Long Paper

Assessing Spectator Positions

A Case Study from Cochasquí, Ecuador

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Abstract: This paper presents a methodology for close-range visibility analysis, taking the aspects into account that are relevant for spectators in theatres or sport stadiums. This methodology is applied in the pre-Inca and pre-hispanic site of Cochasquí, Ecuador that encompasses 15 truncated pyramids, nine of these with ramps, and several burial mounds. Archaeological and historical evidence suggests that large festivities took place at this site in its second phase (ca. 1250–1550 AD). For assessing potential spectator positions, a 3D model of the site is required. This model was computed from contour line data with a vertical distance of 1 m. Adequate slopes for sitting positions are derived from photographs taken at a large festival in the archaeological park of Cochasquí. These potential sitting positions are assessed with respect to different event scenarios. The basis of this assessment is data on modern visitors of sites or events. This data allows defining comfortable and tolerable ranges of the viewing distance and viewing angles. A viewing performance indicator for any position on the site's surface is defined that combines the individual viewing parameters. This performance indicator is 0, if one of the individual viewing parameters is neither in the tolerable nor in the comfortable range. A performance indicator of 100 indicates an optimal viewing position, i.e., all viewing parameters are in the comfortable range. For the spectator scenarios investigated, thematic maps are presented that visualise the performance indicators of the potential sitting positions with respect to a selected event scenario. The outcomes allow estimating the number of potential spectators. This number is significantly lower than the number derived from standard GIS viewshed analysis.

Keywords: *GIS—Viewshed Analysis—Close-Range Visibility Analysis—Ecuador—Ethnoarchaeology*

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Introduction

One of the most extensive and impressive pre-Inca and pre-Hispanic sites in the Andean region is situated at a straight-line distance of about 50 km NNE of Quito in Cochasquí, Ecuador (Figure 1). Located at an altitude of about 3000 m near the equator, the archaeological park encompasses 15 truncated pyramids, nine of these with ramps, and several burial mounds. For both the pyramids with a more or less rectangular layout and the round burial mounds the term *tola* is used. The *tolas* date back in the second phase of the site (ca. 1250–1550 AD). This site has a long history of research.

In 1932, the 76-year-old German archaeologist Max Uhle arrived at this site and encountered a trench in the largest pyramid G, dug in the course of an unsystematic search for finds (Ugalde Mora, 2015, pp. 32–39). He analysed the layers and stratigraphy of this pyramid and drew a map of the site. In the 1960s, a German archaeological team excavated parts of pyramid E and dug several trial trenches (Oberem and Wurster, 1989; Ugalde Mora, 2015, pp. 40–58). Detailed publications of the results including pottery and bone analysis are available.

In 2012, one of the authors (Alden Yépez) together with María Fernanda Ugalde of the Pontifical Catholic University of Ecuador was responsible for archaeological investigations on this site before new tourist facilities were set up. This was the starting point of research by the two authors of this contribution who cooperated in investigating if visibility could have played a role in ceremonies at this site. Since that time, the authors have given several talks on this topic and refined the approaches, but did not yet publish the outcomes. This paper summarises previous results and presents new research into the suitability of the location for staging events that can be observed by a large audience.

Several authors have discussed the function of the site. For instance, many well-known ritual sites are associated with astronomical phenomena. But according to a study focusing on sun, moon, and the Pleiades, this is not the case in Cochasquí (Ziólkowski and Sadowski, 1992). Below a layer of a depth of up to 1 m, excavations uncovered circular, baked-clay floors on the pyramid platforms (Figure 2). These features have been interpreted as remains of houses (Wurster, 1981; Bray, 2008). It is assumed that a house was erected on the centre of each of the smaller pyramid platforms, with two houses on larger platforms (Ugalde Mora, 2015, p. 44). Burnt wood and grass are indicators of the houses' destruction by fire, possibly in the course of the battles against the Inca. Wurster (1981) discusses a clay artifact that might represent a pyramid with a house. The platform of this clumsy 3D model is encircled by a wall or fence, blocking the view on the platform except at the house entrance.

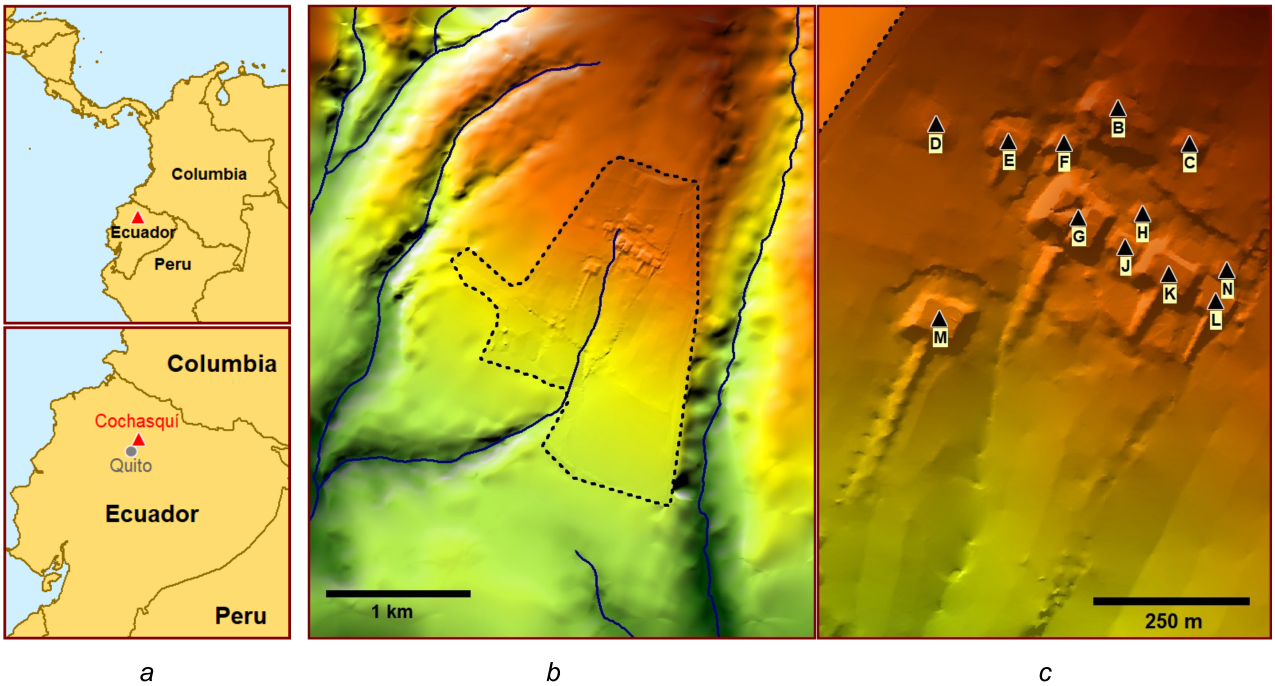

Fig. 1. Cochasquí, Ecuador a) location; b) archaeological park and surroundings; c) central part, the tolas are designated by capital letters (© Irmela Herzog; based on elevation and water course data provided by Ecuadorian authorities).

Fig. 2. Platform of pyramid E – baked clay and probable hearth remains on the right (© Irmela Herzog).

According to Bray (2008), it seems likely that some chiefs were living in houses on *tolas* and that these houses were also places where ceremonies were performed. Excavations of pyramid E revealed trough-like cavities of hard-fired clay on the clay floors of the houses (Figure 2). These are interpreted as hearths, possibly for the preparation of special feasts or ritual offerings (Wurster, 1981; Bray, 2008). But living in such a house was not comfortable because the big hearths took much room and filled the house with smoke when in operation. According to Ugalde and Landázuri (2017), numerous large hearth features recorded on the platforms allowed preparing food for hundreds of people. After reviewing the available historical and archaeological evidence, they come to the conclusion that the site of Cochasquí was not settled, but used for ceremonial purposes. They assume that the large quantities of sherds found in this and similar sites are remains of festivities involving the distribution of abundant food and drink. Probably a large part of the population took part in these celebrations. Moreover, they suggest that the long ramps to the pyramid platforms were ascended by people taking part in some festivity. Hearth features were also documented on the ground surfaces between the *tolas* (Wentscher, 1989; Bray, 2008). It is also possible that these hearths were locations of ceremonial events.

Consequently, the initial aim of the project presented in this paper was to investigate three event scenarios. The first scenario assumes that the audience awaited the appearance of a person at the doorstep of a central house on a pyramid platform bringing new food prepared on the hearths inside. In the second scenario, the long access ramps to the pyramid platforms play an important part in the ceremony. A third scenario is based on the fact that additional hearth remains were found between the *tolas* and that the action at the modern festival also takes place in the fairly flat terrain between the pyramids (Figure 3). In past reality, two or all three of these scenarios might have been combined. Initial results suggested considering an additional event scenario, located at the northern edge of the platform of pyramid M.

Fig. 3. Festival “Mushuk Nina” in Cochasquí, Ecuador, on 21-March-2013 (© Alden Yépez).

In recent non-pandemic years, a large festival at the time of the spring equinox took place in the archaeological park of Cochasquí (Figure 3). It is possible that this festival revives some aspects of festivities that took place about 500 years ago. Pictures of the spectators in modern times are the basis for defining adequate spectator sitting positions.

For each event scenario, the spectator pixels, i.e., 1 × 1 m squares in the area surrounding a proposed stage location, are identified. Each pixel allows two sitting pre-hispanic persons to view the events. This figure was derived from height estimations of seven pre-hispanic skeletons buried in the pyramids – these are in the range of 1.46 to 1.68 m (Kunter, 1989) – and a table presented by Nixdorf (2006, p. 34): a tall person at that time (1.70 m), sitting with outstretched legs (as most people depicted in Figure 3) has a hip width below 0.4 m, and the estimate for the length of legs plus seat depth is 1.275 m resulting in an area of 0.51 m². To assess the viewing properties of each spectator pixel, a 3D model of the site's surface is required, i.e., elevation data.

Digital Elevation Data

The AutoCAD contour line layer based on total station measurements commissioned by the local authorities of Pichincha in December 2009 proved to provide the most reliable and accurate elevation data of the site. The contour lines with a vertical distance of 1 m cover an area of 241 hectares (delimited by a dotted black line in Figure 1b). This data was processed using version 8 of the GIS software MapInfo Professional (https://en.wikipedia.org/wiki/MapInfo_Professional) supplemented by the Vertical Mapper plugin (https://www.manualsdir.com/manuals/740569/pitney-bowes-mapinfo-vertical-mapper.html). The nodes of the contour lines were extracted, some simplification (i.e., removal of nearby nodes) was performed and a raster DEM with a cell size of 1 m was generated using the linear option of triangular interpolation. Generating DEMs from contour lines is somewhat problematic, for instance Figure 1c shows humps on the ramps. As GIS packages nowadays do not provide efficient procedures to address such issues and the main focus of this paper is on the close-range visibility analysis, a simple but far from perfect approach was chosen to deal with the problem, i.e., some smoothing of the DEM was performed.

For covering a larger study area (Figure 1b), additional elevation data was derived from contour lines on a scanned topographic map. The vertical distances of these contour lines vary between 20 and 50 m, depending on the slope. Comparison with the AutoCAD elevations showed that the DEM derived from the topographic map was more accurate than the ASTER and the 1' SRTM DEM.

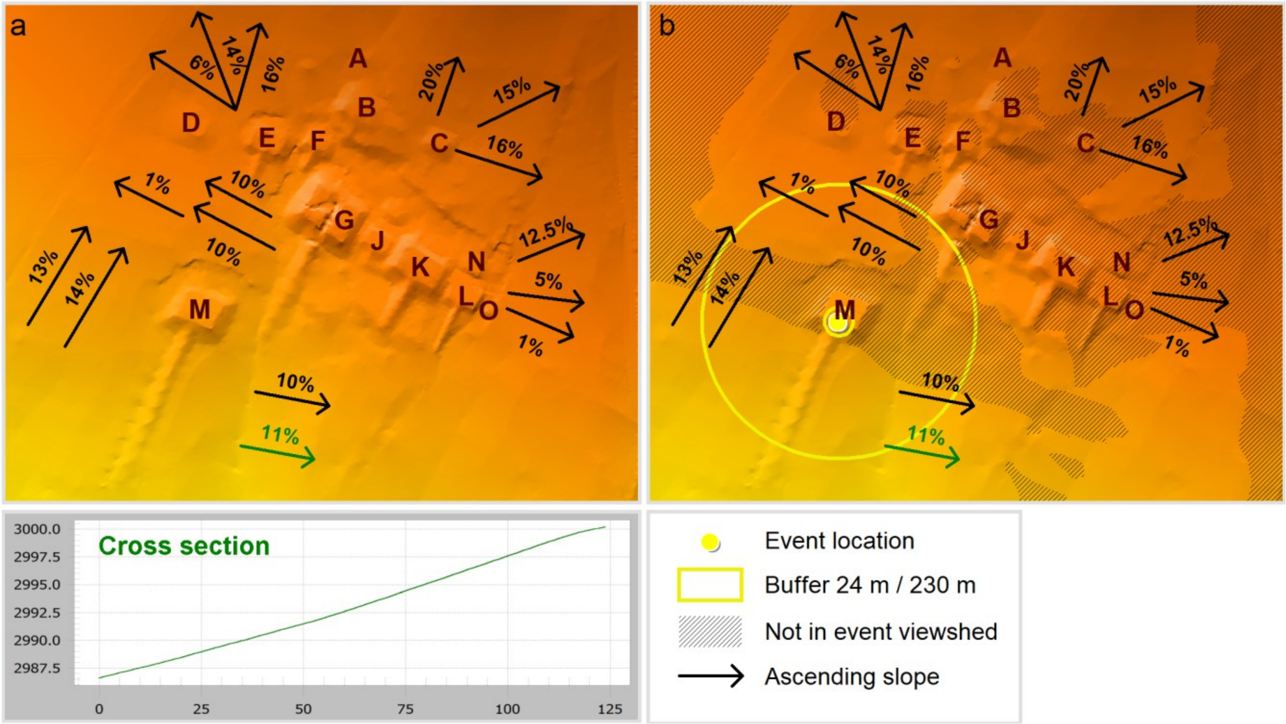

Fig. 4. a) Arrows indicating ascending slopes surrounding the pyramids. The cross section corresponding to the green arrow with length 125 m is shown at the bottom, b) viewshed analysis for an event on the edge of the platform of pyramid M (© Irmela Herzog).

Ideally, the visibility analysis should take changes in terrain relief since the site's construction time into account. The erosion of the pyramid slopes is limited, because for static reasons, soft volcanic stone was used for the construction of the pyramids, and these was covered by some clay-like substance, so that they formed uniform slopes without steps. The grass on these slopes probably prevented substantial erosion and weathering of the stone. But the excavation records of pyramid E suggest that some of the pyramid slopes were steeper in the past (Figure 22 in Wurster, 1989). However, reconstructing the past terrain surface is beyond the scope of this study and is a task for future research.

Methodology for assessing spectator positions

The calculation of viewsheds has become a popular GIS application in archaeological research (Wheatley and Gillings, 2002, pp. 201–216; Conolly and Lake, 2006, pp. 225–233). A viewshed comprises all locations within a predefined area that are visible from a given viewpoint. Archaeological viewshed analysis is typically applied to test hypotheses concerning the location of sites, e.g., the locations provide extensive views across the landscape (Conolly and Lake, 2006, p. 50) or to investigate visual-spatial relationships between archaeological monuments and prominent natural features (Wheatley and Gillings, 2002, p. 204). These applications usually take a viewing radius of several kilometres into account, whereas in this case study shorter distances are considered.

In an early phase of the research, viewsheds were generated for locations on every platform. The results and the observations from the "Mushuk Nina" festival inspired the hypothesis that parts of the site were used as an open-air location for events staged on pyramid platforms. This is illustrated in Figure 4a. Arrows indicate ascending slopes that might have accommodated spectators watching the events. DEM cross sections at the arrow locations mostly showed linear or concave graphs, suggesting slopes suitable for observers. Figure 4 gives an example of such a cross section, the corresponding arrow is green and has a length of 125 m. The more detailed research of close-range visibility presented in the subsequent parts of this paper shows that not all areas with ascending slopes with linear or concave cross section are suitable for sitting spectators.

The methodology for close-range visibility analysis presented in the next sections consists of several steps. For a given event location, an initial set of potential spectator positions is generated by viewshed analysis. These locations are classified according to distance to the event. Additional aspects of viewing are successively introduced, thus reducing the initial set of potential spectator positions.

Parameters of standard viewshed analysis

Standard viewshed analysis requires information on the viewpoint height, in this case, the height of the eyes of the sitting spectator. It is not known if women and children took part in the festivities. A conservative standard observer height of 1.50 m was chosen for the computations. A table presented by Nixdorf (2006, p. 34) indicates that the height of the eyes of a sitting person is about 52% the height of the person. This suggests a viewpoint height of 0.78 m. The impact of an error in this estimate is fairly low, as well as the error introduced by varying the sitting position (Nixdorf, 2006, pp. 121–122). Changes with time of the site's surface probably have a larger impact on the accuracy of the visibility analysis.

Moreover, standard viewshed analysis allows entering an offset value to account for the size of an object that is being viewed. This study assumes that the spectators want to see vessels with food or drink carried by a person. Vessels are typically carried well above navel height. The table by Nixdorf mentioned above indicates a navel height of 58% of the person's height, resulting in an offset value of 0.87 m. Different offset values of target and observer prevent exact reciprocity of intervisibility (Conolly and Lake, 2006, pp. 229–230). Implementation of the close-range visibility analysis is easiest in case of intervisibility. Therefore, both offset values were set to 0.8 m. The viewshed procedure of Vertical Mapper does not support offsets given in centimetres anyway.

An additional parameter in standard viewshed analysis is the viewing radius. Ogburn (2006) presents computations for assessing the visibility of objects focusing on distances beyond 1 km. His research relies on a formula relating the distance at which an object reaches the standard limit of human recognition acuity to the object's size. The standard limit is at the point at which the object subtends a visual arc of 1′. This formula can also be applied for close-range visual analysis (Nixdorf, 2006, pp. 50–52). Spectators in a modern theatre are interested in recognizing the facial features of the actors, therefore a limit of 24 m is adequate. The limits for a modern football stadium or a track and field stadium are 190 or 230 m respectively, allowing the detection of features such as the yellow card (11 × 8 cm) shown by the referee. Based on this data, the comfortable and the tolerable range of the distance values were selected (Table 1, first row). Personal experience suggests a minimum distance of 2 m between the event and any spectator.

For assessing an event scenario, the first step is to identify the 1 × 1 m pixels where the events are taking place, for these the term event pixels is used. A viewshed with the parameters mentioned above (viewpoint height: 0.8 m; offset: 0.8 m; viewing radius: 230 m) is generated using Vertical

Mapper, thus identifying potential spectator pixels. The results of these steps are presented in Figure 4b for an event taking place at the top of the ramp of pyramid M. This set of potential spectator pixels is successively reduced, firstly by eliminating pixels closer than 2 m to any of the event pixels. For each potential spectator pixel, the properties (rows 2 to 6 of Table 1) of the lines of sight connecting this pixel at eye level with the event pixels (navel height) are computed. Based on these properties, a performance indicator is computed for each potential spectator pixel considered.

Additional parameters for close-range visibility analysis

Nixdorf (2006) assesses the view qualities of spectator positions in a soccer stadium. Therefore, his work is most relevant for close range visibility studies such as the Cochasquí case study. In modern soccer stadiums the stand slope successively increases according to a parabolic equation with a maximum slope of 71% (Nixdorf, 2006, pp. 14, 154–155). But no stands accessible by stairs are available at Cochasquí. Therefore, the preferred slope of sitting locations was derived from photos of the Mushuk Nina festival (e.g., Figure 2). The spectator positions were mapped approximately on the elevation map derived from contour lines. Afterwards, the slope value for each spectator position was determined by applying the point inspection function based on the slope map generated from the DEM (software used: Vertical Mapper). Ample space at the Mushuk Nina festival allowed people to choose their sitting location freely. The slope values of the spectator positions are in the range of 14 to 40%. But it is fairly uncomfortable to ascend or descend a slope of 40% or more. According to the research on walking (Minetti, 1995), the slope of most mountain paths does not exceed 30%. Most spectator positions on slopes exceeding 30% are close to the pyramid platform edge or a minor diagonal path on the pyramid slope. Assuming that no such diagonal paths existed in the past, the upper limit of the comfortable range was set to 30%.

Table 1. Spectator parameters.

	Parameter	Comfortable range	Tolerable range	References
1	Distance to the performance (m)	2 to 24	24 to 230	Nixdorf, 2006, pp. 50–52; Ogburn, 2006
2	Slope of sitting location (%)	14 to 30	10 to 14, 30 to 40	“Mushuk Nina” photos
3	Horizontal rotation of the head and eyes, i.e., turn left or right (°)	0 to 30	30 to 60	Nixdorf, 2006, p. 46; Ganslandt and Hofmann, 1992, p. 38
4	Vertical angle of vision, up (°)	-	0 to 20	Higuchi, 1983, pp. 40, 46, 55
5	Sitting Person: Vertical angle of vision, down (°)	5 to 25	0 to 5, 25 to 35	Nixdorf, 2006, pp. 64–65; Higuchi, 1983, pp. 38,40; Ganslandt and Hofmann, 1992, p. 38
6	View blocked by a person sitting in front	Looking up or no staggered arrangement required	staggered arrangement required	Nixdorf, 2006, p. 124

Nixdorf discusses merely spectators that are looking down on a scene, whereas for events on pyramid platforms and ramps, some spectators might look up. For this reason, the work of Higuchi (1983) was taken into account, though it discusses different situations such as the view from a tower or the view on a mountain. Wheatley and Gillings (2002, pp. 205–206) note that some of the GIS procedures computing lines of sight also return the angle of this line and present a map classifying the angle (above, broadly level, below the viewer‘s line of sight). They point out that the visual impact of monuments is likely to be greatest in those areas where the viewer looks up to them. One of the rare archaeological studies taking the vertical angle into account was presented by Zamora (2011). She notes that in general a dominant position gives access to more visual information and allows visual control of larger parts of the landscape. The vertical viewing angle can be determined easily by applying trigonometry.

The publications mentioned in Table 1 often deal with somewhat different situations, resulting in some variations of the optimal values presented. For this reason, some of the parameter values given in Table 1 are compromises between different values in the publications referenced. For instance, line 5 in the Table is based on the following published values: According to Nixdorf (2006, p. 64), a sitting person's vertical angle of vision looking down on a stage in a theatre should not exceed 30°, but the examples given show a vertical angle range between 15 and 58° (Nixdorf, 2006, p. 65). Referring to a view from a tower, Higuchi (1983, p. 38) mentions a preferred vertical angle of vision between 5 and 15°, an image on p. 40 of the book depicts a line with the label "Normal line of sight – sitting" at 15° and the "optimum viewing zone for displays" is given in the range of 0 to 30°. The diagrams presented by Ganslandt and Hofmann (1992, p. 38) indicate that for a sitting person, the preferred vertical angle of vision is in the range of 5 to 40°. The situation depicted suggests a person on a chair working at a table, which is quite different from the situation of a person sitting on the ground watching an event at some distance.

A well-known issue when looking down on a scene is the fact that spectators sitting in front on a lower position might block the field of view (Nixdorf, 2006, p. 124). It is for this reason that in modern soccer stadiums the stand slope successively increases according to a parabolic equation (as mentioned above). For the computations of the view blocking property, it is assumed that the spectators do not wear hats or crown-like hair styles, so that this property can be derived from the height of the average spectator forehead. A forehead height of 11 cm was selected based on the estimated height of the people buried at this site and the table of body measurements presented by Nixdorf (2006, p. 34). It is most comfortable if a person sitting directly in the direction of the line of sight of the spectator considered does not block the spectator's view of the event. It is still tolerable if staggered arrangement of the spectator positions allows viewing the event. Currently, the computations involving some trigonometry do not consider the (realistic) possibility that spectators may choose larger distances to the neighbours in front, thus avoiding view blocking issues.

The detectability of an object does not only depend on the distance and size of the object, but also on lighting conditions, background contrast, weather, the eyesight of the observer, and some other factors. Fuzzy viewsheds allow modelling the probability of detecting objects by a distance decay function (Ogburn, 2006). In this study, a very simple distance decay function is chosen, which is 1 in the comfortable range, 0.5 in the tolerable range and 0 beyond. Equivalent functions are defined for all other parameters in Table 1. The overall assessment of a line of sight connecting a spectator pixel with an event pixel is the geometric mean of these functions, multiplied by 100. This ensures that the viewing quality of a possible view line is in the range 100 (best viewing conditions) to 0 (spectator location not adequate for viewing the event pixel considered). If several event pixels are to be considered, a cumulative viewshed (Conolly and Lake, 2006, pp. 227–228) is computed in the first step. In this case, the set of potential spectator pixels comprises those pixels that are within the viewshed of at least two event pixels. The event viewing performance indicator of a spectator pixel is the sum of the line-of-sight assessments for all relevant lines of sight connecting this pixel with an event pixel. The viewing potential is in the range of 0 to the number of event pixels, multiplied by 100.

Using the GIS software MapInfo Professional, the steps for assessing the potential spectator positions for a given event pixel can be performed manually by querying and updating subsets of the table storing the initial point locations within the event pixel's viewshed. This tedious task was automated by a program developed in the programming language MapBasic designed for creating additional tools and functionality for the MapInfo Professional GIS environment. The program determines the viewing properties and computes the assessment of a table of spectator positions with respect to a set of event pixels. Two input files are required: (i) a point file that contains a point at the centre of each sitting pixel in the viewshed of the event(s) (ii) another point file storing the event location(s). The first point file has to include the two fields *slope* (given in percent) and *slopefactor*, with slope derived from the DEM and *slopefactor* is the assessment of the slope with respect to comfortable sitting. Moreover, the field *aspect* (given in degrees) must be filled before running the program. This input table is updated in the course of the processing by computing the field entries in the columns *DistFactor, HorizFactor, VerticalFactor, BlockFactor*, and the final assessment *SumWeights*. It should be quite easy to translate this program consisting of merely 280 lines to any more popular programming language (for those familiar with this language).

Results

Scenario 1: Awaiting the appearance of a person exiting a central house on a pyramid

For this scenario, pyramid M was chosen because of its size and because its shape appears to be well-preserved. If food and drinks were prepared in the central house on the platform of this pyramid, people in the surrounding area might await the appearance of one or more persons at the doorstep of this house. The focus is on the appearance of these persons carrying vessels who might stay at the edge of the platform for a while for everybody to see like a modern rock star entering the stage. After that, these persons might proceed down the ramps to the awaiting audience (see scenario 3 below). The location of this event was chosen at the edge of the platform, at the top of the ramp because the platform of the clay artifact mentioned above is encircled by a wall or fence with a gap at the house entrance.

The outcome of the first steps of close-range visibility analysis of an event taking place on the top of the ramp of pyramid M is shown in Figure 4b. For this event location, 105,420 sitting pixels are in the viewshed within a radius of 230 m, the slope of 96,173 of these pixels is either in the comfortable or tolerable range (Figure 5 top, left). These 96,173 positions were assessed with respect to the event location on pyramid M in terms of horizontal and vertical angle, as well as the blocking property (see Table 1). The individual outcomes are presented in Figure 5, and the combined result of the spectator assessment is depicted at a larger scale. According to the combined assessment, only about 11% (11,570) of the spectator pixels in the viewshed allow viewing the event at all, i.e. the maximum number of spectators is 23,140. The horizontal angle has the highest impact on the combined assessment, people sitting south of the event location have to turn their head beyond the tolerable range either to the left or to the right to be able to watch the event. Figure 5. illustrates several issues. First of all, the central house (which was not modelled in the DEM) on the platform would probably block the view for most of the pixels with positive spectator assessment. Some adequate spectator pixels are located on the ramp of pyramid G, but if the ramps played an important role in the ceremony, people probably should not sit on ramps. Similarly, spectators on the pyramid platforms are not in accordance with this scenario. Small spectator pixel groups towards the outer limit of the viewshed are not realistic either. In general, fragmentation of the spectator pixel patches is an issue. No tools are necessary to detect this issue in the resulting spectator assessment maps. Nevertheless, it might be nice to take this aspect into account in a future refinement of the spectator assessment.

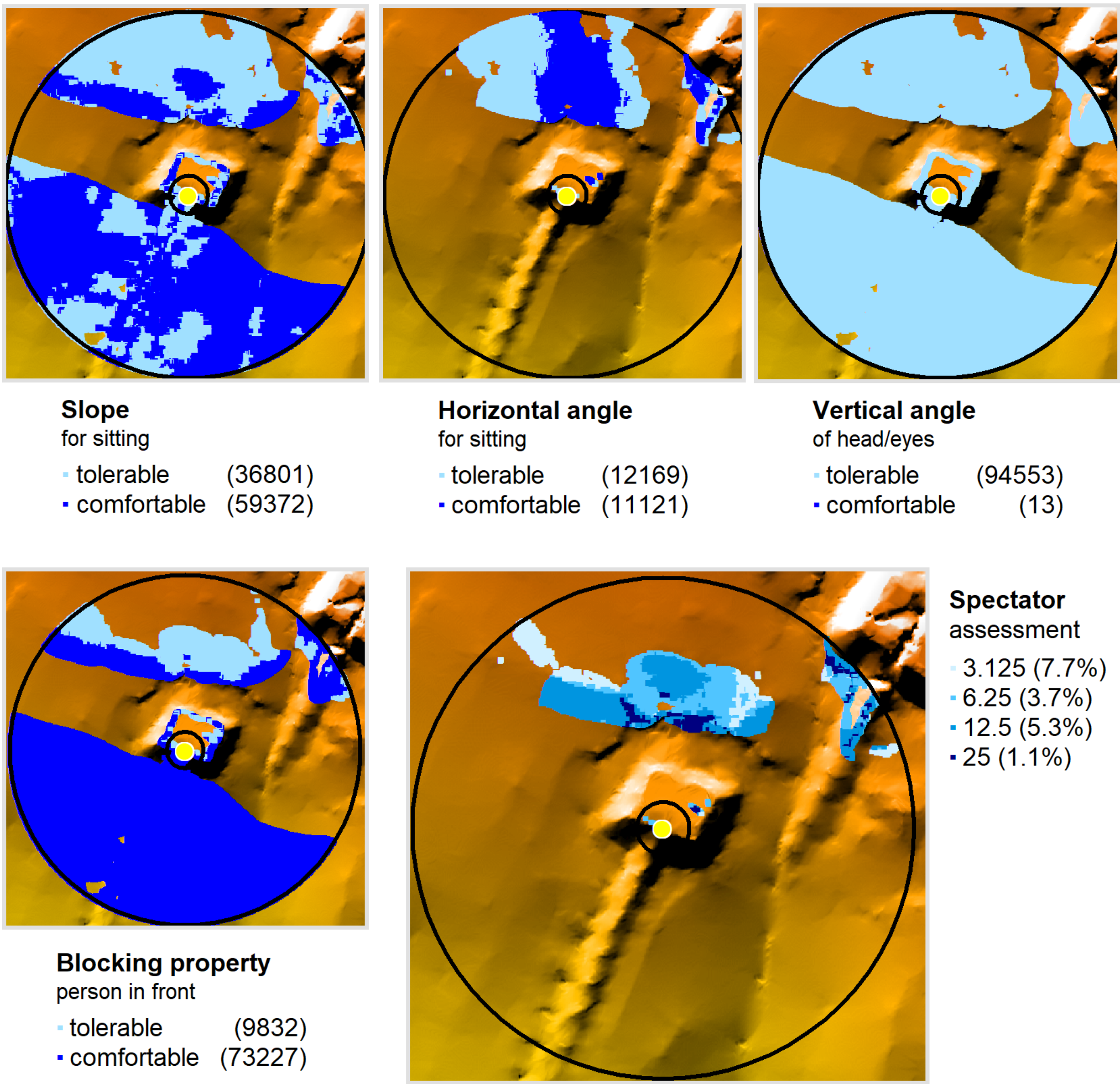

Fig. 5. Assessment of the spectator properties listed in Table 1 for an event on the edge of the platform of pyramid M; radius of the small circle: 24 m; radius of the large circle: 230 m (© Irmela Herzog).

Moreover, the distance from the event to the main group of adequate spectator pixels is quite big. Due to these issues, it is hardly likely that the constructors of pyramid M intended to support scenario 1. Instead the close-range visibility results suggest that a performance on the northern edge of this pyramid's platform is closer to the adequate sitting positions identified in Figure 5 and therefore more realistic. This scenario is investigated in the next section.

Scenario 2: Five event locations on the northern platform edge of pyramid M

Five sample event positions were chosen along the northern platform edge of pyramid M. The cumulative viewshed of these event positions covers 78,002 m², within this area adequate slope for sitting can be found on 62,254 m².

The total assessment of each sitting pixel was computed by adding the individual assessments for each event location. According to the sum total of the combined assessments, about 27% (21,329) of the spectator pixels in the cumulative viewshed allow viewing at least one of the event locations at all. As discussed in the previous section, it is plausible to omit sitting pixels on the ramps, on the pyramid platform and in isolated small groups at a larger distance from the event.

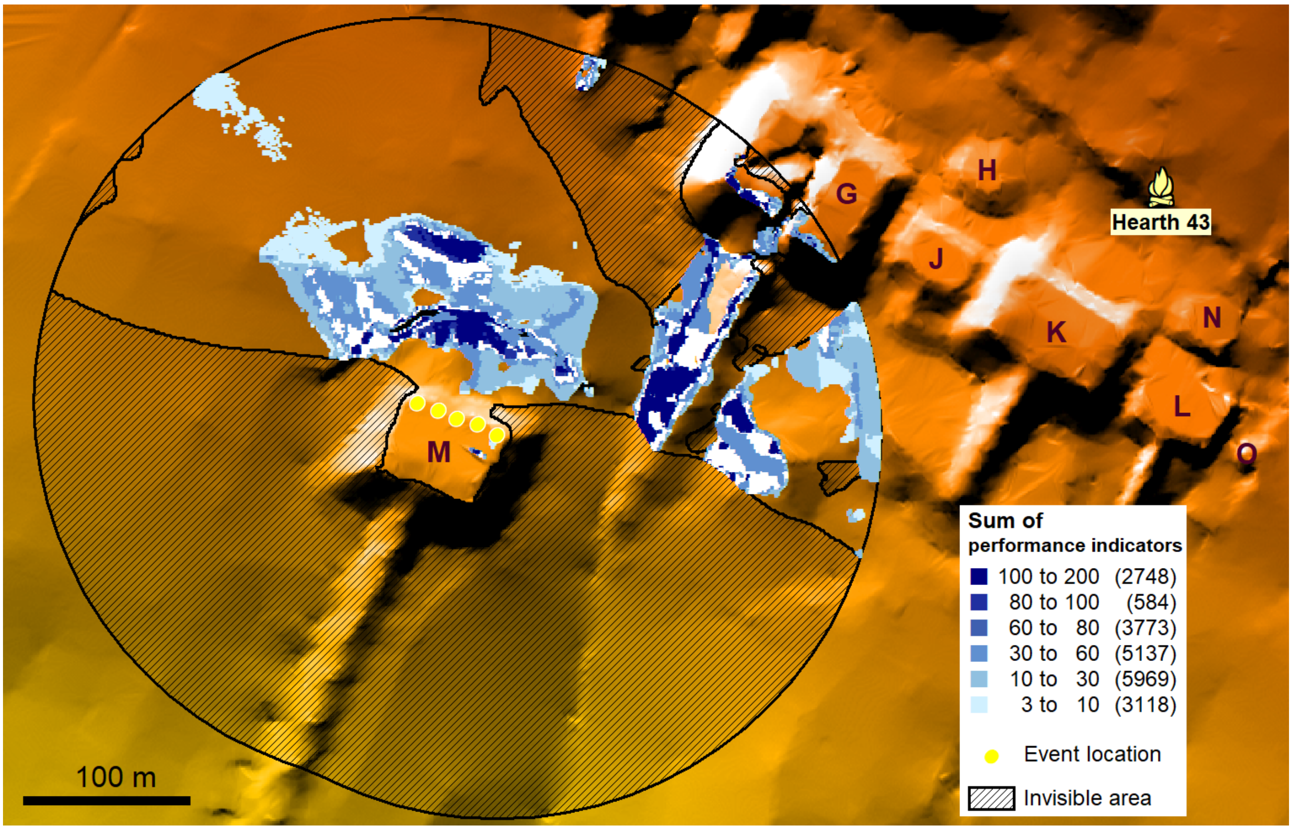

Fig. 6. Classification of potential spectator pixels for five event locations on the platform of pyramid M (© Irmela Herzog).

But the fairly compact zone of spectator pixels north of the pyramid appears to be a reasonable area for spectators. This zone consists of 12,203 spectator pixels, corresponding to 24,406 persons. The largest distance between a spectator in this group and an event pixel is less than 135 m, which is below the recommended maximum spectator distance in a modern soccer stadium (Nixdorf, 2006, p. 52). This group comprises 6788 spectator pixels with a total assessment of more than 25, the total assessment of 3987 of these pixels exceeds 50. Whereas the spectators with a 25+ assessment form a connected spatial group (with some minor exceptions), the pixels with a better assessment of 50+ form two spatial groups with some gaps. Figure 6 highlights the two kernel zones of the 50+ group in dark-blue. A more refined distance decay function might provide a smoother result.

Scenario 3: Event locations on the ramp of pyramid M

This scenario assumes that the spectators wanted to watch persons carrying vessels with food or drink down the ramp. For testing this scenario, eight event locations were selected on the ramp of pyramid M. The cumulative viewshed of these event locations covers 146,531 m², more than 90% (135,344 m²) of this area provides comfortable or tolerable slopes. Figure 7 shows the spectator assessment sums for the eight event pixels selected.

According to the sum total of the combined assessments, about 38% (55,822) of the spectator pixels in the cumulative viewshed allow viewing at least one of the eight event locations on the ramp of pyramid M. In Figure 7, the brown line with triangles delimits an alternative zone for possible spectator locations. This zone consists of a joint buffer for the eight event locations with a radius of 150 m, i.e., the recommended maximum spectator distance in a modern soccer stadium. The ramp and the pyramid are excluded from this zone. Within this zone, Figure 7 shows a large area of potential spectators west of the ramp and a smaller area in the east. Moreover, some small isolated patches of sitting pixels with non-zero assessment can be detected within the brown limits.

Table 2 compares the number of spectator pixels within a specified assessment range for the initially considered 230 m buffer of the event pixels with the number of such pixels in the area delimited by the brown line with triangles shown in Figure 7. The latter numbers are considered more realistic. But it is difficult to decide if a sitting pixel with a very small non-zero assessment was still considered adequate by the spectators at that time. Anyway, Table 2 suggests that several thousand spectators could be accommodated predominantly on the slopes west of the ramp.

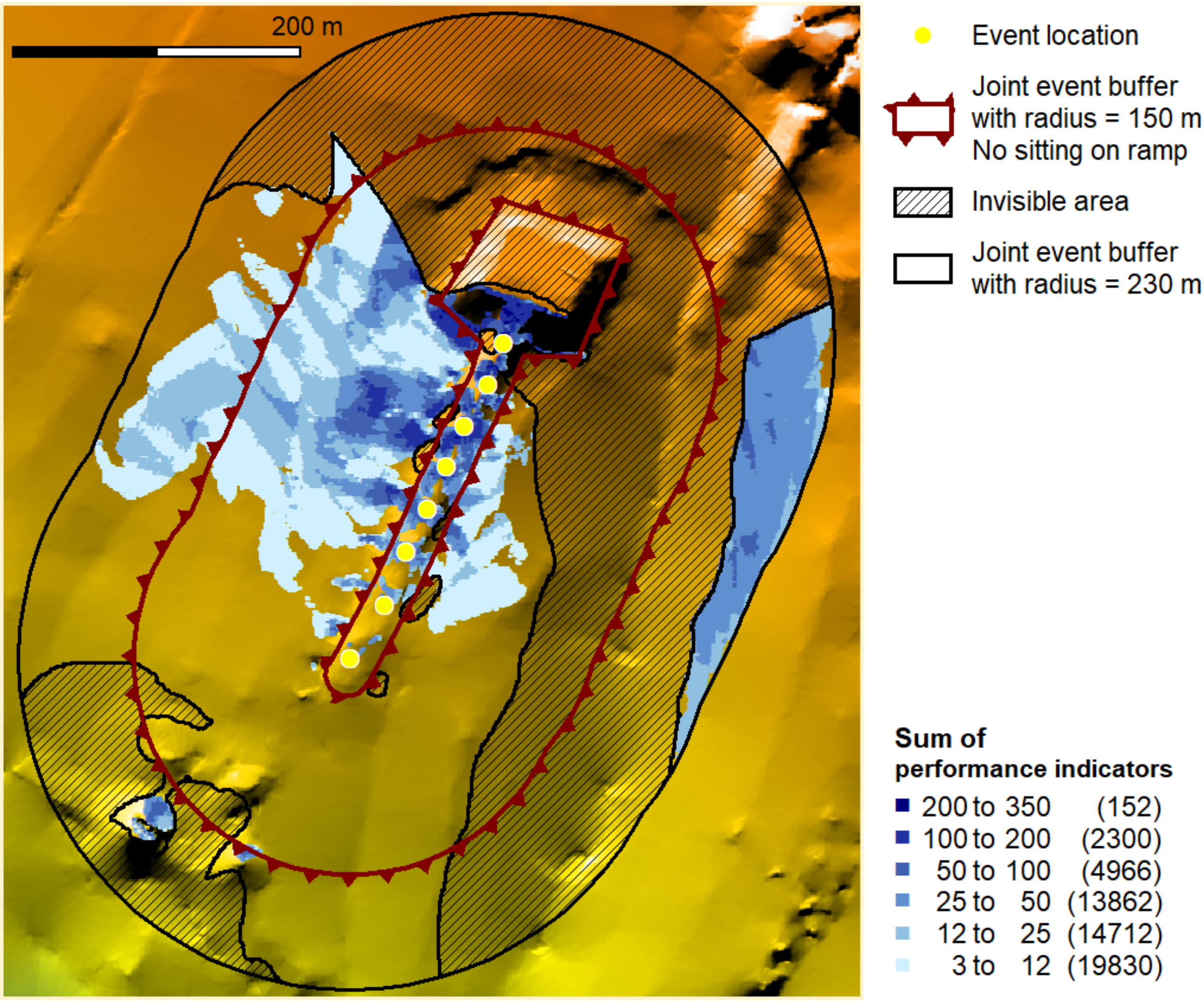

Fig. 7. Classification of potential spectator pixels for eight event locations on the ramp of pyramid M (© Irmela Herzog).

Table 2. Number of spectator pixels with non-zero assessment in the 230 m buffer zone and the area delimited by a brown line in Figure 7.

Assessment	in 230 m buffer	230 m buffer total	in brown limits	brown limit total
200 to 350	152	152	32	32
100 to 200	2300	2452	1221	1253
50 to 100	4966	7418	2754	4007
25 to 50	13862	21280	4421	8428
12 to 25	14712	35992	8435	16863
3 to 12	19830	55822	14450	31313

Scenario 4: Event location at a hearth

In the course of the excavations in the 1960s, two hearth locations in the area between the pyramids were identified (Wentscher, 1989). Spectator assessment was performed for one of these locations (feature 43). The results are shown in Figure 8.

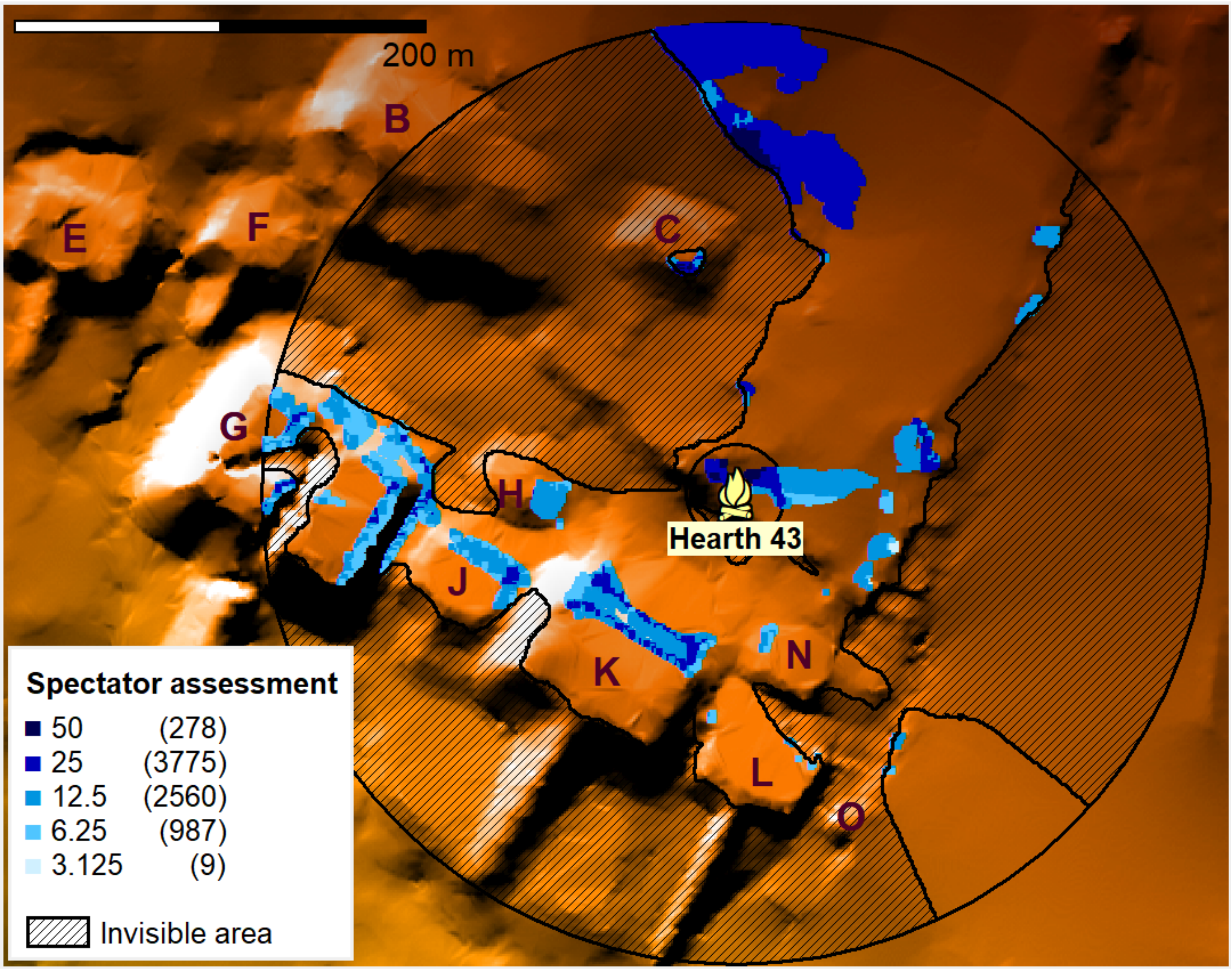

Fig. 8. Classification of potential spectator pixels for a hearth with feature number 43 (© Irmela Herzog).

The viewshed area for the hearth location includes 64,093 m². Within this viewshed, the slope of 49,194 pixels covering 1 m² is adequate for sitting. For merely 7609 spectator pixels, the combined assessment exceeds zero. None of these spectator pixels is comfortable with respect to all criteria outlined in Table 1. Moreover, only 253 spectator pixels with positive assessment are at a distance of 24 m or less from the hearth. These form two patches, northwest and northeast of the hearth location. A group sitting in the corridor separating these two patches would have difficulties watching the event because the view would be blocked by persons sitting in front. When considering the fairly small hearth (preserved length of 60 cm according to Wurster, 1989), compared to the four hearth features documented on the platform of pyramid E (length between 1.9 and 6.4 m), a spectator crowd of up to 506 people is quite a lot. The baked clay area surrounding the hearth suggests that the hearth was in a house. If the house entrance had been in the north, 506 spectators sitting north of the house at a distance of less than 24 m could have seen any person appearing at the doorstep with new food or drinks.

Most of the spectator pixels with positive assessment at a larger distance form isolated patches. These patches are most probably no realistic spectator positions. This is exemplified by a patch consisting of more than 1500 pixels with an assessment of 25 north of pyramid C. In this case, the distance to the hearth event is close to the maximum value of 230 m. As discussed previously, a refined approach might reduce the maximum spectator distance to that recommended for a modern soccer stadium or should model distance decay instead of applying the coarse classification consisting of merely two classes, “comfortable” and “tolerable”.

The excavations in the 1960s revealed a second hearth northeast of pyramid L (Wurster, 1989). This hearth is bigger, but close to the road and modern buildings. Due to this significant landscape change visibility computations for the second hearth based on the modern DEM are clearly not appropriate.

Discussion, conclusions, and future work

The main aim of this paper is to introduce the methodology for analysing the potential of a location as a stage and for assessing the number of possible spectators. Simple viewshed analysis as available in most off-the-shelf GIS software packages is merely a minor step in this methodology. It is well-known that different GIS software procedures use different algorithms for calculating intervisibility (Conolly and Lake, 2006, p. 228). Checking the impact of this issue is a task planned for the future.

For modelling agents sitting and watching comfortably a stage event, additional parameters beyond simple viewsheds must be taken into account, i.e., the slope of the sitting position, the vertical and the horizontal rotation of head and eyes, view blocking neighbours in front as well as the distance to the scene. This methodology could be easily adapted for research of spectator positions at any location that can be modelled adequately by a high-resolution DEM. This includes antique theatres, rituals at standing stone monuments or fairly recent events such as the music festival known as Woodstock held in 1969.

Some improvements of the methodology should be considered with the aim of producing more realistic results. These include the application of a continuous decay function for assessing the properties listed in Table 1. Additional issues that should be addressed are empty spaces allowing people to arrive or leave as well as waiters or waitresses to provide the spectators with food and drink. Moreover, the assessments should be modified by considering empty spaces between the rows of spectators as a means of addressing view blocking issues. Large empty spaces between spectators should be avoided, if one of the aims of the festivity is to convey a feeling of belonging to one group. Therefore, a close-range visibility analysis should take the spatial pattern of the potential spectator locations into account.

The stability of the results could be assessed by varying randomly the heights of the spectators and the surface elevations taking the accuracy of the DEM into account. Such computationally intensive approaches should be implemented using an appropriate programming environment (not MapBasic). The MapBasic program is available from the first author on request.

Since submitting the paper more than a year ago, the program has been adapted for spectators sitting on benches. The well-preserved Roman amphitheatre in Xanten-Birten, Germany, was used as a test case (Herzog, accepted). For this test case, ALS data is available. The assessment results suggest that the blocking property was modelled overly restrictive and should be relaxed for people sitting in staggered rows. As mentioned above, the program currently does not take into account that spectators may choose larger distances to the neighbours in front. Additional modifications of the program are required for assessing the positions of standing spectators.

Another aim of the case study was to provide new insights in the ritual landscape of Cochasquí. The festivity hypothesis by Ugalde and Landázuri (2017) and the modern festival inspired research into the suitability or the location for staging events that can be observed by a large audience. Several event scenarios were investigated by close-range visibility analysis taking the aspects into account that are relevant for spectators in theatres or sport stadiums. The areas suitable for sitting observers were considerably smaller than those computed by the initial viewshed analyses. Still, the number of potential spectators watching people on the ramp of pyramid M is quite impressive. For each event scenario listed in the Introduction, only one example has been presented. In the course of discussing the examples, several issues became evident that should be addressed before proceeding with additional close-range visibility analyses at the site of Cochasquí.

An issue that needs further investigation is the impact of changes of the surface since the site's second phase on the results. Different aspects towards reconstruction of the site are to be considered. Figure 1c clearly shows destructions by looters of the central part of the main pyramid G (Ugalde Mora, 2015). This pyramid platform and many of the other platforms could be reconstructed tentatively. The easiest way to model the platforms as a plane is by erasing the contour nodes on the platforms. But the excavations of pyramid E suggest that the surfaces on the platform were not on the same level. Moreover, the DEM data should be supplemented with the data of the houses that probably were erected on each pyramid platform. Based on the excavation results of pyramid E, Wurster (1989) reconstructs two fairly round houses for this platform: a house in the centre with a diameter of ca. 16 m and a smaller house in the west of the platform with a diameter of ca. 9 m. Considering the clay model and the excavation results, introducing a central round house on each platform of a ramped pyramid seems reasonable. The house diameters probably vary depending on the size of the platform. In some cases, the contour lines of the AutoCAD plan seem to suggest the diameter of the central house. Exact determination of the height of the houses is not possible. For the visibility analysis the main point is that a person can be hidden behind a house. The fence or wall surrounding the platform of the clay model is another feature that could be integrated in the digital 3D model of the reconstructed site. As mentioned above, excavations also uncovered some erosion of the steep pyramid slopes. Reconstruction of the pyramids probably should ensure constant slopes on each side.

Moreover, destructions in the course of battles and final conquest by the Inca in the late 15th or early 16th century most likely modified the site's surface (Wurster, 1989). Wurster also mentions that the *tolas* were not created at the same time and some of them were extended in the course of time. Studying the excavation records may clarify the chronological sequence of the *tolas* and their modifications in some cases. Presumably, additional onsite research is necessary to reconstruct the relative chronology of the *tolas* and their modifications. However, investigating the impact of possible variations of the 3D model will increase the computational load dramatically.

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Author Contributions

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Investigation, Resources: Alden Yépez
Methodology, Software, Visualization, Writing – original draft / review & editing: Irmela Herzog

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