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Towards a Vitruvian Shape Grammar for Procedurally Generating Classical Roman Architecture

Jeremy Noghani[1], Eike Falk Anderson[2], Fotis Liarokapis[1]

[1]Interactive Worlds Applied Research Group (iWARG), Coventry University, United Kingdom
[2]The National Centre for Computer Animation (NCCA), Bournemouth University, United Kingdom

Abstract

The ability to automatically generate urban virtual environments using procedural methods is important for anyone who needs to create plausible virtual representations of human settlements, and these techniques are used in simulation and reconstruction of archeaological sites as well as in education and the entertainment industry. In this paper we present an attempt at providing a shape grammar based on the writings of the ancient Roman architect Virtuvius, encoding rules for procedurally defining the make-up of Roman settlements. Our initial results allow the procedural generation of classical Roman Temples, which include many of the architectural elements found in Roman civic buildings.

1. Introduction

Virtual recreations of cultural heritage sites are increasingly common, being found not just in archeaological reconstruction [Baw10], but also in educational serious games [AML*10], as well as entertainment products. Due to the high costs that are associated with the manual creation of content for rich virtual worlds, automation of the content generation using procedural modelling techniques [NLA10] are becoming increasingly attractive. This is especially true in the case of cultural heritage visualization, where budgets are usually far smaller than those encountered in the entertainment industry. Procedural modelling enables the fast creation of large environments, including both urban and rural environments, based on a set of predefined rules, and over the past few years, virtual heritage has started utilizing these techniques in order to create heritage content in a fast but also accurate manner [HMVG09]. The reconstruction of ancient buildings, which often only exist as ruins or foundations, often relies on interpretation, making it impossible to define an accurate set of procedural generation rules. However, sometimes there are additional sources, such as architectural texts [HMVG09, DG11], which can be used to design procedural rules that can provide a 'best guess' attempt at reconstruction of lost buildings.

With his ten books on architecture [VPBC], the Roman architect Vitruvius (Marcus Vitruvius Pollio) provides us with a "textual coding of the practice of building" [Pat97] from which one can extrapolate the rules for the construction of Roman settlements, which in turn can be used for the procedural generation of 3D Roman settlements using modern CGA (Computer Generated Architecture) techniques. These rules can be used to create plausible visual representations of typical Roman settlements following classical Roman architecture, as built in the late republican or early imperial era (Figure 1).

Figure 1: *Roman Settlement generated by our initial prototype.*

In this paper we present our attempt at developing a shape

grammar [WWSR03] inspired by 'CGA Shape' [MWH*06] for describing Roman settlements derived from the writings of Vitruvius, initially with a focus on the description of classical Roman temples (meaning the main building of a religious site, excluding its courtyard). The construction of Roman temples included a large number of common elements found in Roman architecture, e.g. palaces shared many of these and often also incorporated temples themselves [Bar96]. Structures generated from these Vitruvian rules can provide an exemplar for archetypal Roman architecture in a similar manner as the "Virtual Egyptian Temple" by Jacobson and Holden [JH05] depicts architecture in ancient Egypt.

2. Ancient Rome in Virtual Heritage

In recent years, there have been a number of virtual heritage projects, depicting Roman urban environments (Figure 2). In many cases these projects use hand-crafted building models that are placed into the urban environment [MFPC07, WJD10], while other projects have employed range imaging techniques to capture virtual representations from models [GFD*05] or real archaeological sites.

There are a few examples of the use of procedurally generated Roman architecture such as Müller et al. [MVUVG05], and some projects employed some procedural rules based on the writings of Vitruvius. De Paoli and Bogdan [DPB99] for instance translated the Vitruvian description of Roman theatres into a modelling language, and similarly, Vitruvian rules regarding proportions of temples were used for procedurally generating buildings about which little was known from the archaeological record in the "Rome Reborn 2.0" project [DFM*10].

Figure 2: *'Roma Nova' serious game.*

For any virtual heritage project depicting Roman urban environments, a method of generating the virtual world – including the archaeological sites and artefacts that will be depicted in it – must be chosen. Depending on the extent of the virtual environment, manual creation of sites and artefacts may be too costly or time consuming, which is where procedural content generation can provide solutions. The architectural rules and guidelines provided by Vitruvius, translated into rules for procedural generation, can therefore be used to efficiently generate Roman buildings and settlements. For the procedural generation of architecture and urban environments, the use of shape grammars has proven very successful [MWH*06, LWW08], and the availability of a shape grammar incorporating all of the writings of Vitruvius would be highly desirable.

2.1. Identifying Architectural Rules for Roman Temples according to Vitruvius

In his descriptions of Roman architecture, Vitruvius explains the makeup of buildings both in terms of proportions, as well as actual measurements, the latter usually expressed in terms of the pes, i.e. the Roman foot, which was a unit of length of approximately 29.6cm [DJ80, Ada94]. Two of Vitruvius' books are devoted to the construction of temples (De Architectura III and IV), with rules that can be used to procedurally generate temples (Figure 3). There are several examples of classical 'Vitruvian' temples that can be found in the archaeological record, such as the Maison Carrée in Nîmes [Jon00], which is still standing, or the harbour temple of the Roman city Colonia Ulpia Traiana (Xanten) [HRG09].

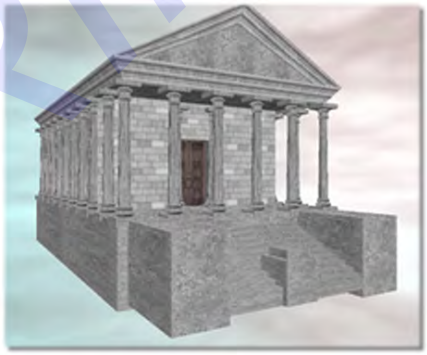

Figure 3: *Low-resolution Vitruvian Temple generated by our system prototype.*

The dominant feature of a temple is its main building, which in most Roman settlements would be built within courtyard and enclosure wall. While the overall makeup of this usually followed the same pattern – the 'cella' (the temple building's enclosed room), fronted or surrounded by a portico and raised on top of a podium – there is considerable architectural variation possible in Roman temple construction. Temple buildings can be built on a podium with steps only at the front (usually facing eastwards) or with steps on all four sides, with the number of steps in both cases being an odd number. The temples proportions would be such that the length of the main temple buildings would be twice the width of the temple with the length of the temple's cella being 25 percent larger than the overall width of the temple.

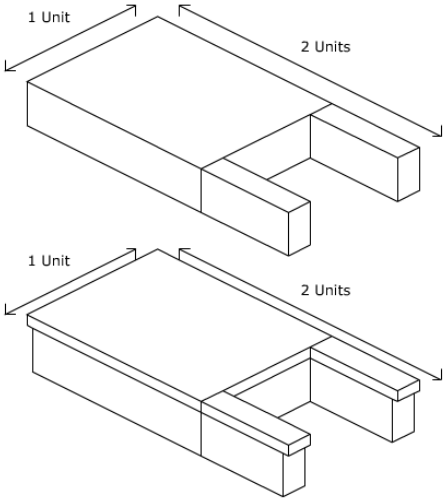

Figure 4: *Proportions of Vitruvian Temple Pedestals.*

2.1.1. Temple Base

The temple base consists of a simple podium that acts as a platform for its cella and portico, and 2 additional podium structures that act as banisters to the stairs. These structures can be seen geometrically as a set of 3 cuboid shapes, with 3 thinner, slightly wider cuboids resting on top. As per Vitruvius' rules, the length of the whole base is equal to twice its width (Figure 4).

2.1.2. Cella

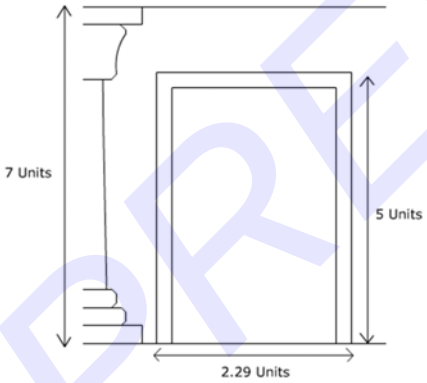

Figure 5: *Proportions of the Cella front in Vitruvian Temples.*

The temple's cella can be generated from a solid cuboid shape that rests between the temple base and its roof. It typically has a single doorway that faces towards the temple steps. The layout and shape of the doorway varies between temples, but Vitruvius specifies that if we assume that the height of the cella is 3.5 units, the height of the doorway ought to be 2.5 of these units. Additionally, if the doorway height is divided into 12 equal parts, its width ought to be 5.5 of parts. Therefore, we can state that the ratio of the door width to door height to cella height is approximately 2.29:5:7 (Figure 5).

2.1.3. Temple Steps

Vitruvius notes that all temple steps would have to be consistent in size, with the step height being between 5/6 and 3/4 of a foot and the depth of steps being between 1.5 and 2 feet. These measurements indicate that the ratio of the step's depth to height is equal to approximately 2:1, which we used as the ratio for the generation of the model steps. During procedural generation, the stairway can be represented as a repeated set of 2-poygon steps (Figure 6). In addition to this, an altar is frequently positioned at the base of the stairs or else in front of them. The size, shape, and detail of the altar varies between temples, but the overall structure can be represented as a small cuboid upon a larger one.

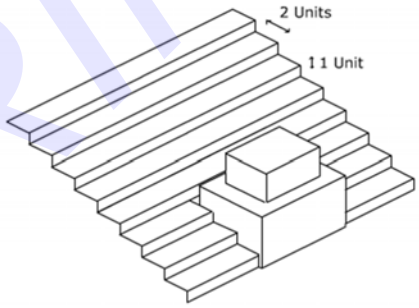

Figure 6: *Proportions of Vitruvian Temple Steps.*

2.1.4. Columns

In his third and fourth book, Vitruvius discusses at length the different styles of columns and how they are used in different temples. In general, the columns of a temple's portico have precisely calculated proportions; the diameter at the base is equal to 1/7 of the column height, and the diameter at the top of the column is equal to 3/4 of the diameter at the bottom. Additionally, the column base height is equal to half the diameter at the bottom of the column, and the whole column height should equal 1/3 of the temple width. The specific nature of these rules makes them simple to implement into a procedurally generated environment. However, the complex nature of the intricate details especially of Corinthian columns requires a much more detailed shape grammar than implemented in our initial prototype.

2.1.5. The Siting of Roman Temples

Vitruvius provides instructions on siting and orienting temples within a settlement. He "importantly defined the structural separation of the buildings in the city by indicating where each element falls" [Lei08], i.e. a differentiation of districts for domestic or public use. This separation was ideally governed by two major roadways of the city, intersecting at ninety degrees, with the 'forum' adjacent to this intersection (De Architectura I, 7). In Roman cities the forum played a central role in the location of communal facilities, with public buildings, including civic, religious and recreational buildings located in close proximity to the forum (De Architectura I, 7; De Architectura V), or along the major axes of the town. Vitruvius states that the main sacred site of a city with temples for the highest deities and the protectors of the settlement should be at its highest point of elevation (if there is a hill), easily reachable from the forum or the main roadways, and in most settlements, the location of this temple district would be adjacent to the forum. Vitruvius makes suggestions as to where the temples dedicated to different deities should be located. The temple orientation should be such that unless it is constricted by surrounding buildings, its front should face eastwards. If the makeup of the site makes this impossible then the doorway of the cella should face passing roads (the entrance being perpendicular to the road) or if possible allow as much of the extent of the city walls as possible to be seen from the cella entrance.

3. Conclusion

In this paper we have presented some of the rules of classical Roman architecture described in the writings of Vitruvius on the construction of temples, which provide guidelines for a shape grammar to allow the procedural generation of Roman buildings (Figure 3). This forms the core of a much larger grammar encoding rules for the procedural generation of Roman settlements (Figure 1), which we hope to refine in the future to allow the generation of much more intricate architectural features.

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