CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION
UN/ECE INTERNATIONAL CO-OPERATIVE PROGRAMME ON EFFECTS ON MATERIALS, INCLUDING HISTORIC AND CULTURAL MONUMENTS

Report No 70:
Pilot study on inventory and condition of stock of materials at risk at United Nations Educational, Scientific and Cultural Organization (UNESCO) cultural heritage sites. Part II Determination of stock of materials at risk for individual monuments.

September 2012

PREPARED BY THE SUB-CENTRE FOR STOCK OF MATERIALS AT RISK AND CULTURAL HERITAGE

Italian National agency for new technologies, Energy and sustainable economic development (ENEA), Rome, Italy
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Part II Determination of stock of materials at risk for individual monuments.

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Summary

The International Co-operative Programme on Effects on Materials, including Historic and Cultural Monuments (ICP Materials) started in 1985. It was initiated in order to provide a scientific basis for new protocols and regulations developed within the Convention on Long-range Transboundary Air Pollution. The main aim is to perform a quantitative evaluation of the effects of multi-pollutants such as S and N compounds, O₃ and particles as well as climate parameters on the atmospheric corrosion of important materials, including materials used in objects of cultural heritage. The primary objective is to collect information on corrosion and environmental data in order to evaluate dose/response functions and trend effects and use the results for mapping areas with increased risk of corrosion, and for calculation of cost of damage caused by deterioration of materials.

Cultural heritage is very sensitive to air pollution resulting in corrosion and soiling on the materials which was used to create the artefacts. Applying the dose/response functions developed in ICP Materials to the specific monument, will permit us to evaluate the corrosion and to calculate the cost of damage due to deterioration of materials of the monument. This was performed for some important monuments in Europe.

In the report we apply the methodology which consist of a real in-the-field inventory, facade by facade, building by building, and monument by monument, applying maps, images and other documents at the available scales. The nature of the materials employed was determined by direct examination of the building facades and using literature data (limestone, rendering/mortar/plaster, painting, brick, metal, modern glass), their proportions was roughly evaluated in percentage. Different types of limestone were used in the construction of the studied monuments.

The dimensions of the monuments was identified using direct examination, images, photos, drawings and other available in literature and internet sources. From the dimensions its surface was calculated valuating the surface covered by windows, doors etc.

As the domminating material is limestone, the dose response function for limestone was applied to determine the corrosion of the materials used for the construction of the monuments.

In this report we study five important UNESCO Cultural Heritage sites: Greece, Athens, Acropolis, (The Parthenon); France, Paris, The Facades in the Centre of City; Czech Republic, Prague, The National Library; Germany, Berlin, The New Museum; and UK, Bath, Royal Crescent. Some of them are very complex.

In this second part in the report series on the UNESCO study we evaluate the exact surface of the studied monuments. The air pollution data for 2009-2010 was used except for Prague were the local data for 2007-2008 was used. Based on the Dose/Response function for limestone this data indicate that only for New Museum of Berlin the corrosion depth was higher than the tolerable corrosion rate.
1. Introduction

Air pollutants, together with climatic parameters, are of major importance for the deterioration of many materials used in cultural monuments. They are emitted by industrial activities and by the transport sector. These pollutants create problems on the local scale but they are also transported in the air over long distances.

One of the international organizations and institutions which study these effects is the UN ECE Convention of Long Range Transboundary Air Pollution (CLRTAP) under which operate the International Cooperative Program on effects on Materials including Cultural Monuments (ICP Materials) that started in 1985. This is one of several effect-oriented International Co-operative Programmes (ICPs) dedicated at studying the harmful effect of air pollution on materials. It was initiated in order to provide a scientific basis for new protocols and regulations developed within the Convention on Long-range Transboundary Air Pollution.

To reduce the harmful effects of pollutants on human health and the environment, the European Directive 1999/30/EC has been issued relating to limit values for sulphur dioxide, oxides of nitrogen, particulate matter and lead in the ambient air. These limit values have been established with reference to health and ecosystem effects but not to effects on building materials and cultural monuments. The European cultural heritage is very large and cost billions of euro to maintain. It is important to understand the fact that such materials from which the cultural monuments are created are sensitive to pollution at even lower levels than biological systems.

The costs for deterioration and soiling of different materials due to air pollution are huge and the damage to culture targets endangers seriously the cultural heritage. Effective policy making requires environmental impact assessment, cost benefit analysis and risk management. All these techniques need a serious scientific basis to support the assessment and the calculation of the effects of pollution.

In this report we apply a methodology to estimate the real surface of the selected monuments and the materials from which they are created, in percentage. After that the ICP Materials dose-response functions was used. This permit to evaluate the corrosion and soiling effect of air pollution on the monuments and in the next study to calculate the cost of damage due to deterioration of materials of the monument.

In this report we selected five important UNESCO Cultural Heritage sites: Greece, Athens, Acropolis, (The Parthenon); France, Paris, The Facades in the Centre of City; Czech Republic, Prague, The National Library; Germany, Berlin, The New Museum; and UK, Bath, Royal Crescent. Some of them are very complex.

In this second part in the report series we evaluate and calculate the exact surface of the studied monuments. The air pollution data for 2009-2010 was used except for Prague were the local data for 2007-2008 was used. Based on the Dose/Response function for limestone this data indicate that only for New Museum in Berlin the corrosion depth was higher than the tolerable corrosion rate.
2. The Methodology

The methodology which we apply consists of a real in-the-field inventory, façade by façade, building by building, and monument by monument, based on maps at the available scales. The dimensions of the monuments was identified using direct examination, images, photos, drawings and other data available in literature and internet sources. From the dimensions its surface was calculated valuating the surface covered by windows, doors etc.

The nature of the materials employed was determined by direct examination of the building facade (limestone, rendering/mortar/plaster, painting, brick, metal, modern glass) or using the literature sources. The proportions of materials was roughly evaluated in percentage. The dimensions of each monument were taken using the literature sources, images and proportions. When this was not available the height of the building was estimated by counting the number of floors and attributing them an individual average height of 3 m. A control of this arbitrary height of 3m per floor was performed using a laser beam measurement and the error did not exceed -10% (Paris (3)).

The determination of the length of the facades was obtained by measurement on the available city maps. Having height and length, the surface was easily deduced. This entire surface was attributed to the constituting materials according to their proportions. The surface of the apertures (windows, doors), classically considered by the architects equal to half of the total surface of the facades was deduced from the materials surface of the monument. In summary, the total calculated surface was attributed to the constituting materials and half of this surface arbitrarily attributed to the modern glass of the windows.

The height and length of the monuments (the Parthenon, the new Museum in Berlin and the National library in Prague) was obtained from the official technical documents which are available and from the literature data.

3. Dose-Response Functions

The most recent development of dose response functions for corrosion in the new pollution situation in Europe have been developed in cooperation with the EU project MULTI-ASSESS based on data obtained in the ICP Materials multi-pollutant exposure program. The degradation of limestone is expressed as surface recession (R, μm). This function (Equation 1) includes a range of pollution and climate parameters. The pollution parameters are the gases SO₂, HNO₃, and particulates as PM₁₀, expressed in μg m⁻³. The climatic parameters are temperature (T, °C), quantity wet precipitation (Rain, mm), relative humidity (RH, %) and acidity in wet precipitation (H⁺, mg L⁻¹). For limestone the effect of relative humidity is introduced through the parameter RH60, which is equal to (RH-60) when RH>60, otherwise is 0.

Portland limestone

\[
R = 4.0 + 0.0059[SO_2]RH_{60} + 0.054Rain[H^+] + 0.078[HNO_3]RH_{60} + 0.0258PM_{10}
\] (1)
4. STOCK AT RISK

We need of a uniform approach for policy makers to may indicate them a target levels of corrosion.

When the UN/ECE Mapping Manual is applied to tolerable levels, the tolerable corrosion rate, first year exposure ($K_{tol}$) can be calculated as:

$$K_{tol} = n \times K_b$$  \hspace{1cm} (2)

here $n$ is a factor and $K_b$ is the background corrosion rate, first year exposure for Europe. It was established that, the target for 2020 y. (correspond to $n=2.5$) and taking into account the background corrosion rates during the first year of exposure, taken from the UN/ECE Mapping Manual, the estimated tolerable corrosion rates calculated from Equation (2) are almost identical to the tolerable levels established from maintenance intervals (corrosion depth before action/tolerable time between maintenance). It was decided that the target for 2050 y. (correspond to $n=2.0$). In Table 1 the tolerable corrosion rate for the first year of exposure for limestone is indicated for the target for 2020 and also for the target for 2050. The tolerable corrosion rate given in Table 1 are those used for further assessment of target levels and is thus considered a conservative lower estimate of the tolerable level.

We may calculate the corresponding acceptable pollution concentrations from the tolerable corrosion rate using the dose-response functions. From the tolerable corrosion rates indicated in Table 1 and the real measured or estimated corrosion rates we may establish if a specific site may be classified as tolerable or exceedence (risk) site.

**TABLE 1. Tolerable corrosion rate based on background corrosion rates and the target for 2050 y. (n=2.5) and the target for 2020 y.(n=2.0)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Background corrosion depth (BCD)</th>
<th>Factor for acceptable corrosion</th>
<th>Tolerable corrosion rate per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone</td>
<td>3.2 µm</td>
<td>2020 target (2.5 times BCD)</td>
<td>8.0 µm year$^{-1}$</td>
</tr>
<tr>
<td>Limestone</td>
<td>3.2 µm</td>
<td>2050 target (2.0 times BCD)</td>
<td>6.4 µm year$^{-1}$</td>
</tr>
</tbody>
</table>
3. UNESCO Cultural Heritage Sites

a) **Greece, Athens, Acropolis, (The Parthenon)**
- Coordinates: N37° 58′ 15″.132, E23° 43′ 34″.248
- Included in UNESCO CH list in 1987.

1. **Historic data:**
   The Acropolis hill (acro - edge, polis - city), so called the "Sacred Rock" of Athens, is the most important site of the city and constitutes one of the most recognizable monuments of the world (Fig.1). Over the centuries, the rocky hill was continuously used either as a cult place or as a residential area or both. During Perikles' Golden Age (5th B.C), ancient Greek civilization was represented in an ideal way on the hill and some of the architectural masterpieces of the period were erected on its ground. During the Classical period (450-330 B.C.) three important temples were erected on the ruins of earlier ones: the Parthenon, the Erechtheion, and the Temple of Nike, dedicated to Athena Parthenos, Athena Polias, and Athena-Apteros Nike, respectively. **The Propylaea**, the monumental entrance to the sacred area was also constructed in the same period. The history Acropolis was described in Report 68 (1).

![Fig. 1 The Acropolis hill](image)

The monuments on the Acropolis reflect the successive phases of the city's history.

2. **Dimensions:** 3.045 ha
3. **Types of main external materials used in percentage:** limestone -pentelic marble- (95%), porous stone, sandstone
4. Info regarding area in which the monument is (urban)

Fig. 2. The map of the Acropolis with the monuments and periods of creation.

1: Parthenon
2: Erechtheion
3: Pandroseion
4: Statue of Athena Promachos
5: Propylaia
6: Altar of Athena
7: Sanctuary of Pandion
8: Temple of Athena Nike
9: Chalkotheke
10: Brauroneion
11: Arrephorion
12: Approach of Classical times
13: Odeon of Herod Atticus
14: Stoa of Eumenes
15: Asklepieion
16: Ionic stoa
17: Nikias monument
18: Thrasyllos monument
19: Sanctuary of Dionysos Eleuthereus
20: Odeion of Pericles
21: Peripatos  
22: Theater of Dionysos  

**Orange:** Monuments of the 5th century BCE  
**Rose:** Monuments of the 4th century BCE  
**Blue:** Hellenistic and Roman monuments

Considering that the Acropolis is extremely complex regarding periods of construction and materials used (Fig. 2) and that it is very difficult in so short time to evaluate with reasonable level of certainty the surfaces of the different buildings it was decided to concentrate our efforts on the most important monument of the complex, the Parthenon.

**The Parthenon.** It is the most important and characteristic monument of the ancient Greek civilization and still remains its international symbol. It was dedicated to Athena Parthenos (the Virgin), the patron goddess of Athens. It was built between 447 and 438 B.C. and its sculptural decoration was completed in 432 B.C. The construction of the monument was initiated by Perikles, the supervisor of the whole work was Pheidias, the famous Athenian sculptor, while Iktinos (or Ictinus) and Kallikrates (Callicrates) were the architects of the building. The temple is built in the Doric order and almost exclusively of Pentelic marble (Fig.3). It is peripteral, with eight columns on each of the narrow sides and seventeen columns on each of the long ones. The central part of the temple, called the cella, sheltered the famous chryselephantine cult statue of Athena, made by Pheidias.

The rest of the sculptural decorations, also by Phidias, were completed by 432 BC. The sculptural decorations of the Parthenon are a unique combination of the Doric metopes and triglyphs on the entablature, and the Ionic frieze on the walls of the cella. The metopes depict the Gigantomachy on the east side, the Amazonomachy on the west, the Centauromachy on the south, and scenes from the Trojan War on the north.
Methodology for calculating the surface of the monument.

As we indicate before to may valuate quantitatively the loss of materials due to the air pollution and to may calculate the economic assessment is important to know the surface of the studied monument. From the literature we found the general external measures of the monument. The rest was valuated using the ratios between known and not known dimensions of the temple. For this we valuate and calculate the surface of the external (visible) part of the Parthenon.

Many original parts of the Parthenon are lost. And now the Temple is without roof and internal cell (naos) in which the God’s statue originally was situated. Fig. 3, 4.

Four of the columns are broken. The most important parts of the Parthenon which exists are the columns, the lintel, the tympanum.

- Columns: their surface are not smooth but fluted. Fig. 6. The columns are 10 m. high and it diameter is 1.9 m. The columns are not cylinders but the lower part is around 30% larger than the higher one. To may find the circumference of the column we use a section of it and applied the Autocad program.

In this way was find the circumference of a column which is 7.05m.

The surface of one column is 10 m (h) x 7.05 m. = 70.5 m²

In the temple we have 47 columns. Four of them are broken and we consider that they are 50 % lost. Fig.4.

The surface of the columns are: 43 columns x 70.5 m² = 3031.5 m²

4 columns x 35.2 m² = 140.8 m²

Total surface of the columns is = 3172.3 m²
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Fig. 5 Scheme of Greek temple.

- **Lintel**: the short sides of it are relatively integral. They are 29 m long and 3.5 m high.
  - The East side is 29 m (l) x 3.5 m. (h) = 101.5 m²
  - The West side is 29 m (l) x 3.5 m. (h) = 101.5 m²
  - The North side is relatively integral and is 69.2 m (l) x 3.5 m (h) = 242.2 m²
  - The South side is damaged and 29 m. are lost, so it is 69.2 – 29 = 40.2 m x 3.5 m. = 104.7 m²
  - The total surface of the lintel is **549.5 m²**

- **Tympanums** (triangles):
  - The East side is relatively integral and is 29 m. (l) x 4.2 m. (h) / 2 = 60.9 m²
  - The North side is very damaged. Using the rations between the integral east part end remaining pieces from the north one we calculate it as around 15 m²
  - So the total surface of tympanums is: 60.9 + 15 = **75.9 m²**

- The total surface of the Parthenon is:
  - Columns – 3 172.3 m²
  - Lintel - 549.5 m²
  - Tympanums - 75.9 m²
  - Total visible surface of the Parthenon is - **3 798.1 m²**
The Dose response function which we used to calculate the recession of the limestone material (see equation 1) for the Parthenon indicate that the corrosion depth after one year of exposure is **5.60 µm**. From the Table 1 is seen that this result is lower than the tolerable corrosion rate per year for the 2020 target which for the limestone is 8.0 µm year⁻¹. This result is very close to the tolerable corrosion rate per year for the target 2050 which is 6.4 µm year⁻¹. And the other hand the calculated corrosion rate for the Parthenon is almost two time higher than the background corrosion depth indicated in Table 1 (3.2 µm). This means that in 2009 – 2010 the corrosion depth in the Parthenon was almost two times higher than the background corrosion rate, which is due to the air pollution, but it is steel in the rang of tolerable corrosion rate for the target 2020.
b) France, Paris, The Facades in the Centre of City

Coordinates: N48 51 30 E2 17 39

The banks of the Seine have been included on the UNESCO List of the World Cultural Heritage (Fig. 7) since 1991. We should have to considered that in this area are situated many important monuments. See Report 68 (1).

This study consists in the evaluation of the stock of materials at risk of degradation (corrosion, soiling) due to atmospheric pollution, between the Sully Bridge on the eastern side, and the Pont-Neuf on the western side. It include, the Ile Saint Louis, the Ile de la Cite´ and the right bank of the Seine facing these two islands (Fig. 7). This sector is the very centre of Paris. The territory inscribed on the UNESCO List, extends towards West as far as the Eiffel Tower. This study, include roughly one-third of this territory and contains buildings dating from the 17th and 18th centuries, Haussmannian buildings (end of 19th and beginning of 20th centuries), as well as important monuments like Notre Dame and Sainte Chapelle dating from the Middle Ages.

In the Ile de la Cite´, the quantity of historical monuments and official buildings is very high. On the right bank of the Seine, there are three important monuments and two theatres. There are only two historical monuments in the Ile Saint Louis. All the other historical buildings in this island are private property.

Quays and bridges were not taken into account in this evaluation.

Methodology for calculating the surface of the monument.

As we indicate before to may valuate quantitatively the loss of materials due to the air pollution and to may calculate the economic assessment is important to know the surface of the studied monument The authors methodology consisted in a real in-the-field inventory, façade by façade building by building, and monument by monument, based on the Paris Map at the scale of 1:2 000. They determinate the nature of the materials employed by direct examination of the building façade (Lutetian Parisian limestone, rendering/ mortar/plaster, painting, brick, metal, modern glass) and their proportions were roughly evaluated in percentage. They estimate the height of each building by counting the number of floors and attributing them an individual average height of 3 m. A control of this arbitrary height of 3m per floor was performed using a laser beam measurement: the error does not exceed - 10%. The determination of the length of the façade was obtained by measurement on the Paris Map. Having height and length, the surface was easily deduced. This entire surface was attributed to the constituting materials according to their proportions. The surface of the apertures (windows, doors), classically considered by the architects equal to half of the total surface of the façade, was not deducted because it compensates for the roughness of the façade (sculptures, decoration, balconies. . .). In summary, the total calculated surface was attributed
to the constituting materials and half of this surface arbitrarily attributed to the modern glass of the windows. Only the street facing, external facades taken into account due to their direct exposure to pollution from traffic and the inaccessibility of interior private courts.

The authors decided to measure the surfaces of historical monuments directly in the field according to the same methodology employed for the private buildings. In the Ile de la Cite’, the quantity of historical monuments and official buildings is very high. On the right bank of the Seine, three important monuments exist and in the Ile Saint Louis there are only two historical Monuments.

In total, the measurement of the length of each construction on the map of Paris, the counting in the field of the number of floors and the characterization and evaluation of the respective proportions of the constituting materials were performed on the facades of 525 buildings and monuments in the Centre of Paris giving an excellent statistical value to the results presented below.

The total surface in m2 of the 525 facades of buildings and monuments of the Ile Saint Louis, Ile de la Cite´ and of the right bank of the Seine facing them, and the distribution of the different materials in these facades are given in below on the basis of a 3m mean height. The surface of modern glass is arbitrarily estimated as half of the total surface of the facade. The two historical monuments of the Ile Saint Louis have their facade entirely in limestone, covering 768m2, and the other six, in the Ile de la Cite´ accounting for 71,586m2.
With these results the authors demonstrate that the main material present in the façades in the Centre of Paris is the Lutetian limestone (roughly 76%), followed by painting (15%) and then by rendering (7%). Brick (1%) and metal (0.02%) play a very minor role. Thus, limestone dominates in the Ile de la Cité and on the right bank facing it, due to the presence of many important monuments and Haussmannian buildings, while painting and rendering are more important in the Ile Saint Louis, where the buildings dating from the 17th and 18th.

Total Paris Centre: 525 façade = 200,305 m², length of 11,203 m Limestone: 15,933 m² (76%) Modern glass (estimated): 100,152 m² (50%), others 47,247 m² (24%).
(Monuments): 72,354 m² - 100% Limestone.

The geographical distribution, on a grid of 100m x 100m cells, of the total surface of facades, of the surface in limestone and of the percentage of limestone in the facades is given in Figs. 8, 9. These confirm more detail that limestone is in the majority in the western part of the studied area, meaning that the most important monuments and the highest number of Haussmannian buildings are concentrated in the Ile de la Cité and on the right bank of the Seine facing it.

Fig. 8 Geographical distribution of the total surface (m2) of the facades of buildings and monuments of the Ile de la Cité, the Ile Saint Louis and of the right bank of the Seine facing them, on a grid with cells of 100 m x 100 m (floor mean height: 3 m)
Fig. 9 Geographical distribution of the percentage of limestone in the facades of buildings and monuments of the Île de la Cité’, the Île Saint Louis, and of the right bank of the Seine facing them, on a grid with cells of 100 m x 100 m (floor mean height: 3 m)

The main risk for buildings and monuments in the centre of Paris is air pollution due to the traffic causing the soiling of facades by deposition of black carbonaceous particles, especially in the parts sheltered from rain, and the surface recession of these facades by erosion-dissolution in the parts exposed to the rain.

The Dose /response function which we used to calculate the recession of the limestone material (see equation 1) for Paris Centre indicate that the corrosion depth after one year of exposure is 5.75 µm.

From the Table 1 is seen that this result is lower than the tolerable corrosion rate per year which for the limestone for the 2020 target is 8.0 µm year⁻¹. This result is very close to the tolerable corrosion rate per year for the target 2050 which is 6.4 µm year⁻¹. And the other hand the calculated corrosion rate for the Paris Centre is almost two time higher than the background corrosion depth indicated in Table 1 (3.2 µm). This indicate that in 2009 – 2010 the corrosion depth in the Paris Centre was almost two times higher than the background corrosion rate, which is due to the air pollution, but it is still in the range of tolerable corrosion rate for 2020 target.
c) **Czech Republic, Prague, The National Library**

- The Klementinum (National cultural heritage object)

- Coordinates: 50° 5'11.874"N, 14° 24'57.809"E

Large complex of the Klementinum is situated next to the Charles Bridge, right in the historical centre of Prague. Its history was illustrated on Report 68 (1).

Fig. 10. The air view of The Klementinum
Fig. 11 The drawing view of The Klementinum

At present, the Klementinum is home to the National Library and many valuable collections of books can be found here.

Methodology for calculating the surface of the monument

- Dimensions
  The Klementinum is a complex of many buildings spread around 3 courtyards built on an area of 2 hectares. Total built area without churches is 10355 m².

  The Klementinum includes halls (e.g. mathematical hall, musician hall), classrooms, two churches (St. Clement and St. Salvatore), four chapels (Mirror chapel, St. Eligius chapel, St. Johan from Nepomuc chapel, Italian chapel of the Assumption of the Virgin Mary) and the Astronomical tower. The dimensions of each building are given on the ground plan, which show that it is very nonregular.

  The height of buildings:
  - the building along Krizovnicka street (building A) – 14.8 m, roof 7.2 m,
  - the building along Platnerska street (building B) – 15.8 m, roof 8.4 m,
  - the building around Grape Courtyard (building C) – 15.9 m,
  - the building around Technical Courtyard (building D) – 19.4 m,
  - the Astronomical tower 68 m.
Fig. 12 The ground plan of Klementinum - the dimensions are given in meters.

The walls external and in the courtyards of the complex are totally 1,216 m long. Here we have 4 buildings:
- along Krizovnicka street (building A) – 147 m (long on both sides) x 14.8 m (h) = 2131.5 m².
- along Platnerska street (building B) – 234 m (long on both sides) x 15.8 m (h) = 3697.2 m²
- around Grape Courtyard (building C) – 87 m (long on both sides) x 15.9 m (h) = 1383.3 m
- around Technical Courtyard (building D) – 74 m (long on both sides) x 19.4 m (h) = 1432.6 m²
Total: 8644.6 m²

The study reported the number of windows:
- the building along Krizovnicka street (building A) – 21,
- the building along Platnerska street (building B) – 20 + 4 large (in front).

The windows in the 1st floor are 3.0 – 3.8 m high (in front windows 4.2 m), ones in the 2nd floor are 2.1 – 2.5 m high, ones in 3rd floor are 1.6 – 1.7 m high.

As this data regards only two of the buildings we decided to valuate the surface of the apertures (windows, doors), as classically considered by the architects equal to half of the total surface of the facade.
Total surface 8644.6 m² - 50% = 4322.3 m²
1. north view, Parlerska street

2. south view, inside courtyards

west view, Parlerska street

Fig 13. Some drawings of the monument with the general dimensions.

- Types of main external materials used in percentage

The basement is built from brick and stone masonry and brick vaults. The floors are contemporary – concrete. Vertical bearing structures are made from bricks to 3 floors and ceilings are made from bricks too. From 3rd floor the vertical and horizontal structures and roof structures made from reinforced concrete poles, beams and plates.
The original **wooden structures** of roof left in the object of Karlova street, Astronomical and O´clock towers.

Facades are **rendered** in majority, only sporadically completed by **stone elements** (portals, plat-band s, socles, string courses). The rendering is not dramatically profiled and it is in relative good condition, only with local defects. Facade in the contemporary technical courtyard is deteriorated, it pull off locally and partly is covered by plants. The painting is in worse condition, mainly in Krizovnicka and Platnerska streets.

The majority of roofs are covered by traditional **ceramic tiles**.

In period 2007-08 the air pollution was measured at 3 localities outside the building and at 6 localities inside the building. Using the outside air pollution data reported in this study we calculate the recession of the limestone material.

The Dose /response function which we used to calculate the recession of the limestone material (see equation 1) for Klementinum indicate that the corrosion depth after one year of exposure in 2009-2010 is **6.16 µm**.

From the Table 1 is seen that this result is lower than the tolerable corrosion rate per year which for the limestone for 2020 target is 8.0 µm year \(^{-1}\). This result is very close to the tolerable corrosion rate per year for the target 2050 which for the limestone is 6.4 µm year \(^{-1}\). And the other hand the calculated corrosion rate for the Klementinum is almost two time higher than the background corrosion depth indicated in Table 1 (3.2 µm). This means that in 2009 – 2010 the corrosion depth around Klementinum was almost two times higher than the background corrosion rate, which is due to the air pollution, but it is steel in the range of tolerable corrosion rate for target 2020.

In this study we used the pollution data measured from 3 stations around the Complex during 2007-2008. The air pollution measured in this stations are different. (see Fig. 14). Calculating the recession of the limestone using the Dose/Response function we individuate different recession of the limestone in different sides of the Complex. (see Fig. 15) On the side of Karlova str. the recession is 7.06 µm year \(^{-1}\), which is very close to the tolerable corrosion rate for 2020 target and is higher then this of the 2050 target.
Fig. 14. The air pollution measured around Klementinum complex 2007-2008.
Fig. 15. Corrosion map of the Klemntinum complex 2007 – 2008.
d) Germany, Berlin, The New Museum (5)

Coordinates: N52 31 11 E13 23 55
Included in the UNESCO CH list in 1999.

situated in the Museum Island

Fig. 16 Map of Museum Island (in red)

As was indicated in Rep. 68 (1), the **Museum Island** is the name of the northern half of an island in the Spree river in the central district of Berlin, Germany, the site of the old city of Cölln. It is so called for the complex of five internationally significant museums, all part of the Berlin State Museums, that occupy the island's northern part:

- The Altes Museum (Old Museum) completed on the orders of Karl Friedrich Schinkel in 1830.
- The Neues Museum (New Museum) finished in 1859 according to plans by Friedrich August Stüler, a student of Schinkel. Destroyed in World War II, it was rebuilt under the direction of David Chipperfield for the Egyptian Museum of Berlin and re-opened in 2009.
- The Alte Nationalgalerie (Old National Gallery) completed in 1876, also according to designs by Friedrich August Stüler, to host a collection of 19th century art donated by banker Joachim H. W. Wagener
- The Boduesse Museum on the island's northern tip, opened in 1904 and then called Kaiser-Friedrich-Museum. It exhibits the sculpture collections and late Antique and Byzantine art.
- The Pergamon Museum, the final museum of the complex, constructed in 1930. It contains multiple reconstructed immense and historically significant buildings such as the Pergamon Altar and the Ishtar Gate of Babylon.

The history of the New Museum was illustrated in Report 68 (1).
Architecture of Neue Museum

Fig. 17 The New Museum with the main dimensions in meters*

Built from 1841 to 1859, the Neues Museum was designed by Friedrich August Stüler as the second museum on the island in the River Spree.

Methodology for calculating the surface of the monument

- Dimensions
The dimensions of the museum was valuated from some drawings and images provided from a private communication and find in literature and in internet.
From the Fig. 17 on which the main dimensions are reported is seen that:

The front façade is formed from left part, central module and right part.

Left part: 40 m. (l) x 20 m (h) = 800 m²,
Right part: 40 m. (l) x 20 m (h) = 800 m²,
Central module: 20 m. (l) x 21.5 m. (h) = 490 m²,
Triangle: 20 m. (l) x 1.5 m (h) : 2 = 15 m²
Total surface of the façade = 2100 m²

*Note: in UN ECE ICP Materials Report 68 (1) on fig. 33 erroneously was published the images of Altes Museum instead of Neues Museum.
The short side is: 30 m. (l) x 20 m. (h) = 600 m²

The total museum surface is:
The front façade is 2100 m²
The back façade is 2100 m²
The left side is 600 m²
The right side is 600 m²
Total surface is 5400 m²

Considering that the from the drawings and images some sides of the museum was not completely visible we decide to valuate the surface of the apertures (windows, doors), as classically considered by the architects equal to half of the total surface of the facade.

Total surface 5400 m² - 50% = 2700 m²

The material used for the construction of the museum is limestone.

Fig. 18 Plan of the New Museum in Berlin.
The main risk for buildings and monuments in the Centre of Berlin is air pollution due to the traffic causing the soiling of facades by deposition of black carbonaceous particles, especially in the parts sheltered from rain, and the surface recession of these facades by erosion-dissolution in the parts exposed to the rain.

The Dose /response function which we used to calculate the recession of the limestone material (see equation 1) for New Museum of Berlin indicate that the corrosion depth after one year of exposure is 8.36 µm. From the Table 1 is seen that this result is higher than the tolerable corrosion rate per year which for the limestone for target 2020 is 8.0 µm year⁻¹. This means that in 2009 – 2010 the corrosion depth in the Berlin Centre was higher than the tolerable corrosion rate, which most probably is due to the air pollution coming from the traffic.
**e) UK, Bath, Royal Crescent**\(^{(6)}\)

Included in the UNESCO CH list in 1987.

This urban site (51° 23’ 13” N, 2° 22’ 6” W) is located in the City of Bath. The surrounding area consists mainly low rise urban buildings, with parkland/open space to the East, the immediate area has a low intensity of traffic. The monument originally contained 30 houses, most of the houses have remained as residential dwellings (some of them converted into flats), the remaining houses have been converted into offices, a museum and a hotel.

The history of Bath, Royal Crescent, was illustrated on Report 68 (1).

**Methodology for calculating the surface of the monument**

- **Dimensions**
  Approximate dimensions, 12.50 m high, distance between south easterly corner of number one and south westerly corner of number 30 is 192m. Dwellings approx.. 17.5 m wide.

![Fig. 19 The dimensions of the crescent, internal and external ellipse with the dwellings.](image)

Fig. 19 The dimensions of the crescent, internal and external ellipse with the dwellings.
Fig. 20 The dimensions of the crescent, the height.

Internal ellipse: \(288 \text{ m (l)} \times 12.5 \text{ m (h)} = 3600 \text{ m}^2\)
External ellipse: \(340.5 \text{ m (l)} \times 12.5 \text{ m (h)} = 4256 \text{ m}^2\)
Two end sides: \((17.5 \text{ m (l)} \times 12.5 \text{ m (h)}) \times 2 = 437.5 \text{ m}^2\)
Total surface: \(8293.5 \text{ m}^2\)

Considering that the from the drawings and images some sides of the complex was not completely visible we decide to valuate the surface of the apertures (windows, doors), as classically considered by the architects equal to half of the total surface of the facade.

Total surface \(8293.5 \text{ m}^2 - 50\% = 4146.8 \text{ m}^2\)

The material of which the Royal Crescent is build is limestone.

The Dose /response function which we used to calculate the recession of the limestone material (see equation 1) for the Royal Crescent indicate that the corrosion depth after one year of exposure is \(4.87 \mu\text{m}\). To may calculate the limestone corrosion in 2010 we used the 50x50 km EMEP data in the cell which cover the city of Bath.

From the Table 1 is seen that this result is lower than the tolerable corrosion rate per year which for the limestone for 2020 target is \(8.0 \mu\text{m year}^{-1}\). This result is lower then the tolerable corrosion rate per year for the target 2050 which is \(6.4 \mu\text{m year}^{-1}\). And the other hand the calculated corrosion rate for the Royal Crescent is almost one and a half time higher than the background corrosion depth indicated in Table 1 (3.2 \(\mu\text{m}\)). This means that in 2009 – 2010 the corrosion depth in the city of Bath is higher then the background corrosion rate, which is due to the air pollution, but it is in the range of tolerable corrosion rate for 2020 target and for 2050 target too.
4. Conclusions

The present report gives results from quantitative census of materials in monuments based on a real in-the-field inventory, facade by facade, building by building, and monument by monument, and on direct examinations, applying maps, images and other documents at the available scales, was reported.

The type of the materials used in the monuments was determined by direct examination of the building facade (limestone, rendering/mortar/plaster, painting, brick, metal, modern glass) and in some selected sites their proportions was roughly evaluated in percentage. Different types of limestone were used in the construction of the studied monuments.

The dimensions of the monuments was identified using direct examination, images, photos, drawings and other available in literature and internet sources. From the dimensions its surface was calculated valuating the surface covered by windows, doors etc.

The air pollution and climatic data for the 2009 – 2010 was used to may valuate the corrosion. As the dominating material is limestone the dose - response function for limestone was calculated to determine the corrosion of the materials used for the construction of the monuments.

Using the pollution data for 2009 - 2010 the estimated recession rate only exceeds the 2020 target for limestone (2.5 times the background or 8.0 µm year⁻¹) in the Neues Museum of Berlin. However, the 2050 target (2.0 times the background or 6.5 µm year⁻¹) is exceeded at all sites.
5. Acknowledgements

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6. References

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