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# A new section of the Extended Matrix methodology: Transformation Stratigraphic Unit (TSU)

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*Abstract* – **This paper illustrates the preliminary results of an ongoing research concerning new investigative methods and tools useful to formalize transformative processes on built heritage, in a chronological perspective, through the study of surface alteration and degradation pathologies as Stratigraphic Units. This study aims at proposing a new section of the Extended Matrix (EM) method, composed of cutting-edge software solutions for managing and representing information, as a possible bridge between the archaeology of architecture, strictly connected to chronology, and the conservation science field of research, based on the surface analysis. The goal is to allow more accurate comparative analysis for conservative purposes and produce scientific-based reconstructive hypotheses. Present workflow, still being tested, is based on open-source tools, and is designed to be reproducible on any type of artifact according to FAIR principles.**

## I. INTRODUCTION

This paper presents an open and generalised formal tool, the Transformative Stratigraphic Unit (TSU), to study degradation phenomena with a chronological perspective related to construction phases. This tool permits to record and visualise not only the current state of conservation, but all the transformative processes of degradation and alteration related to the life of an historical building. This perspective makes it possible to illustrate the time span of every process highlighting the moments of beginning and end, the synchronicity of phenomena, the relationship between degradation and construction phase, etc... The need to formalize these links between the archaeological and architectural field emerged at the end of the last century [1, 2, 3, 4] and has continued to evolve to the present day with new research and the development of technology. This study proposes a new section of the Extended Matrix method to manage documentary and graphic data about stratigraphy and state of conservation in a single 3D environment.

Alteration and degradation phenomena cause important changes in the general appearance of historical architectures and artifacts. The importance of protecting and studying the tangible evidence on historical surfaces has been a well-known issue and a subject of discussion during the last century and it is still relevant [5, 6, 7, 8].

Recognizing all the modifications of surfaces is therefore essential not only to identify suitable restoration solutions, but also to appropriately examine the objects of study, especially built heritage. Architectural finishes, for example, play a crucial role in studying ancient construction techniques and understanding possible different facies belonging to previous phases. However, the analysis of architectural surfaces, especially the undecorated ones, often shows a lack of depth which leads, in most cases, to plan rough interventions, lose the authenticity of the artifacts and, eventually, create a potential fabrication of history.

Therefore, the documentation process is fundamental for analysing and comparing the mutual interaction of different phenomena and their relationship with the context. Documentation methods change and update as technology evolves. Therefore, it is important to develop and test ever newer and more accurate archiving methods. The more accurate the recording of every information, the greater the chances of recognizing the possible modifications to study, conserve and propose evidence-based reconstructive hypotheses (virtually and/or physically).

Moreover, the examination of the state of conservation of artifacts in a diachronic way supports the study of virtual reconstruction of structures and objects in terms of colour, texture/consistency, and roughness.

Present paper illustrates some of the results achieved by applying this new section of the EM to the ongoing study of the architectural complex of S. Pietro in Segni (RM), which includes the analyses of both state of conservation and stratigraphy.

## II. TSU ANALYSIS

The workflow proposed in this research divides the analysis phase into three moments (*see* section III). The first two deal with the data collection and analysis of sources and stratigraphy (when visible), to document the construction phases, and the documentation of the degenerative phenomena, with analysis of the pathologies concerning the different materials and stratigraphic units to which they belong. A final step of the research consists of a critical synthesis of the results derived from the comparison between the two moments of the analysis. This phase permits to both draw conclusions for the virtual reconstruction of the historical phases of the building and use reconstructive data as a basis for any conservation, restoration, and enhancement interventions. It is noteworthy that the results of the first two steps represent a coherent output related to the documentation of the state of conservation of the monument. Eventually, the third step is about the possibility to use this within a reconstructive project.

Historical sites and buildings are complex systems, which we investigate in a moment of their life path, in a temporary situation, during a period of continuous transformation. For example, architectural artifacts are usually formed by additions and subtractions, which took place at different times for different purposes, and by modifications due to the degeneration of matter.

Archaeological investigations and state of conservation analyses are both fundamental and necessary to read the sequence of historical events on architectural surfaces, identifying the dynamics of the material transformations. The concept of degradation goes far beyond the natural decay of matter, since often its concrete manifestation is the evidence of a specific transformative dynamic of the object [9].

Deterioration of a building and its transformation are inevitably intertwined with the history and evolution of the building itself, with its use and also with its changes. Indeed, degradation phenomena are associated with the natural passage of time, they are connected to the physical history of the structure, the natural history of the materials that make it up, the atmospheric agents of degradation, the cultural history of its builders, and the men who have allowed its conservation, and all those who have used it [10]. Therefore, coding degradation phenomena through stratigraphy could facilitate their recording as a 'source' and also their placement in a complete and more complex chronological framework in which each sign is part of a larger historical moment.

The first general analysis of the different pathologies is mainly carried out through sight, touch, and hearing. The documentation is carried out with the compilation of datasheets (one for each pathology) according to methods already in use [11] and with the Italian and international standards [12-13]. Pathologies are identified with a code and are divided by type and category with progressive numbering. The documentation includes a general description of the pathology with the identification of any indirect signs and other coexisting degenerative phenomena and a close-range description divided according to sensory perception. Finally, any in-depth diagnostic analyses recommended are listed and the possible causes are described. The filling activity is normally divided into 4 steps: recognition of the various phenomena in progress, autopsy analysis, photographic documentation, compilation of the data sheets and subsequently - where necessary - new in-depth investigations.

The described workflow can be replicated in any archaeological and architectural context.

## III. MATERIAL AND METHODS

The proposed new methodology is based on the implementation of an already consolidated workflow adding the analysis of surfaces conservation as a necessary step for the virtual reconstruction. To make it operational it has been inserted within the EM as a new section of the method.

### *A. The method*

The proposed methodology is divided into 3 distinct phases:

1. Data collection
2. Data analysis (2.1 Stratigraphic analysis, 2.2 Analysis of construction techniques and finishes; 2.3 Analysis of the alteration and/or degradation phenomena)
3. Data implementation (3.1 Critical synthesis; 3.2 Virtual Reconstruction)

1. Data collection

The first step of the process entails detailed research of all the necessary information (graphical documentation, images, 3D survey etc..) useful to start the data analysis phase.

2. Data analysis

The second consists in visual analysis, study of indirect sources and comparative studies with structures that are similar in type, year of construction, geographical-political position, etc…. If necessary, in-depth diagnostic analyses can be scheduled.

This phase is divided in:

2.1 stratigraphic analysis.

2.2 analysis of construction techniques and architectural finishes.

2.3 analysis of the alteration and/or degradation phenomena.

According to the standards of identification and classification of the various already mentioned surface degradation pathologies [12-13], four different groups of problem typologies have been identified. The different pathologies have been grouped according to the type of modification they generate on the surface, according to stratigraphy principles:

a. colour change;
b. detachment and material loss;
c. deposit and bio colonization;
d. crack and deformation.

3. Data implementation

The third, which is the last of the sequence, is articulated in two main steps:

3.1 Critical synthesis with the identification, if possible, of portions of the surface that are in good condition and can be used as a model for virtual reconstruction and

3.2 Virtual Reconstruction

Following an in-depth study of the sources and analysis of the materials and their degenerative pathologies, the reconstructive methodology can be based on the different types of alteration / degradation, according to the division already set out in point 2.3.

To organise, examine and represent all the data, results obtained during the analysis phase are entered in the EM graph through the formalization of a new section.

### *B. The new section of the EM method*

The Extended Matrix [14] consists of an Open Science Framework, the so-called Extended Matrix Framework (EMF), developed by the Digital Heritage Innovation Lab (DHILab) of the Institute of Heritage Science of the CNR of Rome and the Extended Matrix Community. The method has been designed to: create a comprehensive documentation of a Heritage objects with a strong focus on the data provenance (which source documents, 3D surveys, etc… are included in the documentation) as well as to implement a reconstruction pipeline digital, transparent, easy to understand, and repeatable.

EM refers to solid formal and theoretical bases such as: the Harris Matrix and Stratigraphy, to manage the chronological sequence of events; CIDOC-CRM standards, to control data storage and data management; Computer Graphic, to represent data within a 3D environment. The Extended Matrix method extends the Harris Matrix to document and map the reconstruction of an archaeological context. The so-called "extension" has been controlled with a formal language, which is composed of a proper node-based grammar, and some open-source software solutions. The latter are tools, developed by the DHILab of the CNR of Rome, useful to manage reconstructive data and paradata within Blender (EMtools [15]), edit 3D geometries also in Blender (3DSC [16]), and share online both 3D models and reconstructive information (EMviq [17]).

On this occasion, a novel (on an early-stage phase of development) section of the Extended Matrix method has been used to digitally map, manage, and virtually visualize alterations and degradation phenomena of the monument. This new development of the method allows to register, within the EM graph, both information and geometrical annotations, concerning the state of conservation of the ancient monument, useful for reconstructive purposes.

As already mentioned, from an Extended Matrix point of view, to implement this new section of the method, it has been necessary to create a new part of the formal language, linked to the research field of conservation science.

In this case both a new node, the Transformation Stratigraphic Unit node (TSU node), and a new theoretical definition of the node itself have been formalized within the EM method.

*Table 1. TSU Properties.*

| TSU properties | Notes |
|---|---|
| ID | id number |
| TSU | Transformation Stratigraphic Unit |
| ATP | Abbreviation Type Phenomenon |
| Typology | type of modification (a, b, c, d) |
| Phenomenon | Phenomenon codification |
| Localisation | Geographical location of the object of analysis |
| Date of survey | The moment when data has been registered |
| Element | Architectural/decorative element |
| Material | Type recognition of the altered/degradeted material |
| Exposure | Orientation of the phenomenon based on cardinal points |
| Description | "5 meters from the altered area" |
| Close range description | Visual assessment |
| Close range description | Tactile assessment |
| Close range description | Hearing assessment |
| Indirect signs | Indirect sign of phenomena |
| Coexistent phaenomena of alteration/degradation | List of other coexistent degenerative phenomena |
| Analyses | Carried out and/or recommended in-depth analyses |
| Diagnostic conclusions/causes | Results of the analysis |
| Anteriority | *ante quem* relation |
| Posteriority | *post quem* relation |
| Contemporaneity | contemporary stratigraphy units |

The TSU node stores in the EM graph all the information, the so-called "Properties" (Phenomenon, Localisation, Date of survey, Element, etc..; see Tab. 1), concerning the conservation status of the subject of a research/analysis and their chronological order of appearance. In the case of a reconstructive process, this information can be used as a new informative layer to improve the reliability of the reconstructive proposal. Therefore, within the method the TSU node has been conceived as a real and tangible Stratigraphic Unit with a double scope. The TSU is both the witness of a transformation, an event that has changed the original aspect of a structure or an artifact (such as: “erosion” can modify the external aspect; “chromatic alteration” can drastically change the original colour of finishes; “biological colonization” can mask the original layer of the surface; etc..), and a source of information suitable to support the reconstructive process (such as: in the south-west tower of the Ss. Quattro Coronati case study where TSU mapping allowed the identification of an unknown previous construction phase of the structure [18]).

Currently there are a few ways to create annotations in Blender: (i) extruding single points; (ii) using the Grease Pencil command; (iii) using the Annotation command. On the other hand, the theoretical improvement of the method, useful to map and manage state of conservation data, has proceeded simultaneously with a development of the add-on employed to manage, and visualize in Blender EM nodes, paradata, and, if necessary, connected databases [19]. In the latter case, two principal actions have been carried out: 1) EM tools have been taught to recognize and visualize TSU node and its related data; 2) a set of new Blender materials have been realized starting from an already existing list of symbols designed by the National Research Council of Italy (CNR) and the Istituto Centrale per il Restauro (ICR) guidelines [20]. Therefore, these materials have been included within an EMtools’ material library to be applied automatically when a specific type of TSU is indicated in the EM graph.

## IV. CASE STUDY

The church of S. Pietro in Segni, already studied and published [21] by the project #SegniArcheologia [22], is located in the area of the ancient Acropolis of the city, the building preserved in a single architectural organism several important elements of the ancient city (Fig. 1).

The structure, built on the remains of a Roman Republican temple consecrated to Giunone Moneta, is characterized by the overlapping of multiple construction, abandonment, and restoration phases [23]. The wall faces of the structure appear today as an articulated palimpsest in which it is still possible to identify at least five different construction macro-phases. The first plant in the area seems to coincide with the construction of the vast polygonal podium dating back to the Archaic age, on which today the remains of the Roman temple in opus quadratum are visible. In late antiquity the site seems to have undergone a period of neglect with the partial demolition of the architecture and the subsequent reuse of the structures for the installation of the medieval church, which also shows multiple constructive moments. From the comparison between the iconographic documentation and the direct study of the current conformation of the monument, it was finally possible to identify two further phases in the 19th and 20th centuries.

*Fig. 1. View of the photogrammetric model of the church of S. Pietro in Segni in Blender.*

## V. RESULTS

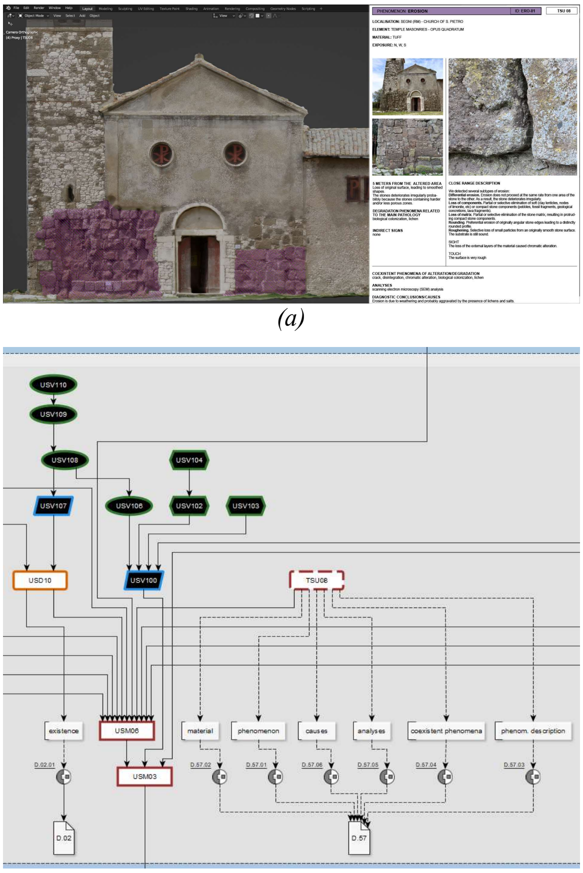
State of conservation of the church of S. Pietro in Segni is fairly good. No portions of optimal preserved wall facing useful for a possible sampling of the texture were found; however, some walls were built with well-known construction techniques that can be reconstructed by analogy based on already studied/published examples.

Several degradation pathologies were found. The most representative ones were annotated on the 3D model and related to other SU on the EM graph. The SU were recognized and filed. Subsequently, the various pathologies of degradation were analysed and mapped, dividing them according to type, material and SU to which they are related. On the main facade (S) 1 alteration and 11 different degradation pathologies were detected. These pathologies were organized into 23 TSUs and related to 4 USM: TSU1-7 to USM06; TSU8-12 to USM07; TSU13-19 to USM08; TSU 24 to USM09 (Figg. 2, 3).

Within Blender, the add-on EMtools allows users to establish a link between the conservation data, stored for each TSU inside the EM graph, and the related geometries created in Blender.

In general, for each annotation indicated on the digital replica of the case study, these geometries represent both a spatial location and an informative layer.

At the moment, 24 types of alteration and degradation have been identified. In order to both distinguish all these typologies and automatically attribute them to the related geometries, through EMtools, a new representation pattern has also been implemented within the list of materials embedded in the same add-on.



(a)

(b)

*Fig. 2. a) Left side, proxy model of TSU08 (degradation: Biological colonisation) in Blender. Right side, preview of the corresponding datasheet – ID ERO01 (D.57). b) Focus on the EM graph related to TSU08.*

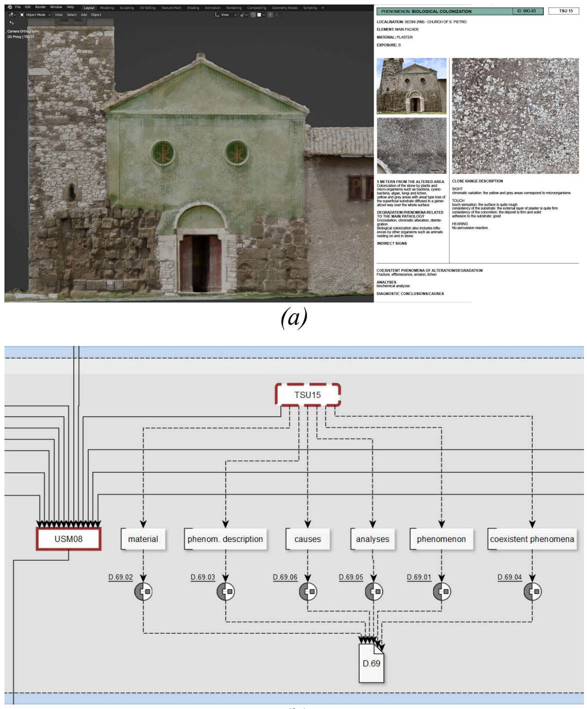
EMtools allows to: geometrically annotate both alterations and degradation phenomena within a 3D space; visualize annotations within a 3D environment; consult within the 3D software all the information stored in the EM graph; export data in csv\xlsx format.

## VI. DISCUSSION

In the past years great progress has been made thanks to the standardization of different types of alteration and degradation pathologies.

Present research wants to take the methodology to a new level with the use of innovative data acquisition and management tools.

By following this workflow, scientifically valid results can be obtained. All surfaces are examined with the same level of detail without distinction between decorated and undecorated parts.



(a)

(b)

*Fig. 3. a) Left side, proxy model of TSU15 (degradation: Biological colonisation) in Blender. Right side, preview of the corresponding datasheet – ID BIO03 (D.69). b) Focus on the EM graph related to TSU15.*

## VII. CONCLUSIONS

The results described in this paper have outlined a promising perspective regarding the connection between the archaeology of architecture, strictly connected to chronology, and the conservation science field of research, based on the surface analysis.

Due to this new specific section of the EM approach, it will be possible to connect the investigation analyses to the conservation and enhancement phases according to the FAIR principles.

This new section of the EM method will also be a place to experiment a proposal for an international standard to represent surface degradation and alteration.

The case study illustrated in this paper confirms that the Extended Matrix is completely open to multidisciplinary implementations.

## VIII. ACKNOWLEDGMENTS

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