ENVIRONMENT AND DETERIORATION OF THE MONUMENTS OF BARI

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Abstract

Deterioration is and irreversible transformation that results from the interaction between environment and artefact, often facilitated by the presence of the pollutants and thermal stresses charateristic of urban areas. At times, though it is not possible to alter the non-uniformity of works of art, one can reduce dererioration by modifying the intensity of environmental stresses, wind, thermal and hygrometric, by means of architectural or plant barriers. Such screening actions must be both non-invasive and removable, since the morpological evolution of urban centres may result in changes in the prevailing directions of the masses of air circulating within the area to protect, as well as changes in surface condensation phenomena over the exposed areas. To intervene in the way indicated, it is necessary to have a detailed knowledge of the local environmental parameters: air temperature, RH, rainfall, and wind speed and direction. Bari is one of the historic Italian cities in which deterioration phenomena are linked to both marine aerosol and urban pollution. An environmental study has been carried out in this city which analyses some of the most recent data available (source ITAV), from which there emerge some indicators on the aforesaid environmental parameters in defferent seasons of the year. Even when measures are not possible, maintenance and restoration work should be carried out in a way that takes account of the different intensities and directions of environmental stresses.

Deterioration

Until now, deterioration has generally been understood as loss of material. In reality, one often finds forms of deterioration without any loss of material and in some cases even an addition (for example black crust formation). This implies a partial revision of the concept of deterioration. A more adequate definition might be "loss of information" in the sense that what is lost in the case of a work of art is truly the original information, whether it be an image, an inscription or an architectural element. It is certain that deterioration is an irreversible transformation that derives from the interaction between environment and artefact and manifests itself following exchanges of energy and mass. In study of the causes of deterioration, and especially in research on methods of conservation and protection, it is important to identify accurately what phenomena are principally responsible for the deterioration and their source, so as to reduce their effects or in any case control their mode of action. Deterioration is normally not due to a single cause, but is the result of the interaction of a number of agents which combine to define or originate processes of disintegration of the material. It goes without saying that in addition to knowing the material that constitutes the work, that is its composition and physical and chemical characteristics, one must analyse the surrounding environment as thoroughly as possible, since in deciding on corrective measures, emphasis must be put on reduction of the causes of deterioration and if possible their elimination, rather than treatment of effects, as is usually the case in restoration work.

It might be objected that reduction of the causes of deterioration is not always an easy process to launch, but at times exact knowledge of the phenomena at work and a few simple measures to reduce the effect of the agents of deterioration, at least locally, by appropriate targeted measures, are sufficient.

Agents of deterioration

The principal agents responsible for deterioration are heat flows originating from daily cycles of surface temperature stress, and moisture flows associated with

absorption and evaporation, as well as cumulative thermo-hygrometric effects that may induce condensation and in some cases ice formation.
Another factor in deterioration is wind which, in addition to exerting a mechanical action, especially on surface particles already weakened in their cohesion, generates an increase in evaporation and therefore cooling, which in some cases may result in the formation of salt crystals with loosening effects.

To these and other phenomena there is added the accelerating effect of air pollutants. In some cases these can have an enormous influence on the conservation status of artefacts because, in special conditions of moisture, they may give rise to acids that interact directly with the material. In other cases the acids originate on the surface following surface condensation phenomena. However one must not forget the contribution, even though it is a limited one, of chemical-physical phenomenon in dry conditions (with a low R.H.).

Unevenness of deterioration
From what has been said it is clear that deterioration of monuments is the result of interaction between different stresses (wind, thermal, moisture) and is facilitated by the presence of pollutants. These stresses, however, do not act homogeneously and therefore create a type of differential deterioration that varies over time and from point to point. In other words, we must assume that the velocity of deterioration is a function of space and of time. In fact some manifestations of deterioration occur only in certain seasons or at specific points of the work.

The effect of pollution, like that of the other factors considered, is not uniform over the whole work. For example, the particulates will settle in certain zones according to the prevailing winds and the conformation of the work, in zones not subject to washing by rain. In addition, the açcumulation of particulates is in some way facilitated in zones where the temperature is lower, either because condensation occurs more readily there, or because the particles exchange more energy on impact and no longer have enough to detach themselves from the surface. Exchanges of energy and mass, and in particular of heat and moisture, between the environment and the artefact can take place in both directions and can be more intense at some points than at others. One need only think of condensation phenomena, which appear at certain periods of the year and some points of the artefact. The mechanical stresses exerted by wind and passing traffic also have a different influence from point to point, according to the type of stress or more properly to the frequency with which they occur, as well as their intensity. These stresses manifest their effects on minute elements already loosened or on larger elements in which the stresses may be amplified if they coincide in frequency with the resonance frequency of the object.

If we conduct an initial analysis of deterioration phenomena we see that their causes are many and not uniformly distributed, but that they can be put in two distinct categories. On the one hand there are the causes external to the artefact, which can manifest themselves differently from point to point or zone to zone, thus exerting a non-uniform action (one need only think of the zones near heat sources in which the heat flow is greater than in other zones where the temperature is lower). On the other hand, we must also look at the internal causes, those that depend on the non-uniformity of the material and differences in surface exchange characteristics. In this case we are dealing with different moisture or heat transfer characteristics in the body of the material, which induce different surface phenomena. In fact the hypothesis that the artefact behaves homogeneously is not always valid. This diversity is attributable to two causes (Fig. 1)

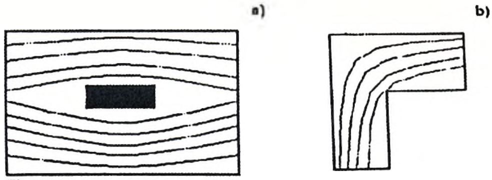

Figure 1

a) structural non-uniformity, which appears when there are a number of materials in the same structure, resulting in local differences in exchange phenomena.
b) non-uniformity of shape, due to the configuration of the artefact in some way modifying the direction and intensity of the various flows.
This means that in certain zones, where the flow is greater, the phenomena are accentuated.

Pollution and deterioration at Bari
The monuments in Bari city are subject not only to thermo-hygrometric and wind stresses but also to various actions associated with the high level of pollutants present, arising from vehicle traffic, heating (though less than in some other cities) and the marine aerosol. In fact Bari is one of the historic Italian cities where deterioration phenomena are simultaneously associated with the marine aerosol and urban pollution.
Pollution and environmental deterioration require a scale of priorities that is not limited to emergency measures but aims at developing a planning policy of restructuring, decentralisation and rehabilitation of our cities. Environmental analysis and control are today proving essential for this purpose.

In general in urban areas, and in historic city centres in particular, human activity and deterioration of monuments are closely linked. The problems deriving from their interaction become considerably more acute in parallel with industrial and urban development and with the uncontrolled expansion of linking infrastructures (the road network).

The city of Bari and its development
The particular form taken by the city in present times therefore exerts a very significant influence on the conservation of its ancient parts.

The old city of Bari is today on the margins of the present city's economic life, squeezed between the modern port area to the north and northwest (Corso Antonio de Tullio), the shoreline to Porto Vecchio at the north east and east (Lungomare Imperatore Augusto), the "Borgo murattiano" with the government buildings to the south (Corso Vittorio Emanuele) and the Norman-Swabian castle to the east of the commercially most important area of the old city (S. Sabino Cathedral quarter - Fig. 2).

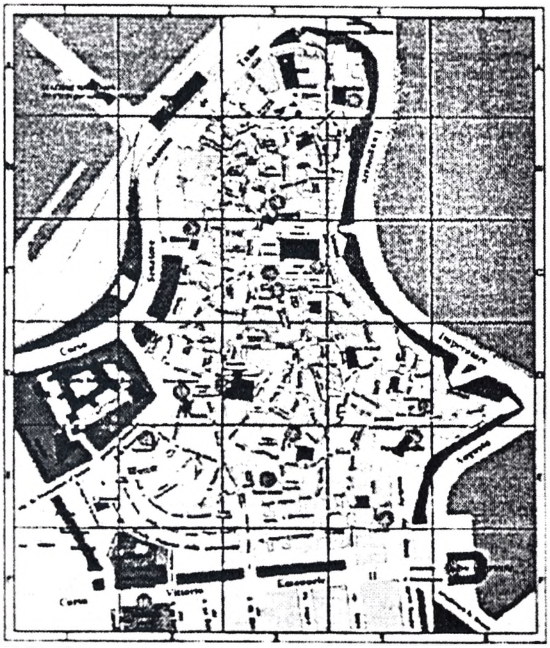

Figure 2

This ring of main roads with high traffic densities, into which the main urban and provincial trunk roads flow, both shows and increases the social and economic isolation of the Old City and hence its deterioration and abandonment. The intensity of the vehicle traffic is no negligible factor for deterioration of the monuments of the ancient area, not least because of the mechanical stresses induced. In this context, it was judged essential to launch a campaign of environmental monitoring at some of the principal monuments of the old city, and specifically the S.Sabino cathedral and the Sedile dei Nobili Palace.

Condition of the artefacts

The limestone and marble used in Bari cathedral are subject to sulphate formation and de-cohesion phenomena comparable to those found in other monuments exposed to a polluted urban environment (from the effects of carbonic and sulphuric acids).

Recent examinations and past analyses have revealed severe forms of deterioration (black crusts, flaking, erosion) and specifically the formation of gypsum and other soluble salts, including nitrates and chlorides, with the formation of surface deposits. These are favoured by the presence of chlorine in the coastal environment and are subject to crystallisation-solution cycles that create stresses.

As is well-known, the deterioration agents at the root of these phenomena are normally present in the atmosphere but have a greater influence in urban areas.

Sulphur, typically a by-product of heating, can give rise to harmful acids and in certain conditions to sulphuric acid, and thus provoke surface reactions at specific points, as already described. Nitrous anhydride (NO2) can combine with water vapour to produce nitrous and nitric acids, which also have a disintegrating action, but their effects are difficult to demonstrate because the salts produced are extremely soluble and are washed off with the first rain. The presence of these salts can be detected only in areas where there is no washing action. In addition, chlorine ions, generally present near the sea, are injected into the city air in specific weather conditions through atmospheric particulates. Obviously the wind direction has a decisive influence on this phenomenon as it localises certain deposits in various forms.

Meteorological conditions at Bari

Many studies have sought to analyse decay of monuments in relation to the presence of pollutants and microclimatic conditions, but links to local meteorological conditions have rarely been made. Knowledge of these conditions is fundamental to study of deterioration since it makes it possible not only to interpret some phenomena and forecast certain effects, but above all to correct or reduce the primary stress imposed in the artefacts. This is what we aimed to do in analysing the most recent meteorological data available for the city of Bari (1981-85). The data examined comprise daily values for air temperature, rainfall, relative humidity, and wind speed and direction.

On the question of temperature, it seems fairly clear that the distributions of both maximum and minimum values are not symmetrical; that is, they are not normally distributed but show a slight skew (Fig. 3).

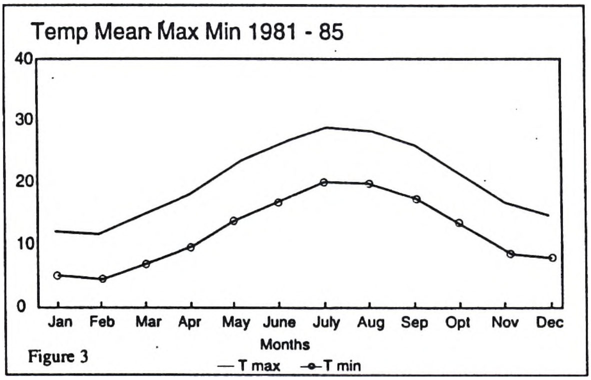

Figure 3

This means that the temperature increases slowly during the spring-summer period, but falls more rapidly in the autumn-winter period. In other words, there is a sharp change from maximum temperature values that permit a greater water vapour content in the air, to lower values that contribute to a substantial rise in relative humidity. However relative humidity remains very high throughout the year, with maxima of about 90% and minima that hardly ever fall below 60%. Such a high minimum is attributable to closeness to the sea (Fig. 4). Such a high relative humidity obviously increases the probability of condensation on the surface of the artefacts, which readily appears if the temperature drops sharply, even if only a little.

Another parameter that needs to be taken into account is the specific humidity (SH), that is, the water vapour content of the air per unit of mass. This value has been calculated from the values for the at temperature Ta and the relative humidity RH, applying the following formula.

SH = 100*(0.0063 + 0.038 RH/100)*(1.0618 RH/100 0.0073) Ta.

As appears from Fig. 4, the trend of the specific humidity closely follows that of the temperature, though with a slight delay. From this one can deduce that it is in some way controlled by the temperature. Again in Fig. 4, one notes that the decrease in RH in the summer months is accompanied by an increase in the specific humidity, SH.

As regards rainfall, it can be stated that there is a definite linkage with the values for relative humidity (Fig. 4).

In fact, in the central portion of the year, the decline in rainfall (June-July) is accompanied by a comparable decline in relative humidity. Vice versa, to the rather sharp increase in rainfall from August on, there corresponds a more gradual but consistent rise in relative humidity.

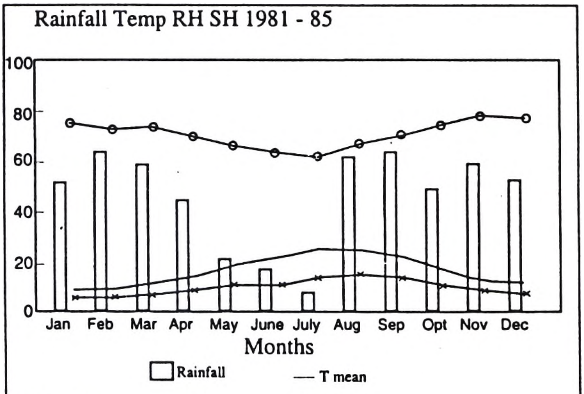

Figure 4

In the winter period, January-February and November-December, the values for relative humidity do not necessarily follow those for rainfall but seem more controlled by the temperature, since when temperature falls the relative humidity rises (even when rainfall declines). Using the meteorological data for 1981-85, a modelling approach was attempted that linked relative humidity values to those of temperature and rainfall. The results of this model are expressed in the equation

RH = 72.85 + 0.1375 P - 0.5 Ta

where P is the rainfall in mm and Ta is the air temperature.

It emerged that there is a considerable rise in the temperature in Bari during the summer, accompanied by an absence of rainfall, which should lead to a considerable drying out of the monuments. In reality, this effect is partially mitigated by the specific humidity, which rises in this period as a result of evaporation from the sea. Therefore drying phenomena will certainly be evident but not such as to result in extreme dryness of the materials, since they can re-absorb moisture at night.

From the analysis of wind direction one observes a cycle typical of zones exposed to a marine climate, since at 7 a.m. (Fig. 5)

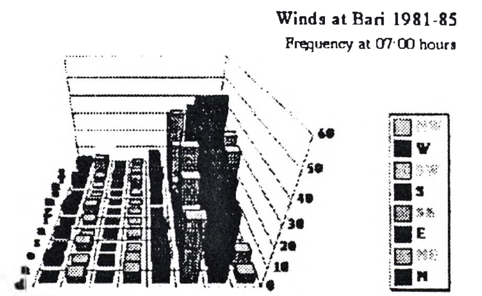

Figure 5

the winds come prevalently from W-SW over the whole of the year, whereas in the afternoon, and specifically at 1 p.m. there is a reversal and the winds are prevalently from the opposite (NE) direction (Fig. 6).

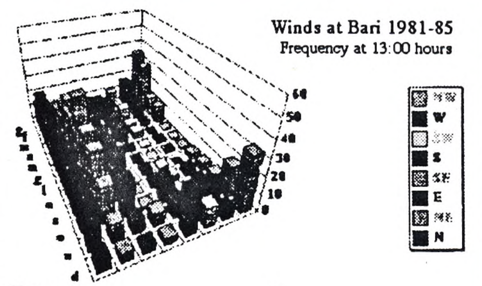

Figure 6

The situation in the evening (7 p.m.) is less clearly defined; all directions have similar probabilities (Fig. 7).

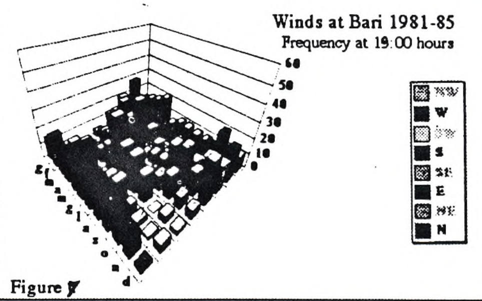

Figure 7

Analysing the distribution of maximum wind speeds, one notes some peculiarities. Winds from the Southeast are almost completely absent throughout the year, while

North-easterly (N-NE-E) winds prevail in summer and westerlies (SW-W-NW) prevail in winter (Fig. 8).

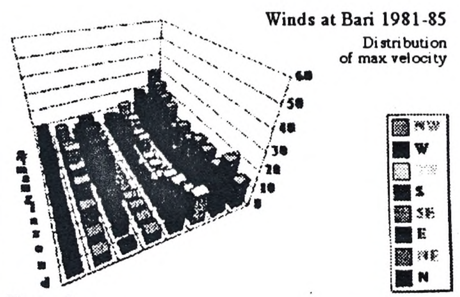

Figure 8

We also note that the mean wind velocity is around 8 knots with a typical log-normal distribution (Fig. 9)

On the basis of the data analysed, we can say that for the periods examined this distribution corresponds to the expression

y = a + b exp (-0.5(ln(x/c)/d)^2)

with a = 0.10

b = 18.0

c = 7.1 a

nd d = 0.3

The values for maximum velocity are around 20 knots, again with a log-normal distribution (Figures 10, 11)

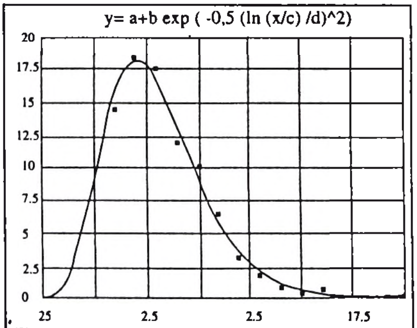

Figure 9

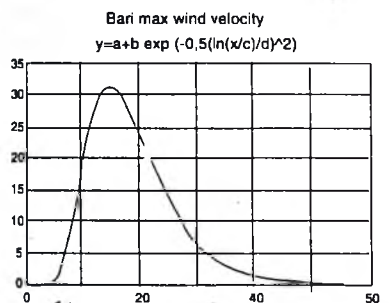

Figure 10

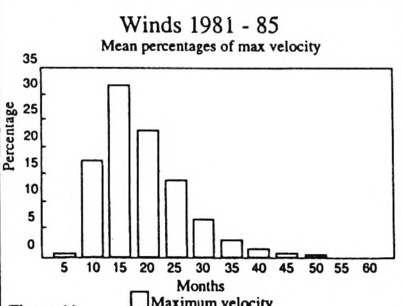

Figure 11

which can be expressed by the relationship

y = a + b exp (-0.5(ln(x/c)/d)^2)

with a = 0.02 b = 31.3 c = 15.1 and d = 0.3

In Fig. 12, which shows the values for maximum velocities over the course of the year, one notes that the highest velocities appear in November, followed by January and March, whereas the lowest velocities are in the summer months, except for August, which shows some irregularities.

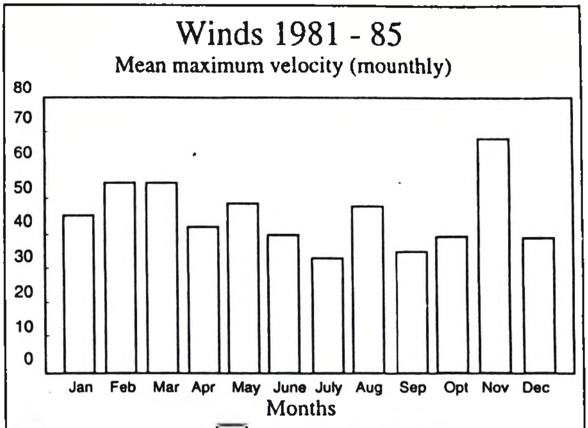

Figure 12

Conclusions

At Bari in particular, the problems arising from surface condensation as a result of high relative humidity could be increased, on cold days and at night, by the fact that the fall in the ambient temperature in the autumn is steeper in than the rise during the spring (Fig. 3). This is still more so for artefacts and monuments exposed in the open air, which radiate the heat gained during the day, especially in the calm evenings which are not rare in autumn at this latitude. The phenomena associated with thermal expansion of materials, which can occur with rather high temperatures, also and chiefly manifest themselves in the transition period in late spring, though the effects appear later, with a certain time lag. Identification of wind direction and strength in association with other environmental factors, helps in understanding when and where deterioration processes such as wind erosion and thermal shock might occur.

As has already been pointed out, not only the transport of pollutants and particulates, but also the possibility of their deposition on monuments and the points where they accumulate depend on the wind direction. Winds also determine the direction and angle of incidence of rain, and afterwards the speed of drying of surfaces, as well as exerting a deleterious mechanical action of surfaces that have already lost cohesion.

At 13.00 hours in the summer period (Fig. 6) the prevailing winds are from the east and as a result, since zones exposed to the east are normally colder, receiving less solar radiation, it is more likely that moisture will be absorbed at night and that these zones will therefore be more critical in terms of wetting/drying cycles. On the other hand, if we look at the conservation status of already deteriorated architectural works, the directions carrying most risk are north-easterly (Fig. 6), especially during the month of November, because of the intensity of wind action which aggravates the condition of already loosened portions of material.

If we want to conserve works exposed to the open air in the best way possible, it is necessary to identify the parts of the monument most subject to stress and to analyse not only the wind direction at the various times of day but also the temperature, humidity and pollutants present in the same periods of the day. This analysis should make it possible to identify the most critical directions and therefore to study possible protective measures. Such measures might be on a city scale (such as measures to reduce pollutants) or on a smaller scale, limited to the environment surrounding the monument (such as creating architectural or tree barriers). Even when actions on this scale are not possible, it should be remembered that both maintenance and restoration works need to be done differently according to the intensity and direction of the stress. In theory it would be necessary to adjust the "weight" of conservation and restoration operations to compensate for the unevenness of deterioration, whether this depends on environmental agents or on the type of material or on the conformation of the artefact.

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