Library Grammar: A Shape Grammar for the Reconstruction of Fragmentary Ancient Greek and Roman Libraries

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This paper presents a shape grammar that formalizes the architectural form of ancient Greek and Roman libraries and encodes it into shape rules for the reconstruction, evaluation and prediction of ancient Greek and Roman libraries. The grammar is briefly presented and the different contributions of the computation to archaeological research are discussed.

Keywords: Shape grammars, Ancient Greek and Roman libraries, Archaeological reconstruction

GENERATIVE GRAMMARS FOR THE RECONSTRUCTION OF ARCHAEOLOGICAL UNCERTAINTY

Reconstruction of archaeological fragments includes a high degree of uncertainty. Typically this task is taken up by archaeologists, who interpret available data and propose the initial state of an artifact based upon its type, structure, technologies, materials, ornaments, scale in comparison with other similar objects. Often experts disagree about the interpretation of available evidence and the resulting conjectures about an artifact's original state. Therefore, a substantial gap remains between the representation of the fragmentary existing object, produced through fieldwork, and the proposed representation of a proposed initial state, and this gap can be filled in various ways.

Generative grammars have been used in archaeology to describe, interpret, and evaluate findings and as a systematic tool of reconstruction that allows possible reconstructions and interpretations (Chippindale 1992; Hodder 1982; Knight 1994), and recently have been implemented in software applications of procedural modeling for the reconstruction of extensive archaeological sites, as for example in the reconstruction of Rome (Dylla et al. 2009), and Mayan Architecture (Muller et al. 2006). This work takes the notion of grammars and proposes a shape grammar as a computational methodology to identify, understand, and reconstruct ancient libraries of diverse and variant scale, design and monumentality.

The ancient library offers a great example for the exploration of the capacities of shape grammars in ancient architectural history and archaeology, because it was one of the most important institutions in the Hellenistic and Roman city, and yet it remains one of the least easily identifiable building forms and one of the most difficult to reconstruct, because unlike architectural types such as the temple, stoa, or theater, the library exhibits significant variety in design, scale and monumentality and the use of different component elements.
THE CORPUS OF ANCIENT LIBRARIES

The corpus of ancient Greek and Roman libraries that are identified with building remains consists of seventeen libraries spread out around the Mediterranean sea and spanning a period of 400 years, starting with the early Hellenistic libraries until the imperial libraries in Rome and the provinces of the Roman Empire. Built as part of complexes, or as independent buildings, libraries consisted of several spaces to accommodate their diverse functions, storage and retrieval of text, and they showcase big variation in form, layout, and scale. In some occasions libraries were part of larger complexes, like in the Serapeum in Alexandria, or the Temenos of Athena in Pergamon, or the Temenos of Apollo in Rome. In other cases, and primarily in the provinces, libraries were independent buildings, like the library of Celsus, and the library of Nysa. Or they were complexes themselves, consisting of more than one spaces, like the library of Pantainos, the Library of Hadrian in Athens, and the Library of Rogatinus. In all cases though, underlying principle is the association of the library hall with a stoa and a courtyard, where intellectual activities, discussions and lectures could take place. At the very least, a library consisted of one single hall, the main hall preceded by with a stoa. This main hall apart from the books included a statue to Athena, the patron goddess of libraries, set on axis.

In the Roman period, the interior design of the main hall became formalized and monumentalized. The armaria are most often not placed on the floor but are embedded in rectangular recesses in the walls, the niches, about 1 m. wide and 60 - 90 cm deep and about 2 m high. The focal point of the room with the statue of Athena is also constructed either as a projection in the podium, or a widened niche in the wall, or a large semicircular apse, or an aedicula, and was in one or two levels. Niches and Focal point are often preceded by a raised platform, the podium on which sometimes was set an interior colonnade. The columns framed the niches and the focal point. The podium was either u-shape along the side and back walls of the main hall, or interrupted in front of the focal point, thus forming two L-shaped podia.

A first effort to order and formalize the design of libraries was by Makowiecka, who suggested that Roman libraries could be classified into eight schemata (Makowiecka 1978). However, these eight schemata do not account for all Roman libraries, they mislead us to believe that components that appear in one schema cannot be identified in the other and limit our ability to understand the diversity in the design of ancient libraries, and the variation with which a library can be reconstructed. This work takes the notion of grammars and proposes shape grammars as a new, computational methodology to identify, understand, and reconstruct ancient libraries of diverse and variant scale, design and monumentality.

THE LIBRARY GRAMMAR

The library grammar is a parametric grammar, designed in Autocad in two dimensions, after the Palladian grammar (Stiny 1978). It consists of 91 design rules that work both with addition and subdivision and summarize and encode the design principles of ancient libraries. The grammar consists of two major parts that roughly correspond to the generation process of a building or a building complex: the first set of rules defines the main hall of the library and its architectural articulation; the second set defines the building envelope and the general layout of the building or the building complex. It is not suggested that the grammar corresponds to actual design processes carried out for the design and execution of the buildings. These two generation processes and the rules used to characterize them are presented here to define a uniform treatment of the design of these buildings. Both consist of several sub-sets or stages, each defining a proper part of the generation process. More specifically, each part of the grammar consists of six stages. Stages I through VI generate the layout of the main hall of the library with its interior design: the podium, the niches, the focal point, the interior colonnade and the entry. Stages VII through XI generate the rest of the layout of the library, the side rooms, the stoas with the exedras, the
entrance and the courtyard, if any. Last, stage XII generates the interior design of the side rooms.

The initial shape is a parametric cell with bilateral symmetry that stands for the main hall of the library, and includes spatial labels for the aggregation of additional rooms on the sides and a threshold in the front facade (Figure 1). By following the rules, the user can generate library halls of diverse monumentality by adding architectural components such as the niches, the focal point, the podium and colonnades or just skip them by erasing the labels with the erasing rules. Also, the user can generate libraries of diverse scale by converting the threshold into a simple stoa or by adding a U-shape stoa or a peristyle with or without a monumental propylon.

The rules are accompanied by metadata that point to the libraries in the corpus on which each rule is based. The more instances in which a rule is identified, the more important this rule is in the type definition of the library and the more probable it is that this rule will apply in a hypothetical library or a library under reconstruction. The rules are parametric; the range of valid values of the parameters is extracted from the archaeological record of the seventeen libraries in the corpus. Figures 2 and 3 give a sample of the rules that generate the main hall and the general layout of the library. The full grammar has been described in detail in the dissertation of the author (Mamoli 2014).

**GRAMMAR-GENERATED LIBRARIES**

The application of the rules generates libraries of diverse sizes and monumentality, libraries known in the corpus as well as hypothetical. The user of the grammar can start with the underlying plan of the state of preservation of a library, deprived of earlier and later building phases and interventions, and by plugging in the actual dimensions of the building components as preserved in the archaeological record can reconstruct the plan of the building. Also, the user can start from scratch and design a possible hypothetical design that might be excavated one day. The grammar cannot generate specific stylistic characteristics, for example the polyrhythm in the colonnades, or projections of walls, or case-specific typological characteristics such as the such as the duplication of halls.

**Derivations of well-preserved libraries**

In cases that a library is well-preserved, the computation works primarily as an evaluation of the grammar as a valid descriptive and analytical tool of building remains. Since the grammar is able to generate the forms of libraries well documented and reconstructed with a high degree of certainty, the grammar is evaluated as a trustworthy tool for the description, analysis and reconstruction of other libraries in the same style.

In addition to the library plans that are captured with certainty by excavation and on-site work, the grammar can also generate other variational schemata. By comparison to the actual, these computations can help the researcher evaluate the design choices of the architect and the patron, and gain an understanding of the social aspects of the library. For example, alternative derivations of the Celsus library (Figure 4) with a different than the actual focal point and by introducing niches to all intercolumniations generate alternative plans with more than double capacity in storage of books. These computations make us think that it was the choice of the architect and the patron to built a funerary monument with some books, rather than a well-informed public library.
Stage I rules that generate the main hall of the library with an apsidal or rectangular shape and subdivides and labels its walls for the optional addition of the architectural components, the niches, the focal point and the podium.

Conditions: \[ \{a, b, c, d, f, g, i, j, k, l, m, n, o, p\} \]

Occurrences: \[ \{c, h, q\} \]
Figure 3
Stage VII rules that generate the layout of the library with the addition of side rooms symmetrically to the main hall, or only on one side of it.

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**Derivations of partially-preserved libraries**

In cases that a library is not well preserved, the recursive computation of the rules generates a plausible reconstruction that is in the same style, and is a possible option for reconstruction of the specific library. Multiple options of reconstruction can be suggested depending on the evidence and the space it allows for speculation, as for example in the case of the Neon Library in Sagalassos.

Also, in cases where multiple phases of a library survive, the grammar helps the researcher look with fresh and objective eyes at the remains and avoid the tendency of traditional methods of archaeology to project the final form of the remains into the original phase of the building. The grammar is solely based on the archaeological record of the phases of libraries and not later modifications of the buildings that might have had nothing to do with the library. The grammar suggests reconstructions for the missing parts that are based on the style and type of ancient libraries. This is demonstrated in the computation of the Neon Library (Figure 5), from which the only remains of the original phase of the building come from the back wall. Later phases include the entry wall to the building where there is no connection to a stoa. In archaeological research, the later phases led archaeologists to think that the original phase was similar to the final. However, the grammar is not able to verify such an entry to a library, and suggests several reconstructions of the façade not based on later remains, but based on the design principles in the type.

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**Figure 4**
Two different derivations of the Celsus library: the derivation of the verified archaeological remains, and a hypothetical but possible derivation based on the site restrictions that maximizes the capacity of the library.

**Figure 5**
Two variant derivations of the Neon Library as consisting only of one main hall and as a complex with two side rooms.
**Derivations of non-preserved libraries**

In cases that a library is not preserved at all, the grammar functions as a guide for identifying the possible spaces of the library among the building remains. If the initial shape is embedded in part or all of the building remains, then this is a valid hypothesis for the identification of the library.

This selective identification of the archaeological record, and the embedding of the rules in all or in part of the remains gives a clarity and guidance to the user of the grammar to create scenarios that might not stand out using traditional techniques of reconstruction.

The computation of the library in the building remains of the Serapeum demonstrates this condition (Figure 6). The building remains are limited to the foundation trenches in the basement. So far no suggestion has been made for the position of the library due to the lack of evidence. The grammar was able to generate a possible solution by embedding the side walls of the main hall in part of the building foundations and assuming that these walls would repeat on the first floor. Thus the grammar succeeded in making a hypothesis and verifying it as valid. This selective identification of the archaeological record, and the embedding of the rules in all or part of the remains, gives a clarity and guidance to the user of the grammar to create scenarios that might not stand out using traditional techniques of reconstruction.

**Derivations of possible libraries**

Also, the grammar works as an evaluative tool for possible libraries, i.e. buildings that have been suggested as libraries, but for which there is no reference in ancient testimonia to verify the identification. The grammar provides an effective computational tool for their evaluation. Derivations have been made for these buildings, which can be classified into three categories: a) derivations that capture and reconstruct all the building remains of the proposed buildings are identified as Libraries. Such an example is the Private Library in Tivoli, b) derivations that capture some of the features of the proposed buildings are identified as exceptional libraries. Such examples are the library at Trajan’s Baths in Rome and the libraries in Side and Nime, and c) derivations that can not generate the mandatory features of a library are identified as Non-Libraries. Such examples are the room in Domus Aurea, and the so-called Philosophers’ Hall that cannot be identified as libraries because there is no threshold and there is circulation through their side walls.

**Derivations of hypothetical libraries**

Lastly, the grammar can generate plans of possible but hypothetical libraries. The formal description of hypothetical possible plans can be used to guide new buildings that come to light. The archaeologist can use the grammar as a prediction tool, and lead the excavation in parts of the building that appear more probable to uncover remains of the library.

Also, the formal description of hypothetical libraries can help reconstruct libraries not identified in the record, but known through descriptions in literary sources or dedicatory inscriptions. The grammar can map the parts of the building described in ancient testimonia with corresponding generative rules to provide alternative scenarios of reconstruction and help identify them on site. Such an example is the Grammatophylakion of Aphrodisias, probably more an archive rather than a library, which is extensively described in one dedicatory inscription. The building remains to be found. Possible grammar
CONCLUSIONS
The paper presented a shape grammar for the generative description of ancient Greek and Roman libraries that provides a theoretical and constructive description of the ancient library as both an independent building with one hall and a complex. In both cases the expressive emphasis is on the core of the library - the main hall with its architectural elements including the podium, niches, focal point, interior colonnade, entry sequence and proportional relations encoded in parametric rules. Also, the grammar has been designed to generate library main halls of simpler forms, for example libraries without a podium and interior colonnade, or libraries without niches and focal point but with armaria and a statue set directly on the floor, against the walls of the hall. Thus, the grammar is able to generate a whole spectrum of libraries, from the most monumental to the simplest. The underlying principle in all of them is the existence of a main hall in association with a colonnaded entrance or stoa.

Aspects of the buildings, which are evident in the archaeological record but cannot be generated by the grammar are stylistic characteristics unique to specific libraries. These constitute a level of detail that the grammar does not engage, but could be added in the future. Other characteristics of libraries that the grammar does not deal with are case specific typological characteristics that are the outcome of specific context or functional circumstances.

The grammar has been able to generate the libraries in the corpus, for which the building remains give the complete plan of the library. In these cases, the derivation worked as verification that the grammar is a trustworthy rule-based system for the generation of libraries. For the libraries in the corpus that are not well-preserved and include several missing parts, the grammar helped make meaningful suggestions about the distinction of earlier and later phases, and generated variant possible plans, not necessarily copying the form of later phases, but speculating on what would have been possible in the language of ancient libraries, given the site and context restrictions. Also, in cases where the existence of a library is known through ancient testimonia but no exact building remains have been identified for the main hall, the grammar was able to embed the rules in the possible building remains and generate possible reconstructions.

Possible libraries were either verified or refuted based on whether they can be derived by the grammar. Last, the grammar was used to generate hypothetical libraries that are not testified by any building remains, but follow the same design rules, and therefore represent possible forms that we should consider when confronting archaeological remains.

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