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Water - A Paradox, the Prerequisite of Life But the Cause of Decay

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Abstract

Throughout the centuries human beings have sought shelter. Initially their needs were extremely simple, no more than protection against rain and wind and the simple structures were built by the people who lived in them. As time went on building developed into a specialised activity carried out by the master builder and his craftsmen. As increasingly complex buildings were required, architects took over the designing of the buildings according to architectural rules. The shape and the detailing were always designed to lead the water off the building and prevent leaks and seepage. Usually local materials were employed and the builders were familiar with their characteristics such as capillarity, permeability and frost resistance, all of which are related to water. Experience was gained over the centuries during an extended process of trial and error. As new materials were introduced and the nature of the buildings became even more complex, natural building materials such a wood and stone were increasingly replaced by manufactured products such as bricks, concrete, iron and steel and the architects and builders were faced with new problems. In this contribution attention will first be paid to the ways in which people coped with the need to protect their buildings from the effects of exposure to the various actions of water in the past. Only then will the decision to use a water-repellent agent be taken.

1 Introduction

Looking for shelter in the past meant creating protection against rain and wind. The shelters were simple structures built by the people who lived in them. Even today we can find these types of structures in underdeveloped areas. To support the structure branches or small tree trunks were embedded in the earth. Walls were also often were made of branches covered with materials such as loam, while the roof extended over the walls to prevent water from the roof from reaching the walls. A variety of materials were used to cover the roof including palm leaves in tropical areas, reed thatch in marshy areas, straw thatch in grain growing areas, and slate or stones. A well maintained system could last for many years. Some parts were vulnerable to decay and this stimulated the improvement of the building system

Wood in direct contact with the ground was replaced by in stone- and later brickwork to - prevent the moisture from the ground rising into the wooden structure above it

In North Africa, buildings made of loam or rammed earth can cope with moisture aggression because each year a new layer of fresh loam is added to the building to replace that part that came off after the rain period. n fact the need for regular maintenance lead to architecture in which maintenance could easily be executed, while the culture of the area could be expressed with the help of loam. . I

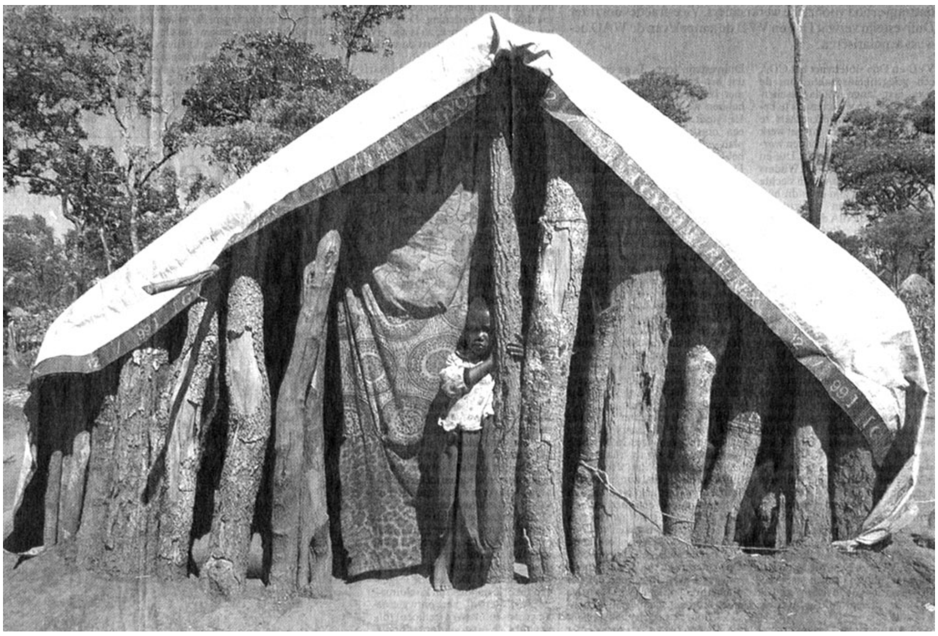

Figure 1: Hut in a refugee camp in Zambia anno 2001 [1]

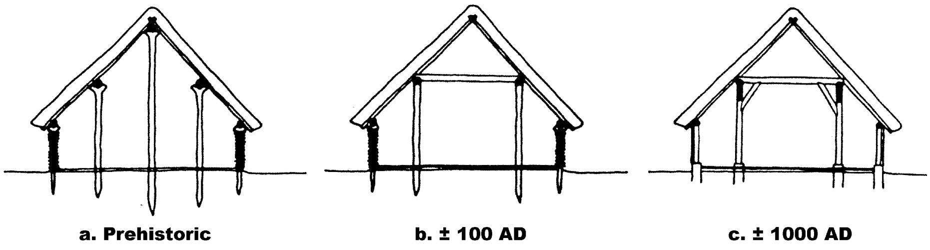

Figure 2: Development of the “hallenhuis” as a building type [2]

Figure 3: In Djénné, maintenance could easily be executed by adding a new layer of fresh loam [3]

Giving expression to a building always was based on the basic principles of ‘containing’ the influence of water, with the objective of prolonging the useful life of the building. An example from the 17th century is the Dutch wooden townhouse. The roof was often thatched; the walls were made of wood, while the first floor, coming in direct contact with the ground was made of stone or brick. The shape of the facade in particular, show that its beauty, results primarily from the need to lead off the water from the facade. After the big fires in the 17th century it was forbidden by law to build wooden houses in towns. Facades had to be made of stone or brick, possibly covered by plaster, all of which are capillary systems. In the past

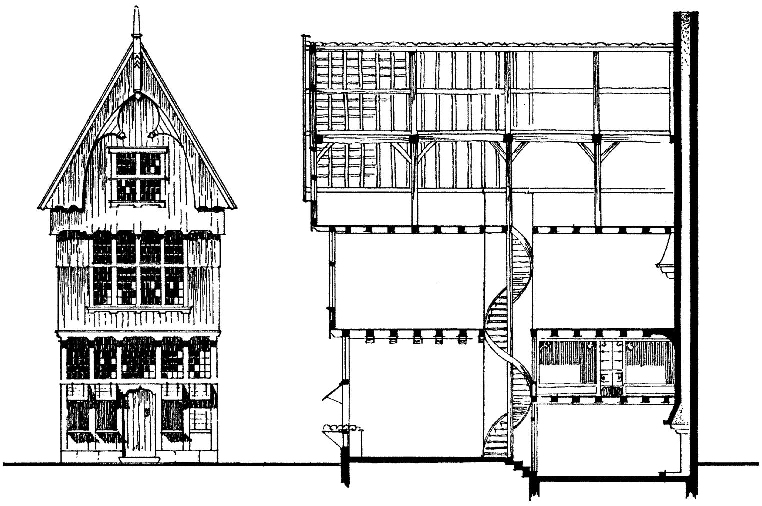

Figure 4: Gothic wooden townhouse [4]

architects designed buildings according the building style of their time, but also according certain principles.

These principles were:

- To cover,
- To divert water, and
- To drain.

Covering is especially meant to protect the upward facing stone or other surfaces. The facade itself must be designed in such a way that water will be diverted from it. In order to avoid any further contact with the facade the water that collects has to be drained off. For example, the Gothic style clearly demonstrates the attention given to the protection of facades and to drainage. Stone-made Gothic windows project from the wall surfaces and are detailed in such a way that water is thrown clear. The windowsills slope sharply and also project from the wall surface, allowing the water falling onto the glass surfaces to be thrown clear of the facade immediately. The filigree ornamentation is well rounded and bevelled in form to ensure that water is not given the chance to remain on the stone for any length of time. Water spouts (gargoyles) are now substantially larger in size and project from the facade for a considerable distance, throwing water from the surface of the facade. The vertical stonework is always protected.

The building materials are influenced by moisture in such a way that the maintenance of our cultural heritage is one of our biggest concerns. Protection is necessary. This protection is dominated by the significance of moisture in all its forms. Moisture can manifest itself in many ways. In the form of water vapour it is always present in the air. Apart from water vapour there are other forms of moisture such as rain, snow, hail, sleet and ice. This means that moisture can manifest itself in the three phases: gas, liquid and solid.

2 Moisture transport systems

In principle 5 moisture transport systems can be distinguished. Sometimes two or more systems are working together. For example gravity is always present, even when we are speaking about capillary transport. Nevertheless here we divide the systems into:

- Gravity
  This is especially important in determining the flow of water over buildings. The force of gravity is a continuing system, which affects all flowing water on the earth.
- Capillary systems
  Our historical buildings are almost exclusively built from natural materials, which constitute big capillary systems. There are exceptions, like iron, but even then we have to deal with a capillary system in the linking of materials together. This transport system is not as slow as the diffusion system but it is also a continuing system.
- Diffusion
  A slow transport system, but also a continuing system which, in time, can lead to serious problems.
- Hydrostatic pressure
  This has much quicker effects.
- Transport through cracks, which is very quick.

3 Gravity

In the nineteen seventies, the Swede Oscar Beyer did research on the rain runoff from buildings. Depending on the intensity and the duration of a rain shower, he determined how much rain could reach a facade and on which places it accumulated. He also examined the rain runoff in relation to the materials used and whether the rain runoff could reach the ground or stopped somewhere on the facade. His aim was to explain soiling phenomena, but the same information can be used to acquire understanding of how buildings have to be designed to protect them.

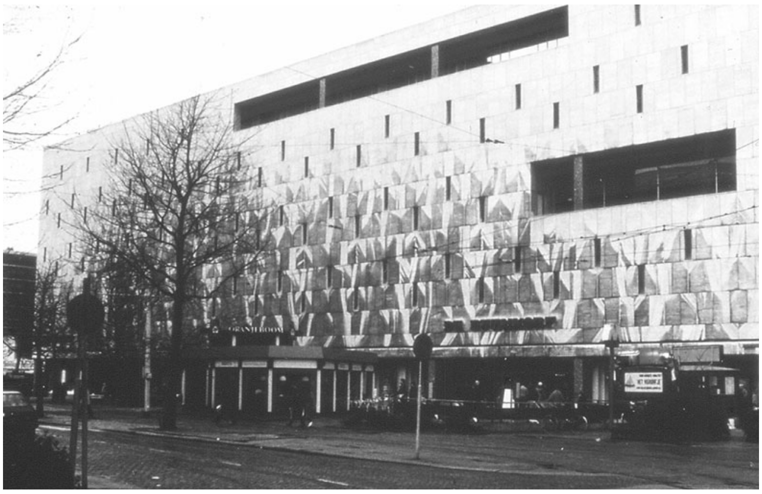

Figure 5: The top edge and the side ribs of the facades are well washed by rain runoff

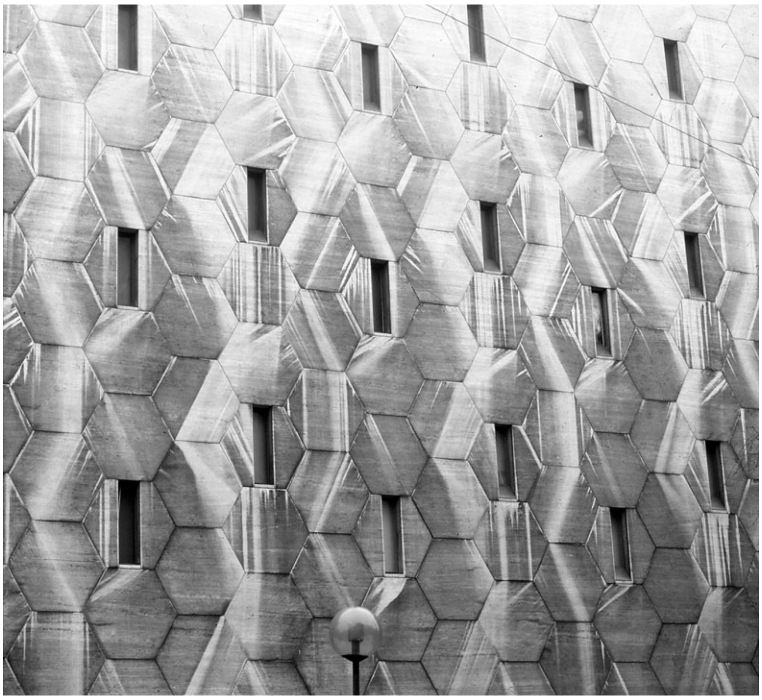

Figure 6: Specific runoff due to the texture

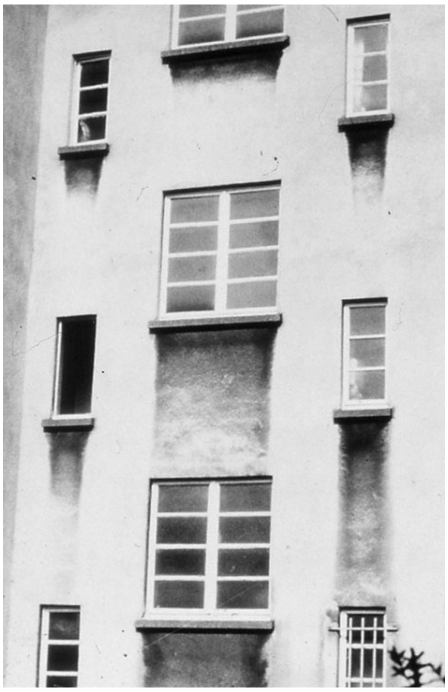

Figure 7: The rainshadow on the façade shows the rain angular

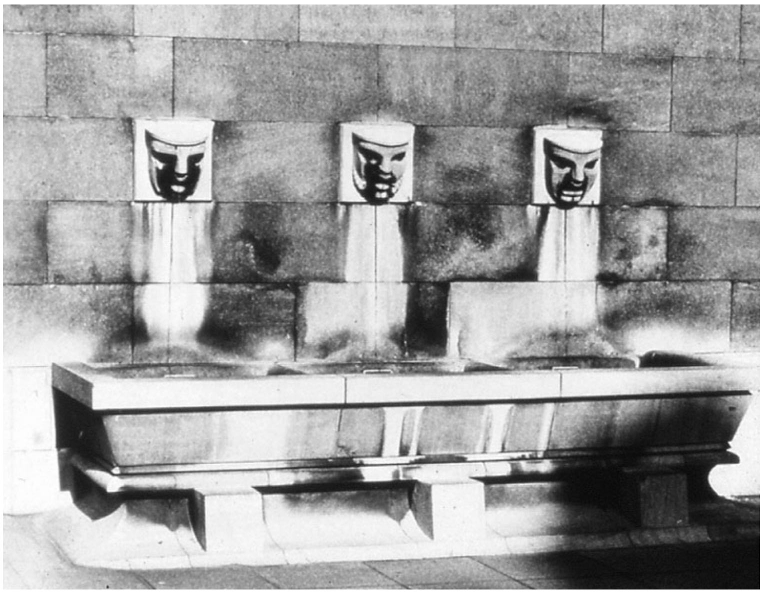

Figure 8: Elements sticking out of the façade close to the earth catch a lot of water

We can learn how the airflow moves around buildings and also in what places the water accumulates. It is interesting to see that in places with strong wind curves, for instance around corners or obstacles, water will be deposited. Most of the rainwater is deposited on the upper part of the facade and on the corners of buildings. Near the lower part of the building water falls practically vertically and cannot reach the facade, so only elements projecting from the facades can be reached by the rainwater.

With enough rain on the facade to run down and to wash it, the facade itself shows the direction of the rain impact. The picture of the “Bijenkorf” in Rotterdam shows very clearly how water reaches the upper part of the facade and the corners. It also shows that the texture of the facade can lead the water along the direction of the grooves. The facade with projecting sills immediately shows the direction of the incoming rain. Under the topmost sill the zone that is protected from rain is small, whereas lower down an increasing rain-shadow area can be seen. The last picture of three faces projecting from the vertical plane of the wall shows that only the projecting part can receive the downward falling rain.

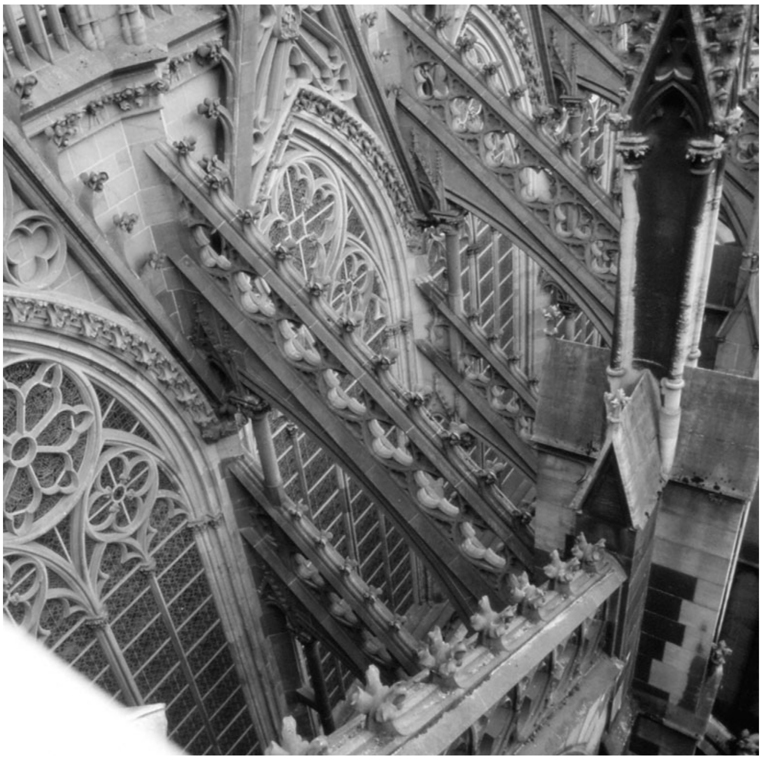

Figure 9: Flying buttress, sharply inclined

The detailed design of facades always has to be a reaction to the expected rain deposition and rain run off. Buildings from the past show a lot of examples of how architects made designs to cope with the phenomena of rain deposition and run off. Often the target of design detailing was to prevent big water flows and to divert the flow from the facade before it could acquire momentum. A clear example is the structure of flying buttresses. Not only are flying buttresses sharply inclined on the upper side, but they are also equipped with crockets that give Gothic buildings their subtlety and delicacy. The crockets are designed primarily for their function, which is to prevent the flow of water from damaging the stonework below, rather than for their beauty.

Vertical stonework or brickwork has to be protected, as can be seen from the sharply inclined covering of a buttress. If this concept is not fully understood water can penetrate the walls. For instance the upright course placed on the lower part of the walls can catch a considerable amount of water. Weak mortar joints will be washed out and water can easily infiltrate into the wall.

The primary intervention is to protect the upright course in an architectonic way. The use of water-repellent systems is a secondary intervention.

4 Walls

Rain does not fall uniformly onto a building. Some parts, such as ribs and projections, receive a higher moisture loading. This effect is even stronger because the walls themselves are not homogenous. As a result of various maintenance measures, many different types of stone are found in the walls of historic buildings The

Figure 10: Using architecture to prevent water penetrate into the upright course of the buttress

use of different types of stone is problem enough in itself, because their behaviour varies, especially in relation to moisture. The reason for choosing a different type of stone may have been that a quarry had become inaccessible owing to quarrels between princes, or that war was being waged between a prince and a bishop and the quarry was in the field of battle, or perhaps the quarry was no longer in production. The water run off from less porous stones is stronger.

The research carried out by Künzel, Kiessel and Krus [5] is interesting and indicates that:

- the equilibrium moisture content (hygroscopic capacity) of various types of stone at the same relative humidity (RH) can vary greatly,
- the capillary water flow can vary greatly,
- the variation in moisture content on stone surfaces is greatest as a result of precipitation and drying by diffusion and radiation, but on an annual basis these surfaces are much drier than the layer several centimetres behind it. Rain penetrates relatively deeply into mortar joints but the joint itself dries out more quickly than the stone. One reason for this is that the water vapour diffusion resistance of the joint is lower than that of the stone; moreover, because of the smaller diameter of the pores in the stone the stone sucks moisture out of the mortar. Behind the surface of the stone moisture can remain against the mortar joints for a long time..

Sometimes the outermost part of lime mortar joints may be replaced by much closer and stronger mortar (re-pointing). As a result of the difference in hygroscopic-thermic behaviour and also the initial shrinkage, micro-cracks will arise that can carry the moisture more easily into the facade and also retain the water in the area round the joint for much longer. The moisture absorbing capacity of the newly applied joints must conform to that of the surrounding wall construction. That joints contain micro-cracks can be observed, for example from precipitation tests of masonry in which the infiltration of the rain occurs primarily in the heading joints.

An unusual case of moisture influence on calcareous facade materials is the formation of gypsum. Gypsum is soluble in water, certainly when the pH is low. The supply of water must be sufficient ensure that the rainy sides of churches is often rinsed clean. On the less rainy sides or on sides that are protected against rain by the shape or design details, there is sufficient moisture for sulphate from the air to combine with the lime and form gypsum in the facade. The replacement of limestone by gypsum leads to the formation of a top layer, or skin, which behaves differently. If, in time, this layer becomes too thick, cracking and curling up of the gypsum layer will occur so that in localised areas rain will be trapped against the facade and the process of degradation of the layers of masonry behind will be accelerated. For

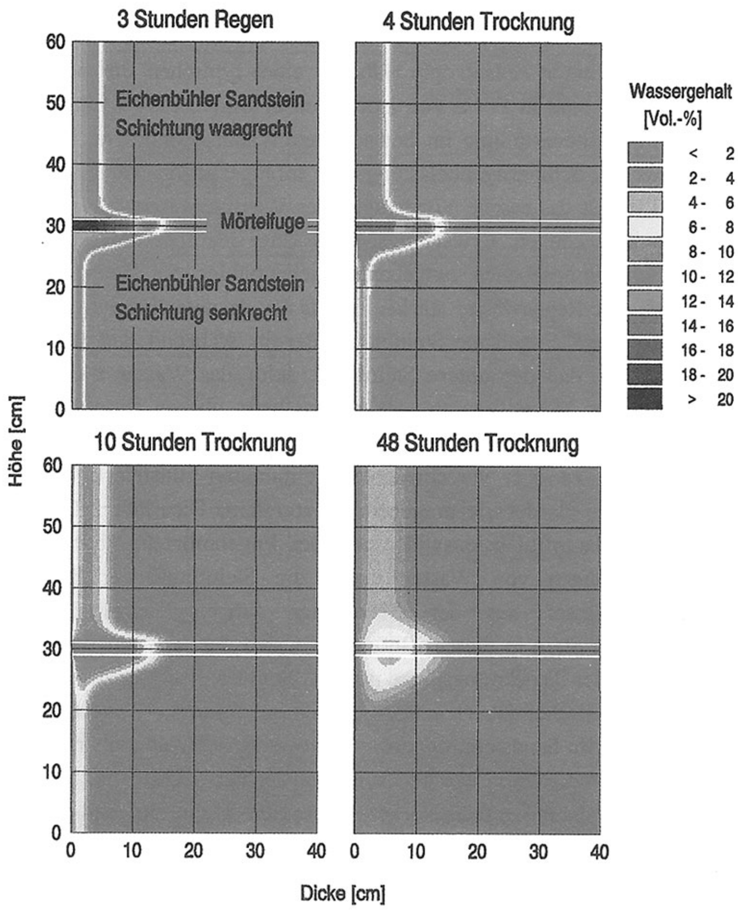

Figure 11: Two dimensional moisture distributions, plotted as isolines, in a section of natural stone masonry after three hours of intensive driving rain and during the following drying period. The blocks of the anisotropic Eichenbühler sandstone are layered horizontally resp. vertically. [5]

these reason the gypsum crust should be removed so that the condition of the joints can be checked, nevertheless heritage protection organisations would often like to keep the 'patina' and doing this also the gypsum crust. When joints with an incorrect composition must be replaced the gypsum crust should be removed to provide a good view of the work to be done.

It is very important to make the re-pointing work as small as possible in order to prevent the retention of too much water in the area surrounding the joint.

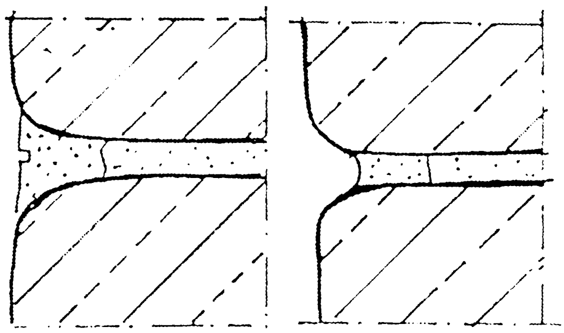

Figure 12: The left joint form keeps the bottom side of the stone longer wet. The right joint form allows quick drying out simply and well

5 Diffusion

Moisture in the form of water vapour is always present in the air. The specific amount of water vapour it can hold depends on the temperature. If more water vapour is present this will condense on cold surfaces, first on the coldest one where the air is in contact with the surface and thus has the least capacity to contain water vapour. Because air with a higher water vapour content has a higher vapour pressure than air with less water vapour, diffusion transport will occur from areas with a high pressure (much moisture) to areas with a low pressure (little moisture). In other words from a higher temperature to lower temperature. This also explains why ice lenses in the ground under foundations can swell and cause parts of buildings to rise up. Diffusion is a continuous process.

In addition to the presence of surfaces with relatively low temperatures, the presence of salt in porous materials such as plaster, stone or brick can cause condensation. The air above a salt solution has a lower RH than air can normally contain. Thus there will be diffusion of moisture out of the air and condensation above the salt solution until the solution is so diluted that the RH above the solution is in equilibrium with that of the surrounding air. The condensation of water vapour to moisture can considerably increase the moisture content in the porous material and lead to a darker coloration of the damp salt-affected areas.

A third form of diffusion occurs in capillary activity. As the capillary radius decreases condensation can occur at a lower RH. In view of the fact that condensation first occurs at approx. 100% in large capillaries, there can be a RH of the air at which condensation is already occurring in smaller capillaries. All materials have an equilibrium moisture content that depends on the RH of the air.

6 Removal of moisture

Moisture is the cause of damage. By removing the moisture it might seem possible to remove the cause of damage, but this is not always the case. If porous materials are scontaminated with salt, the increased concentration of salt in the moisture as this is removed may lead to crystallisation. Reducing the moisture content of a historic building by the use of localised heating results in more evaporation, so there is insufficient moisture present to keep the salt in solution. The salt crystallises out and some types of salt form needle shaped crystals. These can exert very high forces on the porous material, which may lead to failure, especially of the outer layer. Materials containing sulphate are especially prone to severe damage.

7 Protection against moisture from above and below

Precipitation falls onto buildings and flows off them. The rate of flow is determined by the absorption capacity of the masonry. Sometimes, with very dense types of stone the rainwater flowing off the building can reach the ground. This was the case in the Church of Our Lady at Breda. The masonry consisted of two Belgian limestones, Leede and Gobertange. And it has to be kept in mind that after using a water repellent system more water will run off.

Behind the stone facing, the walls of this church are made of brick, as well as the foundations. After excavation of the foundations it was clear that these were seriously affected by moisture. For this reason this part was screeded and covered by a vapour- permeable foil that carried the water via coire fibre to a drainpipe. Draining the water away from the building can solve some of the problems resulting

Figure 13: The brickwork under the stone absorbs water easily (left). Protecting the brickwork by plaster and after that by foil (right)

Figure 14: Right product and wrong way of application, top down method (left). Right product and right way of application, bottom up method (right).

from rising damp. This is possible because in the Netherlands churches are often built on a low mound so the watertable is a little lower than is usual. In spite of this, the ground behaves as a porous material into which water is always drawn up above the watertable (phreatic plane) so that the actual water saturated level is higher than the watertable.

8 Conclusions

Before the decision to protect the building with a water-repellent system is taken a number of normal maintenance measures must be taken, such as:

- Cleaning the building to obtain the right insight in the problems,
- Repairing the damage in such a way that new damage such as cracks can be prevented,
- Determining the presence of contaminants, especially salts and what kind,
- Laboratory testing that reproduces the real situation. Laboratory tests are often executed according standards. More often, the laboratory situation is different than the situation in practice! Careful interpretation of laboratory results is necessary.
- Re-pointing work has to be small in dimension and the materials used must be of the same family as the existing pointing,

- Water repellent material used at a higher concentration has a much longer lasting effect, which makes its application cheaper in the long run,
- The application of repellents has to be from the bottom up and not from the top down,
- Regular monitoring. This is necessary since any damage should be repaired immediately.
- Documentation about the building and the measures that have been taken. It should become common practice to include a description of the methods and materials used as is the normal procedure when work is carried out on monuments.

9 Literature

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