AIR POLLUTION AND CLIMATE IMPACT ON THE BUILT CULTURAL HERITAGE: PAST, PRESENT AND FUTURE

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AIR POLLUTION
Different materials exposed to different atmospheric conditions

PARAMETERS
- Gas (SO₂, NOₓ,..)
- Particles
- Sea salts
- pH precipitation
- Temperature
- Relative Humidity
- Precipitation
- Wind

INTERACTION
MATERIALS
- Stone/Masonry Materials:
  - Marble
  - Limestone
  - Sandstone
  - Lime mortars
  - Bricks
  - Clay containing mat.
- Metals
  - Iron
  - Bronze
  - Copper
  - Lead
  - Zinc
- Glass
Building Materials in Urban Areas

Nanjing, China

FORMATION OF BLACK CRUSTS

- Sulfation by SO₂
  - limestone to gypsum
  - deposition of soot
  - rain sheltered

- Gypsum soluble
  - Rainwashed areas may be white

White Tower, London

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WASHINGTON DC, 11 MAY 2009

FORMATION OF BLACK CRUSTS

\[ TC = CC + EC + OC \]

Stone substrate

- Atmospheric deposition
- Biological weathering
- Surface treatments

Particles emitted by combustion processes

Tracers of fix and mobile combustion emissions

Ghedini et al., EST (2006)

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CRUSTS European Monuments (carbonate stone)

OC prevails on monuments in European towns due to urban traffic.

CNR Project Sustainable mobility

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CATHEDRAL OF LEARNING - Pittsburgh

- Soiling patterns on a tall limestone building: changes over 60 years
- Built in the late 1930’s
- Rapidly soiled: 1960
- 1990: loss of steel industry meant building became cleaner...
- Effect of rain washing since 1950s

Balance EC/OC deposition/accumulation and rain re-distribution

C.I. Davidson et al., 2000 Washington DC, 11 May 2009
Gulf War – Effect of the Kuwait oil fires in 1991 on the Iranian Cultural Heritage

Spring 1991: burning of ~4.6 million barrels of oil per day

Vulnerability of building materials is different depending on chemical composition and porosity. Reactivity towards SO$_2$: laboratory tests

Cement mortars most reactive!

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GYPSUM FORMATION ON CEMENT

Atmosphere

SO₂ gas

SO₄²⁻

Catalysts aerosol

SO₃⁻

SO₄²⁻

Catalysts material

GYPSUM

Cement Mortar

CALCIUM CARBONATE
CALCIUM ALUMINATES
CALCIUM SILICATES

SABBIONI et al., Atmos. Env. (2001)

SECONDARY DAMAGE PRODUCTS

Gypsum + Calcium aluminate

ETTRINGITE

Gypsum + Calcium silicate

THAUMASITE

SABBIONI et al., Atmos. Env. (2001)
Laboratory tests

ETTRINGITE FORMATION

ETTRINGITE DISSOLUTION/DECOMPOSITION

THAUMASITE FORMATION

Damage occurs also if SO₂ decrease

EC Project EDAMM
Washington DC, 11 May 2009

SECONDARY DAMAGE PRODUCTS:
HYDRAULIC MORTARS IN THE MEDITERRANEAN AREA

VILLA DOMITIA, GIANNUTRI (ITALY)
JUPITER TEMPLE, DAMASCUS (SIRYA)
MEKAWER FORTRESS (JORDAN)
PETRA (JORDAN)

EC Project PRODOMEA
Washington DC, 11 May 2009
CONTEMPORARY AIR POLLUTANTS AND STONE

Sulfation of stone decline and will continue in the future

EC Project NOAH’s ARK

Climate change impact on the built cultural heritage

May become a more important factor a central part of the EC project NOAH’S ARK

Global Climate Change Impact on Built Heritage and Cultural Landscapes
HOW?
- Selection of the critical climate parameters affecting CH
- Data output from the General Hadley Model (HadCM3) relative to 1961-1990, 2010-2039 and 2070-2099
- Data output from and the Regional Hadley Model (HadRM3) relative to 2070-2099
- Scenario IPCC SRES A2
- European window
- Selection of materials and models of damage processes

OUT PUTS
Mapping of vulnerable areas in accordance with the types of impacts

Area and periods selected

Area: European window
HadCM3
Latitude: 33.75W – 67.50E
Longitude: 80.00N – 25.00N
23 x 28 grid points

HadRM3
Latitude: 34W – 71E (approx.)
Longitude: 72N – 25N (approx.)
109 x 104 grid points

Periods
- 1961-1990: Baseline
- 2010-2039: Near Future
- 2070-2099: Far Future
**Methodological Approach**

**CRUCIAL PARAMETERS** selection for the damage on the build cultural heritage

Construction of a European **DATABASE**

**CLIMATE MAPS** production

Identification of **RISK AREAS**

**RISK MAPS** and **MULTI-RISK MAPS** production

Further data elaboration through using **DAMAGE FUNCTIONS**

**DATABASE**

Monthly, Seasonal and Annual mean of the following parameters:

**TEMPERATURE DERIVED PARAMETERS**
- Temperature range
- Freeze-thaw cycles
- Thermal shock

**WIND DERIVED PARAMETERS**
- Wind speed
- Wind driven rain
- Wind speed counts
- Wind driven sand

**WATER DERIVED PARAMETERS**
- Precipitation Amount
- Rain days: total number of rainy days
- Extreme rain
- Consecutive number of rainy days
- Mean Relative Humidity
- Relative Humidity range
- Relative Humidity shocks

**POLLUTION DERIVED PARAMETERS**
- SO₂ air concentration
- HNO₃ air concentration
- O₃ air concentration
- Rain pH
Maps Produced

CLIMATE MAPS

HERITAGE CLIMATE MAPS

DAMAGE MAPS

RISK MAPS

THEMATIC PAGES

Relative humidity cycles = 75.5%
(Salt crystallisation)

Brick masonry

2070-2099
Salt crystallisation

....will increase over the 100 years all across Europe

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Surface recession

Future scenarios of surface recession of carbonate stone due to precipitation and CO$_2$ concentration change

$L(\mu m/year) = L_v R$

Central Europe, UK, Iceland, Scandinavian Peninsula and the northern Spain will experience the highest surface recession (20-30 $\mu$m/year)

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Surface recession

General increase (> 6 µm/year) throughout Europe, particularly noticeable in high rainfall areas. The change can be > 6 µm/year in regions with recession = 20 µm/year.

30% increase

Bonazza et al., STOTEN (2009)

Thermal Stress

The Mediterranean Basin in general will continue to experience the highest level of risk. In the near and far future thermoclastism will threaten more and more Central Europe.

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WATER: IMPACT ON EARTH ARCHITECTURE

Annual Precipitation amount 2070-2099

Structural damage
Erosion
Clay swelling
Cracking for drying-wetting cycles
Plaster dissolution

Demonstrated to be the main weathering agent during the 21st century

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Cultural heritage is not mentioned among the indicators for the identification of mitigation and adaptation strategies

Absence of cultural heritage in the Intergovernmental Climate Change Panel Reports (IPCC)

No mention

IPCC Fourth Assessment Report:
- Climate Change 2007: Impacts, Adaptation and Vulnerability
- Climate Change 2007: Mitigation

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POLLUTION, PARTICULARLY PARTICLES, IS A MAJOR THREAT AFFECTING THE BUILT CULTURAL HERITAGE IN URBAN AREAS

MODERN BUILDING MATERIALS, e.g. CEMENT, ARE LESS DURABLE THAN ANCIENT MATERIALS WITH RESPECT TO POLLUTION

FUTURE CLIMATE CHANGE IMPACTS ON HISTORICAL BUILDINGS AND ARCHAEOLOGICAL SITES REMAIN A CHALLENGE

Some publications

SABBIONI C., ZAPPIA G., RIONTINO C., BLANCO-VARELA M.T., AGUILERA J., PUERTAS F., VAN BALEN K., TOUMBAKARI E.E.
Atmospheric deterioration of ancient and modern hydraulic mortars

SABBIONI C.
Mechanisms of air pollution damage to stone

SABBIONI C., GHEDINI N., BONAZZA A.
Organic anions damage layers on monuments and buildings

GHEDINI N., SABBIONI C., PANTANI M.
Thermal analyses in cultural heritage safeguard: an application.

BONAZZA A., SABBIONI C., GHEDINI N.
Quantitative data on carbon fractions in interpretation of black crusts and soiling on European built heritage.

GHEDINI N., SABBIONI C., BONAZZA A., GOBBI G.
Chemical-Thermal Quantitative Methodology for Carbon Speciation in Damage Layers on Building Surfaces.

BONAZZA A., BRIMBLECOMBE P., GROSSI C.M., SABBIONI C.
Carbon in Black Crusts from the Tower of London.
Environmental Science and Technology 41, 4198-4204, 2007.

BONAZZA A., SABBIONI C., GHEDINI N., HERMOSIN H., JURADO V., GONZALEZ J. M., SAIZ-JIMENEZ C.
Did smoke from the Kuwait oil well fires affected archaeological sites and monuments of Iranian cultural heritage?

BONAZZA A., MESSINA P., SABBIONI C., GROSSI C.M., BRIMBLECOMBE P.
Mapping the impact of climate change on surface recession of carbonate buildings in Europe.

BONAZZA A., SABBIONI C., MESSINA P., GUARALDI C., DE NUNTIS P.
Climate change impact: Mapping thermal stress on Carrara marble in Europe
European ERA NET Project

European network on Research Programme applied to the Protection of Tangible Cultural Heritage

• Coordinator: Italian Ministry of Cultural Heritage and Activities (MiBAC)
• Partnership of 14 EU Member States
• CNR is actively involved

Started: 1 October 2008
www.netheritage.eu