Toward Comparative Visual Analysis of Ancient Roman Millefiori Artifacts

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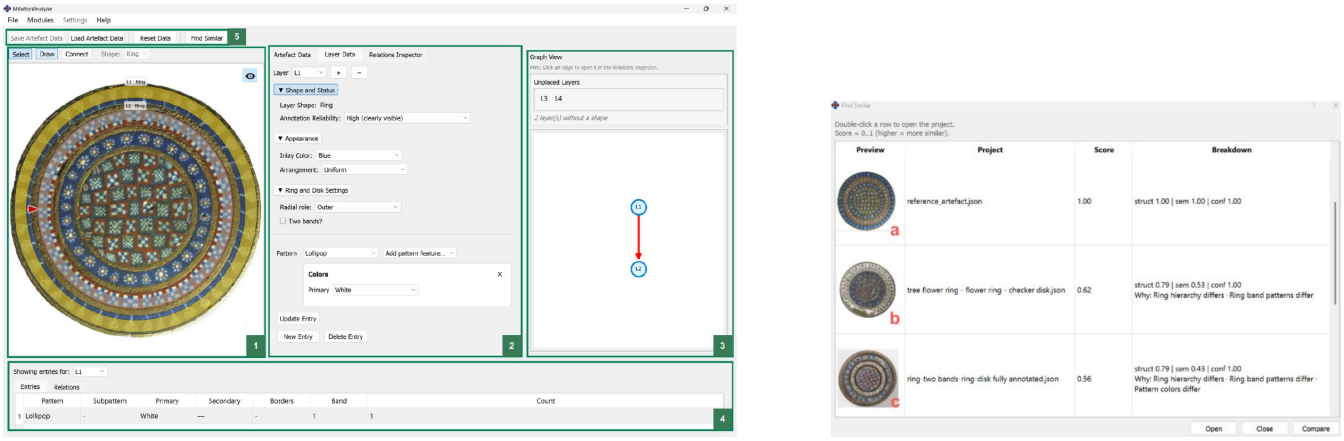

Figure 1: *Grammar module (left) and automatic similarity-based artifact comparison feature (right) of* MillefioriAnalyzer. *The grammar module consists of ① annotation view, ② attribute view, ③ graph view, ④ table view and ⑤ project toolbar.*

Abstract

We present an approach toward comparative visual analysis of ancient Roman objects decorated with millefiori. The goal is to make the "grammar" of the decoration of the artifacts as a whole to be analyzable in order to investigate possible region-specific differences between them. For this purpose we developed a grammar module *for the MillefioriAnalyzer framework. The module enables interactive topological annotation of the artifacts and simultaneously converts them into a graph representation. This graph aims to present the topology of the decorations in a abstract and concise manner. Based on the graph, a similarity analysis of the artifacts is performed and the foundation for a subsequent grammar-based comparison of the artifacts is provided.*

CCS Concepts

• ***Human-centered computing*** → ***Visualization systems and tools;*** • ***Applied computing*** → ***Archaeology;***

1. Introduction

Archaeologists have studied a distinctive group of Roman copper alloy objects (Figure 2, right), which has millefiori ("a thousand flowers") decoration, for nearly a hundred years [Exn39] [Hen33]. About 1200 of these objects have been found across the Roman world. Millefiori florets, small polychrome patterns, are created by slicing (Figure 2, left) glass rods (canes). These florets are arranged in elaborate, highly symmetrical and striking patterns on a copper-alloy base. To date, there is only a general assumption of production in workshops in the Rhineland, Belgium or the Danube province on general stylistic grounds. In our project, we are working toward systematic, detailed comparison in order to identify workshops.

In this work, we devise an interactive module supporting annotation and visual analysis of whole artifacts (in contrast to single florets as in [WGE25]) in order to explore the "grammar" of the motifs and color combinations and study the placement of different designs on the items of personal adornment. The first iteration of the module, presented in this work, focuses on annotation of high-level structures and their topology, and a similarity analysis based on attributed relational graphs derived from these annotations.

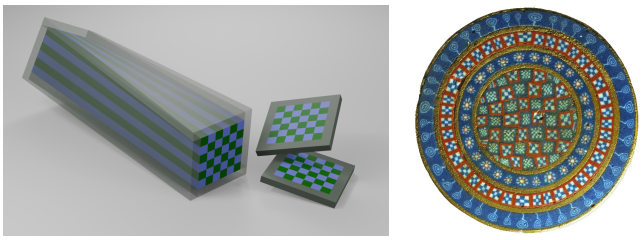

Figure 2: *Left: Illustration of a glass cane and millefiori florets (slices) cut from it. Right: A copper alloy and enamel stud inlaid with florets, from Usk, UK. Photo © Amgueddfa Cymru - Museum.*

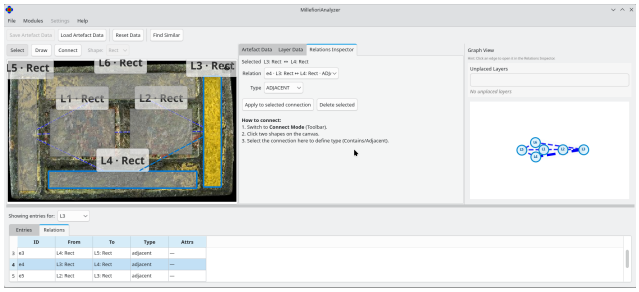

Figure 3: *Annotation of an artifact producing a more complicated graph. Photo: Roman belt plate, © Amgueddfa Cymru - Museum.*

2. Related Work

The concept of grammar originates from linguistics, where it defines rules for sentence structure, but it has been extended to describe spatial and visual structures. Stiny and Gips [SG71, p. 125] introduced "Shape Grammar," where visual structures are rule-based and can be formally described. An early example of this concept is heraldry, where coats of arms are described using standardized terminology, enabling precise reconstruction from text alone (cf. [FD09, pp. 99ff.]). Furthermore, Egyptian tombs show that hierarchical structures and design rules can aid in reconstructing missing or damaged elements (cf. [WD21, p. 319, 330]). In sum, complex structures can follow underlying rules and patterns. To uncover these, a systematic approach is needed to analyze properties like relative positions, hierarchy, frequency, and relationships.

As "*archaeology is a quintessentially 'visual' discipline*" [Bar10], we are not the first employing visual analytics (VA) in archaeological research. Related approaches have already been suggested over a decade ago [Llo11]. For example, knowledge discovery by arranging archaeological artifacts or their elements in clustering views has been suggested by Deufemia et al. [DIPPdR14] for petroglyphs, by Li et al. [LLZY24] for the evolution of pottery motifs, and for similarity of millefiori florets by Wiebel et al. [WGE25]. Furthermore, Zhang et al. [ZKL*13] presented a VA framework for analyzing the degradation of grotto wall paintings. Yet, no approaches allowing for interactive exploration of the visual grammar in a group of objects exist.

3. Analysis Approach

The grammar module provides three main representations and analysis steps. They are described in the following.

Annotation The annotation workflow comprises three steps: drawing shapes to mark regions ("layers") on the artifact image, connecting shapes to form relations between them, and adding meta information to regions, e. g. which florets are present in a region. Drawing the shapes and adding connections is performed in the annotation view (Figure 1①). Currently the available shapes are rings, disks and rectangles, and the available connections are containment (arrows, Figure 1①③) and adjacency (dashed lines, Figure 3. Meta information can be entered in the attribute view (Figure 1②). All annotations can be made persistent in a project file (Figure 1⑤). In order to be interoperable, the files use the JSON format [Bra17] which is also used in related [RGSGGC*24] and prominent [MKEB17] [Ric97] archaeology databases.

Graph View The graph view (Figure 1③) shows an overview of the attributed relational graph (ARG) which is implicitly created by the annotation. The layout is heuristically based on the positions of shapes in the annotation view. Colors and stroke styles of edges indicate their connection type. The graph view receives automatic updates as shapes and connections are added in the annotation view. All views (①②③) are linked such that selection of a relation in one view highlights the relation in all other views and vice versa.

Similarity-based Grammar Comparison The ARG is the basis for an automatic similarity computation comparing different artifacts. The similarity score considers the structure of the graph (weight 35%) and the meta information of the nodes (weight 65%). When analyzing a certain artifact, users can request (Figure 1⑤, "Find Similar") an ordered list of the most similar artifacts. This list (Figure 1, right) shows images of the artifacts, their similarity score, and an explanation of the score. Users can then hypothesize that very similar artifacts have been crafted in the same workshop.

4. Conclusions

The first iteration of a *grammar module* for analyzing millefiori artifacts, presented here, supports archaeologists in the initial steps toward identifying a grammar of motifs for the artifacts. For this purpose, it allows them to annotate homogeneous regions of the artifacts, note their properties, and define their topological relations. The derived ARG is visualized as an abstract overview and used for automatically identifying artifacts with similar global structures. For archaeologists, the latter and the possibility to store annotations are the main benefit of the current version of the grammar module. **Limitations:** The automatic comparison based on the similarity score is currently focused on artifacts with concentric layout (Figure 2) and is less reliable for other layouts (Figure 3). Additionally, the weight parameters of the similarity score have been chosen based on experience with only a limited number of artifacts. **Future Work:** The module will be integrated into the open-source MillefioriAnalyzer [UX-25] tool by April 2026. A detailed description of the implementation is available [Bre26]. We intend to generalize the visual analytics approach to grammar extraction to other areas where visual or shape grammars are applicable. We also work on supporting the annotation process by automatic floret detection (YOLOv8 [JCQ23]) and classification (EfficientNet-B0 [TL19]).

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