Savonnières limestone (FR) Vaurion / Massangis limestone (FR) Muschelkalk limestone (D) Portland limestone (GB)
Igneous rock	*Plutonic rock*	Drachenfels Trachyte (D)	Weidenhahn Trachyte (D) Tepla Trachyte (CZ)
	Eruptive rock	Eifel Tuffstone (D)	Mayen Basalt (D) Peperino Duro (I) Volvic (F)
Metamorphic rock		Slate (diverse) Carrara marble (I)	Quartsite (diverse)

2.4 – Diagnosis of damage

In order to determine whether intervention is required and, if so, what kind, it is very important that the preliminary investigation does not stop with the identification of the stone types and the documentation of the damage (and its severity). It should also identify the underlying damage mechanism. It is only possible to determine which intervention is desirable when the damage mechanism is known. To this aid, a damage atlas has been compiled through various European projects and, with a final adaptation within the MonumentenKennis-project (https://mdcs.monumentenkennis.nl), and included as part of the Monument Diagnoses and Conservation System (MDCS).

MDCS is an interactive support tool for the inventory and evaluation of damage to historic buildings. MCDS helps to identify the types of materials and the types of damage during visual inspections. MDCS focuses on various materials - including natural stone. Other sources for damage diagnosis, such as the Illustrated Glossary on Stone Deterioration Patterns published by the ICOMOS International Specialist Committee for Stone in 2008, which is partly based on MDCS, focus specifically on natural stone (ICOMOS-ISCS, 2008). Damage to (natural) stone can be identified and defined relatively easily with the help of the description of the damage and the accompanying photographs of examples [TABLE 2.2].

TABLE 2.2 The structure of the damage atlas in MDCS

Surface change	**Disintegration**	**Cracking**	**Deformation**	**Mechanical damage**	**Biological growth**	**Missing part**
Chromatic alteration	Layering	Crack	Bending	Scratch	Higher plants	Lacuna
Deposit	Detachment	Hair Crack		Cut / incision	Lichens	
Transformation	Loss of Cohesion	Crazing / Craquelé		Perforation	Liverworts	
		Star Crack		Splitting	Algae	
		Diaclase		Chipping	Mosses	
					Moulds	

Source: https://mdcs.monumentenkennis.nl

2.5 – Intervention

Principles

There is hardly any situation imaginable that prescribes only one unique intervention, no matter how well the identification, the definition of the damage and the investigation of the cause of the damage have been carried out. There is always a range of options available which, depending on the preconditions, can also be carried out in various ways. Four principles of intervention with subdivision can be distinguished [TABLE 2.3], based on Henry (2006), English Heritage (2012) and the URL 4007 – Restauratie Steenhouwwerk (2013). It should be noted that damage to natural stone sometimes involves surrounding materials and consequently the conservation of natural stone often implies the conservation of joints. Although important for the overall conservation of the construction, these types of interventions are left out in this chapter.

Based on the principle of doing ‘as much as necessary and as little as possible’ from the Burra Charter, minimum intervention prevails over consolidation, over repair and over complete replacement. An intervention principle can be chosen based on the state of conservation of the natural stone component, which can then be further elaborated on the basis of durability and compatibility requirements.

TABLE 2.3 The most important intervention types applied in the conservation of natural stone

PRINCIPLE	EXECUTION	COMMENT
1. Minimal intervention	Removing loose flakes/pieces	This falls under regular maintenance and does not necessarily need to be followed by another intervention in itself.
	Cleaning	Cleaning often takes place in preparation for another intervention. Various cleaning methods are available, depending on the type of stone, the type of soiling and the purpose of the cleaning (cf. MDCS, https://mdcs.monumentenkennis.nl/wiki/page/30/cleaning-of-facades).
2. Consolidation	Surface level stone reinforcement treatment	If, for example, the stone surface shows chipping or sanding, the stone surface can be hardened with a stone hardener in order to slow down the decay (more information: Nijland & Quist 2017).
	Complete impregnation	Single natural stone parts can be impregnated with PMMA (Polymethylmethacrylate) in a vacuum in a laboratory. This in principle makes further deterioration of the stone almost impossible.
3. Repair	Replacing damaged parts	The damaged area is cut out and the element is supplemented with a tailor-made piece of stone affixed with the help of a mortar and possibly a dowel. As a general principle, the same stone with a similar composition as the stone to be repaired is used (see ASTM C1722)
	Mortar repair	The damaged area is cut out and completed and finished with a repair mortar, affixed with small dowels and reinforcement if necessary (see ASTM C1722)
4. Complete replacement	Natural stone	The damaged stone is removed and completely replaced by a new stone. As replacement the choice can be made for the same or a different type of stone, depending on the situation.
	Mineral stone replacement mortar/ artificial stone	The damaged stone is removed and completely replaced by a replica in mineral stone replacement mortar/artificial stone. This is mostly applied to repair sculptures.

Durability

In addition to compatibility, the cultural-historical value of the natural stone part or its surroundings, the desired durability and the costs of the intervention also play a role when choosing an intervention technique or material. Nowadays, large-scale complex projects often look at the restoration horizon: how long should it take before restoration – in addition to regular and service life-extending monitoring and maintenance – is needed again? Particularly in the case of large inner city churches, where the costs of site design are very high, it is unaffordable to regularly erect scaffolding for conservation purposes. Often horizons of at least 25, 30 or 50 years are used. In these cases, therefore, not only is intervention based on the state of conservation, but an expected development of the technical state is also anticipated. In addition, the restoration horizon gives direction to the desired minimum lifespan of the intervention.

Anticipating further degradation of natural stone in the future is difficult. There are no models available for this; on the basis of experience, an estimate will have to be made with the risk that, on the one hand, restoration will be required earlier (than the intended restoration horizon) or that unnecessary historical material will be removed. Extensive intervention due to the avoidance of risk then threatens the maximum preservation of historical material. In order to still intervene as little as possible, it is necessary to clearly identify the risks. [TABLE 2.4] shows a number of example situations with a higher risk in which consideration must be given to how the risk can be reduced. In some cases, this is possible by taking extra precautions, in other cases it will lead to a heavier intervention principle being chosen.

TABLE 2.4 Risk situations that may help determine the choice of intervention on natural stone (based on Lubelli et al. 2018, see also Lubelli et al, 2021)

	SITUATION	POINTS OF ATTENTION TO AVOID OR REDUCE RISK
Lifespan	Distant restauration horizon (30-50 years)	Don't use stone consolidants. Don't use repair mortars. In the case of partial replacement, and depending on the geometry, provide extra securing and ensure that new elements are not too small.
Safety	Risk of safety in the event of failure	Don't apply repair mortars, or fix the mortars extra secure to the substrate. In the case of partial replacement, and depending on the geometry, provide extra securing and give extra attention to the size of the elements. Inspect regularly.
Use	The repair must be able to bear a mechanical load (including overhanging and cantilevering repairs)	Don't use repair mortar or provide extra fixing to secure the mortar extra to the substrate and/or use a mortar with high mechanical strength. No partial replacement or additional securing to the substrate.
Extent	Damage over 80-100% of the surface of the stone	Don't use repair mortar or pay extra attention to compatibility requirements or provide extra fixing to secure the mortar extra to the substrate.
Form	Damage with minimal thickness at the edges	Remove additional material to improve the form.
Thickness	Component to be repaired is more than 20 mm thick	Don't use repair mortar or provide extra securing and reinforcing to the repair.
Substrate	Difficult to repair stone (e.g. tuff stone)	Do not apply repair mortar or pay extra attention to compatibility requirements. Partial replacement only of large pieces.
Type of damage	Flaking, delamination or exfoliation	Carefully cut back to sound stone.
Salinity	Substrate has high saline load and/ or salt damage	Do not apply repair mortar or desalinate substrate and/or pay extra attention to compatibility requirements. In case of partial replacement, desalination and/or extra attention to compatibility requirements of repair mortar and replacement stone.
Dampness/moisture load	Substrate has high moisture load	Do not apply repair mortar or address source of moisture and/or pay extra attention to compatibility requirements. In case of partial replacement, address moisture source and/or pay extra attention to compatibility requirements of fixing mortar and replacement stone.

Compatibility

When maintaining natural stone, the most basic principle should be that the intervention should be compatible with the existing and at the same time be as durable as possible. Aesthetic and technical aspects are taken into account to determine compatibility. Historical aspects can sometimes also be taken into account (Quist 2011). In principle, repair or replacement with the same stone type as the original is the most compatible option. If this is not possible (availability) or desirable (durability), or if too much historical material is lost as a result, an alternative should be sought. The most suitable alternative can be found by formulating the compatibility requirements as clearly as possible, also in relation to earlier interventions.

TABLE 2.5 Table for formulating principles of natural stone repair or replacement based on (Quist 2011 and Lubelli et al. 2018, Lubelli et al 2021)

		PERFORMANCE REQUIREMENT
Aesthetic compatibility	Colour – new	
	Colour – after a period of time	
	Texture	
	Finishing/treatment	
	Geometry	
Technical compatibility of stone	Mineralogical composition	
	Moisture transfer	
	Environmental factors	
	Geometry	
Technical compatibility of a repair mortar	Moisture transfer	
	Adhesion	
	Elasticity module	
	Hygroscopic and thermal expansion	
	Chemical compatibility	
	Geometry	

Those aspects relating to aesthetic compatibility in the event of repair or replacement are similar. The requirements will mainly relate to the colour and texture, but the desired finish and geometry will also have to be formulated in relation to the substrate and the immediate surroundings. As far as technical compatibility is concerned, the aspects for replacement stone differ slightly from those for repair mortars [TABLE 2.5].

It can be very helpful to first draw up an abstract restoration vision in which the broad outlines of the goals are laid down, because the conservation of natural stone is rarely a stand-alone intervention in a restoration. Examples such as the Eusebius Church in Arnhem, the Cunera Church in Rhenen and the Royal Palace in Amsterdam show how a restoration vision that includes an integral vision on the conservation of natural stone, can be a good guideline for taking decisions on the conservation, repair and replacement of natural stone in stages (see also Kooten et al. 2012).

2.6 – Example: Conservation of Bentheim sandstone

Bentheim sandstone is quarried near Bad Bentheim in Germany, just across the Dutch border. Bentheim sandstone has been in use as a building stone in Germany and the Netherlands for many centuries. It has a very high quartz content and is basically a durable stone that can withstand the Northwest European climate. Over the years, the material acquires a light grey to almost black patina. Despite its high durability, monuments made of Bentheimer sandstone are subject to many interventions for a variety of reasons. Of these, replacement with other types of stone are the most visible, but mortar repairs and partial replacement are also common. The diversity of choices is illustrated and explained here.

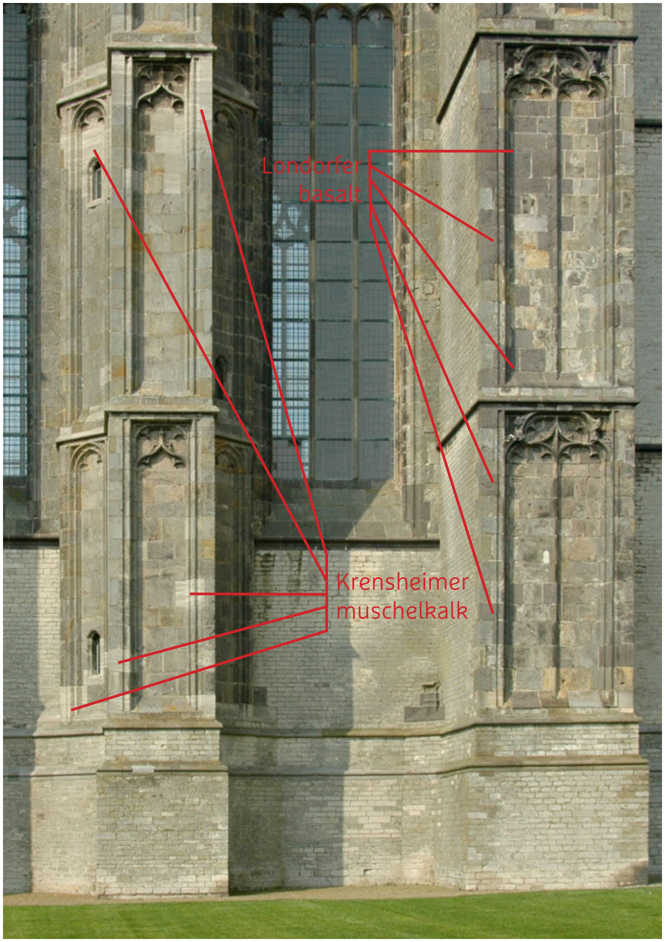


FIG. 2.4 Two adjoining buttresses on the Lievensmonster Tower in Zierikzee, with Krensheimer muschelkalk (left) and Londorfer basalt (right) as replacement stones for Bentheimer sandstone / Photo: W.J. Quist

FIG. 2.5 Londorfer basalt was used as a replacement stone in the lower section of the south side of the Lievensmonster Tower in Zierikzee. At the top and on the west side, mainly Mayen basalt can be seen / Photo: W.J. Quist

Due to its high quartz content, and thus the high risk of silicosis, Bentheim sandstone acquired a bad reputation in the Netherlands at the end of the nineteenth century. Stone carvers and sculptors were no longer keen to work with this particular stone type. This was seen as much less of a problem in Germany, as stonemasons there often worked outdoors rather than in a workshop, which meant that large clouds of quartz dust were much less common. In the Netherlands, limestone or sandstone, which contain less quartz, was chosen more often for repairs and for new work.

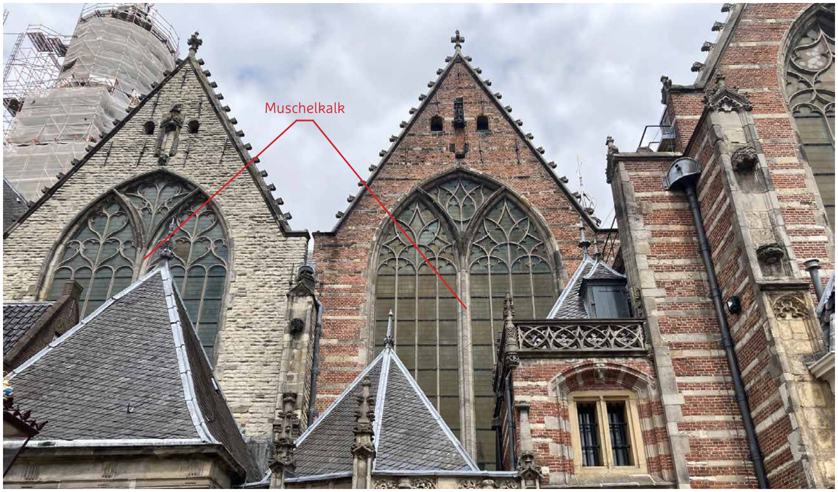


FIG. 2.6 Muschelkalk limestone as a replacement for Bentheim sandstone in the middle posts of the windows of the southern side aisle of the Oude Kerk in Amsterdam / Photo: W.J. Quist

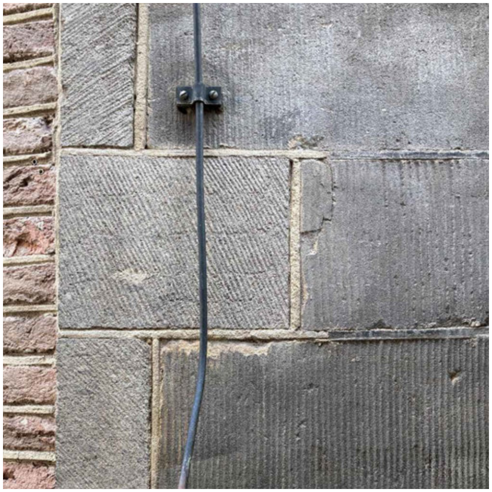


FIG. 2.7 Peperino Duro (left) used to replace Bentheim sandstone (right) in the Nieuwe Kerk in Amsterdam / Photo: W.J. Quist

The use of Bentheim stone was first restricted in the Steenhouwerswet (Stonemasons Act) and its decrees (1911/1921) and later in the Zandsteenbesluit (Sandstone Decree, 1951) (Quist 2011a, p.75-8). When the stone types used to replace Bentheimer sandstone are analysed, it appears that they were often chosen because of a colour corresponding with the grey-patinated Bentheim stone. The National Sculptor Slinger initially selected two types of stone for the restoration of the Lievensmonster Tower in Zierikzee because of the similarity in (weathering) colour and their high durability: Londorfer basalt and Krensheimer Muschelkalk. Trial applications are still a reminder of this decision making moment [FIG. 2.4]. Londorfer basalt was selected as the best choice for this restoration, but halfway through the restoration another replacement stone, Mayen basalt, was chosen because of the high cost associated with the former. Mayen basalt is a very dark basalt type and it unfortunately has little in common with the (weathered) sandstone for which it serves as a replacement [FIG. 2.5] (Quist 2012a; Quist 2012b).

The (financial) progress of the restoration was given priority over the return to the original aesthetic compatibility requirements. Other examples include the use of Krensheim Muschelkalk (limestone) as a replacement stone for Bentheim sandstone at the Oude Kerk in Amsterdam [FIG. 2.6], while Mayen basalt and Peperino Duro were used at the Nieuwe Kerk in Amsterdam [FIGS. 2.7/2.8]. Incidentally, the Bentheim Sandstone of the balustrade of the Nieuwe Kerk in Amsterdam has a much blacker patina than the Bentheimer Sandstone of the Lievensmonster Tower, so the black basalt here more closely approaches the colour of the original balustrade. Basalt from the French Volvic is frequently used as a replacement stone on the Utrecht Dom Church [FIG. 2.9]. Because of its grey colour, the Volvic basalt is, at some distance, difficult to distinguish from the weathered Bentheim sandstone that it replaces.

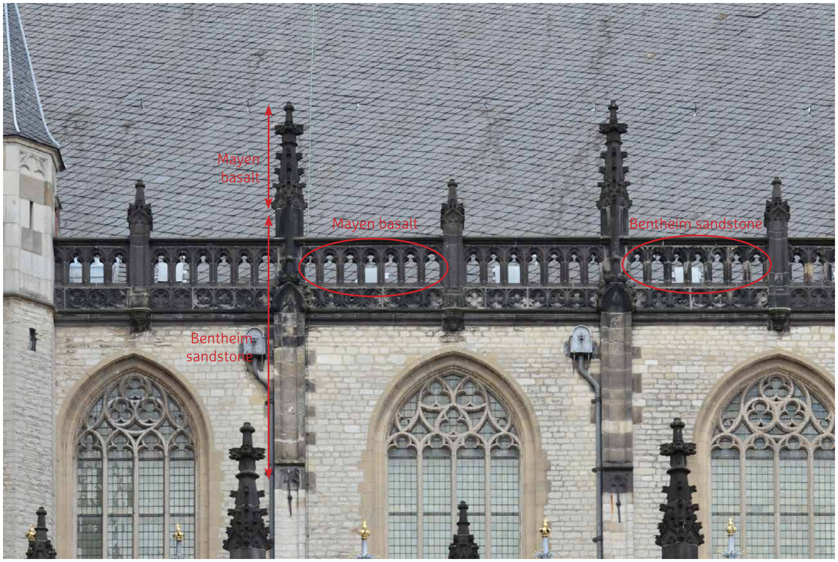


FIG. 2.8 Mayen basalt used to replace Bentheim sandstone in the Nieuwe Kerk in Amsterdam / Photo: W.J. Quist

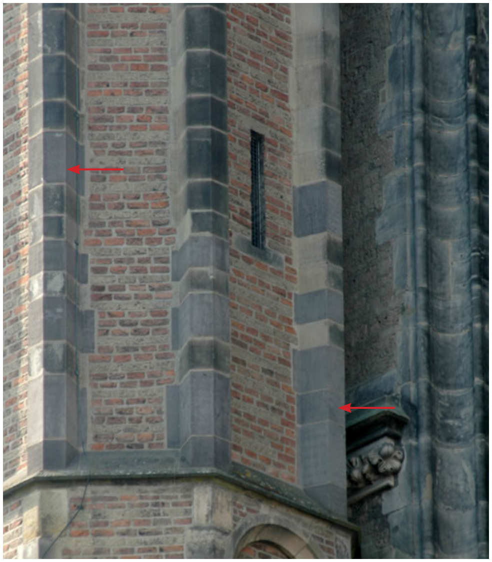


FIG. 2.9 Volvic basalt on the stair tower of the south transept of the Dom Church in Utrecht, as a replacement for Bentheim sandstone / Photo: W.J. Quist

The ban on sandstone processing from 1951 onwards did not only led to the use of many other types of stone, as also the replacement of whole stones took preference over patch repairs affixed with dowels or using repair mortar. This is because a lot of sandstone dust is released during the preparation of the stone for affixing with dowels, as is when the stone is roughened to ensure a good adhesion surface for a mortar repair. The use of sandstone has been allowed again under health and safety legislation since the 1990s, partly in reference to the continued use of sandstone in Germany. An example of a large-scale application of sandstone was the use of Rackowicze sandstone in the restoration of the Pieterskerk in Leiden during 2000-2011 [FIG. 2.10]. Here Ettringen tuff stone, which was used in the early twentieth century as a replacement for the original Bentheim sandstone, was replaced. The use of Bentheim sandstone for the restoration of Bentheim sandstone also returned to such a degree in this period that currently almost no other replacement stone is used [FIG. 2.11]. The (large) colour difference between the dark weathered old sandstone and the light, cream-coloured fresh stone is a factor to consider. Sometimes the choice is made to show this difference, including also the difference in surface finishing, but more often the choice is now made to 'artificially patinate' or 'undisturbe' (as opposed to restore) the new stone. This involves either applying colour to the stone surface using chalk in various shades, which is then fixed with a binding agent, or by spraying several colours of silicate paint (Brans 2012; Nijland 2012).

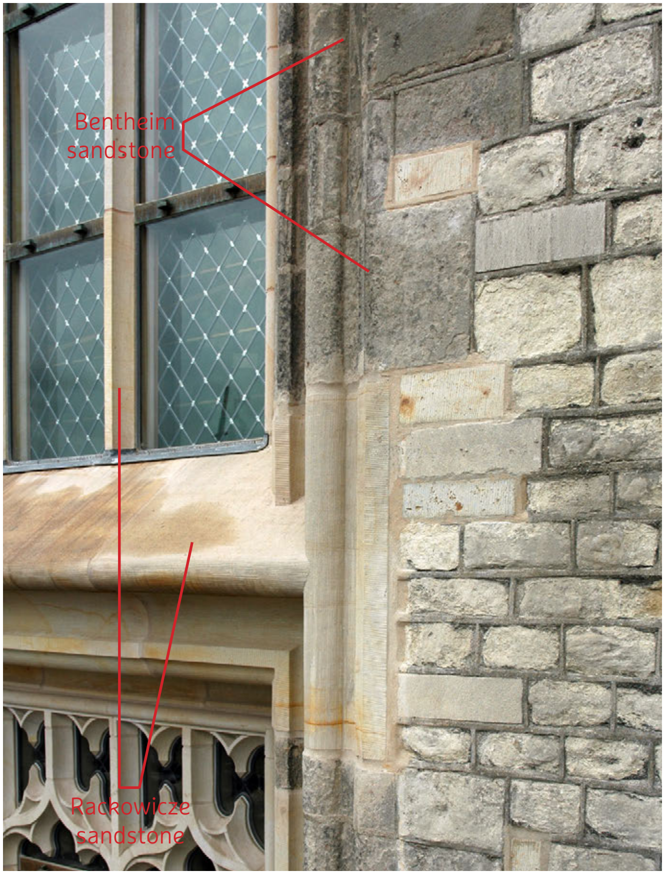


FIG. 2.10 Rackowicze sandstone at the large window in the north transept of the Pieterskerk Leiden / Photo: W.J. Quist

FIG. 2.11 Bentheim sandstone at the south portal of the Sint-Joriskerk Amersfoort / Photo: W.J. Quist

FIG. 2.12 The painted lantern of the Laurens Church tower in Rotterdam before conservation / Photo: W. Quist

FIG. 2.13 The lantern of the Laurens Church tower in Rotterdam after conservation / Photo: W. Quist

FIG. 2.14 Artificially patinated Bentheim sandstone on the lantern of the Laurens Church tower in Rotterdam / Photo: T.G. Nijland

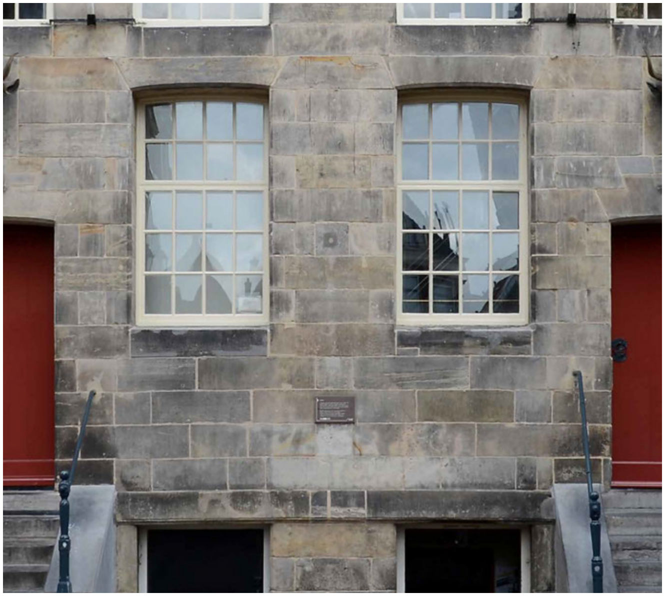
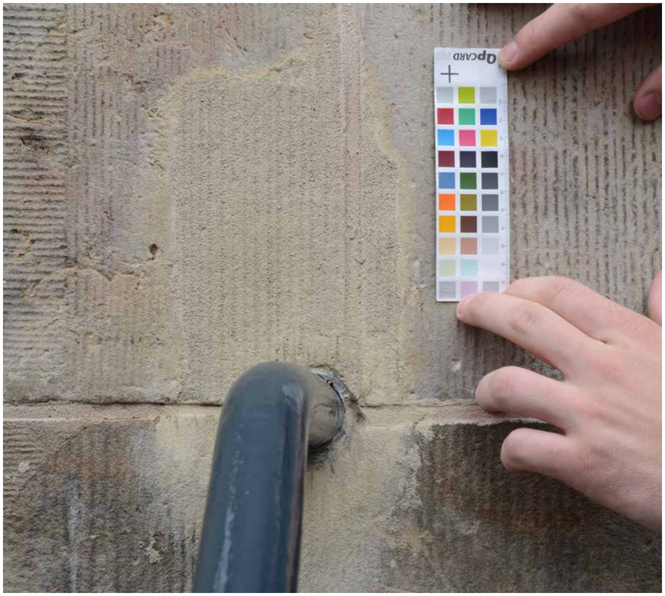


FIG. 2.15 The front façade of the Koornbeurs in Delft / Photo: W.J. Quist



During the conservation of the lantern of the tower of the Laurens Church in Rotterdam, all layers of paint were removed and the tuff stone – from an earlier restoration – was largely replaced by Bentheim sandstone, of which the lantern had once consisted entirely. In order not to let the fresh new stone stand out from the weathered old stone, an artificial patina was applied to the sandstone in the lantern. It was, however, decided not to patinate the – completely replaced – cornice pinnacles, as they together form an architectural unity [FIGS. 2.12/2.13/2.14]. Over time, the balustrade with corner pinnacles will develop a patina, depending on their orientation. The argument for architectural legibility was also used in the restoration of the facades of the Royal Palace in Amsterdam. For these façades, which consist of Bentheim sandstone and Obernkirchen sandstone, a detailed vision on the conservation was formulated at block level: it was decided to use a mix of cleaning, patch repair, replacing and artificially ageing, with the aim of bringing the façades into technical order and creating architectural unity (Bommel, 2012; Nijland 2012).

The use of repair mortar also increased simultaneously with the renewed use of Bentheimer sandstone. Jahn mineral mortars, whether or not specially made to colour, were often used to repair Bentheim sandstone (Lubelli et al., 2018; Lubelli et al., 2021). This repair mortar has proven its worth especially in facades with a large number of relatively small damages to several natural stone blocks, due to rusting iron or mechanical impact. The facade of the Koornbeurs in Delft has, for example, regained its aesthetic and technical unity through a combination of cleaning, repointing and a great deal of attention to the colour and finish of the mortar [FIG. 2.15]. There are still some traces of paint on this façade, which raises the question of what historical aesthetic unity has been reinstated. It is known that many natural stone facades were once painted. Discussion on the application of a new coloured finishing layer to natural stone during restoration has become a more and more frequent occurrence in the Netherlands over the past decade, but this is still only rarely applied (Naldini 2016, Kip 2007).

2.7 – Lessons learnt

In the Netherlands, the absence of comparable replacement stones for many years meant that the choice of a stone type had to be explicitly substantiated. Probably because of the dark patina that Bentheim sandstone develops – which in many cases is not harmful to the stone – blending with the appearance of the darkened stone was the main compatibility requirement for decades. This is in contrast to the different arguments for choosing substitutes for Lede or Balegem stone as those show a wider variety ranging from (expected) durability, via availability to the rustic looks (Quist 2013). The choice of Muschelkalk, Volvic basalt and Londorfer basalt proved to be appropriate and durable over time. The subsequent choices of Peperino Duro and Mayen basalt have worked out well as far as durability is concerned, but turn out to be too dark as far as aesthetic compatibility is concerned. To what extent 'artificially ageing' or cleaning can offer a solution to this challenge in the future will have to be investigated further. In such cases this will have to result in lightening rather than darkening the stone. The return to the use of Bentheimer sandstone has underlined the importance of restoring with 'the same' material as original. Great strides have been made in terms of compatibility and durability, especially in combination with the possibilities offered by repair mortars and artificial patinas.

2.8 – Discussion

Not a single historical building is still in exactly the same state as it was once built. All buildings are subject to ageing, and during the course of history, various interventions are made for various reasons. All these changes affect the building and determine, to a greater or lesser extent, the choices for interventions. The Venice Charter (1964) already pays attention to this in its Article 11. The use of building materials and techniques is regionally and often even locally bound. In this chapter, general attention has been paid to the conservation of natural stone in historic buildings, and the influence of national regulations on how to deal with a specific conservation problem has been discussed using an example of conservation of Bentheim sandstone in the Netherlands. An exactly similar example cannot be found anywhere else in the world; the conservation of Bentheim sandstone is even handled differently in neighboring Germany. The specific characteristics of regional situations – together with the general approach of identification, damage diagnosis and the pursuit of compatible interventions – determine the framework conditions within which interventions can be designed.

The many variables therefore also indicate that no universally applicable and unambiguous answer can be found to the issue of conservation of natural stone. Within the general requirement of compatibility [TABLE 2.5] various choices can be made, all of which can be 'good'. Compatibility requirements arise from material-technical aspects on the one hand, and on the other hand are determined by the way in which the cultural-historical value is dealt with. The final choice for an intervention is also influenced by the intended lifetime, the technical risk [TABLE 2.4] and the cost.TABLE 2.6 presents the characteristics of various principles of intervention in general terms, giving a rough indication of the lifespan, the impact of the intervention on the historic material, the technical risk involved and the cost of the intervention.

TABLE 2.6 Classification and characteristics of various conservation techniques for natural stone

PRINCIPLE OF INTERVENTION	EXECUTION	LIFE EXPECTANCY			IMPACT ON HISTORICAL FABRIC			TECHNICAL RISK			COST		
		H	M	L	H	M	L	H	M	L	H	M	L
Minimal intervention	Removing loose flakes/pieces	•	•	•			•			•			•
	Cleaning	•	•			•	•		•	•		•	•
Consolidation	Stone consolidants on the surface			•		•	•	•	•			•	
	Complete impregnation	•			•	•		•			•		
Repair	Replacing parts (Dutchmen)	•	•				•		•	•		•	•
	Mortar repair		•	•			•		•	•			•
Complete replacement	Natural stone	•			•					•	•		
	Mineral stone replacement mortar mortar/artificial stone	•	•		•				•		•	•	

H = High, M = Medium, L = Low

2.9 – Conclusion

Systematically describing of the points of departure, the considerations and the final choice is not only valuable during the execution of a restoration, but has especially great benefit afterwards. Every restoration is unique, but by systematically following a process it becomes possible to evaluate the effects of the different starting points and choices over time. Monitoring not only concludes a phase in the conservation of a heritage building, or more specifically, of a natural stone component, but will also bring to light any new degradation, making it the first step in a new phase of the heritage building's life.

Salt efflorescences in masonry /Photo: B. Lubelli