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Natural stone floors monitoring – inference on persistence of humidity spots

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ABSTRACT: In order to study the links between staining on natural stone and the climatic conditions at and within natural stone flooring, the Swiss Natural Stone Association (NVS) started a thorough monitoring at the test-facility located in Hunzenschwil (Switzerland). The facility is partly sheltered and consists of three natural stone types laid on three different kinds of foundation. One set of three sensors was installed for each natural stone – foundation pair. In this way, the sensors measure the temperature and the relative humidity in the stone, at the top of the foundation, and at its base. The monitoring of the staining occurs with an on-site camera.

In this paper we present the results of the first phase of the project, which was carried out over a period of two years (2014-2016). In particular, we report the links between climatic conditions, the variation of the humidity measured in the stones, and the occurrence of stains at their surface. Our observations indicate that the foundation is generally extremely humid and supplies water to the natural stone, causing this way rapidly changing humidity stains at its surface. We summarize these observations in a preliminary water-transport model. Additionally, we present the problems related to set up humidity sensors in harsh environments.

1 INTRODUCTION

In recent years, natural stone has become a trendy tiling material, both as interior as well as exterior decoration. Likewise, the tiling process evolved to a point where high-quality technical performances are a requirement. In particular, the outstanding optical appearance of natural stone floors is for most customers a request.

Sheltered and unsheltered terraces are – under certain circumstances – ideal substrates for the growth and the persistence of colorations, humidity spots and efflorescences. As a consequence, in the recent years an increased number of complaints due to the lack of outstanding optical appearance has been reported. For this reason, in 2014 the Swiss Natural Stone Association (NVS) started a project aiming at explaining the processes underlying these optical changes and at finding sustainable solutions for avoiding them. The project is carried out together with the association of Swiss tilers (SPV), with the Swiss gardener association (Jardinsuisse) and with the German natural stone association (DNV). The project is structured in two phases and will end in 2018. In the literature, the processes leading to colorations and humidity spots are generally categorized into condensation, capillary and hygroscopic. According to Krug et al. (2014) 0.5 ml water on the lower side of a Padang-Granite plate with a thickness of 1 cm produce a humidity spot about 3 cm large on the frontside of the plate after 3 hours. The plate and the foundation capillarity, expressed according to norm EN 1925 as the w-value, is responsible for the movement of the water to the surface. Snethlage (2005) classifies natural stones as „light absorbing“ (w-value < 0.5 kg/m2h), „medium-absorbing“ (0.5 kg/m2h < w-value < 3.0 kg/m2h) oder „strong-absorbing (w-Wert > 3.0 kg/m2h). Granites are in general light absorbing, whereas sedimentary and metamorphyc rocks show a huge variability. Lanicca (2005) tested the absorpion of gravel foundations and found a maximal water height of 15 cm. Dissolved salts get also absorbed by capillarity and can lead to water retention in the plate. As a consequence, humidity spots can form already at low air humidity (Frössel, 2002).

During the first phase (2014-2016), the project focused at characterizing the links between climatic conditions and the occurrence/persistence of colorations. For this purpose, a facility with a set of various tiling-systems and natural stones, which are defined as *fields*, was built in Hunzenschwil (Switzerland). On each field we placed a number of sensors measuring the temperature and the relative humidity in the stone and in the foundation. The monitoring of the staining occurred with an on-site camera. A database stored the measurements and the pictures that were performed every 10 minutes. The second phase (2016-2018) is currently ongoing and focuses at studying the efficiency of various solutions envisaged for avoiding humidity spots. In this paper we present the results obtained in the first phase and we discuss the technical difficulties we faced by placing the sensors in a wet environment.

2 FACILITY SETUP

2.1 General setup

The facility is partly sheltered and consists of three natural stone types laid on three different kinds of foundation (Figure 1). In order to simulate the terrace of a block of flats, the base of the facility consist of a concrete plate. On top of it we laid the foundation and the natural stone plates. The facility was built with a 1.5% slope.

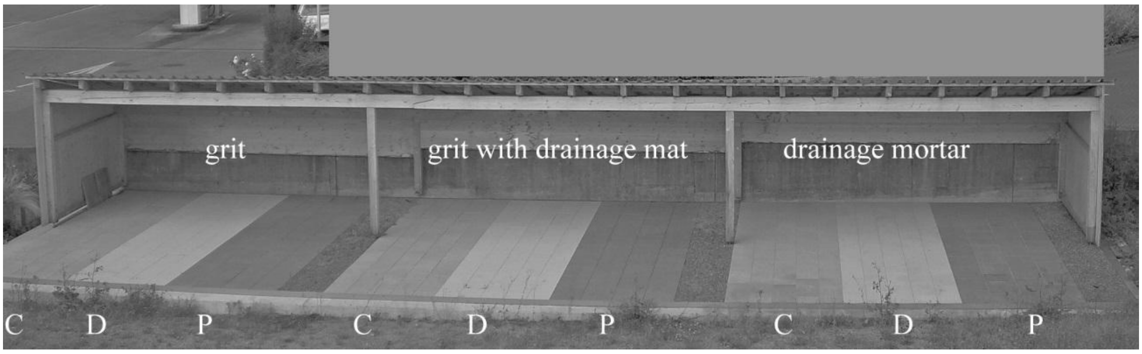

Figure 1: Overview of the facility. On three foundation types (grit, grit with drainage mat, and drainage mortar), we laid three different natural stone plates (C: Cresciano, D: Dietfurter, and P: Padang). The facility is partly sheltered and shows a 1.5% slope.

2.2 Natural stones and foundation setup

The three natural stones employed are widely used on the market. The *Cresciano* is a compact, clear Swiss gneiss excavated in Ticino (Southern Switzerland), which consists essentially of feldspar, quartz and mica. The *Dietfurter* is a light-brown german limestone with medium porosity. This limestone is rich in fossiles. The *Padang* is a Chinese granite with anthracite color. Despite its dark appearance, this rock consists essentially of clear feldspar and quartz. Dark mica and pyroxene are present in smaller amounts.

The three natural stones were laid on three types of commonly used foundation. The *grit foundation* consists of a 5 cm thick grit-layer (washed, 4-8 mm coarse). The *grit with drainage mat foundation* is similar to the grit foundation with the addition of a drainage mat (type Gutjahr T+) at its base. On these foundations the plates were laid loosely. The *drainage-mortar foundation* consists of a 5 cm thick drainage mortar layer. On the drainage-mortar foundation the natural stone plates were laid using a cementious adhesive and the joints were sealed.

2.3 Sensors setup

One set of three sensors (Sensirion SHT75) was installed for each natural stone – foundation pair. In this way, the sensors measure the temperature and the relative humidity in the stone, at the top of the foundation, and at its base. The instruments measure the relative humidity by means of capacitative sensor with high performance and long term stability. Nevertheless, it is known that their operation during long periods at relative humidities larger than 80% can cause drifting or malfunctioning. The Temperature is measured with a band-gap sensor within -20°C and 100°C.

3 MEASUREMENTS

3.1 In situ measurements

A suite of measurements were performed in situ. The measurements of temperature and relative humidity of each sensor, as well as the climatic condition with a dedicated weather station were collected every 10 minutes along with a high resolution picture of the terrace. Every month we carried out a visit of the terrace in order to check its state. During these visits we sometimes took grit out of the foundations in order to determine the absolute amount of water present in the foundation.

3.2 Problems with in situ sensor measurements

Shortly after the beginning of the experiment it became clear that the relative humidity in the foundation and in the plates lies often above 80%. Even so, most of the drifting described in the technical datasheet of the manufacturing company was observed in the unsheltered area. In that area the humidity lies always close to 100%.

Failure occurs when the sensor stops drifting and generates only error values (default -50). In general this occurs after long exposition to wet environments (Figure 2). The first sensor to fail is in general the relative humidity one. Sensors that completely failed (that is both temperature and relative humidity not working) were replaced by new ones. In total there were 6 sensors replaced in the foundation of the unsheltered area and 1 in the stone of the sheltered area. Bad measurements due to drifting or sensor failure were algorithmically filtered out during the evaluation of the data. For this purpose we discarded all values not falling in the operational range of the device. Concerning relative humidity, we decided to remove values where an abrupt change between two consecutive measurements (drift) was observed. Also, we did not accept relative humidity sensor’s values lower than air relative humidity at the weather station. In other word, we assume that the air cannot be more humid than the stone and the foundation.

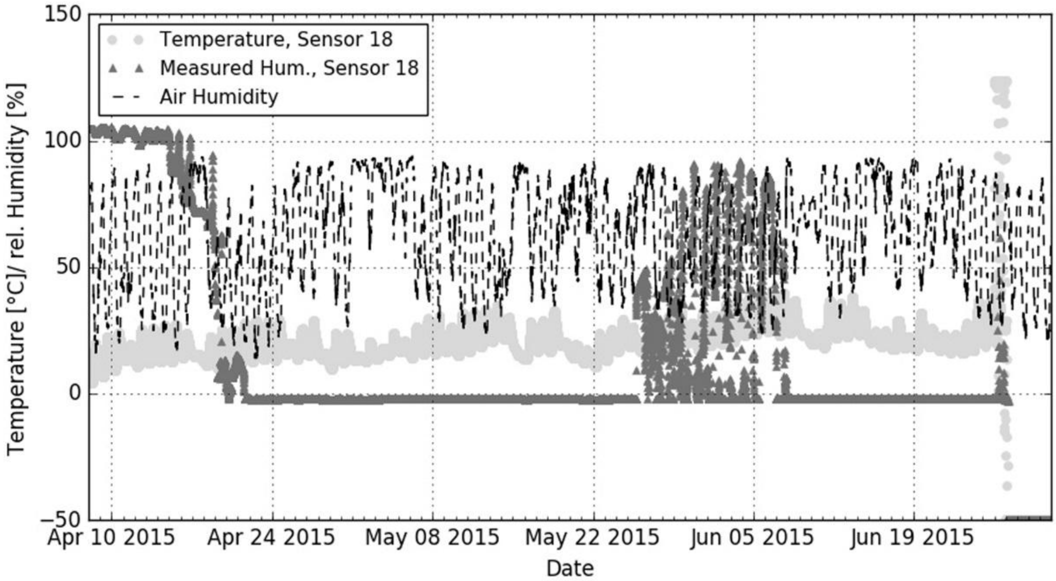

Figure 2: Example of sensor failure – sensor 18, at the base of the grit foundation in the unsheltered area, complete failure on June 26th, 2015. The relative humidity starts drifting around April 15th, the temperature sensor works correctly until June 26th.

4 RESULTS

4.1 Long term averages of the sensor measurements

The yearly average temperature in the sheltered area is rather homogeneous for each natural stone (13-14°C). In the unsheltered area the temperature varies as a function of the plate-color. The light colored Dietfurter and Cresciano show values of 12-14°C, whereas the darker Padang reaches on average ca. 15°C. The maximal Temperature reached by these plates in summertime is close to 70°C. The presence of a drainage mat causes a detachment between the soil and the plates. For this reason in this area we observe the largest temperature variation between summer and winter. The relative humidity data indicate average values between 85 and 100 % in the sheltered area and close to 100% in the unsheltered area, independently of the foundation type. In this respect, there is no evidence that a particular foundation type works better than another. In all cases the average values lie close to the observed peaks, showing that in general the system is strongly humid.

4.2 Absolute humidity of the foundation and sensor measurements

Figure 3 shows the average amount of water content for all fields – both sheltered (Figure 3a) and unsheltered (Figure 3b) - measured between July and Novemeber 2015. The climatic conditions when the sample was collected are also depicted on top of the figure. The amount in the sheltered area does not vary with time, it remains constant at about 0.1 l water per m^2 grit. In the unsheltered area there is as expected a clear correlation with the climatic conditions, and so the water content varies between 0.5 and 3.0 l water per m^2 grit. In most cases the grit in the unsheltered area was clearly wet, independently of the use of a drainage mat. Furthermore, we notice that the grit dries in an irregular way, that it, under a single plate wet and dry patches can coexist (Figure 3b). Therefore it is not surprising that the sensors values always lie in general above 80 % relative humidity. The only clear decrease in relative humidity values was recorded during the heat wave (July-August 2015). The sensors show that it takes about one week in the sheltered area to reach a minimum value (that is to dry the grit) and about two weeks in the unsheltered area.

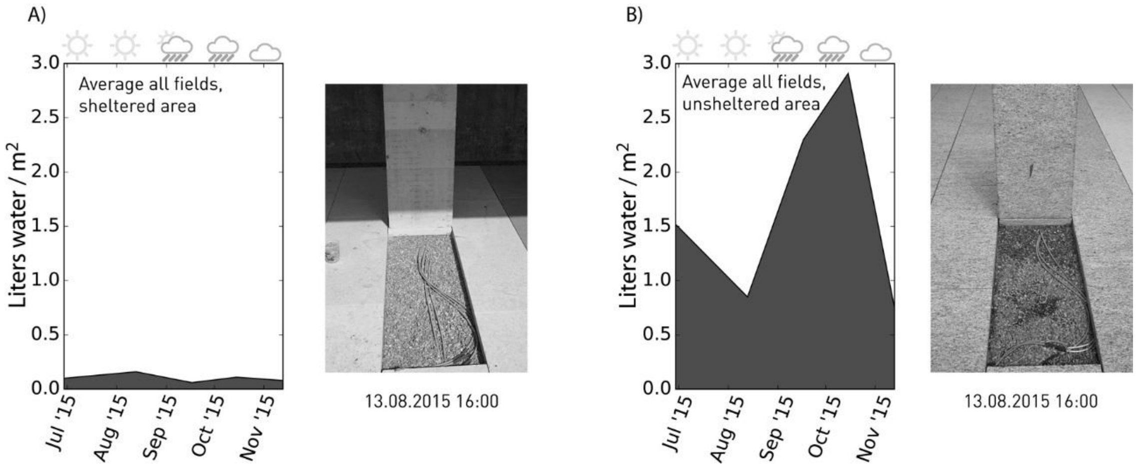

Figure 3: A) sheltered area. Left: amount of watered measured in the foundation (average of the 6 sampled locations), right: example of a sampling location. B) unsheltered area. Left – amount of water in the foundation (average of the 6 sampled locations), right: example of a sampling location. In the unsheltered area dry (clearer) and wet (darker) patches in the foundation can coexist.

4.3 Stains development

Stains developed in the unsheltered area only and were categorized in two groups: pulsating stains occurring on foundation types *grit* and *grit with drainage mat*, and hygroscopic stains occurring on the *drainage mortar* foundation. In most cases spots were observed on the Cresciano and Padang plates, but not on the Dietfurter ones. Pulsating stains originate from the irregular distribution of dry and wet patches in the foundation (Figure 3b), whereas hygroscopic ones are linked to the presence of salts (in particular sulfates) in the drainage mortar. The latter kind of stains shows no time variability.

4.4 Correlation between stains and sensors measurements

In order to check whether there is a correlation between stains occurrence and climatic parameters, we checked if the plates on each field in the unsheltered area showed spots and compared it with the air temperature / air relative humidity measurements at a given time (every day at 9.00 and 15.00). A comparison with the sensor values measured directly in the plates was difficult due to the sensors drift and the relative humidity values constantly close to 100%.

The scatter plots (Figure 4) show the field condition (dry, solid contours; wet, dashed contours) as a function of air temperature and air relative humidity pairs. The contours show the percentage of measurements falling within them. Dark grey areas correspond to 25% of the measurements, grey areas to 50%, and light grey to 75%. In particular we observe two almost distinct cluster for the Dietfurter plates, which show a dry condition when the temperature lies above 10°C and the relative humidity below about 50%. The Padang and the Cresciano plates show overlapping clusters, indicating that a clear distinction between the two conditions is not feasible in these terms. In this approach the time variation of the climatic conditions is not taken into account, however the climatic condition preceding the observation has an influence on the dry or wet state of the plate. In terms of practical applications the main result is that both

Cresciano and Padang can show humidity stains under normal Swiss climatic conditions. In the case of drainage mortar, both Cresciano and Padang show persistent hygroscopic stains. For that reason only the contours for the wet condition are visible.

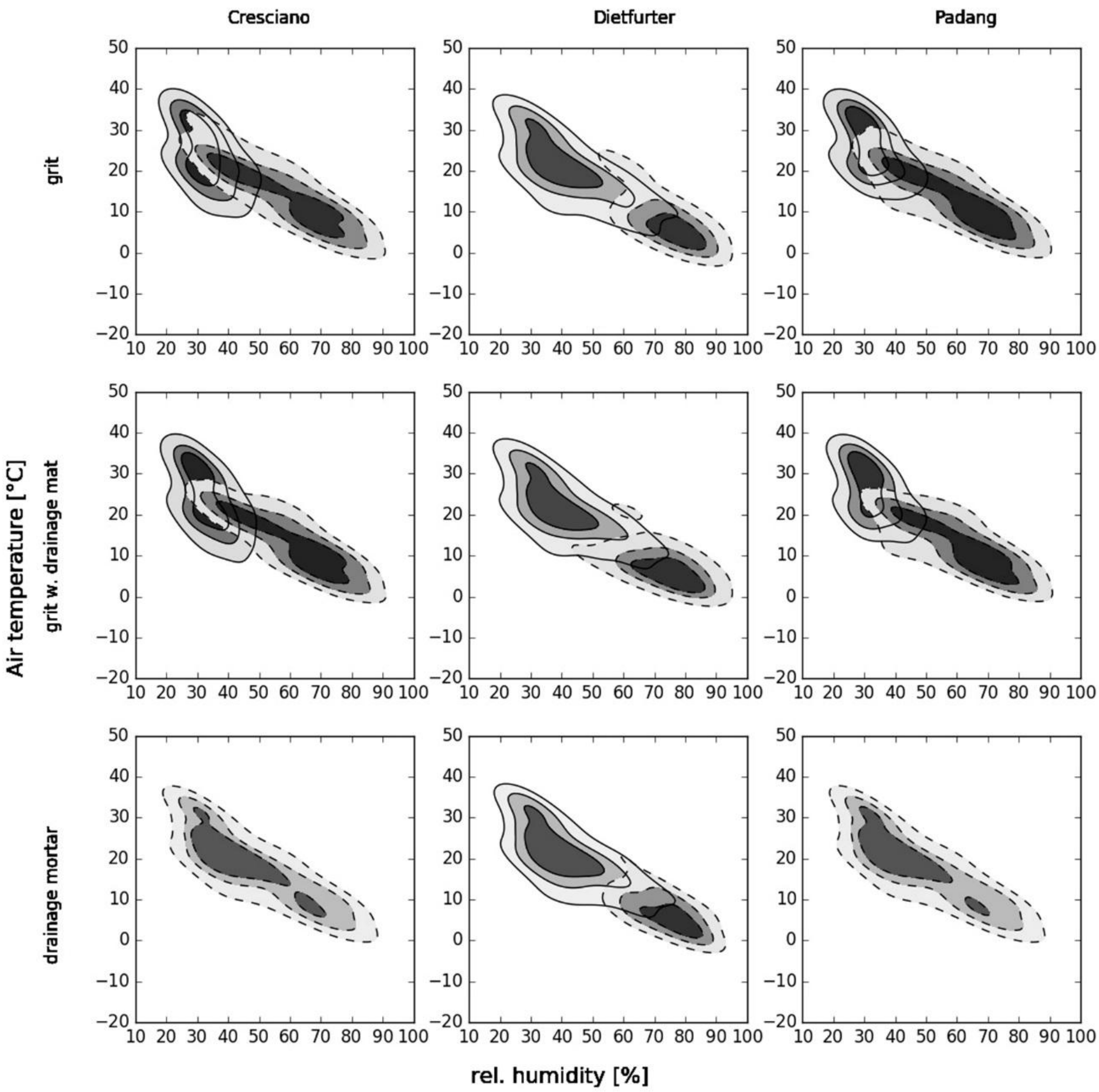

Figure 4: Air Temperature and air relative humidity pairs showing the occurrence of dry (solid contours) or wet (dashed contours) fields in the unsheltered area. The grayscale represent the amount of data within a contour: dark grey = 25% of measurements, gray = 50% of measurements and light gray = 75% of measurements.

5 DISCUSSION AND CONCLUSION

The results obtained during the first phase of the project can be summarized as follows. First, the lack of stains in the sheltered area indicates that there the risk of defects is minimal if built according to the state-of-the-art techniques. In the unsheltered area we notice that the usual foundation types are not efficient. All foundation tested act as water reservoirs and keeps getting refilled after each precipitation. It must be stressed here that we used a drainage mat with fleece, which easily clogs up with fine sediments. The version with plastic net should improve the seepage, particularly when unwashed grit is used. The capillary forces of the grit account for the water transport towards the base of the plate. There again, the capillarity of the plate transports the water towards the plate surface and creates the spots. The formation of spots depends on the capillarity, on the drying conditions at the plate surface, and on the transparency of the plate itself. The model we established (Figure 5) is based on actual measurements and observations, partly reported in this paper. Further, if salts are present in the foundation, as it is in the case of the drainage mortar, then water retention also occurs. In that case we observe the formation of persistent hygroscopic stains. Clearly, the interaction between foundation and plate plays an important role in the formation of humidity spots. Therefore, the envisaged solution to avoid it consists in placing a capillary barrier between the plate and the foundation. Four kinds of capillary barriers are currently tested in Hunzenschwil and show promising results.

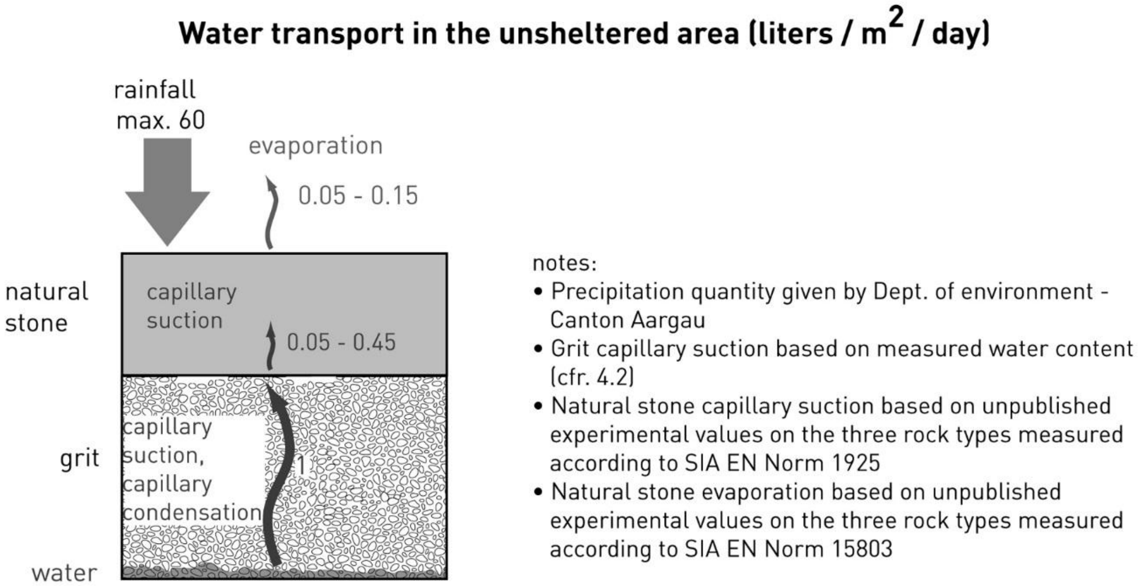

Figure 5: Water transport model based on actual observations and measurements. All values reported were carried out within this study.

The foundation-plate system described above indicates that the sensors employed are taken to their operational limits. In this respect, the measurements confirm the harsh humidity conditions in the foundation and in the plates. On the other hand, the values obtained do not allow us to establish a clear link between the occurrence of stains and the climatic conditions in the foundation-plate system. For this reason we analysed the link between stain occurrence and air climatic conditions. This analysis shows that stained and pristine fields form distinct clusters in case of the Dietfurter limestone and partly overlapping ones in case of the Cresciano gneiss and the Padang granite. If the outstanding optical appearance is requested, the use of Cresciano and Padang as tiling materials should be done only in combination with an efficient capillary barrier between the plate and the foundation.

In the second phase of the project we will have a closer look at various tiling systems where we place a capillary barrier between foundation and natural stone plate. Further, the occurrence of stains depends on the type of natural stone. For this reason we will perform laboratory tests on several natural stones to assess their likelihood to develop humidity stains.

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