

Grammar Modelling and the Visualisation of an Uncertain Past: the Case of Building 5 at Portus

Matthew Harrison, Simon Keay and Graeme Earl
University of Southampton, UK

Abstract:

The grammar-based procedural modelling technology 'CGA Shape' allows the creation of parametric architectural models that can be adapted through both user input and probabilistic processes, and thus can be used to generate alternative visualisations of buildings based on archaeological data. We explore the capacity of this technology to model and communicate the interpretative uncertainty inherent in the process of archaeological visualisation. A review of previous applications of CGA Shape within cultural heritage demonstrates its potential for uncertainty visualisation, but also shows limited incorporation of large, detailed and complex archaeological datasets. The technology is thus assessed through a case study, the reconstruction of a possible ship-shed from the site of Portus, which comprises a heterogeneous dataset based on geophysical, archaeological, architectural and artistic sources. The strengths and limitations of this approach are assessed, considering its influence on interpretative processes, communicative ability, and its potential to provide transparency in the modelling methodology.

Keywords:

Visualisation, Procedural Modelling, Shape Grammars, Uncertainty

1. Introduction

Archaeological datasets are incomplete, ambiguous and continually open to both expansion and revision. Yet visualisations of archaeological sites, structures and objects often fail to communicate this uncertainty to their audience, instead presenting a single holistic image of the past - one that does not differentiate speculation from well-deduced interpretation or hard data. As archaeologists these images are so appealing as research tools due to their ability to crystallise and communicate our interpretation of the past to both academic and lay audiences. But in reality is this an illusion of simplicity that misleads audiences, as well as a practice that limits us as archaeologists to a single path of interpretation?

This paper will explore the use of 'shape grammar' based technologies as a process of modelling interpretative uncertainty in archaeology, and to communicate that uncertainty to the public, through the formation of parametric and stochastic procedures to

generate multiple visualisations of architecture. Through application of this methodology to an archaeological case study we will test whether the approach can accommodate the interpretative complexities of a dataset based on a wide range of sources, assessing the interpretive influence and transparency of the methodology, as well as the aesthetic and communicative power of the resulting visualisations.

2. Archaeological Visualisation of Uncertainty: Approaches

The issue of certainty and authenticity within digital visualisations of the past is by no means a new one, having been continually raised over the past two decades (Miller and Richards 1995; Ryan 1996; Zuk et al. 2005, Bentkowska-Kafel et al. 2012). Awareness of these issues has caused scholars to suggest the need for new modes of visualisation that signal uncertainty (e.g. Zuk et al. 2005), as well as the documentation of interpretative processes or 'paradata' (e.g. Bentkowska-Kafel et al. 2012).

Despite new methods of visualisation being successfully demonstrated, the vast majority of approaches within cultural heritage have continued unabated to aspire towards the production of photorealistic images that forgo communicating subjectivity to their audience. More than taking focus away from issues of false certainty, the realism afforded by such approaches can be seen to compound the issue; conveying an environment so familiarly 'real' to the viewer that one may presuppose an authentic representation of a past reality.

The pursuit of photorealism is in part a perceived need for cultural heritage to keep up with the increasingly impressive images of film, television and gaming. These are partially concerns of public appeal, which are inevitable given the quasi-commercial application of archaeological visualisations in museums and media, but are also pertinent to the communicative power of the image. Through masking the complexity of source data and interpretation, and solely providing the audience with familiar elements of perceived reality (convincing lighting, materials and geometry) as well as established media for representing reality (artistic or photographic composition, lens flares, depth of field, etc.) the image is instantly readable and coherent. It is the consistency and familiarity of the aesthetic composition that make it so legible, i.e. it can be read as a photograph of a past reality, and therein lies the double-edged sword of communicative power and false certainty.

We propose that the academic concerns over the issue of uncertainty and visualisation have made limited impact, despite the validity of their criticisms, because the majority of alternative visualisation approaches compromise one of these two strengths of photorealism: its impressive aesthetic or its communicative simplicity.

Perhaps the most common approach to rectifying issues of uncertainty is to add visual cues within a conventional rendered image

to signal levels of confidence or probability of particular elements, such as colour or transparency (for possible indicators see Pang et al. 1997). Yet the mix of familiar and alien aesthetics compromises the coherence of the image. One fails to get an impression of a plausible architectural or artefactual whole when parts of a building or object are perhaps almost invisible or differently coloured, despite getting a clear indication of which parts are most reliably reconstructed. Such approaches have been applied most successfully where there is a single independent factor of uncertainty, such as temporal uncertainty (e.g. Zuk et al. 2005), but how can one accommodate complex dependencies between uncertain elements (i.e. if x is true, y is more likely to be true) as well as communicate a multiplicity of possible forms.

Another approach is to use non-photorealistic rendering techniques to effect a comprehensive aesthetic change, emulating the media of traditional artistic illustration (e.g. Roussou and Drettakis 2003). Replacing photorealistic immersion with a sense of the constructed and subjective through association with traditional illustration acts as a general qualifier to the audience about uncertainty. It is unlikely, however, that such an approach would ever be adopted widely in cultural heritage as the photorealistic is too entrenched in the heritage industry and public expectations.

A seemingly simple solution is to present multiple possible forms of a past environment or object in a series of images. The strength of digital visualisation over traditional illustration has always been the ability to manipulate and alter a model, yet these alterations are still effort intensive. One must therefore consider how many alternatives are reasonable and achievable in terms of labour. In terms of presentation, one must then choose which possible elements to include in final images, in which specific combinations (for example 10 variables each with 10 different possible values would result in ten billion possible final images, even ignoring the possibility of continuous

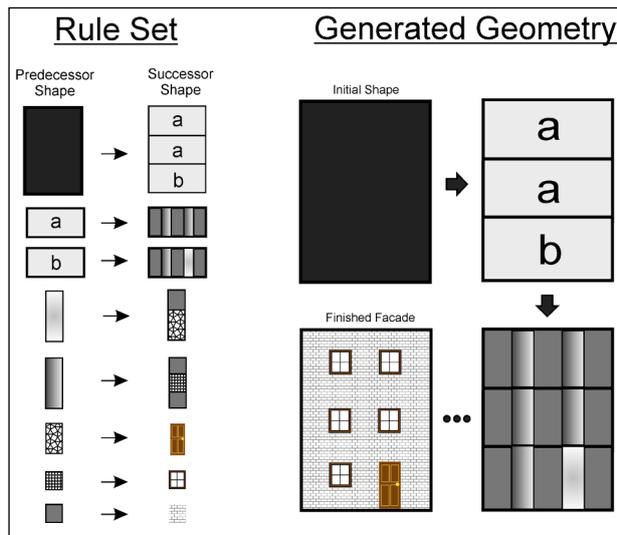


Figure 1. Illustration of principles of CGA 'split grammar' to create an architectural schema. The grammar creates architectural detail through rules which successively subdivide shapes, most typically dividing facades into elements such as windows and doors.

variables). Furthermore, while each image is in itself coherent, as a whole a collection of images can be overwhelming. As such, frequently one will be highlighted and then reproduced elsewhere as the most probable, as exemplified by the reproduction of one of Millett and James's alternative illustrations of timber framed buildings at Cowdery's Down (Millett and James 1983; James 1997, 29).

These limitations of presenting multiple images are remedied by interactive models which utilise parametric relationships. In such systems alternatives can be generated automatically from user input. The implementation of such systems can be seen in early examples with VRML and HTML/java (Roberts and Ryan 1997), as well as bespoke virtual environments such as CREATE (Roussou and Drettakis 2003). In these systems users can explore uncertainty within the parameter-space of a model as defined by the creator, in order to gain an impression of the range of possible pasts without being overwhelmed by several parallel images.

The strengths and limitations of these past approaches to presenting uncertainty in

archaeological reconstructions will now be considered in light of the recent development of procedural modelling technologies based on shape grammars, which have been designed for architectural visualisation – namely CGA Shape grammar (Müller et al. 2006a), incorporated into the CityEngine modelling package (Procedural, Esri). This technology affords a system of modelling that can incorporate parameterisation, as well as stochastic or probabilistic expression of these parameters, thereby allowing both dynamic adaptation of geometry as well as quantified conceptualisation of the relative certainty of variables.

3. Shape Grammars and Modelling the Past

3.1 Shape Grammars, Architecture and CGA Shape

Developed in the 1970s as a procedure to generate and conceptualise painting and sculpture (Stiny and Gips 1972), shape grammars consist of a vocabulary of shapes, and rules that successively replace one shape with another to create increasingly complex geometry.

Shape grammars have been used since the 1970s in the analysis and generation of design, including several applications in archaeology and anthropology (e.g. Hodder 1982; Weissman-Knight 1986). More recently, computational procedures based around shape grammars, though incorporating only some aspects of the original concept and adding others, have been developed into commercially available systems to create three dimensional architectural models - namely CGA Shape grammar (Müller et al. 2006a). Within CGA Shape the rules of replacement predominantly takes the form of subdivision of shapes, and as such is considered a 'split grammar' at its core. The underlying premise is that architecture can be expressed as a nested series of such divisions

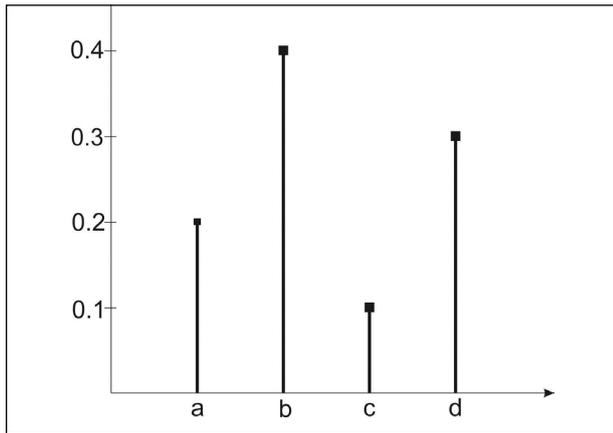


Figure 2. Illustration of a discrete probability distribution, where probabilities are assigned to one of several discrete values, in sum equal to 1.

into a number of functional or decorative elements (Fig. 1).

Such division-based rules are seemingly evident in the architecture Classical world, but only become explicit in architectural thought during the Renaissance within the re-interpretation and adaptation of Classical architectural style, most notably the work of Palladio (1570).

Within CGA Shape grammar, procedures or rules are written (in an ASCII scripting language) that express the relationship between architectural elements, comprising an adaptable method of geometry creation that and defines the limits within which any example of an architectural schema must fall. The adaptability, and therefore the expression of uncertainty, resides in two elements of the procedure: parameterisation and stochasticism.

Where rules are used to express an architectural form or style, parameters referenced in these rules control the dimensions, angle, colour, material, presence/absence, etc. of specific elements. Control of these parameters allows adaptive, holistic changes that can be used to create variations on a style instantly.

The expression of parameters as either discrete probability distributions (Fig. 2) or

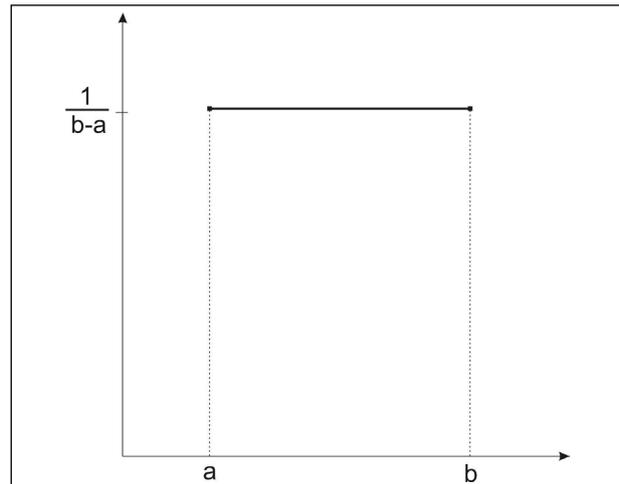


Figure 3. Illustration of a uniform continuous probability distribution, in which the parameter is expressed as existing between two limits (a and b) with an equal chance of all values between these limits.

uniform continuous probability distributions (Fig. 3) means that the execution of the grammar results in unpredictable variations in the resulting geometry, illustrated in Figure 4. Utilisation of stochasticism to automatically generate variation is at the heart of many procedural modelling technologies from Perlin's Noise (Perlin 1985) to L-system vegetation (Rusunkiewicz et al. 1996). In these examples the variation is added to phenomena repeated across a modelled scene – a surface/material in the case of Perlin's Noise and instances of modelled plants in the case of L-systems – in order to mimic the heterogeneity of the physical world without the need for excessive manual input.

3.2 CGA Shape Cultural Heritage Applications

The capability for stochasticism within CGA Shape has been utilised within cultural heritage in much the same way as the aforementioned technologies. Reconstruction of past cities can be achieved by creating rule sets applicable to domestic architectural styles, then generating numerous different examples of that style. Examples include models of Pompeii (Müller et al. 2005), Imperial Rome (Dylla et al. 2010; Wells et al. 2010) and Mayan Xkipché (Müller et al. 2006).

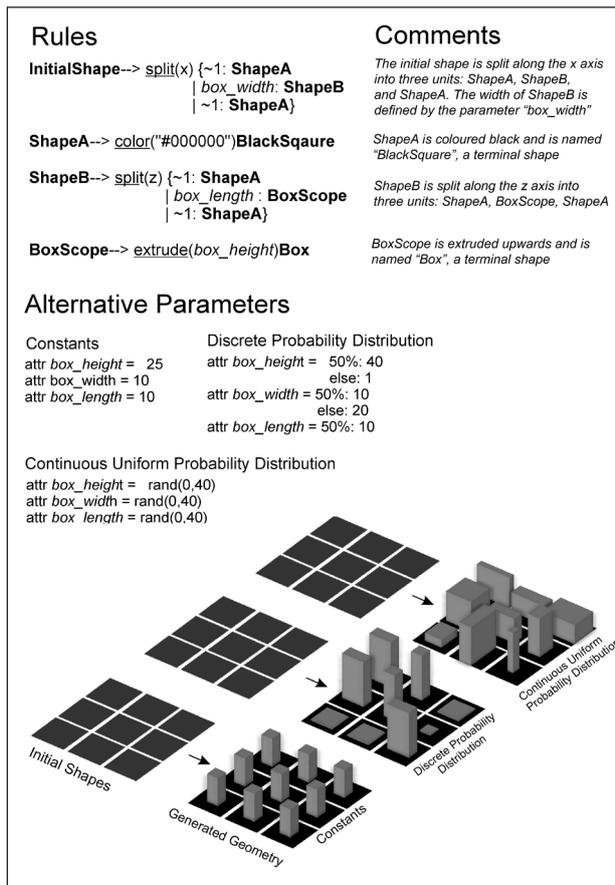


Figure 4. Demonstration of CGA Shape's use of probabilistic parameters to create variations each time the procedure is run. A single set of CGA Shape rules (bold indicates shape names, underline indicates functions to transform shapes, italics indicate parameters) is executed nine times in each case, but each case uses different parameter types.

The models produced as part of these projects all have the ability to reflect interpretative uncertainty and to explore hypotheses through the production multiple alternative variations of a building, either by stochastic parameters or simply by user control. Such potential is illustrated by using two of the project rule sets (Pompeii and Rome) to probabilistically generate alternative reconstructions in a paper by Haeglar, Müller and Van Gool (2009). Yet elsewhere the presentation of these projects focusses on single

that these facades are applied to are derived from a laser scan of the Gismondi plastico of Imperial Rome created in the mid 20th century. The stochastic rule set creates varied facades that conform to our understanding of that generic architectural form (based on examples from Rome and nearby Ostia) but consideration of historical or archaeological data relevant to a specific structure is absent, or at least is a static reflection of Gismondi's interpretation of the location and general form of domestic architecture.

In sum, the grammar in these examples becomes a tool to *create the effect* of an authentic historical city. Although informed in a general sense by archaeological and historical data of architectural styles it is not arguably being used to *reconstruct* the respective sites: it does not attempt to reflect the available archaeological data for specific structures, its most current interpretation by experts, and associated certainty experts can ascribe to that interpretation.

This is not true of the CGA Shape modelling of Puuc architecture at the site of Xkipché (Müller et al. 2006b), which follows archaeological remains very closely. However it does not make use of random variation in the grammar, undoubtedly due to the high degree of simplicity and formalism of this style of architecture, as well as the exceptional preservation of the buildings on site. The range of forms existent on the site are presented as more or less certain, with the utility of the approach demonstrated to be the economy of creating different forms through alteration of control parameters. The missed opportunity to confront the issue of uncertainty is demonstrated by the authors' revelation that the buildings may have been plastered and painted with bright colours, though "*since their exact appearance is still under archaeological debate, we did not include colorful textures such as paintings in the current model*" (Müller et al. 2006b, 145).

A different approach is also evident in the use of CGA Shape for digital reconstruction of the Louvre (Calogero and Arnold 2011). Here two models are created - one is the design of the East Wing that survives today, and the other is a 1663 proposed design that never was realised. The source material for the latter was limited, as only a single ground floor plan and a section through the wing survives. These were supplemented by sketches and an elevation that reconstructed the design of the façade, produced in the 1960s. While there is scope to use the technology to explore the variation possible interpretations of the fragmentary design information, only a single visualisation is produced, reproducing (we assume) the interpretation of the 1960s reconstruction. So while the emphasis is not on economy of labour, it is by no means fully exploring uncertainty. Rather, in this case CGA Shape is being used to aid in the interpretation of the structure and meaning of the two designs, in much the same manner conceived by Stiny and Gipps, an approach also seen in the modelling of Regency architecture in Brighton (Calogero et al. 2011)

With this borne in mind, the illustrations of CGA Shape's applicability to uncertainty visualisation (in Haeglar, Müller and Van Gool 2009) are problematic in that it has not been established that the grammar can reflect a real, complex, heterogenous dataset with high levels of uncertainty. As experiments they can afford to choose the simplicity of their hypothetical source data, and it is unsurprising that they choose a high level of certainty for high-level variables such as the building scope and basic structure, and add uncertainty on low-level variables such as materials and decorative elements – such as is easily accommodated within the sequential nature of geometry creation in the grammars. In reality, the archaeological record may present data pertinent to a mixture of high or low level variables, often sporadically and in complex, interconnected ways. It remains to be seen in either of these case studies whether the grammar could account for this – accommodating fixed locations and forms of known smaller elements

within dynamic higher-level changes. It should be noted, however, that several developments of CGA Shape may go some way to solve such issues, though they have not necessarily been incorporated into that available commercially – e.g. ‘snapping’ lines (Müller et al. 2006a, 618) and the persistent naming and modification of elements (Lipp et al. 2008).

The following section will therefore illustrate the authors’ own attempt to use CGA Shape to create a model that reflects interpretative uncertainty based on a real and heterogeneous archaeological dataset.

4. Modelling Building 5 at Portus

4.1 The Site of Portus

Portus is located on the ancient coastline of Italy near the mouth of the Tiber, a few kilometres to the north of the river port of Ostia. The site functioned as a principal port of Rome from the first century AD, its foundation attributed to the Emperor Claudius in around 42AD (Keay et al. 2005).

From the late 1990s the Soprintendenza per i Beni Archeologici di Ostia has been undertaking a major scheme of conservation and investigation of the site, including excavation. As part of this scheme the Soprintendenza collaborated with the Universities of Southampton, Cambridge and Durham and the British School at Rome in a project of extensive non-destructive survey techniques – both topographic and geophysical. This project ran from 1997-2005, and was undertaken as part of a wider project studying Roman urbanism in the Middle and Lower Tiber Valley directed by Martin Millett and Simon Keay, which in turn forms one part of the British School at Rome’s Tiber Valley Project co-ordinated by Helen Patterson (Keay et al. 2005).

2007 marked the start of a new collaborative project undertaken by the University of Southampton, in conjunction with the British School at Rome, the University of Cambridge and the Soprintendenza Speciale per i Beni Archeologici di Roma, directed by Professor Simon Keay and funded by the Arts and Humanities Research Council. The project, known simply as ‘The Portus Project’, is on-going at the time of publication (see www.portusproject.org, www.heritageportal.eu, and Keay et al. 2009). The project has built on the previous topographic and geophysical survey as well as starting a series of excavations.

4.2 Building 5 – Data Sources and Modelling Methodology

The excavation of a large structure referred to as ‘building 5’, which is located between the site’s two ancient harbours and believed to be a ship-shed or *navalia*, provides an interesting case study for grammar based modelling. The interpretation of this building relies on different kinds of source data – geophysical survey, excavation, standing remains, as well as drawing on artistic and architectural parallels. Its materials and principal system of structural support is known, being formed of rows of brick-faced concrete piers, yet there is much uncertainty about the structure due both the lack of survival of the upper structure as well as the limited amount of excavation in comparison to the huge scale of the structure – thought to be 60m x 180m (revisions discussed in 4.3).

The excavations have focussed on a small area in the southwest corner of the building. These revealed two internal spaces measuring c.4m and c.12m in width. Standing remains on the site, preserved in a later city wall, show that such units of standard widths are repeated elsewhere, however there are large parts of the structure with no recorded standing remains. To supplement this data a magnetometry survey across the building’s full extent has revealed indications of unexcavated piers. Both the magnetometry and standing remains survey are

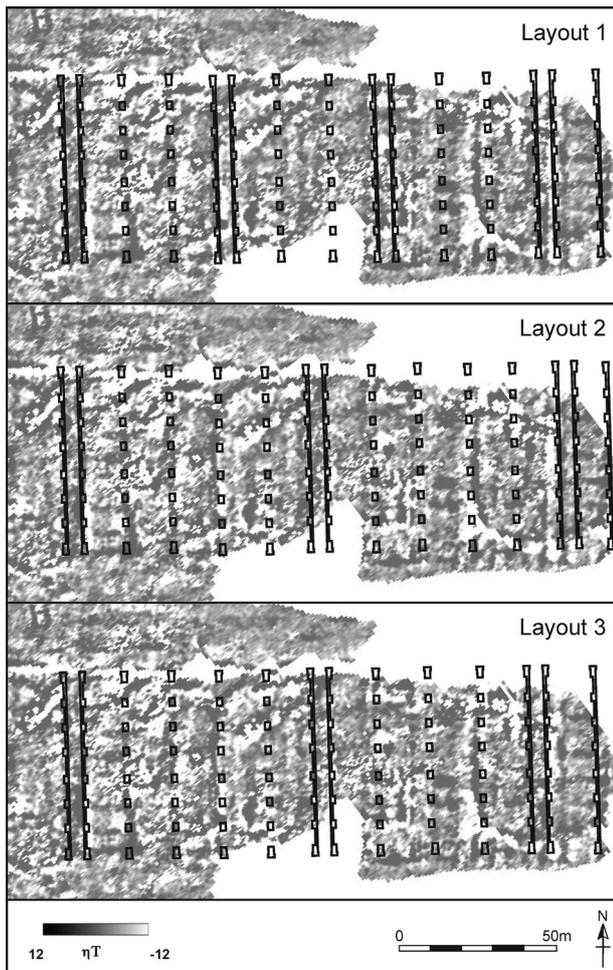


Figure 5. Alternative layouts of building 5 compared with results of the magnetometry survey (The Portus Project).

complicated by the fact that the building had a long history with later phases of adaptation (not considered in this reconstruction), so in each case it cannot be ascertained with certainty that indications of structures do not relate to other phases or structures. Taking these limitations into account, together the sources suggested three probable layouts, each consisting of different sequences of the same units (Fig. 5).

To cover the spaces between the piers, a number of alternatives were possible within the limits of Roman engineering. The space could have been covered by a concrete vault, either cross or barrel vaulted, following 'rules of thumb' determined by Lancaster's survey of concrete vaulting in Imperial monuments (Lancaster 2005). It is also possible that the piers supported a timber framed roof, as



Figure 6. Photograph of the Atarazanas of Seville, built in the 13th century AD. An example of a ship-shed from a later period used to inform the interpretation of the building (Photograph courtesy of Simon Keay).

records of timber lengths and other known timber-roofed structures suggest that beams could be up to 25m in length (Ulrich 2007).

To address the issue of the upper structure, as well as other decorative and structural elements, evidence from other sites was considered. Unfortunately, there are no definitively identified examples of standing or excavated Roman ship-sheds. Therefore the reconstruction drew upon earlier examples from Greek and Punic contexts, as well as later, medieval, examples such as those at Venice, Pisa and Seville (Fig. 6). Representations in Roman art of ship-sheds were also considered. Such comparisons lead to the consideration that the building may have been inclined for the purpose of launching ships, was almost certainly sheltered by a series of pitched roofs, and may have contained various decorative elements.

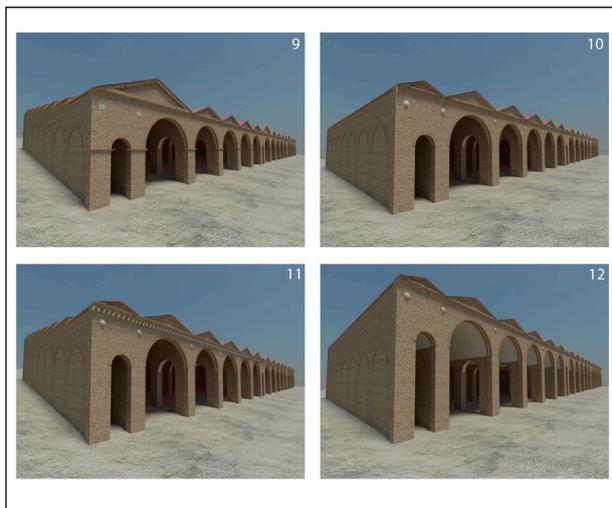
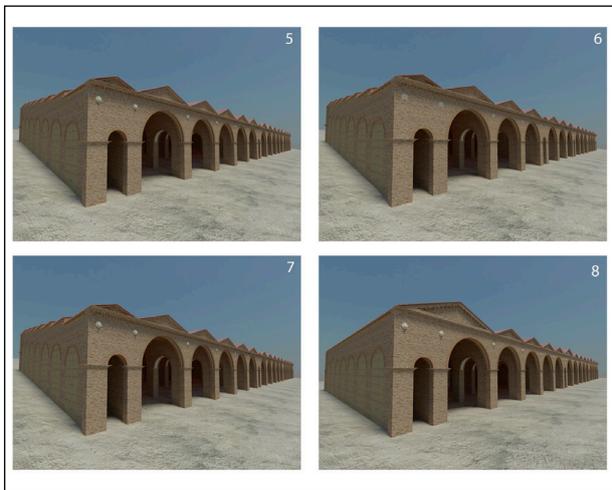
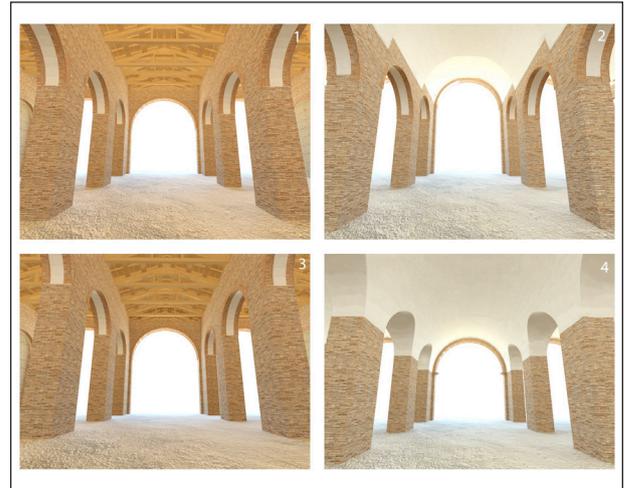


Figure 7. Twelve stochastically generated models showing alternative reconstructions of building 5 at Portus (exterior), modelled in CityEngine and rendered with mentalray.

Figure 8. Twelve stochastically generated models showing alternative reconstructions of the building 5 at Portus (interior), modelled in CityEngine and rendered with mentalray.

Parameter	Value	Source
Building Width	60.1m	Excavation, Geophysical, Standing Remains
Narrow Nave Width	3.74m	Excavation
Wide Nave Width	11.38m	Excavation
Inter-pier Distance (N-S)	5.34m	Excavation
Infilling wall width	0.58m	Excavation
Pylon Buttress Length	0.20m	Excavation
Pylon Buttress Width	1.06m	Excavation
Brick Width (Arches)	0.4m	Excavation, Structural Constraints
Brick Thickness	0.05m	Excavation, Structural Constraints
<i>Vault Height (Narrow Nave)</i>	<i>If cross vaulted:</i>	<i>Parallels, Structural Constraints</i>
	<i>Wide nave width x 0.25</i>	
	<i>If barrel vaulted:</i>	
	<i>Narrow Nave Width x 0.5</i>	
<i>Vault Height (Wide Nave)</i>	<i>If cross vaulted & depressed:</i>	<i>Parallels, Structural Constraints</i>
	<i>Inter-pier distance N-S x 0.5</i>	
	<i>Otherwise:</i>	
	<i>Wide nave width x 0.5</i>	

Table 1. Summary of parameters expressed as constants within the model, parameters dependent on others in italics.

Parameter	Value	Source
Building Length	180-220m	Excavation, Geophysical, Standing Remains
Pier Height	7-10m	Excavation, Structural Constraints
Roof Offset	0.4-0.6m	Parallels, Structural Constraints
Roof Pitch Angle	18-23°	Parallels, Structural Constraints
Gutter Depth	0.5-0.7m	Parallels, Structural Constraints
Gutter Width	0.4-0.6m	Parallels
Corbelling Depth	0.3-0.5m	Parallels
Corbel Height	0.28-0.32m	Parallels
Corbel Width	0.18-0.22m	Parallels
Inter-corbel Distance	0.5-1.0m	Parallels
Tie beam thickness	0.30-0.40m	Parallels, Structural Constraints
Primary Rafter Thickness	0.30-0.40m	Parallels, Structural Constraints
Secondary Rafter Thickness	0.17-0.22m	Parallels, Structural Constraints
Perlin Thickness	0.18-0.20m	Parallels, Structural Constraints
Roof Planking Width	0.25-0.35m	Parallels, Structural Constraints
Inter-truss Distance (roof)	2.00-4.00m	Parallels, Structural Constraints
Inter-perlin Distance	0.90-1.10m	Parallels, Structural Constraints

Table 2. Summary of parameters expressed as ranges within the model.

Taking these sources into account rules were created CGA Shape/CityEngine that reflected principles of Roman architecture of this scale, material and function. Over thirty parameters were used to give control of various aspects of the form. These parameters

were expressed as either constants, ranges (continuous uniform probability distributions) or probabilities (discrete probability distributions), depending on their certainty and relevant source data (the parameters and source data are summarised in tables 1-3).

Parameter	Value	Source
Layout	0.25 : Layout 1 (see Fig.5)	Excavation, Standing Remains, Geophysical
	0.25: Layout 2	
	0.5: Layout 3	
Foundation Slope	0.5 : 0	Parallels
	0.5: 9.16-10.83%	
Vaulting Presence	0.25: true	Structural Constraints, Excavation
	0.75: false	
Vaulting Type	0.499: Barrel Vault	Structural Constraints, Parallels
	0.499: Intersecting/ Cross Vault	
	0.002: Depressed Cross Vault	
Roof Type	If Barrel Vaulted:	Artistic Sources, Structural Constraints, Parallels,
	0.69: Pitched (N-S)	
	0.25: Exposed Vaults	
	0.15: Pitched (E-W)	
	0.03: Flat Roof	
	If Cross Vaulted:	
	0.82: Pitched (N-S)	
	0.15: Pitched (E-W)	
	0.03: Flat Roof	
	If Not Vaulted:	
	0.97: Pitched (N-S)	
0.03: Flat Roof		
Roof of Narrow Naves	0.6: Separate roof	Structural Constraints
	0.4: Roofed with adjacent nave	
Waterspout Presence	If Pitched N-S Roof:	Artistic Sources, Parallels
	0.99: true	
	0.01: false	
	Otherwise: FALSE	
Corbelled Roof	0.9: true	Artistic Sources, Parallels
	0.1: false	
Corbel Material	0.45: Brick	Artistic Sources, Parallels, Excavation
	0.45: Moulded Brick	
	0.1: Travertine	
Impost Corbelling	0.5: true	Artistic Sources, Parallels
	0.5: false	
Roof Tile Width	0.5: 1.0m	Structural Constraints, Parallels
	0.5: 0.4m	

Table 3. Summary of parameters expressed as discrete probabilities within the model, or as a combination of ranges and discrete probabilities. Parameters dependent on another are in italics.

The quantification of the level of certainty posed a major problem to this methodology. Figures were determined subjectively in discussion with members of the Portus Project in a fairly informal manner. Whilst archaeologists are familiar with expressing their levels of confidence, it seemed obvious that the way in which individuals quantified it could vary significantly. A more rigorous approach would perhaps be the collation and amalgamation of expert confidences with Bayesian statistical approaches (e.g. Van Leusen et al. 2010, 127). However, this poses some logistical problems in presenting the full dataset necessary to make an informed decision to significant numbers of experts. It also compromises the contextual and temporal nature of the interpretations, i.e. the ways in which they developed, informed one another, and were transformed through the visualisation process. Separating the processes of modelling and certainty quantification would provide a false distinction which could risk limiting a core value of the process – stimulating reflection.

The resulting stochastic procedure was executed twelve times to generate unpredictable combinations of variables. These were then exported from CityEngine and rendered with mentalray using Autodesk 3ds Max (Figs 7 and 8). The resulting images as a whole reflect the interpretative confidence in the various elements of the reconstruction, as well as testing how robust the rule set is in creating plausible forms whilst incorporating uncertainty at various levels of the procedure.

4.3 Assessment

How appropriate is CGA Shape as the basis for a methodology of archaeological reconstruction that foregrounds uncertainty?

4.3.1 CGA Shape as a modelling technology and interpretive tool

To understand CGA Shape's strengths and limitations one must consider the grammar

as a *modelling* technology, in the wider sense of being a simplified representation of a real-world phenomenon or system for the purposes of comprehension or testing. Working with a system of rules and parameters, rather than controlling geometry more directly, allows the creator to both conceptualise and document an explicit schema of the building's organisation, one written in a simple ASCII scripting language. What may be unconscious decisions that go into constructing a visualisation in a system such as 3ds Max or Maya, even if multiple visualisations are being produced, are brought to light through the process of rule-building and parameterisation. Grammar-based modelling is thus a more transparent process, as it presents assumptions about a structure's organisation (within rules), and identifies key variables along with an assessment of their certainty (within parameters) to other archaeologists and 3D artists. Along with commenting within the code and the documentation of sources informing each parameter, this is a process of providing paradata.

The grammar methodology has acted to guide interpretation through exploration of the parameters, testing hypotheses by assessing the plausibility of overall forms when parameters are pushed to the limits dictated by the source data. It has also helped define where gaps in our data are most crucial, thereby setting new research agendas. Fieldwork at Portus subsequent to the creation of the model has involved full and detailed recording of standing remains in the vicinity of the building 5, primarily in order to reconcile problems in the visualised building layouts.

The methodology's strength as an adaptable mode of testing hypotheses should be reflected not only by the extent to which it can influence data collection goals, but also the extent to which this new data can continue to be fed back into the model as part of an on-going interpretive process. Thus far we have only assessed whether the grammar can take into account the complexities of the dataset at



Figure 9. Render of adapted and remodelled building 5 model created in Autodesk 3ds Max by [name and affiliation removed for blind review].

the point the model was first created (August 2011), this is the data reflected in tables 1-3 and figures 7-8. However, the aforementioned survey of standing remains, as well as on-going excavation, has considerably altered our understanding of the structure.

Some aspects of this new data can be accommodated easily within the model, as they relate directly existent parameters. For example, standing remains indicate that the building is longer than first anticipated – a total of 247m – data that can be added in seconds to the appropriate parameter to update the model. However, this increased scope has implications for the layout of the building, as does the discovery of wider internal spaces of c.19m (perhaps functionally distinct), which would require alteration of rules to generate appropriate forms. Deeper excavations have provided new data regarding the inclination of the floor, which is importantly linked to the proposed function of housing ships. The model accommodates both sloped and flat structures, and excavation has indeed suggested a floor which is sloped (though shallower than suggested by Greek parallels at 6.99%-8.75% or 4-5°), however it is now apparent that the foundation levels of piers are constant. It had been assumed in the model that the foundation and floor levels would be concomitant, and this kind of revision of the structural principles of the building will again require revision of the rule-set.

In sum, the extent to which the grammar-based model can only accommodate new data is dependent on how far its creator has considered variability in each aspect of the model, and reflected this in the process of parameterisation. This reminds us that while parametric systems may be more economic ways of creating variations of a visualised form, they do not completely remove concerns of labour economy. Accommodating variation takes effort, both in research and in maintaining a coherent resulting form despite the many potentially conflicting parameters in the procedure. There will always be assumptions inherent in the rule set, and there will always be archaeological discoveries that challenge those assumptions.

4.3.2 CGA Shape as a visualisation technology and communicative tool

As a system of *visualisation* of uncertainty there are different issues. Our appraisal of past approaches to the issue (above) has suggested that they often compromise the aesthetic of photo-realistic approaches. The capabilities within CityEngine for materials and UVW mapping are limited compared to industry standards. More importantly, the system of geometry creation is focussed on the subdivision of rectilinear faces to create semantically distinct units, which has two important implications. Firstly, it means vertices and edges are placed according to semantic or schematic purposes, whereas in a mesh modelling package they are placed to influence to the resulting aesthetic (particularly important for the purposes of smoothing meshes) and ease of manipulation of the form. Secondly, it means that curved geometry cannot be manipulated within the system easily, being formed of many flat faces. Such complex geometry is incorporated into CityEngine models as ‘assets’ defined in other software used to replace the scope of a rectilinear three-dimensional shape in the model. This presents problems for both the scaling of curved elements (e.g. arch voussoirs) and the interaction of curved elements (e.g. the

creation of cross vaults from the intersection of two variable barrel-like intradoses).

The aesthetic shortcomings of the visualisations meant that for the purposes of publicity and publication it was decided that a single model, that deemed the most plausible, would be improved within Autodesk 3ds Max. Due to the aforementioned eccentricity of the mesh created by the grammar based modelling, this was used more as a guide than a starting state, much of the form had to be re-created manually (Fig. 9).

In this sense, the methodology has fallen victim to one of the pitfalls of previous approaches to uncertainty in reconstructions – a single interpretation often takes precedence either for reasons of labour, aesthetics or communicative simplicity. The only output from the methodology that could have been presented to the public was a series of static renders, which as discussed can be overwhelming to the audience. For the potential of the system to be fully realised one must translate its interactivity into a form that can be presented to the public, allowing them to explore the different possible interpretations both through stochastic re-generation of models based on expert assessments, as well as direct control of parameters to allow their own interpretations to be explored within limits set by the creator.

5. Conclusions and Future Directions

CGA Shape and the CityEngine modelling package comprise a tool to model our interpretation of past buildings, incorporating an explicit and transparent statement of the underlying assumptions, alternative forms, and the confidence attached to various elements of that model. It forces one to both confront uncertainty as well as to quantify it. It has a profound effect on interpretive processes, functioning as an adaptable model to test on-going hypotheses and formally identifying the most profound lacunae in the dataset.

Yet as a system of visualisation, from an aesthetic point of view, it cannot compete with the photorealism that dominates cultural heritage, at least on its own. Its strength in terms of modelling uncertainty is its dynamic exploration of innumerable possibilities, and to present a viable alternative to conventional approaches this dynamic nature must be present not only within the modelling stage but also in public presentation.

Developing such an interactive presentation of this structure is an aim of the Portus Project going forward, as is the exploration of newly developed grammar-based modelling systems to overcome the methodological limitations encountered thus far. We have also explored coupling this approach with structural analysis to test the validity of generated structures (Miles et al. this volume), and aim to use these results to feed back into the continuing grammar modelling process.

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