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# Visibility analysis in 3D built spaces: a new dimension to the understanding of social space

**Abstract**

The existence of a close link between visibility in built space and social life has repeatedly been acknowledged by social theories and has concerned a great number of studies on modern and past built environments. Archaeologists aiming to explore this relationship in a formal way have traditionally been employing one- or two-dimensional visibility analysis techniques using ground plans or sections of the spaces under examination. While these methods have considerably enriched archaeological interpretive schemes, this chapter discusses a number of cases (Roman, Mesoamerican, Aegean Late Bronze Age, and Byzantine urban spaces), where social aspects of visibility in built settings can be better understood with reference to a three-dimensional environment. It then describes briefly two applications of the recently proposed computational methods of visibility analysis in three-dimensional digital spaces, and argues that these methodologies have the potential to contribute new approaches to the examination of built environments.

## 1 Introduction

Visibility is a very popular concept within those bodies of theory that seek to link social relations and human action in urban space to the materiality of the built environment, such as environment-behaviour theory (Rapoport 1990), space syntax (Hillier and Hanson 1984), and reception theory (Lynch 1960). These conceptual approaches, which have been recently classed together under the term “empirical urban theory” (Smith 2011), have appealed to some archaeologists, as they are associated with notions that have identifiable manifestations in the archaeological record, and are susceptible to a formal examination via spatial analysis. In recent years many works have drawn on empirical urban theories to interpret past built spaces using various two-dimensional visual analysis techniques, which rely upon the construction of lines of sight on building plans and sections. The role of these methods in the proposed interpretative schemes is often considered essential, nonetheless, it is frequently acknowledged that two-dimensional analyses describe inadequately the visual properties of three-dimensional space (Moore 1996, p. 227; Fisher 2009, p. 451). The implications of this fact are fairly obvious: since people in the past engaged with three-dimensional architectural environments, certain social meanings encoded in built settings will remain undetected when space is being studied in two dimensions.

This chapter aims to discuss some of the cases where relationships between visibility and social life in past urban spaces can be better understood with reference to a three-dimensional environment. In this discussion special emphasis is given to theoretical concepts associated with Rapoport’s Nonverbal Communication approach and the application of more recent space syntax methods, namely isovist and visibility graph analysis. The archaeological examples used to support the argument belong to very different cultural contexts: Roman, Mesoamerican, and Aegean Late Bronze Age urban spaces, as well as Late Antique churches. Finally, this paper briefly describes two applications of the recently proposed computational methods of visibility analysis in three-dimensional spaces and argues that these methodologies have the potential to contribute new approaches to the examination of built environments, enhancing the interpretive schemes used in archaeological social analysis.

## 2 The visibility of built forms

### 2.1 Environment-behaviour theory and the Nonverbal Communication approach

The relationship between space and social life has concerned a large theoretical corpus that has significantly influenced archaeological investigations over the years. Among these works environment/behaviour theory, and especially Rapoport's Nonverbal Communication approach, proves particularly useful for the interpretation of archaeological remains (Michailidou 2001; Fisher 2009; Fisher, this volume; Thaler 2009), not least because it seeks to infer social meanings embodied in built space in a way that is "relatively direct and simple" (Rapoport 1990, p. 10). The Nonverbal Communication approach argues that urban spaces communicate a variety of latent messages by providing cues, visual, olfactory, and acoustic (Rapoport 1990, p. 106–107), which relate to identity, status, wealth and power, but also to expected behaviour, accessibility and other information that make human co-action possible (Rapoport 1990, p. 221). Within this conceptual framework the role of visual cues is especially stressed and their symbolic function is witnessed in numerous different ways: in the shape, size, scale, colour and materials of built structures, and in spatial relationships, e.g. prominence, centrality versus periphery, exposed versus hidden (Rapoport 1990, p. 107). For instance, a built structure of special significance (a public ritual space, a monument, an elite building) could be easily identified within its architectural context because of its larger size, its central, exposed or prominent location, and its distinct architectural features (construction materials used, decorative elements, distinctive architectural forms and furnishings). Social actors can read, interpret and associate these characteristics with particular uses of space and expected modes of social behaviour, while frequently they consciously manipulate the appearance of built environments to promote their interests. Although Rapoport (1990) refers mainly to modern built spaces, the notion that social meanings are communicated via visual cues such as those described above has always been accepted by archaeologists.

Whilst in prehistoric environments the existence of a close link between visibility in built space and social life is merely being assumed or inferred from an incomplete archaeological record, in historical cityscapes, such as that of ancient Rome, this relationship is clearly evidenced in surviving written sources. For example, Wallace-Hadrill (1988, p. 46), in a paper discussing social aspects of Roman houses, mentions two characteristic passages which suggest that visual access from public spaces to a private residence, successively occupied by Livius Drusus (*tribune* of the *plebeians* in 91 BC) and Cicero, was not only desirable, but also requested and planned:

> A public figure went home not so much to shield himself from the public gaze, as to present himself to it in the best light. Two passages may illustrate Roman sensibilities on this point. One records an exchange between Livius Drusus, tribunus plebis in 91, and the architect in charge of building his house on the slope of the Palatine overlooking the forum: when the architect promised him to make it "completely private and free from being overlooked by anyone", Livius replied, "No, you should apply your skills to arranging my house so that whatever I do should be visible to everybody." (Vell. Pat. Ii. 14.3). ... his successor in the same property, Cicero, felt no differently: "My house stands in full view of virtually the whole city" (Wallace-Hadrill 1988, p. 46)

These quotes offer a valuable insight into some of the intentions that guided choices on the location, form and structure of buildings in ancient Rome. More importantly for the current discussion, they suggest that certain notions of "public" or "private" in the Roman cityscape could be better examined in three-dimensional space rather than with two-dimensional plans. In this case it would be important to know, for instance, whether and which parts of the façade, the back spaces or architectural decoration of a building (e.g. painted and relief decoration) could be seen from public areas of the Roman city. Furthermore, one might like to know which buildings are more visible from certain parts of the cityscape or which structures can be seen with more ease in a given built district.

Similarly, in the case of Mayan architecture human experience in 3D space is considered crucial for understanding socio-symbolic aspects of built space that may have shaped human movement and action in the past. Hohmann-Vogrin (2005, p. 287) observes that the use of a ground plan alone is insufficient for appreciating experience in Mayan sites, where movement was apparently guided by the altitude of monumental structures that could be seen from a distance. Moreover, she argues that visual and physical access in these spaces would have implicitly expressed important social symbolisms:

> Maya sites are like landscapes, resembling mountains, hills, valleys and planes. Open spaces are constituted by plazas, courtyards, terraces and platforms on different levels, while interior space is relatively limited. In some cases access to higher levels was obviously restricted ... Step by step, terraces and platforms become smaller. Sights and views are determined by the altitude of the respective terrace or platform. On the lowest level, the view is limited by walls and platforms taller than the viewer, at least in the smaller courtyards. The field of vision is widened by access to higher levels. On the highest level – presumably never reached by the average person – the view becomes unlimited, so to

speak. Here, social hierarchy is demonstrated literally. This is both functional and symbolic. (Hohmann-Vogrin 2005, p. 285)

In recent years advances in the discipline of urban studies and the increasing availability of computing power have enabled the development of computational analysis methods which aim to quantify aspects of visual experience in built environments. Such approaches seek to permit the comparative investigation of urban configurations, and to examine the social dimensions of their transformation through space and time. Established visual analysis methods, such as axial[1], isovist or visibility graph analysis (Bintliff, Fisher, Hacıgüzeller and Thaler, Hillier, Letesson, Stöger: cf. this volume), cannot be used, however, for the investigation of visibility in 3D cityscapes. These one- and two-dimensional techniques aim to define the visible space between walls that offers possibilities for movement, and were created to underpin different theoretical and empirical considerations than those described above. Thus, they do not take into account the three-dimensional topography of a cityscape or the vertical dimensions of built structures. On the other hand, archaeologists in the past have attempted to develop methods that are more suitable for examining human visual experience in 3D space. For instance, in his analytical approach to Andean architecture Moore (1996) places great emphasis on the vertical dimension of monumental buildings. In order to investigate the visual impact of public built structures he introduced methods of analysis that aimed to quantify the impression of "monumentality" induced to a viewer from different viewpoints[2]; he created isovistas, namely contour maps that define locations in space at which the visual impact of a monument as seen from selected angles of view changes significantly (fig. 1). For the creation of these maps only the highest point of the target structure is taken into account. Moore (1996, p. 227–228) admits that, although sufficient for his analysis, his measures are crude, and suggests that the application of computer-assisted design and Geographic Information Systems (GIS)[3] could offer fuller reconstructions of architectural spaces and potentially more subtle recognitions of constructed patterns. The recent development of fully three-dimensional visual analysis techniques reflects similar considerations.

1 In many recent space syntax studies axial lines are referred to as "lines-of-sight" (Turner 2003, p. 661).

2 These methods were later used by Letesson and Vansteenhuyse (2006) in the context of Minoan palatial architecture.

3 More recent versions of commercial GIS software (e.g. ArcGIS 10) provide the tools for some basic forms of visibility analysis on building facades, such as line of sight calculations. This analysis can determine whether a line of sight will be obstructed by a building or not. However, more sophisticated types of visibility analysis, e.g. viewshed calculations that can determine how much of a façade could be visible from a given location, cannot currently be performed with commercial GIS software.

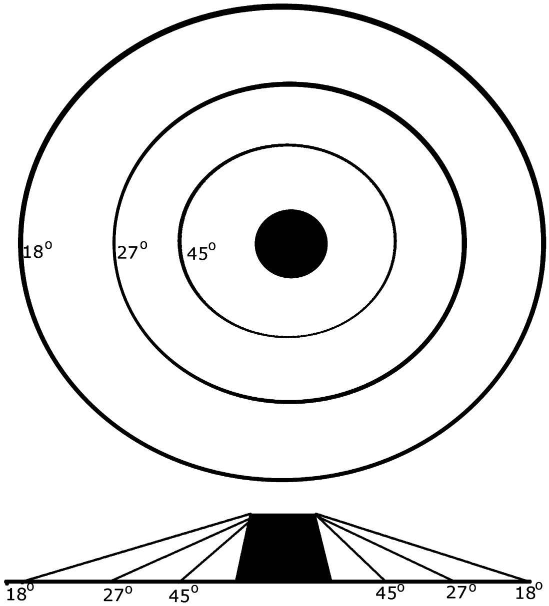


Figure 1 | Example of unobstructed isovistas that mark three different visual thresholds, e.g. those locations where the monument occupies 18, 27, and 45 degrees above the horizontal line of vision (based on Moore 1996, figure 3.7).

### 2.2 Computational approaches to visibility analysis in 3D spaces: The visibility of Theran murals in the townscape of Late Bronze Age Akrotiri

Visibility analysis in fully 3D spaces[4] (Earl 2005; Paliou and Wheatley 2007; Paliou et al. 2011; Paliou 2011; Paliou and Knight, in press; Papadopoulos and Earl, this volume; Earl et al., forthcoming) has been applied in archaeological studies with the aim of permitting the quantitative description of views perceived in visually complex 3D environments by a human observer on the ground. By coupling common 3D modelling and GIS functionalities, this approach manages to quantify visual access to vertical built features (e.g. facades, masonry, mural painting) in architecturally intricate built contexts, such as those often encountered in real world environments. In this respect it is especially well-suited for the formal examination of concepts associated with Rapoport's Nonverbal Communication approach, and conforms well to the line of enquiry outlined above. It has to be noted that in many situations estimating in a formal way the communicative potential of 3D built features can be fairly straightforward. Fisher (2009, p. 445; this volume), for example, has argued that ashlar masonry in Late Bronze Age Cyprus formed an integral part of the identities of the elite, and was strategically used in socio-politically or ideologically important

4 Fully 3D are those digital spaces with three independent x, y and z axes. These should be distinguished from digital models that, although they appear to be 3D, do not have an independent z axis, for example traditional digital elevation models (DEMs), where height is merely an attribute of a set of x, y coordinates (2.5 D models).

contexts. To demonstrate his point he quantifies the presence of ashlar masonry in LBA rooms by calculating their *ashlar elaboration scores*: he first divides the length of the wall(s) constructed of ashlar blocks by the total wall length of the room, and subsequently multiplies the outcome by a value that defines the degree of elaboration for the observed type of ashlar masonry *(elaboration multiplier)*. Nonetheless, when it comes to exploring visual access to vertical built features within complex architectural contexts, the use of more sophisticated spatial representations and analytical processes is necessary.

One of the first applications of visibility analysis in 3D spaces aimed to explore aspects of the visual experience of Theran murals in the Late Bronze Age town of Akrotiri (Thera, Greece: Paliou 2009; Paliou 2011), which was buried by an immense volcanic eruption in prehistory. Akrotiri (fig. 2) is famous for the lavish wall decorations that embellished many of its public and domestic buildings. The Theran murals, like the site itself, are exceptionally well preserved, and are among the best studied finds of Aegean Bronze Age painting. Since their discovery the wall paintings of Akrotiri have fuelled intense debates regarding their uses and intended purposes, with some scholars maintaining that their themes suggest a primary religious/ritual function (e.g. Marinatos 1984; Morgan 1998), while others argue that they had a predominantly secular/social content (e.g. Schachermeyer 1978; Televantou 1994; Doumas 2005). Despite the difficulties involved in interpreting the exact themes of Theran murals, it is reasonably safe to assume that they were elite architectural features, since figurative wall painting in the Late Bronze Age Aegean is linked with palatial architecture and the most elaborate buildings discovered (Boulotis 1992; Chapin 2004; Gates 2004).

It has long been suggested that the unprecedented number of wall paintings found in Theran domestic spaces may have been associated to strategies of social competition among town dwellers who acquired wealth in a relatively short time, due to trade and seafaring activities (Doumas 1992, p. 29; Schachermeyr 1978; Boulotis 1992, p. 89). Nevertheless, most discussion on the visual consumption of wall paintings has concentrated on the practices (ritual, dining etc.) that took place in the decorated rooms (Michailidou 2001; Boulotis 2005; Chapin 2004), mainly during formal occasions, while the possible latent messages of the paintings in more mundane everyday situations have remained less well studied. For instance, it has been suggested that in Akrotiri wall paintings adorning first floor rooms in domestic buildings could have been visible to a passer-by outside the buildings through the open windows (Doumas 2005). If this was true, murals could have been used to mark the houses of those having or aspiring to a high social position and would have communicated messages of status not just to the few people allowed into these rooms on certain formal occasions, but to any individual traversing the prehistoric settlement in the course of everyday life. The possibility to see the paintings also from outside the buildings would perhaps explain why mural decoration was so abundant in Akrotiri. However, appreciating how murals decorating first floor rooms may have been received by those crossing the public open spaces presents a number of challenges: the wall paintings used to

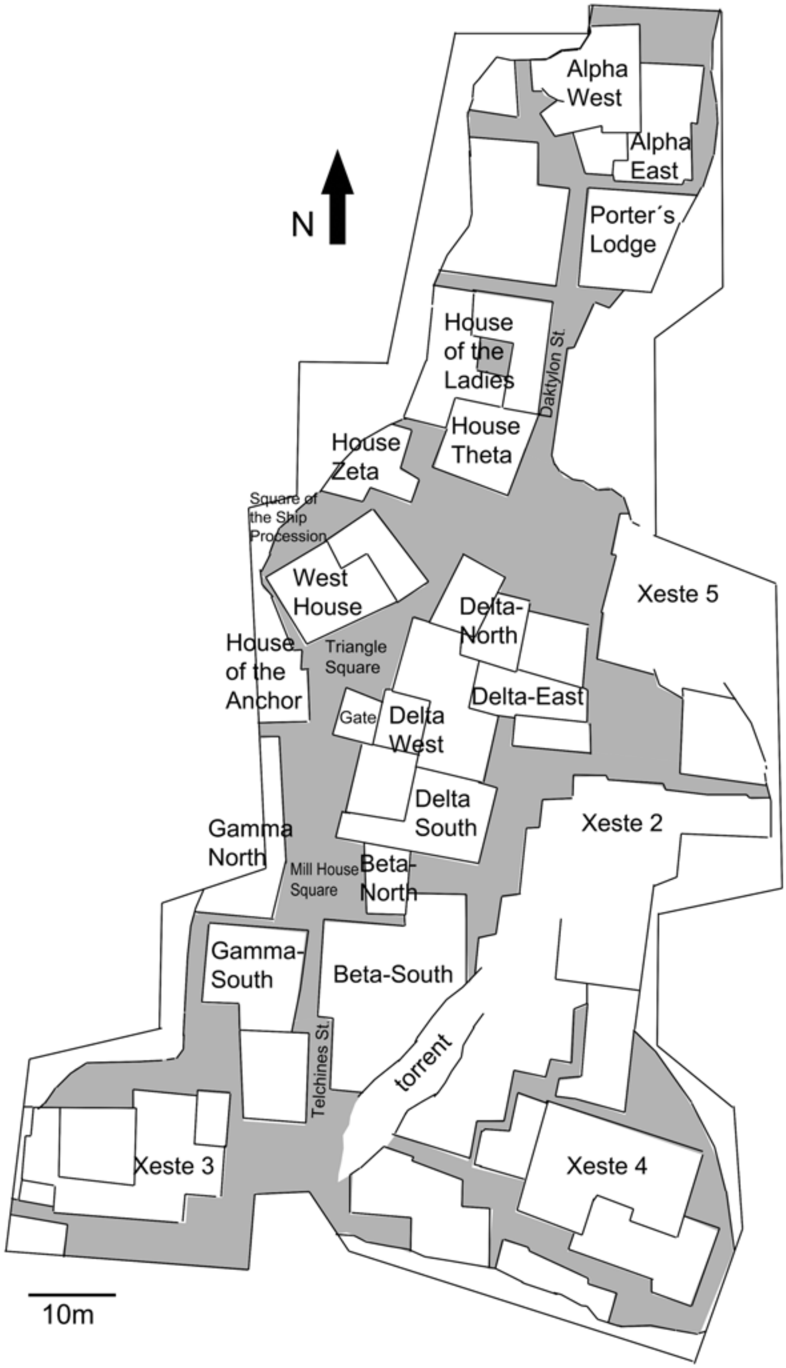


Figure 2 | Building units and public spaces (shaded) at Akrotiri (based on Palyvou 2005, fig. 27).

decorate walls that have nowadays collapsed and could have only been partially seen through wooden window frames, which have disintegrated, as suggested by imprints left in the thin volcanic ash (Palyvou 1999, p. 406–407).

Computational visibility analysis was employed in this case to formally assess the communicative potential of wall paintings in the townscape of Akrotiri. Room B1 of Beta South, Room 5 of the West House, and the first-floor room above the Gate at Delta West (fig.2) were chosen as case studies, since these spaces could be reconstructed with a relatively high degree of certainty and were distinguished by typical features of Theran architecture, (e.g. large horizontal windows, pier-and-window partitions, painted friezes). The procedure of analysis, which has been described in detail elsewhere (Paliou 2009; Paliou et al. 2011), required as a first step the creation of 3D digital reconstructions[5] (fig. 3) of the spaces under study using information provided by the building remains, the excavation process (imprints of wooden window frames and lattices in the volcanic ash) and the restored wall paintings, which indicated the dimensions of collapsed walls. Then the visible area of each painted surface from a large number of defined viewpoints was recorded in the virtual environment, using point-source illumination; this method permits the easy extraction, further analysis and remapping of visual data derived from a 3D model. Such an approach is based on the analogue production of isovist in a digital environment by illuminating a 3D model with a single light source that emits light in all directions (cf. also Benedikt 1979); in this case, illuminated and non-illuminated areas of the model correspond to visible and non-visible surfaces as seen from the location of the light source respectively (Paliou et al. 2011).

Viewer locations at the public open spaces outside the reconstructed buildings were identified by sampling space at equal intervals (20 cm by 20 cm) using a grid (fig. 4). Subsequently, a simple script was used to animate the light source over each one of the observer locations in succession at the eye level of a standing observer (1.55 m). Information on the illumination (visibility) of painted surfaces for each viewing location was then extracted in a raster format (fig. 5), to be further analysed and mapped in a GIS[6] environment using a series of scripts and batch processes (Paliou et al. 2011). This procedure produced maps which showed the amount of the visible area of a targeted painted wall that could potentially be seen from each viewing location (fig. 6). One basic benefit of this method of analysis is that by constraining the light rays within certain angular ranges it can also establish how much of the painted surface could have been observed with relative ease (fig. 6 b, d, f). In this case the painted areas visible within an angular range of up to 25 degrees above eye level were also recorded, viz. the surfaces that could be seen with eye rotation and with no need for additional upward head movements (Higuchi 1983,

5 All 3D models discussed in this paper were created with various versions of AutoCAD and 3Ds Max software.
6 GIS analysis was performed with ArcGIS.

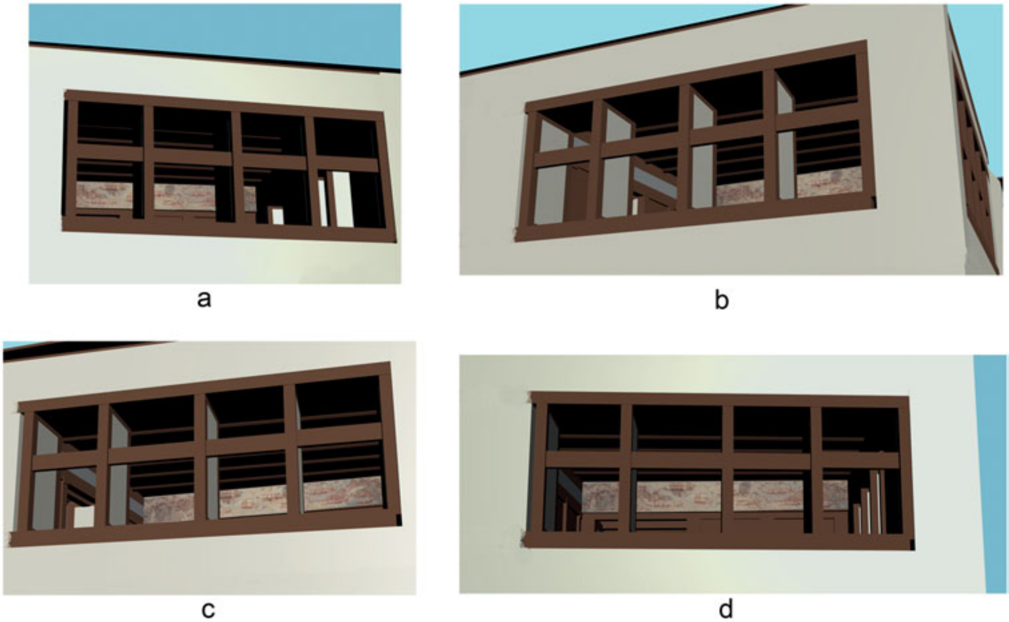


Figure 3 | 3D model of Room 5 (first floor) of the West House. a,b,c,d: Views from the public open space outside the building (Paliou 2011, fig. 3). Created by E. Paliou.

p. 40; Paliou 2011, fig. 6). Within this visual range the communicative potential of the paintings is relatively high, as pedestrians walking in a densely built and possibly populated environment are more likely to encounter the painted walls naturally and with ease, without making particular visual effort or interrupting their movement (Paliou 2011, p. 254).

By applying the above analytical methods, changes in the visual experience of someone moving through the public spaces of the settlement were systematically recorded and analysed, and important spatial relationships, which were not immediately perceivable simply by walking through the digital reconstruction, became apparent. An important conclusion was that a large number of the paintings could have been exposed to the viewer from many locations outside the buildings. The precise themes would not have always been intelligible.[7] Nonetheless, the mere awareness of lavish wall decoration would have been enough to convey latent social messages of status and power to those encountering the paintings,

7 The intelligibility of the themes would have also been affected by lighting conditions, the colour of painted elements and the distance of the paintings to the observer. Although lighting conditions in the Theran houses are hard to reproduce with scientific accuracy (Paliou 2009, p. 87), it makes sense to suggest that rooms with a small area (approx. 4 × 4 m) and large or multiple windows piercing the greater part of their outer walls would have been fairly well illuminated for most part of the day (cf. Doumas 2005).

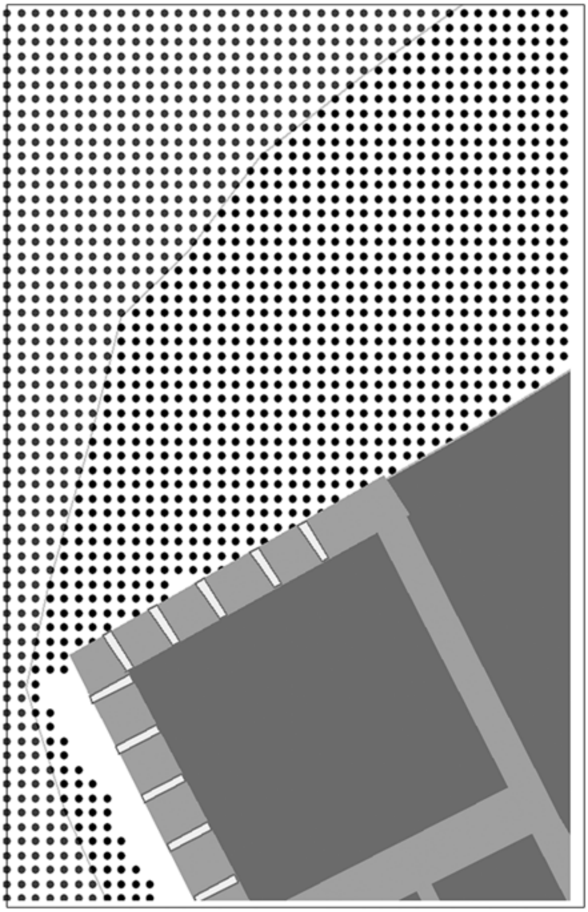

Figure 4 | The grid of viewpoints at the open public space outside the West House (Paliou 2011, fig. 5a).

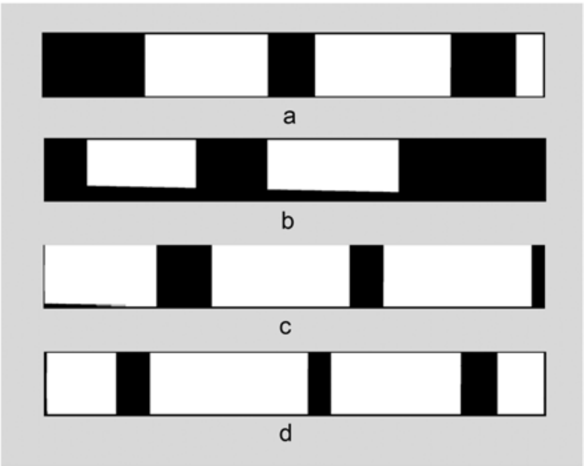


Figure 5 | Textures (viewsheds) of the south frieze of the Miniature Fresco (Room 5, West House) with information on the visibility of the painted wall surface for four different viewpoints (white/visible-black/non-visible): a, b, c, d correspond to fig. 3a, 3b, 3c, 3d respectively (Paliou 2011, fig. 4).

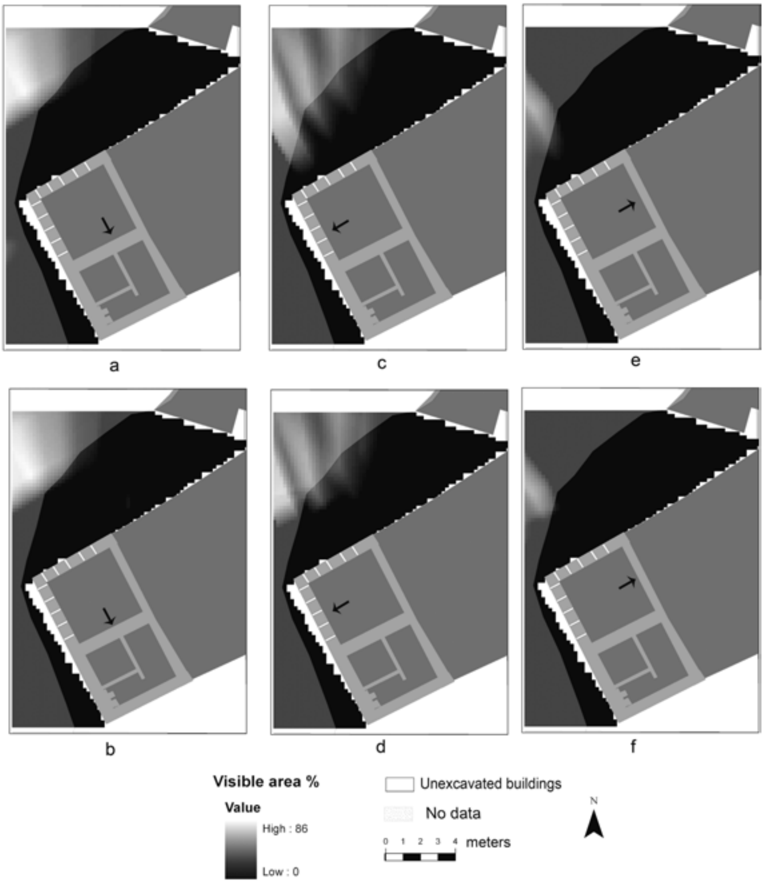


Figure 6 | Changes in visual access to the Miniature fresco from outside the West House (Paliou 2011, fig. 9) – a, b: The visible area of the south frieze from the square without (a) and with angular restrictions (b). c, d: The visible area of the west frieze from the square without (c) and with angular restrictions (d). e, f: The visible area of the east frieze from the square without (e) and with angular restrictions (f). The arrow points to the position of the fresco under study.

and on some occasions to trigger memories of the social events that took place in the decorated rooms. Furthermore, the systematic visibility recording and mapping for virtually all locations outside the buildings highlighted certain necessary and less obvious spatial conditions permitting the visibility of the wall paintings from the street network. The results showed that pedestrians would have to be located in most cases at least three and sometimes four metres away from the walls of a building embellished with murals to be able to observe the painted surfaces. Since main roads in Akrotiri are usually up to 2 m. wide, this suggested that the visibility of wall decoration from public open spaces was possible to a great extent due to the existence of the so-called squares (fig. 2), the relatively wide openings in the street network. Such spaces distinguish this Cycladic town from other more densely built contemporary Aegean urban settlements (Palyvou 2005, p. 29); visual access to first floor rooms in towns that lacked similar openings would have been impossible or rare. In this respect one could argue that it was the particular urban layout of Akrotiri that permitted the visibility of mural decoration from outside the buildings, enhancing in this way the communicative potential of the murals. Hence, the spatial configuration of the prehistoric settlement might have encouraged the surprisingly wide production of wall decoration, as much as social conditions (Paliou 2011).

The case study of Akrotiri is perhaps characteristic of the problems associated with exploring communicative aspects of built features in architecturally complex spaces, and how these may be solved using methods of visibility analysis in fully 3D digital environments. A similar approach could prove beneficial in other cases, viz. for examining the visual impact of built features in Roman or Mesoamerican societies, providing that the suggested methods and interpretive schemes are employed in a context-specific way. The remainder of this paper argues for the benefits of using three-dimensional visibility analysis within theoretical frameworks that place primary emphasis on the social significance of the open space delineated by walls and buildings. The focus will be upon isovist and visibility graph analysis, two techniques that were added to the set of Space Syntax methods almost a decade ago with the aim of identifying patterns of co-presence in the built environment, and of investigating the ways in which spatial configuration encourages movement, social encounters and interaction.

## 3 The visibility of space between walls

### 3.1 Space syntax methods: isovist and visibility graph analysis

Isovist analysis was introduced in the field of urban studies in 1979 by Benedikt, who originally defined *the isovist* as the set of all points visible from a vantage point in space, namely as a three-dimensional entity (Benedikt 1979, p. 49). Benedikt (1979; see also Benedikt and Burnham 1985) argued that certain isovist measures, such as area, perimeter, occlusivity, variance, skewness and circularity, influence the formation of human spatial perceptions and behaviours related to the concepts of privacy, surveillance, prominence, visual access and exposure. He therefore proposed ways of calculating, mapping and analysing these isovist qualities. In his analysis he considered for the sake of simplicity the isovist as a horizontal two-dimensional plane at the eye level of the observer (Benedikt 1979, p. 52). More recently, Turner et al. (2001) drew on the theoretical framework developed by Benedikt, as well as on social theories of networks, such as those proposed by Hillier and Hanson (1984) and Watts and Strogatz (1998), to analyse the spatial configuration of built spaces using visibility graphs (Hillier, this volume).

The applications of isovist and Visibility Graph Analysis in archaeology are underlain by the notion that human perception and communication in built spaces often reflect important aspects of social organization and cultural behaviour (cf. Taft 1998; Moore 1996; Clark 2007). One of the few works that discuss the use of these methods in ecclesiastical space was carried out by Clark (2007), who, following the work of Franz and Wiener (2005), used isovist measures to study the spatial configuration of Byzantine churches in Jordan. Clark considered *isovist spaciousness* (area), *openness* (isovist perimeter$^2$/area) and *complexity* (area/isovist perimeter$^2$) calculated from the altar, the assembly, the ambo and from the seat of the presiding cleric for six distinct church types (Clark 2007). He then performed Visibility Graph Analysis for the same spaces and compared the various levels of visual integration that possibly signify changes in liturgical rites and the relationships between the assembly and the clergy over time (Clark 2007, p. 102).

Clark's work is interesting because it draws attention to symbolic aspects of the spatial organization of congregations during liturgical rites. His analytical approach would appear insufficient, however, if it was to be used for studying certain common types of Byzantine ecclesiastical space. For instance, in some Late Antique churches a part of the congregation would have been situated in second storey galleries, known as *gynaecium* or *matroneum*, and hence would have observed the unfolding ritual events from above. According to written sources referring mainly to Constantinopolitan liturgical rites (Taft 1998), these spaces would have been occupied by women. In fact the same sources suggest that as a rule male and female members of the congregation would have been allocated separate spaces during the liturgy: men would have been situated in the main nave area and perhaps in one of the side aisles, while women, in addition to the second storey galleries, would have occupied one or maybe both lateral spaces of the ground floor, when these were not used by men. Examining the differences in the visual perception of male and female participants could enlighten aspects of interaction among the members of the congregation during the liturgy and highlight certain cultural behaviours in the context of formal settings. Still, the visual experience of the female participants at the *matroneum*, who would have been looking down to observe the ritual activities on the ground floor, cannot be effectively explored with two-dimensional methods of analysis, since these only take into account a single horizontal slice of space at the eye level of the observer.

### 3.2 Visibility and co-presence during the liturgy in San Vitale, Ravenna

Three-dimensional visibility analysis offers new possibilities for exploring perceptual and social aspects in ecclesiastical space. The method was employed to investigate visual patterns in the still extant 6th century church of San Vitale in Ravenna (Paliou and Knight, in press). San Vitale is an octagonal domed church, with a main nave area and side ambulatory aisles on the ground floor as well as second storey galleries (fig. 7a). There are no sur-

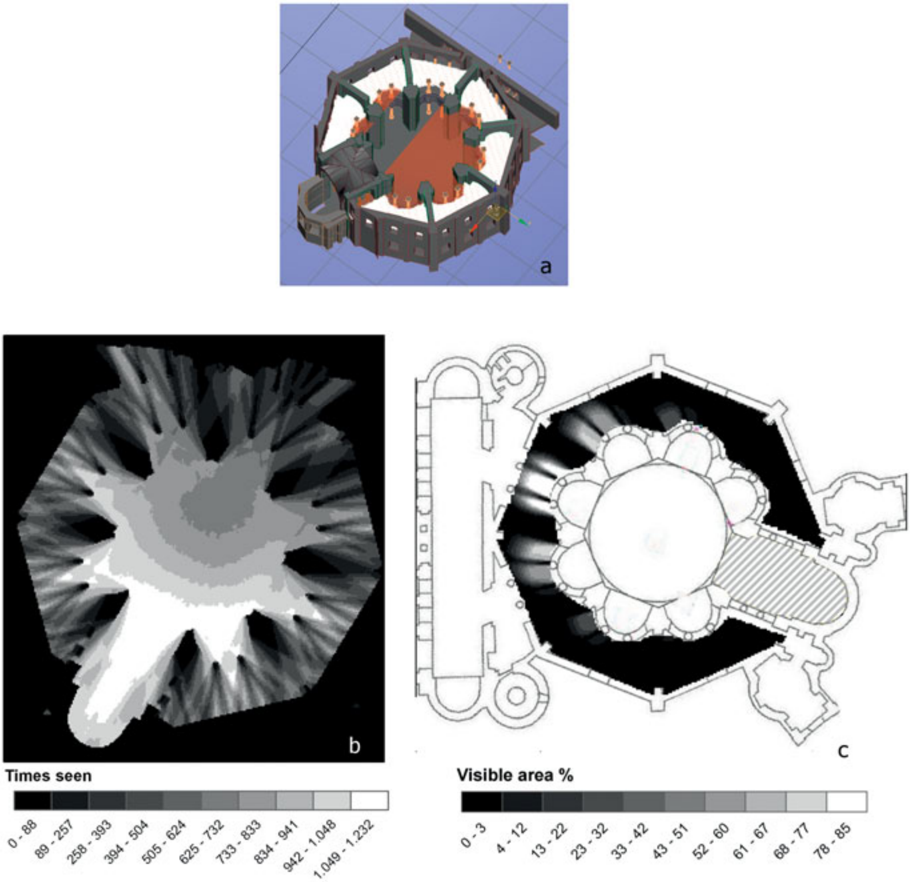


Figure 7 | a) A 3D model of San Vitale (created by I. Giannakopoulou, modified by E. Paliou, based on Deichmann 1989); the sampled area (10,270 viewpoints – sampling every 20 cm) at the *matroneum* is indicated in white. b) Times seen map of the ground floor from the *matroneum*. c) Visible area (%) of the chancel (hatched) from the *matroneum*.

viving written sources informing us about the spatial organization of the congregation in this church; nevertheless, the architectural similarities of San Vitale to contemporary Constantinopolitan churches suggest conceptual trade with the Byzantine capital (Grossmann 1973; Krautheimer 1986; Deichmann 1989; Knight 2010), and possibly a similar use of the second storey galleries as a place for women.[8] Within this context visual access from the galleries to the ground floor can be thoroughly examined in three-dimensional space, as demonstrated previously: first, by defining observer locations in the *matroneum* in equal

8 The spatial separation of male and female members in the Constantinopolitan congregations has been discussed in detail by Mainstone (1988) and Taft (1998).

intervals (one every 20 cm, fig. 7a), then recording the ground floor area that can be seen from each observer location, and finally analysing information incorporated in binary viewsheds[9] using a GIS. In this case, the final output of the analysis was "times seen" maps (fig. 7b), namely raster images composed by summing up binary viewsheds, which describe how many times different areas of the ground floor are sighted from the *matroneum*.

This process allowed quantitative comparisons of the visual experience of men and women in church space. The visual access to the liturgical foci from the ground floor was examined with visual connectivity maps created using Depthmap (fig. 8). These revealed that the chancel area, the main focus of attention during the liturgy, is visible on average from 12,623 locations on the ground floor.[10] On the other hand, the "times seen" map describing the visibility of the same area from the galleries showed that it can be visually accessed only from 1,026 locations on average (out of 10,270 viewpoints defined by a grid of 20 cm intervals: fig. 7a,b). This map also suggests the relatively restricted visual access from the galleries towards the main nave area, where men would have been located. Fig 7c shows that the locations in the galleries which can see a significant part of the area of the chancel (more than 20 %) are rather few (1,643 out of a total of 10,270). It follows then that female members of the congregation had somewhat limited visual access to the performance of the ritual compared with those situated on the ground floor. If women, in addition to the galleries, occupied the aisles flanking the nave (left or right), as applies to the sixth century liturgy at Constantinople (Taft 1998, p. 36–39), then they would still have been situated on the least visually integrated areas of the ground floor (as suggested by Visibility Graph analysis in fig. 9). Visual access from the nave area to these spaces (and vice versa) would have, therefore, been restricted.

On the other hand, it is also important to note that some locations in the *matroneum* would have offered special and literally transcendental views from above (Paliou and Knight, in press) (fig. 10). The few worshippers located in these areas would have perhaps the most advantageous visual access during the service, as they would have been able to observe clearly both the unfolding events on the ground floor, and a large number of congregation members in the nave area at the same time. Still, the locations in the galleries offering such views are limited (fig. 7c); the results of the analysis (fig. 7, 8, 9) mainly suggest restricted visual connectivity between the areas allocated to women and the chancel area, as well as the main nave area occupied by men. Such visual restrictions, which concern locations in church space designated for the female rather than the male participants, are imbued with symbolic meaning. If the liturgical rites in Ravenna are associated with similar social and religious behaviours as those documented for Constantinopolitan

9 Maps that show visible and non-visible areas (fig. 5, fig. 10).

10 The viewer locations on the ground floor were defined by a grid of 20 cm intervals.

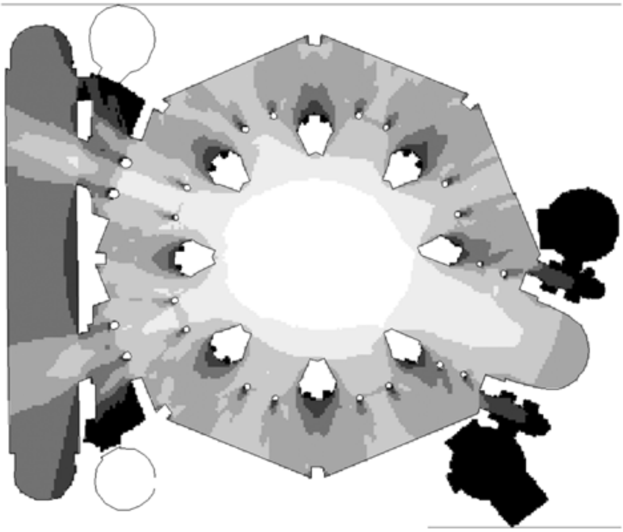

Figure 8 | Visual connectivity for the ground floor (grid spacing 20 cm; created with DepthMap). White: high visual connectivity (max. 18,479), black: low visual connectivity (min. 127).

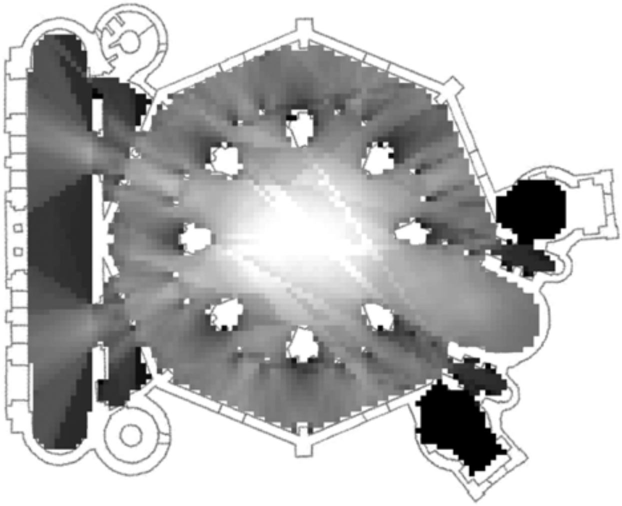

Figure 9 | Visual Integration (HH, white values-high/black-low) for the ground floor of San Vitale.

churches[11] in the 6th century (Taft 1998, p. 87), the separation of the sexes in church space in this particular way may suggest the ranking of women after men during the liturgy, and the intention to discourage communication between male and female congregation members, probably aiming to protect women from "inappropriate" and "dangerous" male behaviour (Taft 1998, p. 82–87; Paliou and Knight 2011, in press).

11 The degree to which similar social and religious behaviour characterizes the liturgical traditions of Ravenna and Constantinople in the 6th century is debatable due to the lack of sufficient textual evidence and, therefore, one should be cautious when making such an assumption.

Figure 10 | Visible area of the ground floor from the *matroneum* measured from a position opposite the chancel (white = visible, black = non-visible).

The analysis described above looked into only certain aspects of visual communication in San Vitale that were affected by the occlussive effects of architecture. In a similar way the visibility of other architectural features (e.g. relief decoration, mosaics, the altar etc) can be explored. It should be emphasised that the results of three-dimensional analytical approaches of this kind, as applies to landscape and two-dimensional architectural visibility analyses, suggest solely what could potentially be seen in space, as opposed to what one would actually see: visual access in the church during the liturgy may or may not have been further restricted by factors of more transient nature, such as the bodies of individuals that would have partaken in the liturgy, artificial or natural illumination, screens and curtains (Taft 1998, p. 49) etc. Nonetheless, the visual properties of architectural configuration were permanent and would have determined to a great extent visual experience during the ritual. The case-study of San Vitale aimed mainly to demonstrate that aspects of visual communication in three-dimensional space are quantifiable and potentially suggestive of social perceptions and behaviours.

## 4 Conclusions and discussion

Methods of visibility analysis in three-dimensional built environments are able to produce new types of spatial patterns that take into fuller account the geometric properties of architectural space and the physiology of the human visual system. This chapter provided some examples of how these new types of mapping can be interpreted within social theories that lay emphasis upon symbolic aspects of visibility in space. The 3D methods described above can be used to analyse visual properties of the open space between walls, as well as visual characteristics of built forms. Environment-behaviour studies and Rapoport's Non-Verbal Communication approach, which seek to examine the ways in which messages of social status, identity and power are encoded and conveyed via visual cues, could benefit from such approaches; maps showing changes in the visibility of a target feature through space (fig. 6, fig. 7c) can help establish the likelihood that this object will be encountered by a mobile individual. Furthermore, such maps could facilitate a better understanding of how landmarks and prominent architectural features could have influenced human movement patterns in built space and vice versa. When attempting to tackle problems of this nature, however, one should always bear in mind that the intelligibility of objects in built environments depends on many factors: for example, the comprehensibility of the theme in a mural painting scene could be affected by lighting conditions (Paliou 2011; Papadopoulos and Earl, this volume), the colour of painted elements and their distance to the viewer. Such factors should be considered when trying to assess the communicative potential of architectural features.[12] Papadopoulos and Earl in this volume offer some good examples of how different aspects of visibility in the built environment can be approached with a combination of formal 3D visual analyses.

Furthermore, as was demonstrated by the case study of San Vitale, the 3D analytical methods proposed in this chapter can also be used to examine the visibility of space between walls that is associated with social interactions. Encounters and movement in formal settings, such as ritual spaces, follow a set of rules that reflect, produce and reproduce social relations and order (cf. also Hillier, this volume). As applies to some types of Byzantine ecclesiastical space, visibility relationships that trigger and shape human interactions cannot always be reduced to two dimensions. Maps such as those presented in Figure 7b are complementary to visual connectivity maps produced with Depthmap (fig. 8) and are expected to be useful additional tools for understanding visibility patterns in built environments. Moreover, it is also noteworthy that maps summarizing visual properties of space can be fused with audibility maps (Paliou and Knight, in press) and produce analytical products that suggest the blending of the senses as advocated by anthropological theorists (cf. also Wheatley, this volume).

Ultimately, a number of other concepts used in urban analysis could be examined and described in quantitative terms with the methods presented here. The notion of "monumentality" that is discussed by Moore (1996) in his work on Andean architecture could be associated with a more refined analytical process, which takes into account the precise form of buildings under study. Furthermore, certain notions of what Lynch has termed "imageability" (Lynch 1960), namely "that quality in a physical object which gives it a high probabil-

12 See footnote 7.

ity of evoking a strong image in any given observer" (Lynch 1960, p. 9), could be explored quantitatively by comparing, for example, the degree to which different building facades are exposed to an observer situated in a given built context.

It goes without saying that the visualisation of archaeological spaces in 3D is not always possible with the same degree of success or certainty: archaeological remains are often hard to interpret in 3D based on surviving evidence, and every attempt to reconstruct an archaeological environment has to cope with data quality issues. Still, in recent years archaeologists have systematically tried to address the problems involved in 3D reconstruction of past environments, and formal ways for dealing with uncertainty in these contexts have been proposed (Paliou 2009; Paliou et al. 2011; Earl et al., forthcoming); methods that have long been known in the field of GIS-based landscape analysis, such as probability or fuzzy mapping, have been employed to incorporate uncertainty in the results of 3D visibility analysis, and identify those occasions where interpretive statements can be made with greater confidence (Paliou et al. 2011). The further development of computational tools that acknowledge and seek to consider the special needs of archaeological data is a worthwhile direction of research that promises to offer new possibilities for the social analysis of past built environments.

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