Environmental characterisation and mapping with respect to Durability

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ABSTRACT

Service life planning calls for characterisation and classification of the exposure environment for the constructed asset(s) in question. Lack of knowledge of environmental exposure data and models among the building sector players is an important barrier for further progress towards service life prediction. The ever more evident climate change highlights even more the need for data and models on the exposure, when it comes to address its impact on the built environment.

In general, requirements for establishing and implementing systems for quantitative characterisation and classification of durability of materials and components are: 1) well defined, and relatively simple damage functions for the materials in question, 2) availability of environmental exposure data/loads, including methods and models for assessing their geographical distribution, and 3) user friendly IT systems for storage, processing and modelling the environmental loads onto structures.

Service life functions related to environmental degradation are today available for a range of building materials and components. As for availability of environmental data and models, as well as proper IT systems, it is shown that for most European countries, such data and models are available from meteorological offices and the environmental research area, and that these data and the work performed are directly applicable for service life planning and life cycle management of constructed assets. A short review of some of the most applicable models for environmental exposure and for degradation and damage of building materials and structures is included.

The global climate system is likely to undergo changes, regardless of the implementation of abatement policies under the Kyoto Protocol or other regimes. Both the functionality of the existing built environment and the design of future buildings are likely to be altered by climate change impacts, and the expected implications of these new conditions are now investigated.

The data and models are often directly exhibited in computer-based systems, often on GIS based platforms. With the rapid development of IFC based standards for digital object oriented models of building products there is a huge need for property sets, such as durability and service life data, linked directly to the building elements. The significant drive within the AEC/IFC community to provide for relevant location based data (GIS) via IFC format will be a major facilitator for access to site specific durability data, described by degradation models containing environmental (and other) degradation factors.

KEYWORDS
Environmental characterisation, service life, durability, climate change

1 INTRODUCTION

Service life planning calls for characterisation of the exposure environment for the constructed asset(s) in question, as described in ISO 15686-1 [ISO 2000]. Lack of knowledge of environmental exposure data and models among the building sector players is an important barrier for further progress towards service life prediction. The ever more evident climate changes under global warming highlights even more the need for data and models on the exposure, when it comes to address its potential impact on the built environment. The significant drive within the AEC/IFC community to provide for relevant location based data (GIS) via IFC format will be a major facilitator for access to site specific durability data, described by degradation models containing environmental (and other) degradation factors.

In general, requirements for establishing and implementing systems for quantitative characterisation and classification for durability of materials and components are: 1) well defined, and relatively simple damage functions for the materials in question, 2) availability of environmental exposure data/loads, including methods and models for assessing their geographical distribution, and 3) user friendly IT systems for storage, processing and modelling the environmental loads onto structures.

2 DEGRADATION MODELS AND ENVIRONMENTAL DEGRADATION FACTORS

Establishing proper dose-response and damage functions for families of common building materials have been the subject of extensive studies for more than a decade [Jernberg *et al.* 2004]. Although many models and functions now are available the lack of knowledge and implementation of the damage function approach still constitute a major barrier for progress concerning the durability and service life aspects within the building and construction community.

The degradation of the buildings and infrastructures are influenced by a whole set of factors such as environmental degradation agents, type and quality of the materials and components, protective treatment, etc. [ISO 2000].

The relationship between the environmental degradation agents and the observed effects are expressed as dose-response functions. The dose-response functions are not directly suitable for service life assessments. To transform the degradation into service life terms, performance requirements or limit states for allowable degradation before maintenance or complete renewal of material or component, have to be decided. The dose-response function then transforms into a damage function, which is also a performance over time function, and a service life assessment can be made.

In order to characterise and report the right type and form of the environmental degradation agents, they have to be related to the degradation mechanism and dose-response functions for the specific materials in question. Further, a holistic approach modelling the physical processes controlling the corrosion needs to be considered across a wide range of physical scales, from macro through meso/regional to local, micro and lastly micron [Jernberg *et al.* 2004, EOTA 1999, Cole 2003], see **Figure 1**. Macro refers to gross meteorological conditions (polar, subtropical etc.), meso or regional refers to regions with dimensions up to 100 km, local is in the immediate vicinity of a building, while micro refers to the absolute proximity of a material surface. The microenvironmental conditions which are crucial to the materials degradation can vary enormously over a real construction.

Surface response then refers to largely physical responses of a surface such as deposition and retention of pollutants or condensation and evaporation. Micron refers to interactions within the buildings and infrastructures/metal/oxide/electrolyte interfaces. In this approach, models on different dimensional scales are linked together so that the models on micron level are informed by models on the macro-, meso-, micro- and surface response regimes.

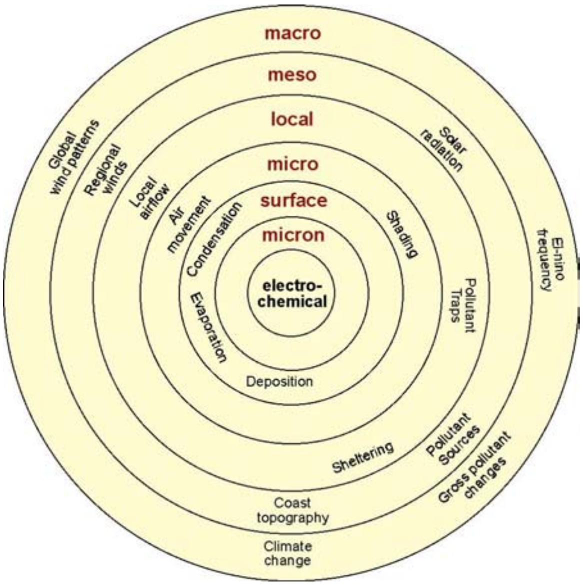

Figure 1 Framework for holistic model of corrosion [Cole 2003]

Valuable contributions are provided from the world wide studies within the environmental research area to establish such functions. They are a necessary basis for the cost-benefit analysis preceeding policy making in this area. The materials studied comprise structural metals (carbon steel, weathering steel, zinc, aluminum, copper, etc), stone (lime-and sand), paint coatings (on coil coat, steel, and wood), electric contact materials, glass- and polymer materials.

For porous and composite materials the functions can with this model become rather complex, as shown by the recently developed models for concrete within the European research projects DuraCrete [Duracrete 2004], and further applied in the object specific project DARTS [DARTS, 2004], as well as LIFECON [Sarja 2004]. In the latter project parametric sensitivity analysis have been performed to establish the ground for a quantitative classification of the main climatic parameters [Lay 2004].

Wind is an environmental mechanical degradation factor, and wind induced damages to buildings is at the same time a complex of several causes. In accordance with the factor method [ISO 2000] both design and craftsmanship are variables that will influence on the damage ratio of buildings exposed to strong winds [Thiis 2005].

Table 1 shows some very important primary environmental parameters/data as extracted from the damage functions for some important building materials, as well as for the building stock as such. Some examples of such functions and resulting environmental mapping and classifications are given below.

Deterioration mechanism	*RH*	*Temp.*	*CO_2*	*Precipi-tation*	*Wind*	*Radia-tion*	*Chloride Conc.*	*Freeze -thaw cycles*	*[SO_2]*	*[O_3]*
Reinforced concrete (DuraCrete models)										
-Carbonation induced corrosion	X	(X)	X	X	X					
-Chloride induced corrosion	X	X		X			X			
-Propagation of corrosion	X	X		X			X			
-Alkali-aggregate reaction	No model									
-Frost attack internal/scaling	(X)	X		X	(X)	(X)	(X)	X		
Other materials (Dose-response functions)										
-Galvanised steel/zink coating	X	X		X			X		X	
-Coil coated steel	X	X		X					X	
-Sealants/bitumen	No function									
-Polymers	No function									
-Aluminium				X			X		X	X
Building stock										
					x					

Table 1 Relevant environmental primary data for degradation models linked to buildings and infrastructures

3 SYSTEMATIC AND OPTIONS FOR CLASSIFICATION OF ENVIRONMENATL DEGRADATION FACTORS AND CORROSIVITY

Characterising and subsequently classifying the exposure environment in order to assess the aggressivity towards buildings and infrastructures have been attempted for about three decades, and some systems do exist. Some of the most relevant systems are described in the following.
For *quantitative* classification of atmospheric environmental loads there are two *options*. Some systems try to classify the *generic atmospheric aggressivity* on a global to local scale [ISO WD/15686-4, 2002 and EOTA 1999], without specific knowledge of damage functions, but based on overall experience of materials degradation at large. The other option and systematic is material (family) specific and based on knowledge of their damage functions, such as ISO 9223 that are specific for metals. This is the preferred systematic but requires that the type and format of the ingoing environmental agents are defined, and that the function(s) are relatively simple for practical purposes. Some examples are:

3.1 EOTA – Annex A Building context [EOTA 1999]

Quoted from the EOTA document on "Working Life of Building Products": "The wide variation in European climatic conditions and in the user stresses imposed on structures depending upon type of structure and use intensity will make it necessary with many construction products to restrict their usage to defined situations in order that these achieve the predicted working life". Then follow examples of possible sub-divisions of climatic zones in Europe, of orientation of products/components in structures, of internal exposure environments in buildings, etc.

3.2 ISO 15686 Service life planning – Part 4

The ISO 15686 suggestions for classification [ISO WD/ 15686-4, 2002], contains a proposal for:

1. Simplified global climatic classification with respect to two main factors, rainfall/humidity and temperature.
2. Simplified Global pollutant classification divided into two main areas, industrial pollution and marine pollution.
3. Detailed classification of moisture from rainfall and relative humidity. Another, more detailed approach for classification of moisture is to use the Annual Rainfall and Annual Relative Humidity.
4. Detailed pollutant classification of Airborne Salinity, frequency of significant salt deposition/frequency of rain.

3.3 ISO 9223-26 Classification of atmosheric corrosivity for metals

The standards ISO 9223–9226 *Corrosion of metals and alloys – Corrosivity of atmospheres* [ISO1992] have been developed for the classification of atmospheric corrosivity of metals and alloys. Based on a huge amount of experimental data for empirical dose-response functions the standards use both the approach of classifying the degradation factors and the corrosion rates. The **ISO 9223 – Classification**, specifies and classify the key factors in the atmospheric corrosion of metals and alloys, which are *time-of-wetness (τ), sulphur dioxide (P) and air-borne salinity (S).* The classification can be used directly to evaluate the corrosivity of atmospheres under known conditions of these environmental factors, and for technical and economical analyses of corrosion damage and choice of protection measures. The ISO 9223 approach has since the mid 80-ies been used by many researchers to classify and map the atmospheric corrosivity [Jernberg *et al.* 2004].

3.4 Proposed system for Concrete

The recently endorsed European standard -"EN 206-1 Concrete - Specification, performance, production, and conformity" [CEN 2001] is a good basis for developing the quantitative system. EN206-1 contains an agreed *qualitative* classification system as a synthesis of "best available" knowledge, covering the relevant degradation mechanisms and exposures in atmospheres, fresh water, seawater, and soil, indicating the decisive character of moisture and chloride. This implies also that National annexes, describing the environmental classes in relation to geography, have to be developed.

The damage functions for concrete, the so-called Duracrete models, are very complex and will have to be simplified for classification purposes. In the LIFECON project this was performed via parametric sensitivity analysis, see **Figure 2** [Lay 2003, Hallberg 2005].

4 METHODS AND DATA FOR ASSESSMENTS, MODELLING AND MAPPING OF DEGRADATION AGENTS

4.1 Data from meteorological and environmental research networks

As for availability of environmental data and models, as well as proper IT systems, it is shown that for most European countries, environmental data and models are available from meteorological offices and the environmental research area, and that these data and the work performed are directly applicable for life cycle management of the built environment. Such gathering of environmental exposure data is necessary to give ground for quantitative classification systems when the service lives of building products are to be declared in quantitative terms [Sjöström and Lair, 2003].

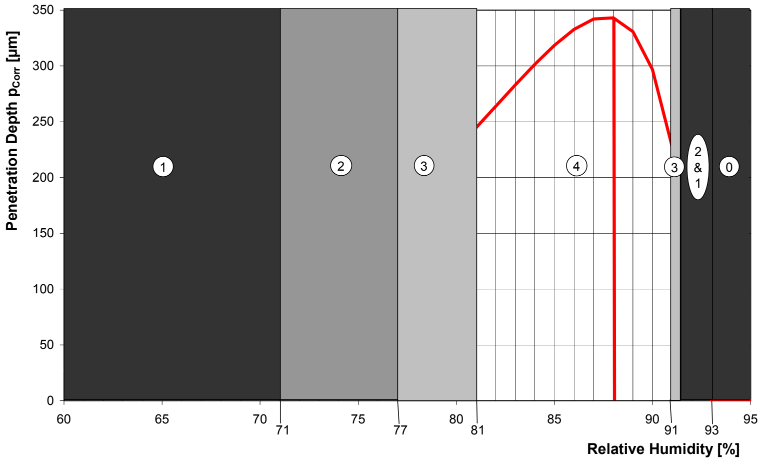

Figure 2 European classification of average annual relative humidity regarding carbonation induced corrosion, regarding 100 years of service life, ToW = 0; T = 10°C

In principle, characterisation of degradation agents has to be based on existing data. The measuring, testing and evaluation of air quality (pollutants) are gaining growing importance in developed countries as elements of a comprehensive clean air policy and geared to sustainable development. All countries in Europe have extensive meteorological and air pollution monitoring networks, many with GIS based information and management systems, allowing for the necessary assessment, modelling and mapping of the relevant environmental degradation parameters on various scales down to the local/micro scale on object level. Point measurements are very expensive, and for a broader assessment of air quality, needed for policy development and assessment, public information etc., measured data needs to be combined with modelling based on emissions inventories, to assess properly the exposure to, and thus the effects of the pollution on public health or on buildings.

The European Environment Agency (EEA) (www.eea.dk) was established in 1994, with the objective "to provide to the European Community and its Member States objective, reliable, and comparable information at a European level enabling the Member States to take the requisite measures to protect the environment, to assess the results of such measures and to ensure that the public is properly informed about the State of the environment " [Jernberg *et al.* 2004]. On the *regional scale*, there is extensive monitoring in addition to the EMEP network, and about 750 sites are in operation totally in Europe. This monitoring is very extensive for S- and N-compounds in air (gases and particles) and deposition, and also for ozone.

On the *local/urban scale*, monitoring is carried out at more than 5000 sites in Europe, operated by local, regional or national authorities. Most of these sites seem to be general urban background sites, while hot-spot sites (traffic, industry) are less well represented. The compounds of the EU Directives (SO_2, particles, NO_2, ozone, lead) are extensively covered.

4.2 Mapping and classification examples

4.2.1 Environmental parameters-on regional and microlevel

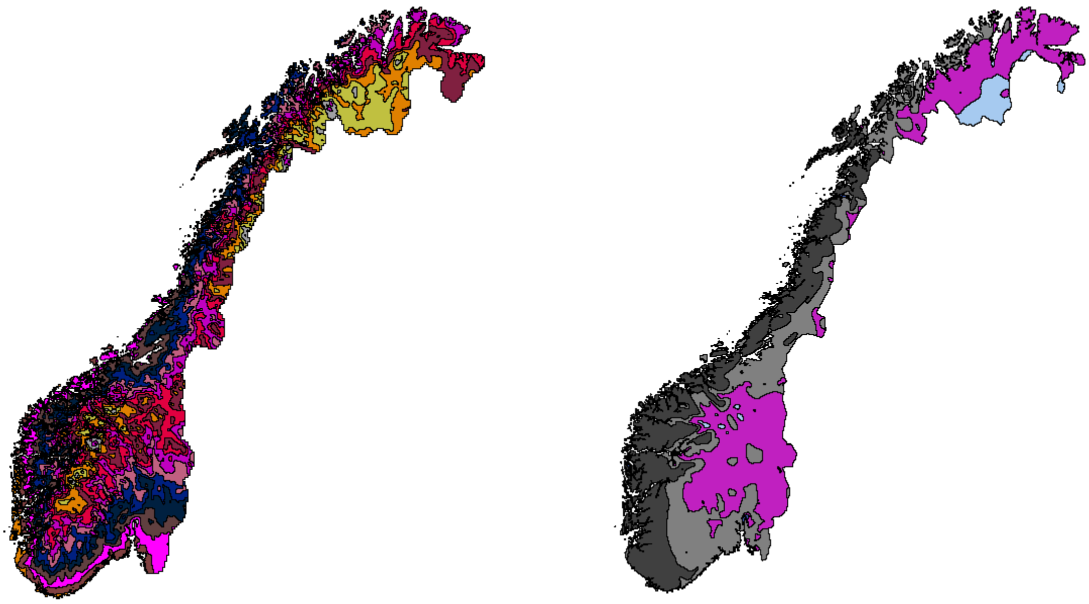

Figure 3a and b for Norway. a- average yearly temperature. The temperatures are classified from –6ºC to 8ºC. b- Average yearly precipitation in where Norway is divided into 4 zones. Zone 1< 400 mm, zone 2 < 800 mm, zone 3 < 1300 mm, and zone 4 > 1300 mm.

Important parameters, *average annual temperature* and *average yearly precipitation*, are shown for Norway in **Fig 3a and b**. Mapping is performed based on data from Norwegian Meteorological Institute, and the class boundaries may be chosen from any classification system. Shown here is for ISO 15686-4, but it could also be for developed concrete classes [Lay 2004].

Micro – environmental characterisation and classification can be done by use of Computational Fluid Dynamics (CFD) simulation, using existing climatic data. Numerical simulation of wind in complex terrain and around buildings has become a good supplement and sometimes a substitute to traditional wind tunnel simulations. Using CFD 3D models Haagenrud *et al.* [2002] have thus numerically simulated several different environmental loads acting on the Ormsundet wharf in the Oslo fjord basin. The models were constructed on the basis of 1:5000 maps and graphs, and used as input to CFD simulations.

The study shows that CFD can be a useful tool in assessing environmental loads, and thus degradation risk zones on dock structures. Such studies are a “first approach”, and simulations needs to be validated with measurements. Point measurements performed at Ormsundet wharf indicate a good correlation with the CFD studies .

4.2.2 Degradation

Mapping of environmental parameters and of areas and stock of buildings with increased risk of corrosion, are performed and co-ordinated for Europe within the UN ECE Working group on Effects (WGE) under the Convention of Long Range Transport of Air Pollutants (CLRTAP), and specifically under its International co-operative Programmes (ICPs), for Modelling and mapping, and for Materials (ICP Materials), respectively [Tidblad and Kucera 2003].The dose/response functions for unsheltered materials are of the type:

$$K = \text{dry}\ (T, Rh, [SO_2], [NO_2], [O_3], t) + \text{wet}\ (\text{Rain}\ [H^+], t) \qquad \textbf{(1)}$$

where K is the corrosion attack, T is the temperature in degree C, Rh is the relative humidity in %, [] is the concentration in $\mu g/m^3$ (SO_2, NO_2 and O_3), t is the time in years, Rain is the amount of precipitation in mm and $[H^+]$ is the acidity of precipitation in mg/l. The corrosion attack can, depending on material, be quantified as either mass loss (ML, g/m^2), surface recession (R, µm), ASTM D 1150-55 1987 (ASTM, 1-10), depth of leached layer (LL, nm) or weight increase (WI, µg/cm^2).

4.3 Climate classifications and exposure indexes

The "robustness" of the Norwegian building stock, including the development of methods for classifying different climatic parameters and their impact on building enclosure performance, are now being addressed as part of the NBI research & development programme "Climate 2000" [Lisø and Kvande 2004, Lisø et. al. 2003]. An important aspect of the programme will be the preparation of a thorough overview of the relevant climatic loads that should be taken into account during the planning, design, execution, management, operation and maintenance of the built environment. A navigable way of ensuring high-performance building enclosures is to develop climate classifications or climate exposure indexes for different building materials and building enclosures [Lisø et. al. 2004]. A new method for assessing driving rain exposure based on multi-year records of synoptic observations of present weather, wind speed and direction coupled with average annual rainfall totals has been proposed by Rydock *et al.* [2004]. Lisø et. al. [2004] are now developing a simple method for risk and vulnerability assessment of frost decay based on multi-year records of one time daily registration of maximum and minimum air temperature and daily precipitation totals in different parts of Norway.

Many meteorologically related damages usually happens during extreme load events as opposed to chemical degradation. Hailstorms is one such load and the hail induced damage to buildings is directely related to the hail kinetic energy [Hohl et.al., 2002]. Modelling of hail damage is today a commercial product. A similal relation between meteorological load and damage to building has been established by using historical events [Thiis et.al., 2004]. By using records of known wind storms and connect this to the actual insurance loss, a close relation can be obtained. This type of models of the load-response of the building stock can be a tool for determining the response of the building stock in the present climate as well as in a climate in change.

4.4 IFC based geographical information-IFG

With the rapid development of IFC based standards for digital object oriented models of building products there is a huge need for property sets, such as durability and service life data, linked directly to the building elements. The significant drive within the AEC/IFC community to provide for relevant location based data (GIS) via IFC format (IFG) will be a major facilitator for access to site specific durability data, described by degradation models containing environmental (and other) degradation factors [Wix et al, 2005].

This will be essential for example for facilitating a seamless, internet based zoning and building plan permit. Key to this development is the integration of GIS information in a central building and property registry with AEC/FM information about the individual buildings that are registered
With the use of the IFC/IFD/IFG technology these functions and the resulting service life for the product can now be directly linked to the building element in question.

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