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NATURAL ASHLARS OF HISTORICAL MONUMENT – MODERN METHODS OF DATA PROCESSING AND STORAGE

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Abstract: *The aim of the introduced contribution is to present the methodology for the research and maintenance of facing ashlars of historical structures. The natural building stone of historic monuments is subjected to various types of deterioration and damages mostly due to weathering processes. If the stone has to be completely changed during the reconstruction, it should be preferentially replaced by variety of the same lithological composition, the same or similar appearance and with the sufficient durability. It is methodologically necessary to generate the ashlars façade plan based on digital photographic procedure in the real scale before the restoration. The aim of this paper is to bring a modern look for the processing, visualization and storage of information obtained in mapping facades of historic buildings. The data processing and their storage in GIS were implemented on the façade of St. Martin's Cathedral in Bratislava. There are also described the basic processes of stone deterioration in this article.*

Keywords: ***Natural ashlars, data processing, GIS, databases, spatial and non-spatial data.***

1. Introduction

The natural building stones in historical monuments ashlars undergo to weathering processes and therefore they are damaged. If the stone has to be completely changed during the reconstruction, it should be preferentially replaced by variety of the same lithological composition, the same or similar appearance and with sufficient durability. Nowadays, it is practically impossible to use the resources of original material, therefore is necessary to find new source of a suitable replacement material. The use of the alternative stone must not change the visual character (color, texture) of monument or ornamental façade elements. From that point of view, the deteriorated façade has to be detailed and well researched and mapped.

The aim of this paper is to bring a modern look for the processing, visualization and storage of information obtained in mapping facades of historic buildings. Processing and visualization of spatial data is processed within Geographic Information Systems (GIS), where used are not only the tools for vectorization (digitalization) of analog data and visualization modulus, but also advanced tools of map algebra. Map algebra is implemented directly in a GIS environment and provides basic and advanced analytical operations with raster and vector data model. Non-spatial data - data stored in the attribute table when processed in the GIS environment and database systems are information about different types of façade damages and their causes, physical and mechanical properties of individual lithological types represented in the object as well as the proposed replacement of whole building blocks. This paper presents the direct examples of the above mentioned approaches of processing of spatial, as well as non-spatial data.

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To be able to provide the required and quality information about building material (physical-mechanical properties, detailed lithology analysis, rate and cause of deterioration, etc.) is sometimes necessary to take samples during the process of façade photo documentation. The use of indirect nondestructive methods of properties assessment is useful, if sampling is impossible.

2. Facades damages and their causes

First, in the process of mapping façade, is necessary to know the cause of damage of building stone ashlars and to determine the main weathering processe that is responsible for the decay.

The weathering of stone ashlars is natural process during which physical and chemical processes take place (Winkler, 1997). The weathering processes cause physical disintegration and chemical changes having the effect on changes of rock structure and its physical properties. The weathering forms are macroscopically (also microscopically) observable phenomena on the stone surface. The cause of the stone decay is obvious in some cases and therefore the identification of concrete weathering process is possible (Smith *et al.*, 1992). The durability of stones is influenced by certain factors. Warke (1996) distinguishes the factors between those factors, which influenced the stone before its placement into the building structure (e.g. way of extraction, processing of surface), and such factors, which modify the stone after the placement into building structure (e.g. internal environment, surroundings materials, cleaning and conservation).

The degree of damage depends on the stone petrography and stone genetic classification. The characteristic component of stone internal structure is its pore space, which is significantly modified during weathering processes. On the other hand, the properties of pores, such as e.g. their shape, interconnection and size distribution also influence the stone durability and consequently the degree of damage. The presence of intergranular spaces influences the porosity, presence and transport of the liquid phase inside the rock.

Physical weathering

Physical weathering is a set of processes during witch stone is negatively influenced as the effect of physical forces (Ollier, 1969). Neither chemical nor mineralogical composition is affected during these processes, but the grain cohesion may be broken and thus the technical properties may be exacerbated (Winkler, 1997). Physical weathering also causes the changes of internal structure. Among the agents causing the physical weathering belongs e.g. temperature changes (frost, insolation), salt crystallization pressure, mechanical influence of organisms.

Influence of water presence

The presence of water in stone is one of the most significant weathering agents, especially during winter. The freezing water in pores can cause large pressures and can lead to the degradation and disintegration of stone grains. Presence of water in the pore system affects the cohesion of grains if their state changes. The action of frost can cause swelling and shrinking of stone surface (Winkler, 1997; Thomachot & Jeannette, 2002). When water freezes, it increases in volume of approximately 9% (Johannesson, 2010). This can cause large pressure and consequently changes in the pore structure. Hardness of frozen water crystals is 1.5 degrees of Mohs scale at 0°C and 6 degrees at -60°C. The total porosity and pore radius increase depending on the number of freeze/thaw cycles (Winkler, 1997).

Sedimentary rocks often contain clay minerals and therefore they may be sensitive by wetting. The presence of water can cause the swelling of expansive clay minerals. The outward forces of the expansion produce tensile stresses in the stone structure (Bortz & Wonneberger, 1997).

The process of hydration, contribute to the degradation as well. The volume of phase increases during the hydration due to the sorption of water and thus more pressure is exerted on the surrounding area. Hydration and dehydration processes take place in response to changes in temperature and relative humidity.

Influence of salts presence

Crystallization of salts in pores can exacerbate the process of degradation. The origin of salt crystals forming from the solution in the pore space can cause large pressure. According to Goodman (1989) the growth of salt crystals depending on temperature causes pressure of several tens to hundreds of MPa, which exceeds the tensile strength of most rocks. Besides crystallization pressures of forming salts, the process of their hydration, contribute to the degradation as well.

On the other hand, not every salt action results in stone deterioration. The production of surface efflorescence is often impressive and highly visible, but generally causes only little damage. Previously fractured material can be actually bound together by various salts (Doehne, 2002). Besides the influence on the process of physical weathering, crystallization of salts may be accompanied by chemical processes and action of organisms (Goudie & Viles, 1997).

The relationship between the action of salt crystallization and frost action was pointed out by e.g. Williams and Robinson (2001). The authors extended the range of salts, which intensify the frost action, and also shown that the degree of stone damage depends on the combination of salts involved.

Chemical weathering

Chemical weathering is a very complicated process during which the interaction among minerals and present solutions causes mineralogical changes and may lead to the degradation of stone. Factors controlling chemical weathering are following (Ollier, 1969; Winkler 1997): i) concentration of hydrogen ions in system (pH); ii) its ionic potential; iii) and its oxidation/reduction potential. The chemical weathering processes especially are dissolution, oxidation and reduction, carbonatization, hydration and hydrolysis.

Chemical weathering is influenced by the presence of water and dissolved chemicals and gases. Temperature, humidity, presence of organic acids and dissolved carbon dioxide are particularly most relevant to the extent of damage caused by chemical weathering (Winkler, 1997).

3. Processing of ashlars facade plan and data storage results

Preparation of input data and assumptions of technical processing issues

The main instruments, except of external graphics modulus for processing, vectorization, analysis and visualization are Geographic Information Systems environment (GIS) and database systems.

There are many definitions that describe the Geographic Information System. Concise definition is according to Maguire (1991), which describes the GIS as an organized set of computer hardware, software and geographic data for the efficient acquisition, storage, editing, management, analyzing and displaying all forms of geographic information. For façade plan processing the vector data model was applied. Vector representation of conceptual models of reality is based on the object; position the explicit modeling of space. Object reality is represented by geometric types (elements) composed of points, lines and polygons. Vector data are stored in computer memory using the coordinates of points and topological relations (Hofierka, 2003).

The basic requirement placed on the facade plans is their positional accuracy. Important problem is the heterogeneity of different sources (http://sk.wikipedia.org/wiki). Positional accuracy varies and results from the scale, method and precision of data scanning, as well as other factors. Therefore, it needs accurate and correct mutual superposition of all inputs. When processing the façade plans a commercial product by ESRI (Environmental Systems Research Institute) - ArcGIS 9.1, working under the Microsoft Windows had been used.

Database System (often RDBMS or DBMS) is a software system for efficient storage, modification and selection of large amounts of persistent data. At present, almost all used database systems are based on relational data model. The performance and capabilities they provide, we can roughly be divided into "high end" (Oracle Database, Microsoft SQL Server, IBM DB / 2) and "low-end" (MySQL, MiniSQL, ...) and systems between (PostgreSQL, ...). Besides these there are also so called desktop relational database systems, which unlike "full" systems do not provide a high level or even advanced features such as transaction processing, authorization, and robustness, multi-user access but on the other hand, are much cheaper (Microsoft Access, dBASE, Microsoft FoxPro, Firebird, Interbase, ...). Microsoft Access database in package Microsoft Office 2003 was used for our targets as the database system.

GIS based processing

Based on detailed photo documentation of historic building within frame of field research, the subsequent generation of facade plans using GIS is very useful. The output of this stage is a detailed and accurate plan of the facade, which has incorporated elements of architectural characteristics, lithological composition of individual building blocks and their properties (including those laid down in the laboratory research) and determination of weathering forms.

The first step is facade mapping and identification of individual ashlars of the object using existing paper plans. Those results are usually scanned to digital raster form (.tiff) and georeferenced in GIS environment (Fig. 1). Usually we use large-scale cylindrical scanner with high resolution. Paper plans often do not correspond to the actual state, so during the mapping phase these should be updated.

Fig. 1: Left - mapping and identification of individual building blocks, right - an example of existing paper facade plan (Vician et al., 1957).

The second step is using of photogrammetric approach, to create photo documentation of the object façade, predominantly for bottom part of the objects, which is the most affected by chemical, mechanical weathering as well as by human activities. These records should be rectify, georeferenced and digitize using vectorization tools within GIS environment (Fig. 2). Using polygon entities per each building block, the vectorization had been completed.

The third step after the vectorization is visualization of the vectorized parts of facade plans. The visualization is based on non-spatial information stored in attribute table directly connected with individual layers (Fig. 3). We can use the non-spatial data for providing of various analyses using map algebra, e.g. how many and which blocks are damaged due to concrete type of weathering, how many and which ashlars of same lithological type should be replaced, percentually which lithological type is predominantly used on the object and many others.

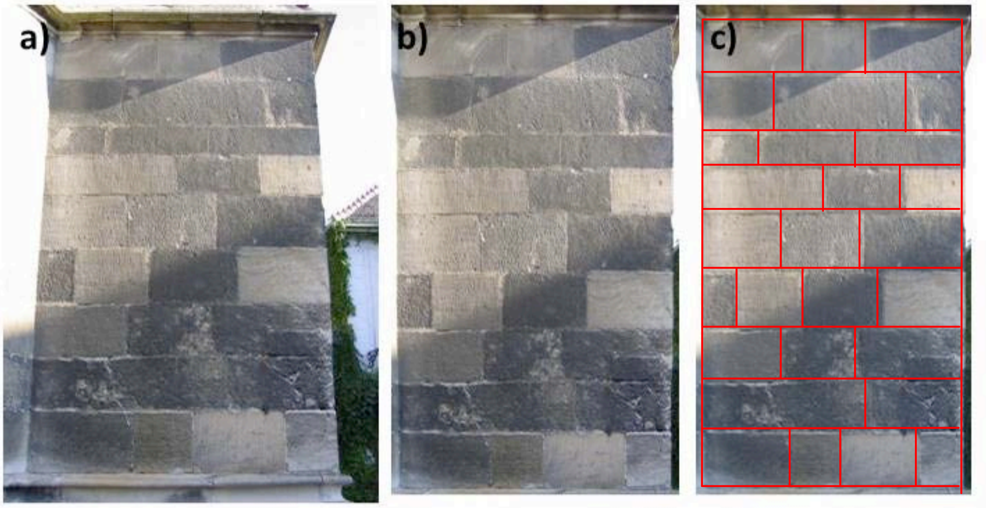

Fig. 2: Using of photogrammetry approach: a) photodocumentation, b) rectification, c) vectorization (Laho et al., 2010).

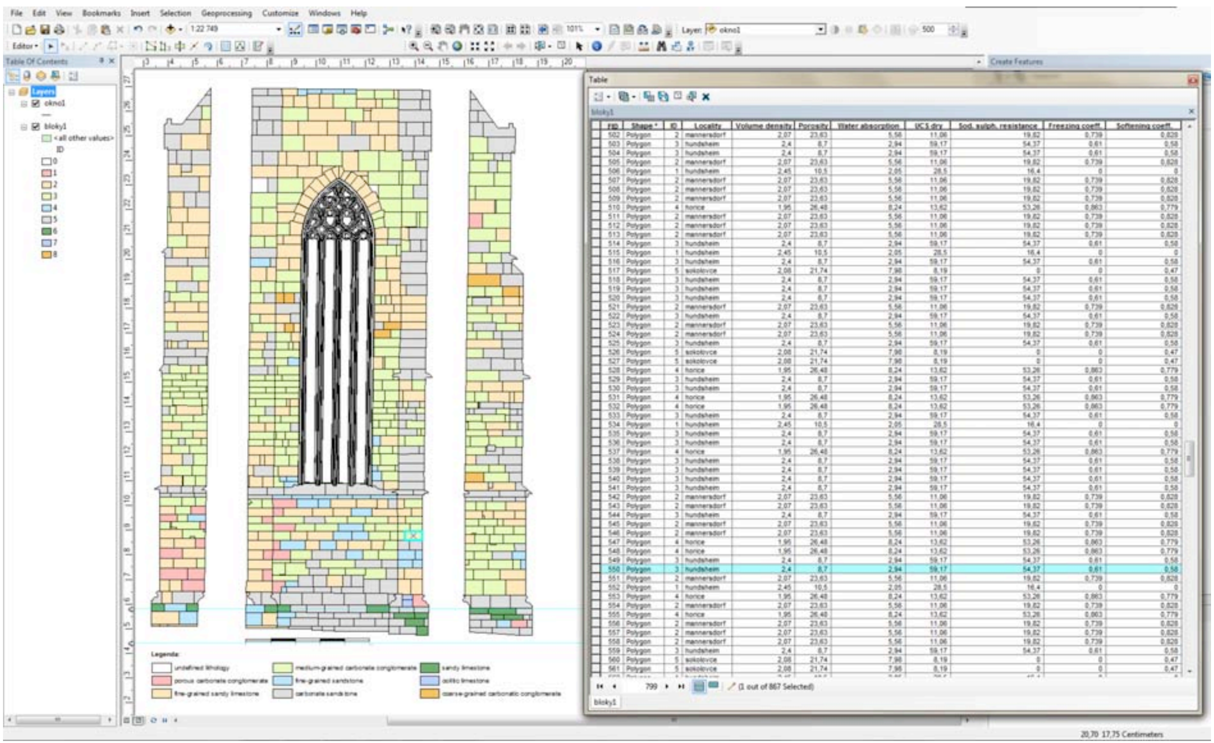

Fig. 3: Processing of part of St. Martin Cathedrale in Bratislava in ArcGIS: left - the visualization represented lithological types; right - the information stored in the attribute table.

Database processing

The modern trend of processing information electronically enables to store a large set of data in a relational database in accordance with modern standards of information technology. Such a process of storage and arrangement of data provides an efficient operation, completion and retrieval of interactive relations.

The methodology used for the database was assembled from generally valid rules for the creation of information structures and for the type and extent of data input assembled in documentation records. The relational database generates an information unit and a tool assembled in documentation records which enables their efficient presentation and processing as specified by the requests of the user. An example of database scheme is presented in Fig. 4. Microsoft Access database in package

Microsoft Office 2003 was used as the database system (Fig. 5). This solution belongs to the cheaper desktop relational database systems.

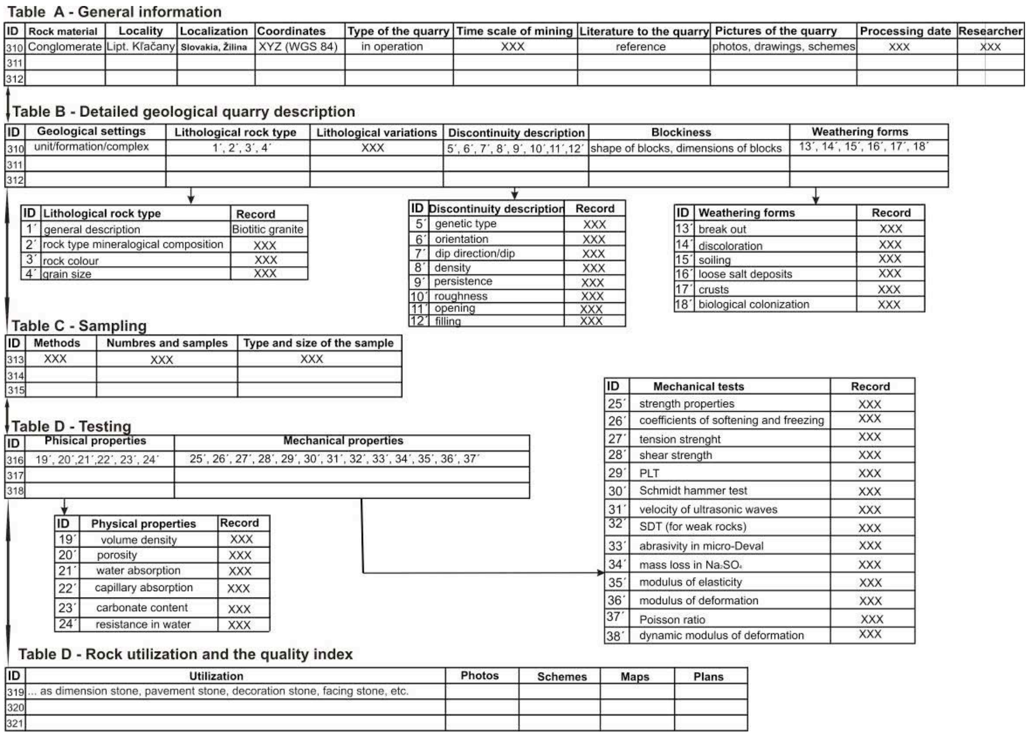

Fig. 4: Database system scheme for data storage (Holzer et al., 2009).

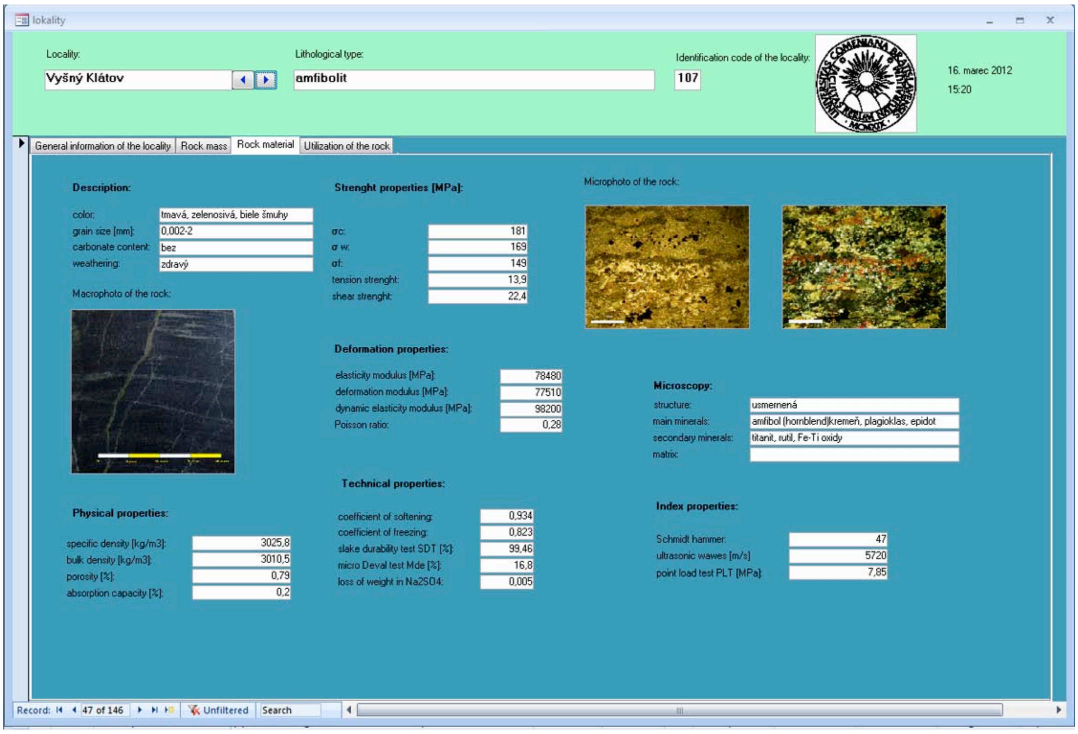

Fig. 5: An example of "user friendly" database using Microsoft Access environment (Holzer et al., 2009).

Spatial and Non-spatial data

Spatial data are bound predominantly to GIS environment. Those data can be presented it two data models. First is vector data model, where all objects are described by point, line or polygon entity and second is raster data model characterized by size of basic cell. Here-in, polygon entity of individual blocks as a vector had been applied to create façade planes.

Non-spatial data can be bound both within GIS environment in the form of attribute tables as well as in database systems. Those data presents huge amount of information from field and laboratory research. For our purposes non-spatial data which are needed for appropriate ashlars replacement can have following structure (modified according to Holzer et al., 2009)):

(1) Position of the object consisting of the object name and district and county name according to the territorial divisions.

(2) The geographical co-ordinates of the JTSK system provide subsequent processing of information for the application of the GIS environment.

(3) The documentation date represents useful information with regard to the history of research.

(4) Façade damages and their causes (see the chapter 2).

(5) Descriptive characteristics of the rock material contain the set of basic data on the character and state of rocks described according the rules of the standard STN EN ISO 14689-1. It concerns:

– Colour of the rock material which predominantly characterizes the weathering degree of the rock;

– Grain size of the rock which is the basic structural characteristic of the rock material. It is described semi-quantitatively according the standard;

– Carbonate content in the rock material which could influence its properties in contact with water. According to the standard three possible states are distinguished: rock without carbonates, carbonate rock and highly carbonate rock;

– Weathering characterizes changes of the rock material, caused by external factors. According to the Technical standard criteria four degrees of rock material weathering are distinguished: fresh – discoloured – disintegrated – decomposed;

– Resistance in water that is one of the most important properties, especially for rocks containing clayey minerals. The water resistance is expressed based on the rock state after a 24 hours submerge in water according to the scale: rock material stable –partly stable – non stable.

(6) Physical properties express the physical state of rock material. They are detected by laboratory tests or by calculation. Within physical properties a Specific rock density (ρ_s in kg.m^{-3}, determined according to standard STN EN 1936), Bulk density of dry rock (ρ_d; kg.m^{-3}; STN EN 1936), Porosity (n; determined according to formula $n = (\rho_s - \rho_d)/\rho_s.\ 100$ (%)), Absorption capacity (N; %; STN EN 13755) and Absorption capacity by capillarity (C_f; g.m^{-2}.s^{0,5}; STN EN 1925) can be presented.

(7) Deformation properties of rock material express behaviour of rock during its loading and unloading. Deformation properties of rock material are detected by laboratory tests or by calculation. Within deformation properties Modulus of rock elasticity (E; MPa; determined according to standard STN EN 14580), Deformation modulus (E_{def}; MPa; STN EN 14580), Dynamic modulus of rock elasticity (E_{dyn}; MPa; which is calculated from the measured velocity of ultrasonic waves and value of bulk density of rock) and Poisson ratio (υ; non-dimensional; STN EN 14580) can be presented.

(8) Strength properties - express the highest resistance of rock material to actuating strength. Regarding to anisotropy of some types of rocks the orientation of strength in axis x (y) or z is expressed in the corresponding rows. Within strength properties the uniaxial compressive strength on dry samples (σ_{c1}; MPa; STN EN 1926), on saturated samples (σ_{c2}; MPa; samples immersed in water for 48 hours) and on freezing samples (σ_{c3}; MPa; samples after 25 cycles of freezing and thawing) can be presented.

(9) Index properties include mechanical properties of rock material, determined by simple and quick tests. The results of these tests have usually good correlation with conventional strength tests of rock material. Point strength of rock (or Schreiner strength; σ_{vtl}; MPa), Rebound hardness by Schmidt hammer (R; non-dimensional), Velocity of ultrasonic waves spread (v; m.s^{-1}) and Point Load Test ($I_{s(50)}$; MPa).

(10) Technical properties of rocks characterize rock material as a material used for various purposes, but foremost in engineering practice. Selection of properties was limited by the possibilities of laboratory testing. Resistance against water expressed by coefficient of softening ($k_1 = \sigma_{c2}/\sigma_{c1}$; non-dimensional), resistance against frost expressed by a coefficient of freezing ($k_2 = \sigma_{c3}/\sigma_{c1}$; non-dimensional), Slake Durability Test (I_d; %), Abrasiveness of rock expressed by coefficient of abrasiveness micro-Deval (M_{DE}; non-dimensional; STN EN 1097-1) and resistance against salt crystallisation ΔM; %; STN EN 12370).

(11) Resources of rock – original or for potential replacement.

(12) Photography of location which contains a general view on location and a more detailed view on the documented part.

(13) Microscopic snap (created at parallel and crossed Nicol prism) with a description of the mineral content and fabric of rock material.

(14) Photography of the glazed surface of the rock sample.

4. Conclusions

The use of the modern approach of façade research and mapping enables to generate a quality façade plan using GIS. This plan provides rich variety of information, especially at the time of reconstruction planning. There are included all the important and useful information about the ashlars material and ornamental façade elements, such as lithological composition, rate of deterioration, weathering forms and as well as the proposal which blocks should by replaced. The modern trend of information electronic processing enables storage of a large set of non-spatial data in a relational database in accordance with modern standards of information technology. At the end, we have the "user friendly" database, which contains all the necessary information.

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