Abstract:

The aim of the research on brick masonry degradation supported by the D.G. XII is presented. The project is delivering the following:

- **Damage Atlas** of ancient brick masonry, a book with a description of the types of damage, and their possible causes, in ancient brick masonry structures;
- **Masonry Damage Diagnostic (expert)-System (MDDS)**, an expert computer system allowing the user to define damage types and damage causes in ancient brick masonry structures;

The scientific methodology used for the development of both documents is given. It illustrates the type, processes and cause of damage that occurs to historic brick masonry structures and the way non-destructive techniques are introduced in the evaluation procedure.

1. Introduction.

The effect of environmental damage on stone is well known but little research has been carried out on its effect on brick masonry. The interest of this investigation stems merely from the complexity of the problem. Brick masonry is composed of bricks which are silica based and relatively acidic while the mortar in most old buildings is made out of lime which is more alkaline. The influence of water on the degradation problem is also complex as water acts as a catalyst in the reactions. It brings about the possibility of the solubilisation of the reactants but also of salts present in the materials. Migration of salts originating from the materials in the masonry, but also from reactants from outdoor pollution (e.g. gypsum) or microbiological conversion (nitrates from conversion of ammonia) in the porous system of the bricks and the mortar, is a major cause of damage in historic brick structures.

The approach of the investigation methodology developed in the research programme and translated in the Damage Atlas and the Masonry Damage Diagnostic System is also very new. It starts with the most well-known non-destructive test used by all the specialist: visual examination. Both instruments help than to define clearly the damage type improving the use of an accurate and uniform terminology. For the evaluation of the damage cause a subsequent series of investigation techniques has been developed which starts from the accurate definition, visual information, non-destructive tests till (destructive) laboratory and in-situ investigations.

2. Aim of the study

2.1 Objective

The objective of the project is to improve the knowledge of the effects of environmental factors on damage to Europe’s cultural heritage and to guarantee better treatment and protection of our heritage by

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providing the professionals who work on the analysis of ancient buildings with an expert system including a
damage atlas.

2.2 Brief description [1].

A systematized questionnaire has been conducted that allows the collection of expertise from different
sources in relation to damage on historic brick masonry structures. The main initial sources are literature,
data from in situ investigation carried out on historic brick masonry buildings and laboratory simulation
tests. This information is collected in an "Atlas of damage to historic brick structures", containing
uniform terminology and a uniform description of damage types and damage origins. This information is
schematized into relations between damage types, causes and the physical phenomena related to a set of
deterioration processes. Particular attention is paid to the interaction between the different materials of
which ancient brick masonry is composed and the effect of environmental factors.

The deterioration causes can only be understood with a knowledge of the different historic brick masonry
construction types and the historic, climatic and geographic context in which those masonry have been
built, used and eventually restored.

A Masonry Damage Diagnostic System is developed that - through systematization of this knowledge
and relations - will guide the person using this expertise towards the assessment of damage type and damage
cause. It also provides information on the type of investigation that has to be carried out on the masonry
being diagnosed, in order to improve the quality of the information about the damage type and damage
origin. Therefore appropriate (monument-friendly non-destructive) testing techniques are evaluated on
their likelihood of increasing the precision of the diagnosis. For the creation of the expert system an experts
system shell is used based on decision tables.

2.3 Methodology

The methodology used is based on the scientific principles of research. In the problem stated, damage to
historic brick structures, and the development of the MDDS defined the scientific description and
deductions of the physical mechanisms causing the damage. Inherent choices have been made in relation to
the order of input taken into account for the deduction: it started with the most easy way of identification
which is visual analysis (this also explains the usefulness of the damage atlas) and then included in order
the in situ and laboratory tests. A thermodynamical model [2] defining damage as a result of stresses and
resistance allowed damage types and damage causes to be linked. This was then developed in terms of
processes within the MDDS. The development of the MDDS allowed us in many cases to limit the
problem description only to those parameters which are really necessary (goal oriented), thus omitting
irrelevant elements while the link with the practice remains guaranteed.

This approach is unique in this field and the experience of the project demonstrated the scientific interest
of this engineering approach for the evaluation of deterioration of ancient brick structures. It is an applied
scientific approach producing practical results for the conservation of historic brick monuments.

3. Research results.

3.1 Terminology and questionnaire

In the first stage of the work common definitions had to be set up which should be useful within the
different instruments of the project. A first set of damage types has therefore been defined which is useful
for the questionnaire and the Damage Atlas but could be developed within the MDDS. The hierarchic
concept allows the user to narrow his definitions gradually. As the questionnaire and the related damage
atlas are related to this first analysis it was logical that the definition of damage types should use visual
criteria.

The original questionnaire [3] with which the project was started and which stemmed from the
 collaboration of the experts of the NATO-CCMS pilot study on Conservation of Historic Brick Structures
has been modified considerably. The main reasons for this development are found in the interaction with the set-up of the terminology which was developed in relation to the MDDS.

3.2 Damage atlas.

In the damage atlas that will be published as a final result of the project [4] a classification of damage patterns found in brick masonry has been set up. The terminology used follows the same structure and set-up as the questionnaire and the MDDS. The definitions are more extensive than the definitions presented in decision table form in the MDDS and possible damage causes are also given. A complete set of illustrations of the different damage types is provided in the atlas with an explanation about the possible causes of the damage. Consistency with the MDDS was guaranteed as they were developed to be used together.

(Fig 1)

3.3 Masonry damage diagnostic system [5], [6].

A. Structure and concept.

The Masonry Damage diagnostic System (MDDS) is a Knowledge Based System (KBS). It is a database with information and additional knowledge to create relations according to given answers and questions. It is the translation of expertise into a system computers can handle. The knowledge is structured and can be consulted using a Decision Table System Shell (AKTS) developed by TNO-Bouw. The knowledge is translated into a large set of decision tables themselves containing sets of conditions and actions. The set of condition tables is structured in a hierarchic way and can be presented as a decision table tree.

Fig. 2 presents the starting branches of the tree with the sub-tree of processes checked by the system. Fig. 3 shows the tree of the damage types.

(Fig 2)
(Fig 3)

B. Consultation procedure:

The computer programme aims to make the consultation of the MDDS user-friendly. In contrast to the questionnaire the MDDS will adapt its questioning according to previous answers given. Comparative data as pictures and comparative results of test trends are also given so that if there is uncertainty or when the answer to be given is not clear, additional information can be consulted. A typical screen picture is given in Figure 4.

(Fig 4)

C. Consultation output.

The output of the MDDS is given immediately on the screen, but a printed report of the consultation is also generated. This document can be used as a report by the user. The results of a consultation can be stored in a file which allows progressive and step-by-step consultation in different stages. During the progress of the project it has been shown that it is very useful to create, using the MDDS, an interesting collection of examples of damage. The structure of the KBS within the MDDS obliged the users to work in a very systematic way while developing the system and using it afterwards.

3.4 Non destructive evaluation techniques in the Masonry Damage Diagnostic System.

As an illustration of the integration of more “technical” means of evaluation in the MDDS, a limited number of aspects of the damage on historical brick masonry monuments will be considered hereafter. Many damages are due to the combined presence of soluble (hygroscopic) salts and humidity. Therefore
understanding of the type of water flow and humidity distribution as well as the characterisation of the salts type and their hygroscopicity is essential. Non-destructive investigation techniques can then be used.

Considering the table tree representing the investigation of salt crystallization process it can be seen that this process is subdivided in 2 sub processes: the chemical conversion process and the pure crystallization process. Information about the main source of water is also requested from the water penetration process. One of the subtables is checking the (possible) presence of salts inferred from existing information or from hygroscopic data.

In the subtable "presence of salts from existing information" the location of the (e.g. at the sea shore) its history (e.g. flooding of sea water) and its use (e.g. as a stable) are indicated as a good basis for establishing the presence and the type of the most important salts in the damaging processes [7]. Further (non-destructive) tests are then proposed to be carried out as the use of magnification glasses and taste as a first indication, followed by measurements of electric resistivity (using commercial available apparatus) and confirmation using petrographical analysis, SEM/XRD, or chemical analysis for determination of ions type. The MDDS allows to skip information from those more in depth data and will then confirm the need to carry them out in the diagnosis. With the function "what if" the data of a test can be introduced in the MDDS at a later stage and the MDDS will properly take it into account and adapts its "reasoning" and depending on the case confirm the previous diagnosis or propose a new one.

In the case of "presence of salts established by hygroscopic data" the hygroscopicity of the grit c.q. powder extracted from the brick masonry at certain heights and depths is related with the presence of salts. The criteria "hygroscopic moisture content (hmc) greater then normal moisture content (nmc)" [8] is used to define the possible presence of salts and the relation with the moisture transfer mechanism.

For the low-intrusive tests proposed in the MDDS, the sampling method is defined and reference to the analysing techniques is given.

4. Conclusions:

The description of the damage types on historic brick structures has been improved. The link between terminology, questionnaire, damage atlas and MDDS is guaranteed by accurate definitions and the hierarchic concept of the damage types descriptions. In the same way the description of possible damage causes and the processes leading towards the above-mentioned damage types have been improved. The increase in systematization which was sought by the project is a necessary and interesting by-product of the creation of Knowledge Base systems (KBS).

The Decision Table System Shell (DTSS) has proved to be a very interesting tool for the development of the KBS.

The collection of different types of information using the questionnaire and other related summary sheets allowed the research team to make an interesting collection of degradations of different types. Those examples are useful for the elaboration of the damage atlas.

Reactions on the complexity of the questionnaire and uncertainty on the part of the user about which information should be mentioned in this document prove the advantage of the MDDS. It is certain that in the dialogue between the expert system and the user the latter will feel more comfortable as he will think that the questions which are asked are relevant to the problem, though on the other hand the expert system will limit his questioning only to that information it can consider in its reasoning.

Further development of the MDDS could be guaranteed by the integration of research results from other projects and by the inclusion of data available on the effectiveness and usefulness of different non-destructive tests.

REFERENCES:


[7] [1], pp. 39-41;
Muzzin G., Les efflorescences dans les maçonneries en briques, in Revue du Centre Scientifique de la Construction, n°4, 1982, Brussels

[8] nmc can be checked in handbooks (e.g. SBR publication n°9); generally for stone like materials it is max. 1-2% m/m; test to define hmc can be found in: R. Van Hees, S. Naldini, Zoutschade Curacao - Fase 3. Systematiek van conservering, unpublished, TNO rapport 94-BT-R0521, September 1994, pp. 14-16

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3.1.2 Frost/Water and Salts

**Building:** Barn

**Remarks:**
Barn used since 17th century to house cows and horses.

**Tests Performed (Bricks and Mortar):**
- Visual analysis
- In situ: Water uptake (Karsten tube), moisture content (cathode bottle)
- Soluble salts
- Frost

**Results of Tests:**
- Lack of maintenance, faulty drainage of roof and soil against wall.
- Salt samples contain 6.8% of nitrate
- Moisture content 2-3%
- Bricks are not frost resistant
- Water absorption 64-70% (6 sec) to 65% (33 sec)
- Quality of brick varies from light red to dark red.

**Contributions to Observed Damage:**
- Frost and salt
- Salts are delivered by urine of animals. In addition to the water entering faulty detailing, the building by splashing and rain water penetration due to and lack of maintenance, the water content is kept high by hygroscopic salts (nitrates)
- Darker bricks (better firing) resist better.

**Building:** Barn of Park Abbey

**Address:** Heverlee, Leuven, Belgium

**Source:** KUL

**Type of Damage:** Spalling

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**Fig. 1** Example of a page of the Damage atlas

**Fig. 2** Tree structure of the main branches of the MDDS: determination of the type of damage and checking of damaging process responsible for the damage ([6], p. 55).
Fig. 3 Structure of the decision tables containing the knowledge about the determination of damage types; the hierarchic approach corresponds with the structure of the damage atlas ([6], p.56).

Fig. 4 Example of a consultation screen using the MDDS ([6], p.21)