From Building Pathology to Durability Via GIS

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ABSTRACT

In this paper, it is demonstrated how GIS modeling and analysis operations can be used as a methodological tool for the representation of building pathology, and in parallel for the control of building materials durability. GIS thematic maps were developed presenting the façade of the historic building of National Archaeological Museum in Athens Greece, and a marble surface of the historic building, where the representative decay pattern of black-grey crust existed and pilot conservation interventions took place. Attribute databases consisting of data of physical-chemical characteristics were elaborated and linked with the internal database of the specially designed GIS decay/conservation mapping/conservation planning projects. After the application of the pilot conservation interventions and since the attribute database is enriched by the new evidence regarding the assessment of the critical performance characteristics of the conservation interventions, and utilizing the GIS geoprocessing procedure, scientists have the opportunity of monitoring the preservation state of the investigated surface, and building material durability. Thus, the use of a GIS platform can create an information-decision management system where datasets concerning building pathology and conservation interventions are recorded, correlated, distributed and attributed to space, during different time periods, contributing decisively to durability control of building materials and strategic planning of periodical conservation interventions.

KEYWORDS

GIS, Relational database, Building pathology, Durability.

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1 INTRODUCTION

The classification and representation of monuments pathology aims to control the decay progress and to improve planning of conservation interventions. This can be accomplished through the recording and presentation of building materials, developed decay patterns and their extent, on architectural drawings [Fitzner et al. 1992]. The use of electronic means and their special tools can achieve, in a modern and effective way, control of building pathology and its life cycle, cost analysis, pointing towards building protection through prediction and prevention [Warke et al. 2003]. Therefore, GIS modeling and analysis operations are frequently used for the above mentioned purposes, due to their special capabilities regarding the processing of different background data which incorporate spatial and attribute (descriptive) data sets. Thus, within the framework of building pathology representation and building preservation, several scientific projects have investigated GIS potential i.e. Salonia & Negri [2002]; Inkpen et al. [2001].

In the present work, GIS is utilized for developing decay/pilot conservation interventions/conservation planning thematic maps for a representative investigation of the marble surface on the western façade of the historic building of National Archaeological Museum, Athens, Greece (Figs. 1a and 1b). Decay diagnosis and pilot conservation intervention results along with GIS capabilities of recording, rouping, managing and analysing large volumes of spatially referenced data, were used for the elaboration of data-bases and spatial data transformation and spatial analysis. The aim of this work was the development of a methodology planning for monitoring the durability control of the marble surfaces of the building studied.

The historic building of National Archaeological Museum (NAM) is located in Athens centre, a city of polluted urban atmosphere. Its construction started in 1866 based on the drawings of the German architect Ludwig Lange, and ended in 1889 under the supervision of another German architect, Ernest Ziller, who made major modifications to Lange’s initial drawings. National Archaeological Museum western façade consists of several types of plasters and pentelic marble surfaces. Due to its historic and architectural importance, this building is a high priority for strategic planning of periodical conservation interventions.

Figure 1. (a) The Historic building of National Archaeological Museum and (b) the representative investigation area of capital.

2 RESULTS & DISCUSSION

2.1 Methodological Approach

In order to perform characterisation of building materials and decay diagnosis, non destructive testing and evaluation (NDT & E) techniques in situ, and analytical ones in lab after sampling, are applied on representative investigation areas which are selected, during building inspection. This procedure constitutes the first part of the diagnosis protocol as presented by Moropoulou et al. [2005]. The proposed protocol concluded to building pathology representation through materials and decay mapping using GIS (Fig. 2), as well as incorporating data of structural analysis, architectural study, and geometric documentation.
The demands of sustainability for rational use of resources, brings to the foreground the urgent need of building materials durability control and buildings’ life-cycle assessments (LCA). Several difficulties arise with monitoring of buildings, like different methodological approaches usually derived for different materials and components, different building uses, extended periods of LCA, different state priorities, lack of funds, etc. Therefore, the use of GIS, as a methodological and analysis tool, for monitoring selected representative surfaces where decay diagnosis and pilot conservation interventions take place, is proposed. In simple words, rather than monitoring a whole building, better economy of scale, management and durability control can be accomplished if carefully selected representative areas of the investigated building are periodically examined, whereby examination results are incorporated into a GIS platform. This will facilitate and possibly optimize the targeted and early evaluation of decay process, identifying and understanding decay mechanisms, in a rather focused scale in the field; aiding, in parallel, integrated assessment of pilot conservation interventions, in terms of real incorporation of durability criterion. Even though exclusively laboratory-derived measures of durability, like accelerating ageing tests, can not and must not be underestimated, the suggested GIS-based methodology (Fig. 3) is a tool for durability control in different building scales, which in addition can embody (through relational database elaboration) lab results of different studies, during different time periods. Thorough decay mapping and monitoring of selected representative surfaces, will assist in developing a robust plan for monitoring of building material durability and building life-cycle assessment. The above analysis does not diminish the importance and the usefulness of building pathology representation via GIS and durability control potential of an investigated building as a whole; it actually acts complementary and it enhances several issues concerning better time and fund management, permitting different approaches for the in-field investigation which depend on working-scale selection.

**Figure 2.** (a) Thematic map of building materials for NAM façade, (b) decay thematic map for marble surfaces on NAM façade.

**Figure 3.** Methodological approach.

Within the context of the above methodological approach, four representative marble surfaces of the NAM, in addition to those in the thematic maps of Fig. 2, were selected to act as GIS pilot projects for...
durability control and monitoring, one of which is hereby presented. In neoclassical buildings like NAM, marble is used as facings or load-bearing structures, presenting smooth or relief finishes. Marble surfaces are of high priority regarding strategic planning of periodical conservation interventions, since even partially reconstruction is out of question and sampling is rather limited not to say restricted. Therefore, the representative marble surface of the capital was selected due to its high artistic value as a sculptured surface and the arising challenges on conservation issues for the preservation of relief surfaces.

The capital under investigation is located on the first (from North) column of the propylon, has an eastern orientation, and is totally protected from rain-wash. During building inspection, it was observed macroscopically that the capital surface presented the characteristic decay pattern of black-grey crusts: gypsum (CaSO$_4$·2H$_2$O) produced by sulphur dioxide (SO$_2$) attack to marble calcite (CaCO$_3$), along with black particles, soot, iron oxides, and alumino-silicates [Moropoulou et al. 2008].

The GIS thematic maps of the capital marble surface were elaborated in ArcMap/ArcInfo 9.2, using the CAD architectural drawing of the capital as the blueprint for the GIS base-map development.

In parallel, during diagnostic study, NDT&E techniques were applied in situ, whereas analytical and NDT&E techniques were used in lab after sampling, resulting in decay diagnosis for the investigated surface. The NDT&E techniques applied in situ were fibre optics microscopy and colorimetry; whereas the analytical techniques used in lab after sampling were optical microscopy (OM) and scanning electron microscopy with energy dispersion by X-ray analysis (SEM-EDS). The NDT&E techniques used in lab in the selected samples were the laser profilometry (LP) and the digital image processing (DIP) of SEM images.

Decay diagnosis results confirmed the presence of black-grey crust that was observed macroscopically, as well as the historic evidence that the building material of the capital is pentelic marble. The pilot conservation interventions that were applied consisted of different cleaning methods like AB57 poultice, poultice of ion exchange resin with deionized water, ion exchange resin with 10% w/v (NH$_4$)$_2$CO$_3$ solution, and a wet micro-blasting method of spherical calcium carbonate particles with diameter less than 100µm. After the pilot cleaning applications and during the study of pilot conservation interventions assessment, the same NDT&E and analytical techniques took place in situ and in lab after sampling. More information on the techniques used as well as on the cleaning assessment criteria for marble surfaces presenting black-grey crusts can be found in Moropoulou et al. [2008].

Assessment of the cleaning interventions focused on the sustained performance of the cleaned surfaces relative to chemical and mineralogical composition, texture roughness, fracturing and colour. Therefore, SEM-EDS was used to assess the chemical and mineralogical composition of the cleaned surfaces, LP was used for the texture roughness assessment, Digital Image Processing (DIP) of SEM images is utilized for the measurement of surface fracturing and colorimetry evaluates colour modifications of the cleaned surfaces.

These physical-chemical characteristics are describing the preservation state of the building material before cleaning, whereas their modification after cleaning, indicate the chemical, microstructural and aesthetical transformation of the investigated surface, depending though on the applied pilot cleaning intervention. These data are considered to be the monitoring indexes for durability control of the investigated marble surface and their modification through time will demonstrate decay processing, achieving integrated assessment of the different cleaning methods in a focused scale in the field. These monitoring indexes of the investigated sculptured surface are representative and corresponding to the ones that the other three capital surfaces of eastern orientation in NAM propylon would have presented if decay diagnosis and pilot conservation interventions had been performed on them. Thus, strategic planning of periodical conservation interventions on sculptured marble surfaces, incorporating durability, can be successfully accomplished.
Decay and cleaning interventions data, comprised the attribute data sets which describe the corresponding thematic maps features. Moreover, physical-chemical data derived by the above mentioned techniques, before and after pilot conservation interventions, were used for building the relational data-bases, in order to store the attribute data of each thematic map feature.

2.2 Development of Decay – Pilot Conservation Interventions Thematic Maps and Databases

Decay and pilot conservation interventions data comprised the attribute data sets which describe the characteristics of the recorded spatial entities of the investigated surface. Therefore, ascribing the decay and conservation intervention results of the physical-chemical study to the features of the GIS base map, during building topology, led to the development of the thematic maps of decay and pilot conservation interventions (Figs. 4 and 5). During spatial data input in ArcMap/ArcInfo, the process of topology building is of high importance. Topology building, in addition to building spatial relationships among features which configure a layer, is directly related to the recording and storing of the corresponding attribute data sets that describe real world entities or conditions [Padmanabhan et al. 2002].

In decay thematic mapping each layer was classified and recorded according to its spatial properties and physical-chemical characteristics, before cleaning treatments. The sculptured surface of anthemia present front and side relief surfaces for which decay diagnosis results had indicated different physical-chemical characteristics like gypsum layer width, roughness, surface area, fracture density, etc. Therefore, two different layers were elaborated, one for each relief surface (front and side), which were displayed by different colours, light and dark brown respectively (Fig. 4).

Furthermore, accordingly to the decay thematic map, two different layers were elaborated in the pilot conservation interventions thematic map, one for each relief surface (front and side), whereas the areas of the pilot applications of the different cleaning methods were elaborated as features and displayed by different colours (Fig. 5).

Moreover, attribute databases consisting of physical-chemical characteristics data were elaborated and linked to the attribute table of the corresponding GIS decay/pilot conservation interventions mapping project of capital surface, thus resulting in relational databases (RDBs). In particular, the GIS attribute tables, which include topological characteristics like perimeter, area, adjacency info etc were linked with external databases where data regarding petrography, chemical and mineralogical composition and stratification, total crust width, macro-crystalline gypsum layer width, and micro-crystalline gypsum layer width (results of OM and SEM-EDS), roughness Rq and surface area (LP results), fracture density and friability index (DIP of SEM images results), luminosity L, difference in red-green a*, difference in blue-yellow b*, and total colour difference ΔE (colorimetry results in CIELab colour space) were stored and classified. The databases were built using text and numerical elements as type of entries; whereas the data fragmentation permits the user to interrelate data regarding decay diagnosis and pilot cleaning interventions with the vector data, locating the info in a geometrically exact point or area, respecting the topological relationships among the various parts of the investigated surface [Padmanabhan et al. 2002]. This is possible since the first field of the above mentioned databases is flagged with the same identification code as the topological element to which the descriptive data refer to and the user can view the information, whenever the corresponding themes are active.

Data retrieval is accomplished by the use of the relational operators that the GIS platform provides in order to compare values associated with spatial data. Boolean operations (logical combinations of data, involving union, intersection, complement and exclusion), as well as logical operations (like equal to, greater than, etc) were used for different entities and attributes access, manipulation and analysis. As shown in figure 6a of the decay thematic map the geometric entities that comply with the combined expression of logical and Boolean operations of “black-grey crust total width greater than or equal to 80µm AND fracture density greater than or equal to 35.3” are highlighted on the map and
on the database with light blue colour. Furthermore it is demonstrated, by the database highlighting, that only one feature of the investigated surface (central area of the anthemia relief), satisfy the defined logical and relational criteria, a fact that reflects the dynamic and direct interrelation of the database to the vector data.

**Figure 4.** Decay thematic map for the capital surface, along with RDBs for both front & side anthemia surfaces.

**Figure 5.** Pilot conservation interventions’ thematic map for the capital surface, along with the RDB of the front anthemia surface.

**Figure 6.** GIS analysis using Boolean and logical operations on (a) decay thematic map for the capital surface, and (b) pilot conservation interventions thematic map for the capital surface.

In accordance, as shown in Fig. 6b of the pilot conservation interventions thematic map the geometric entity that comply with the combined expression of logical and Boolean operations of “total colour difference $\Delta E$ less than 9.56, AND micro-crystalline gypsum width greater than or equal to 30, AND roughness less than or equal to 15, AND fracture density less than or equal to 26.4” is highlighted on the map and on the database with light blue colour. The only feature of the investigated surface that satisfies the defined logical and relational criteria, which in parallel are considered as accepted threshold values of the cleaning assessment criteria, is the cleaning method of ion exchange resin with deionized water applied for 10 minutes.

### 2.3 Development of Conservation Planning Thematic Map

Using geoprocessing procedure and in particular the intersection operation tool for both decay and pilot conservation interventions thematic maps, the resulting output theme is the conservation planning thematic map. This output theme includes features with attribute data from both input and overlay themes (decay and pilot conservation interventions themes respectively). Therefore, the new thematic map of conservation planning contains combined spatial information and the aggregation of the attribute data of both decay and pilot conservation intervention thematic maps.
Data retrieval is also accomplished in the conservation planning thematic map by the use of the relational operators that the GIS platform provides in order to access, manipulate and analyse different entities and attributes. As shown in Fig. 7 the geometric entities that comply with the combined expression of logical and Boolean operations of “micro-crystalline gypsum width before cleaning less than or equal to 60, AND micro-crystalline gypsum width after cleaning greater than or equal to 30, AND fracture density less than or equal to 26.4” are highlighted on the map and on the database with light blue colour. The features of the investigated surface that satisfy the defined logical and relational criteria are the cleaning methods of ion exchange resin with deionized water applied for 10 minutes and the ion exchange resin with 10% w/v \((NH_4)_2CO_3\) solution applied for 10 minutes.

Furthermore, comparative diagrams of selected attribute data sets can be elaborated, whereas features holding the selected attributes are highlighted on the vector data. In Fig. 8 the comparative diagram of fracture density (FD) for two different areas, presents the shift of the FD attribute values before and after cleaning for the features where ion exchange resin with deionised water for 10 and 20 minutes respectively were applied. The diagram demonstrates the increase of FD value in the area that ion exchange resin with deionised water for 20 minutes was applied, whereas accepted threshold value decrease for the FD attribute took place in the area of ion exchange resin with deionised water for 10 minutes application.

It is clear that when a new conservation assessment study takes place in the future using the same NDTE and analytical techniques, the attribute database will be enriched by the new evidence regarding the critical performance characteristics of the applied cleaning methods. Utilizing in parallel the GIS geoprocessing procedure, scientists will gain the opportunity of monitoring the selected physical-chemical indexes of the investigated sculptured marble surface in relation to environmental parameters on real scale, deciding the best one incorporating the durability criterion. Moreover, planning of conservation interventions for all the capital surfaces of eastern orientation in the NAM propylon, can be successfully accomplished.

3 CONCLUSIONS

Diagnostic study results concerning building material and decay data, as well as pilot conservation interventions study results were recorded and attributed to spatial entities of the representative investigated pilot surface of the capital, resulting in the development of GIS thematic maps, which after the use of GIS operational analysis provide valuable info regarding: (a) the presented decay and its physical-chemical characteristics, as they resulted by the application of NDT&E techniques, and of analytical techniques after sampling, and (b) how these physical-chemical characteristics altered after the application of pilot conservation interventions. The application of geoprocessing procedure on the above mentioned thematic maps, led to the conservation planning thematic map. This final map incorporated spatial and attribute data regarding decay and pilot conservation interventions, contributing to the planning of conservation interventions of the investigating surface.

The potential of the methodological approach using GIS to monitor selected representative surfaces, in order to continuously assess the critical performance of conservation interventions, and to control building materials durability, was demonstrated in practice.

It is concluded that the use of a GIS platform can create an information-decision management system where datasets concerning building pathology and conservation interventions are recorded, correlated, distributed and attributed to space in different working-scales, during different time periods, contributing decisively to durability control of building materials and strategic planning of periodical conservation interventions.
Figure 7. GIS analysis using Boolean and logical operations on conservation planning thematic map for the capital surface.

Figure 8. Comparative diagram of fracture density before and after cleaning for two highlighted areas, using GIS analysis operations on conservation planning thematic map for the capital surface.

REFERENCES


