



3D VISIBILITY ANALYSIS AS A TOOL TO VALIDATE ANCIENT THEATRE RECONSTRUCTIONS: THE CASE OF THE LARGE ROMAN THEATRE OF GORTYN

ANÁLISIS DE LA VISIBILIDAD EN 3D COMO HERRAMIENTA PARA VALIDAR LAS RECONSTRUCCIONES DE LOS TEATROS ANTIGUOS: EL CASO DEL GRAN TEATRO ROMANO DE GORTINA

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Abstract:

With the diffusion of virtual archaeology, many projects in the field of cultural heritage attempt to virtually reconstruct historical buildings of different types. Unfortunately, some of these three-dimensional (3D) reconstructions still have as principal aim to impress the external users, while the correct interpretation of the buildings modeled is much more important in the domain of archaeological research. Still more critical is the situation when we have to encounter a reconstruction of a monument which is not visible anymore, or which consists only of few architectural remains. The main purpose of this paper is to introduce an innovative methodology to verify hypothetical scenarios of 3D architectural reconstructions, specifically for ancient theatres. In very recent time 3D visibility analysis applied to archaeological context using ArcGIS has been developed, in particular about social-urban studies. In this paper, visibility analysis in 3D contexts is used as an additional instrument to correctly reconstruct architectural elements of the large Roman theatre of Gortyn, in Crete. The results indicate that the level of visibility of the stage, and consequently of the presumed actors, from some of the more representative sectors of the cavea, is of crucial importance for leading to a right reconstruction model of the theatre.

Key words: 3D visibility analysis, 3D modelling, virtual archaeology, Roman theatre, Gortyn, Crete

Resumen:

Con la difusión de la arqueología virtual, muchos proyectos en el campo del patrimonio cultural intentan reconstruir edificios históricos de varios tipos. Desafortunadamente, algunas de estas reconstrucciones 3D tienen todavía como principal objetivo impresionar al/a la usuario/a, cuando la correcta interpretación de los monumentos modelados es mucho más importante en el campo de la arqueología. La situación es aún más crucial cuando tenemos que reconstruir algo que ya no es visible, o de lo que hay solo unos pocos restos. Por esta razón, el principal propósito de este artículo es presentar una metodología innovadora para verificar escenarios hipotéticos de reconstrucciones arquitectónicas en 3D, específicamente de teatros antiguos. Recientemente, el análisis de la visibilidad en 3D utilizando ArcGIS ha sido aplicado al contexto arqueológico, en particular a estudios socio-urbanos. En este artículo, el análisis de la visibilidad en contextos 3D se usa como un instrumento adicional que reconstruye correctamente elementos arquitectónicos del gran teatro Romano de Gortina, en Creta. Los resultados muestran que el nivel de visibilidad de la plataforma, y consiguientemente de los supuestos actores, desde algunos de los sectores más representativos de la cavea, es de crucial importancia para conseguir la reconstrucción del modelo más correcto del teatro.

Palabras clave: análisis de la visibilidad en 3D, modelado 3D, arqueología virtual, teatro Romano, Gortina, Creta

1. Introduction

The discipline of archaeology has seen a great development in last century: theories, methodologies, documentation, methods and instruments have evolved progressively to obtain as much information as possible and above all to follow a scientific approach. More recently, virtual archaeology was born in order to help the understanding of archaeological data and expressing a more valid interpretation, thanks to the 3D visualization

of sites, monuments and artifacts. In addition, these reconstructions also represent a way to preserve the memory of archaeology (Pletinckx, 2011). Another advantage of virtual archaeology is the attraction of people's attention through 3D reconstructions allowing a wider diffusion of the culture.

In some cases this advantage is used only to impress people through the powerful instruments of computer graphics used for 3D reconstructions, which are more

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fanciful than well-established archaeological approaches, as it has been already widely explained by Frischer, Nicolucci, Ryan & Barceló (2002, p. 5). In archaeology is never easy formulating clear hypothesis but by applying a rigorous methodology it is possible to obtain valid data useful for a correct or at least a scientific interpretation. The same accuracy must be used for virtual archaeology: this is the reason why the Seville Charter set some principles to be considered as guidelines for the realization of projects in this field (López-Menchero & Grande, 2011). Principle 5 states, "to achieve optimum levels of historical rigour and veracity, any form of computer-based visualization of the past must be supported by solid research, and historical and archaeological documentation" (Principles of Seville, 2012).

The aim of this paper is to introduce a new methodology that, together with the well-established one (use of archaeological reports, written sources, plans, pictures) plus geophysical prospection and 3D modelling, can fulfil principle 5 of the Seville charter.

Geographic Information System (GIS) already largely contributed to the study of archaeological context but now with the introduction of 3D spatial analysis tools (e.g. 3D analyst toolkit in ArcGIS) it is possible to analyze also 3D archaeological environments. By means of visibility analysis five 3D models representing different reconstructions of the large Roman theatre at Gortyn have been investigated to verify which one is the most efficient, focusing on the efficient visibility of the stage from representative groups of seats. The results show that the visibility in all the reconstructions is good and very similar among them, but they also highlight small differences that led us to propose a model which can be the more descriptive of the original structure.

2. Case study: large Roman theatre of Gortyn

Gortyn is located in the Messara plain, in the south of Crete. The first settlement is dated to the Minoan civilization but it flourished after the Roman conquer of the island, when Gortyn became the capital of the Roman province of Crete in 67 B.C. Until the Ottoman conquer in the 8th century, Gortyn was a flourishing town and some of its magnificent monuments are still there to testify its glorious past. The site is being investigated by archaeological excavations since the end of the 19th century but unfortunately the history of some of its monuments is still unclear and some of them are still underneath (Di Vita, La Rosa & Rizzo, 1984).

The large Roman theatre of Gortyn is located on the south-east slope of the acropolis and according to one of the recent studies its last phase should be dated between the 2nd and the 3rd century AD (Barresi, 2004). Several documents, dated to different periods, describe this monument but a systematic study about it has not been done yet, so the information we have, is often too generic and not always reliable.

Onorio Belli, a physician from Vicenza (Italy) was the first one to report the theatre at the end of the 16th century: besides to describe it in some letters addressed to his uncle, he also added its plan (Beschi, 1999). Even if this is the first detailed plan of the theatre, it is important to underline that he was neither an

archaeologist nor an architect and usually his plans are considered with scepticism, even if, in a number of cases, they have been proved to contain a number of details that are not obvious today.

In the 19th century, British traveller Spratt had the occasion to see the ruins of this monument, and he described his impressions in his diary (Spratt, 1865). It was in the same period that the architect Edward Falkener (1854) decided to re-elaborate Belli's plan using his knowledge about the topic, and he made some modifications regarding the dimensions and the number of columns and seats of the theatre.

Finally, at the end of the 19th century we have some more scientific data coming into the pool as a result of the research run by the Italian School of Archaeology in Athens all around Crete. In particular, Antonio Taramelli (1902) carried out a small excavation and he managed to report many distinct spatial measurements and in addition he added a plan and a section of the cavea, as he probably did not find any particular architectural element which marked the scene building.

The archaeologist Ian Sanders (1982), recorded the status of the monument in the second half of the last century but he did not report any substantial detail useful for the understanding of the original aspect of the theatre.

The last study about this building involved all the above documents plus new technologies such as geophysics (Sarris and Papadopoulos, 2010) and 3D visualization (Manzetti, Parthenios & Sarris, 2015). In order to realize an accurate 3D reconstruction of the theatre, traditional instruments and new technologies have been integrated: Belli's plan, Falkener's plan and Taramelli's plan have been transformed into a 2D vector digital drawings through AutoCAD 2013. Each one of them has been superimposed to an orthophoto of the area occupied by the theatre, generated by using digital images from the satellite system Astrium at a spatial resolution of 50 cm (taken from Google Earth), and to the plan of the geophysical anomalies found (Fig. 2). Belli's plan resulted to be the most correct one among the three: it fits better with the site where the monument arose and it corresponds with some geophysical anomalies, as the internal part of the cavea and the north corner of the scene building. Belli's plan has been scaled through Autocad2013, using as reference a segment representing a length of 10 feet as explained by the same author; a vicentine feet corresponds to 0,356 m (Fig. 1). In the end, a 3D model has been reconstructed to visualize the theatre and it shows that, following Belli's plan and the Vitruvian rules (Pollione 29-23 a.C.) for the elevated of the scene building, the height of the cavea corresponds to the height of the *scaenae frons* (scene building), as it should be in the Roman theatres. What is unusual in this reconstruction is the position of the stage, which is too far from the *scaenae frons*, as it is for a Roman theatre that distinguishes itself from the Greek theatre to be a closed block. This kind of characteristic is a very interesting aspect to investigate through 3D visibility.

Currently, the area occupied by the large Roman theatre is under archaeological excavations by the Ephorate of Prehistoric and Classical Antiquities of the Municipality of Herakleion (Kanta, Lirintzis & Nikolopoulou, 2013).

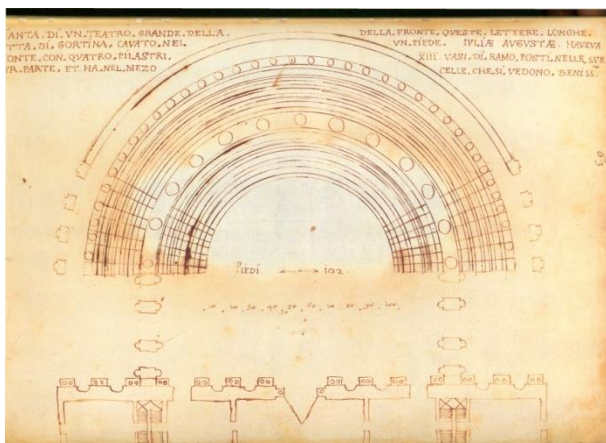


Figure 1: Plan of the large theatre of Gortyn by O. Belli. From Beschi, 1999.

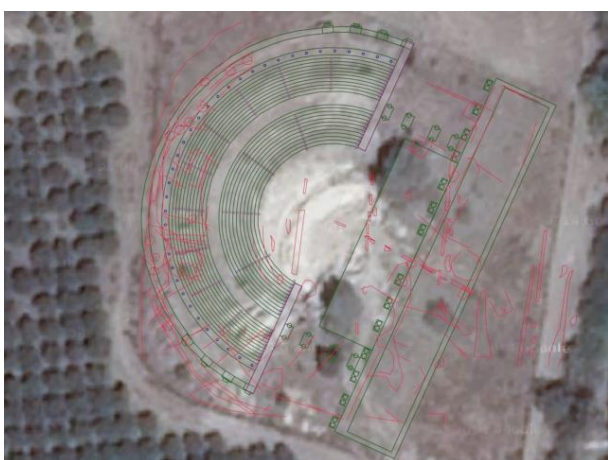


Figure 2: Resulting plan of the large theatre of Gortyn obtained by the combination of architectural elements indicated by Belli, Falkener and Taramelli, according to an orthophoto of the area and the results of geophysical prospection.

3. Related works

It is since several years ago that landscapes and urban spaces have been investigated in order to better understand their organization and their function above all related with human activity. The methodologies used, as isovist (Benedikt, 1979) and visibility graphs (Turner, Doxa, O'Sullivan & Penn, 2001), and also viewshed in GIS, have the limitation to work only in 2D or 2½D environments, missing in this way the fundamental third dimension. As a consequence, these approaches do not produce completely accurate results, in particular when the analysis regards environments with possible vertical obstruction to visibility, as vegetation and architectural elements (for a summary about the several methodologies see Paliou, 2013).

Paliou, Wheatley & Earl (2011) proposed an innovative methodology to investigate the visibility in archaeological contexts using 3D reconstructions. More precisely they developed an approach that integrates 3D modelling and GIS functionalities in order to obtain information about what is visible and what is not of a wall painting in a room, from the perspective of people walking in the surrounding area of a reconstructed building of Akrotiri (Thera, Greece), dated to the late Bronze Age. The process can be divided into two steps:

1. After having modelled the building, the visibility of the painting from the windows is calculated using an animated point light source placed at the centre of cells of a grid representing the positions of the observers. Recording the scene with a camera, from different points of view, framing the fresco, the renders obtained are numerous series of binary images where the white part is the highlighted one and therefore the visible one. The black part is the one not highlighted and thus it is not visible. So, the visibility is calculated thanks to lines of sight drawn by the rays of light emitted towards all the directions (ray-tracing system).
2. Subsequently, by mean of GIS functionalities, the binary images obtained by the render have been transformed into a cumulative viewshed in order to realize different kinds of maps that clearly show the percentage of visibility for each figures represented in the fresco and many other related information such as how its visibility changes moving along paths, visual clarity and several distances from where the fresco could be seen.

In this study they compared the results of the analysis with the interpretations given of the singular figures represented on the fresco and actually they found out that the most visible character is that one considered the most important one from an iconographic point of view. So, the scholars used a visibility analysis in an archaeological-urban context to investigate the social importance of the wall painting considering how frequently that painting was seen by the population and which part was the most exhibited.

Only few years later, a complete visibility analysis of 3D models of archaeological sites in a 3D GIS environment has become possible through a method which takes advantage of the 3D spatial analyst tools such as ArcGIS 3D Analyst toolbox. It is possible to import 3D models in ArcGIS and directly check the visibility between observer and target (represented by points or lines) through the algorithm that constructs lines of sight which can be of two colours, green or red, indicating if the target is visible or not, considering any obstruction placed between it and the observer. Landeschi, Dell'Unto, Ferdani, Leander Touati & Lindgren (2014) have applied this algorithm in the 3D reconstruction of the *insula* V 1 of Pompeii to analyse the visibility of two different kinds of inscriptions, an alphabetical one and an electoral one, from the people walking around the street, in order to identify which one is the most visible and therefore the most important in the public life. They constructed the lines of sight and then they showed through a couple of graphs the visibility of each one of them explicating that obviously the electoral inscription is placed on a more visible point than the other one.

In both cases, the fresco of the Akrotiri's room and the inscriptions of Pompeii, we have a socio-symbolical study within urban and architectural contexts, and both methodologies are very valid, but the convenience of the second method with respect to the first one is evident: it is quicker and there is the advantage to immediately visualize the results of the visibility analysis from multiple observers locations and the 3D reconstruction together in a 3D environment.

In this paper the 3D Analyst toolbox has been used within one singular monument in order to understand its

own structure and to give a more accurate reconstruction of the architecture of the large theatre of Gortyn but of course the same method can be applied to other monuments as well.

4. Methodology and results

The large theatre placed on the south-east slopes of the acropolis of Gortyn was modelled through the software 3D Studio Max 2013 and several reconstructions have been made taking into account different characteristics.

1. The first 3D model (No. 1), taken as reference reconstruction for the rest, is the result of the integration and interpretation of three different plans (Belli, Falkener and Taramelli), Taramelli's section, geophysical prospection, orthophoto, Vitruvian rules, descriptions of travellers and scholars.
2. In the second model (No. 2) the stage has been placed closer to the cavea because in the first model it is in an unusual position, indicated by Belli, namely too far from the seating area.
3. For the third model (No. 3), the first one has been used modifying the wall of the *diazoma* (corridor dividing the two sectors of the cavea) and making it 1.40 m higher. This wall is often higher than the one indicated by Taramelli, because in many ancient theatres arcade are opened in that wall to allow the entrance of the spectators and actually these possible arcades are testified by Barresi (2004). The difference height of this wall is also evident in a picture within the paper about the current excavations of the theatre mentioned before, but it does not record any measure and it does not show any arcade.
4. Another model (No. 4) was constructed as a combination between the second and the third, therefore with the stage and the *diazoma*'s wall modified.

All these 3D models have been exported as 3DS files in order to easily import them in ArcScene (3D viewer for 3D Analyst) as a multipatch shapefile (ArcScene has been preferred to ArcMap because it allows 3D visualization).

A grid indicating the observer's locations, at some of the spectators' seats, has been realized in AutoCAD 2013 and then added to ArcScene catalog. The grid consists of six rows of points, for a total of 133 observers, each one of them placed 0.75 m up the corresponding seat, that it is the eye-level height of a seated man/woman. It has been decided to experiment with only six rows of points, located in the most interesting areas of the theatre, because the process for the visibility analysis in ArcGIS is time consuming and six rows are enough to verify the quality of the visibility, considering that from the large part of the central area of the theatre, the stage is obviously visible (Fig. 3). In particular, it is important to examine the visibility conditions of the spectators seating at the sides of the building, whereas other rows are placed also in the central area to compare the results among different seats. The following step was to edit a line, approximately at the centre of the stage that covers almost the full length of the stage, placed at 1.60 m from the floor of the stage; this line represents the possible

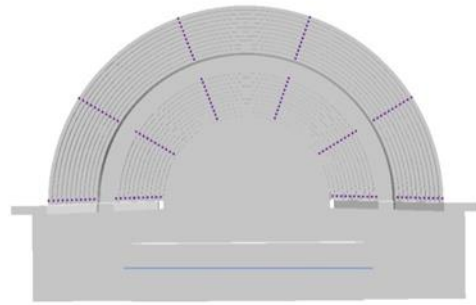


Figure 3: Grid of observer points (purple) in the seating area plus blue line representing position of the actors on the stage.

positions of different actors playing a performance, so it is the object observed by the grid's points. Subsequently, sight lines among the observers' locations and the line on the stage have been constructed through the "visibility" kit of ArcScene 3D Analyst toolbox. This step is necessary in order to built the lines of sight, that show through two different colours which spectators have a full visibility of the actors (green lines) and which have a partial visibility of it (red lines) (Fig. 5). In addition, the obstruction points have also been identified: they mark the exact points which impede the complete visibility (Fig. 4). In case of virtual architectural reconstructions based on uncertain data, this option is very useful because it gives the possibility to easily find the potential errors and modify the structure accordingly. In this specific case of study, obstruction points are, as expected, on the converging walls of the *analemmata* (external walls sustaining the cavea) which cannot be made lower because they have to respect some safety measurements for spectators. Instead, the distance of the stage from the cavea has been easily modified to verify how it is possible to obtain a proper visibility. More exactly, in Figure 4 we can see that the obstruction points are placed on the top of the converging walls of the *analemmata* of the model number 3, that means this kind of reconstruction is pretty good, otherwise the obstruction points would have been directly against the walls placed at the sides of the seats and in that case these walls would be a big obstacle to the visibility of the stage.

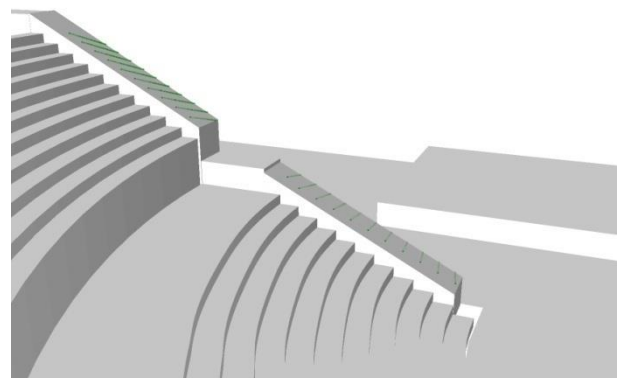


Figure 4: Obstruction points on converging *analemma* of model number 3, produced by 3D visibility analysis.

This first procedure has been realized in order to have a 3D visualization of the lines of sight: it allows users to comprehend from which area of the theatre there is a total visibility and from which part there is a partial

visibility, in order to decide which modifications could be necessary in the architectural structure of the building. Figure 5 shows that the observers sitting at the sides of the cavea have more issues to see the supposed actors if these ones are located at the extremities of the stage, but the visibility is good also for them when the actors are playing in the central part of the *pulpitum* (stage).

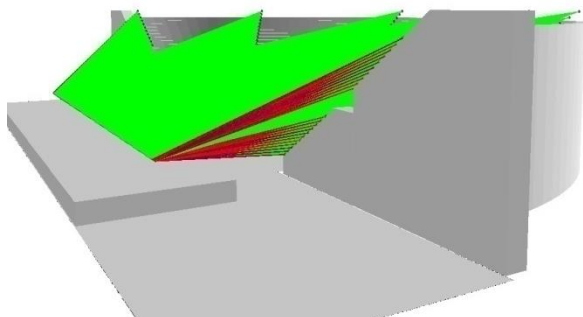


Figure 5: Example of lines of sight of the model number 1, produced by the 3D visibility analysis.

The second procedure that was employed in this research indicates the frequency of visibility of the theatre from the observers' locations and the result of the process is a raster with different colours representing the more and the less visible area. After having imported the 3DS file as a multipatch in ArcScene, a raster can be produced from it and used, together with the grid, to process the visibility analysis. In this case, it is necessary to set the Z offset of the grid with respect to the raster that is 0.75 m. This procedure produces a better output showing if the stage is actually visible from the large part of the spectators (in this case we are talking about the surface of the stage, we are not referring to the line representing the actors on the stage). In the images (Figs. 7-11), as the corresponding legend explains, we can observe that the blue area is visible from a range of 127-133 spectators (that is the total number of the observer points). Therefore, in all the cases there is a high visibility of the stage (highlighted by a green rectangle in the above mentioned figures) from the selected seats, but it is clear that when the stage is farer (as indicated in Belli's plan) and the wall of the diazoma is higher (as sustained by Barresi and by recent excavations), the visibility expands at an even larger part of the stage. Check for example Figure 9, where the purple-fuchsia colour, that means a visibility limited to a range of 103-118 spectators, occupies a smaller area (only the upper corners of the stage) than in the other images (Figs. 7, 8 and 10); therefore almost all the spectators have a full visibility of the stage.

Having established that the reconstruction with the stage far from the cavea and with the wall of the diazoma 2 m high (No. 3) can be the most correct one, as showed by the raster resulting from 3D visibility analysis, another test has been done using this reconstruction but with a higher stage. The first stage has been modelled with a height of 1.30 m because of the Vitruvio's indications about the architecture of the Roman theatres, and because that height looks coherent with the rest of the structure. But if we consider the other Roman theatres with converging *analemmata* (as in Gortyn's theatre) in Greece and Asia Minor, they have a much higher stage, from 2.13 to 3.55 m (Aphrodisia, Tralles, Ephesus,

Miletus and Sagalassus). Then a stage of 2.75 m (average of the heights of the above-mentioned theatres) was added to this reconstruction (in place of the first one), and a new 3D visibility analysis has been processed (No. 5), and its result indicates that the whole area of the stage is visible only from a range of 112-118 spectators (light purple colour) and consequently not visible at all by 21-26 spectators (Fig. 11). It is clear how this option cannot be taken into account as a possible reconstruction being the theatre a place to watch performances; excluding at least 21 spectators from this main activity would not make any sense. This confirms that the stage is more largely visible in the model No. 3.

The results of this analysis show as the height of the stage influence significantly the visibility of the stage from the sector of the cavea, while the position of the stage and the height of the diazoma's wall are less conditioning.

Finally, the 3D model realized in the previous work has been modified accordingly to the new results, making the wall of the diazoma 2 m high instead of 0.60 m as indicated in Taramelli's section (Fig. 6).



Figure 6: 3D model of the large Roman theatre of Gortyn.

5. Conclusion and future works

A new methodology has been presented in this paper in order to achieve a better accuracy in virtual archaeology projects. 3D visibility analysis is a powerful tool to investigate the correctness of 3D reconstructions, in particular regarding historical monuments which we do not have clear information about their architecture. Through 3D visualization we are able to observe our hypothesis and to understand them better, visualizing problems and incongruities of the reconstructions: this is the main advantage of working in a fully 3D environment. 3D visibility analysis is a tool that permits to work directly in a 3D environment, allowing the identification of potential obstacles in the visualscape and therefore to comprehend the inconsistent parts of the reconstruction.

The aim of this study is to demonstrate that archaeological and architectural interpretations can be easily and quickly sustained by 3D visibility analysis, and that it helps users to make new significant improvements to 3D models.

Until now, 3D visibility analysis has been used to understand the influence of historical and symbolical spaces of ancient towns on the population. It means to obtain information about the social importance of some characteristics and elements of buildings and quarters. Instead, this research is focused on the use of 3D

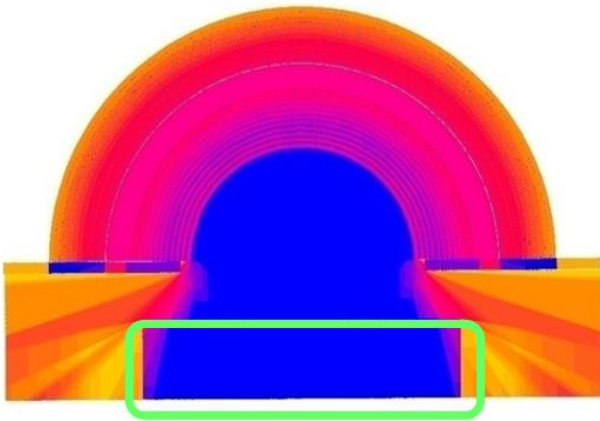


Figure 7: 3D visibility analysis' result No. 1

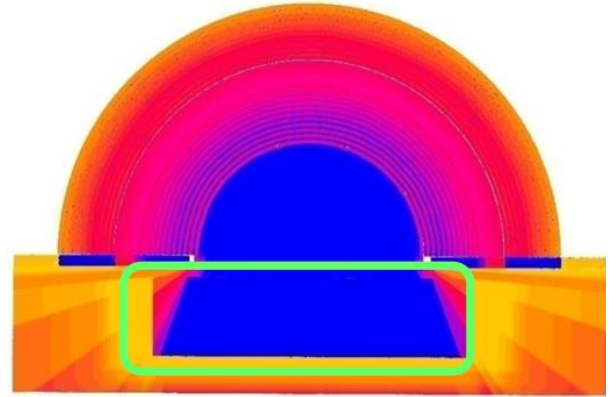


Figure 10: 3D analysis' result No. 4

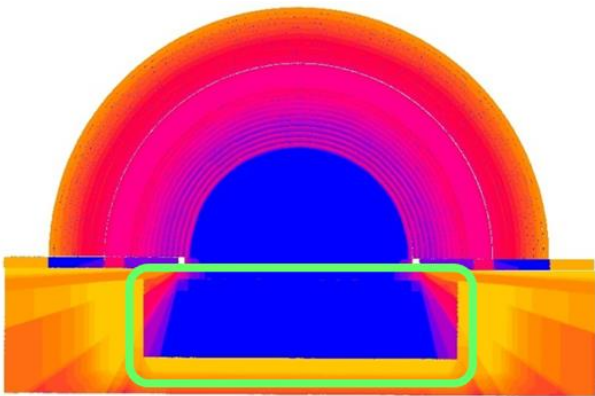


Figure 8: 3D visibility analysis' result No. 2

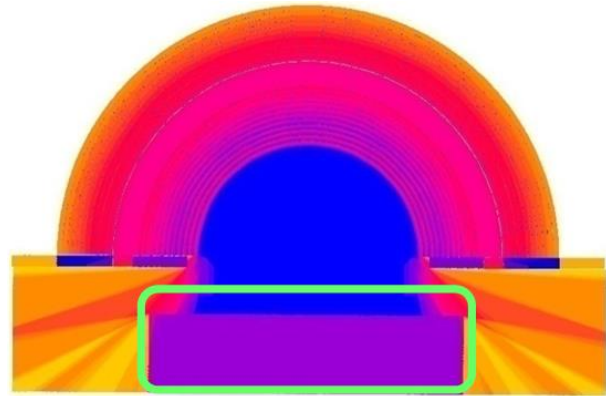


Figure 11: 3D analysis' result No. 5

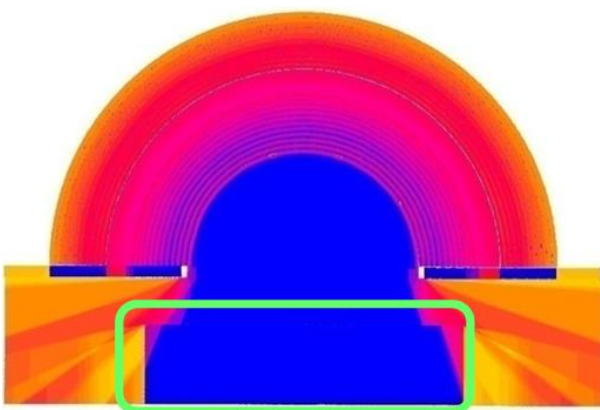
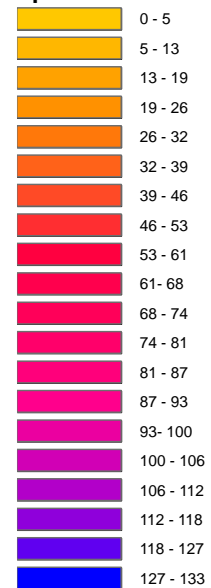


Figure 9: 3D visibility analysis' result No. 3

3D visibility analysis

Spectators



visibility analysis to validate 3D reconstructions and to investigate the architectural structure of not existing monuments. The innovation of this study is the elaboration of a methodology to analyze architectural reconstruction of a single monument. The realization of a full 3D visibility analysis contributes to create an accurate and reliable 3D reconstruction of monuments which remains are very few.

A correct 3D model is helpful to collect information about building typologies, building constructions, practical aspects of the monuments, and it is also a powerful mean to divulgate archaeological knowledge throughout the population being more attractive and easier to understand than a simple drawing or text. Such a clear and accurate reconstruction would not be possible without making a full 3D visibility analysis (Manzetti, 2016).

In the future, the 3D models of the theatre will also be investigated through virtual acoustics analysis in order to further validate the correct one according to 3D visibility analysis. It might also be used to identify incorrect features and formulate new possible hypothesis.

These researches will stimulate new archaeological questions, as in this case “Why the stage would be so far from the cavea?” Obviously, the traditional instruments used in archaeology are still fundamental to understand, as excavations and comparisons. Only the Roman theatre of Pola, in Croatia, and the Roman theatre of Bovillae, in Italy, can be assimilated to the

large Roman theatre of Gortyn for the position of the stage so far from the cavea. They also have other similarities with the large theatre of Gortyn: they are located on natural slopes and they are half digged in the rock and half built on substructures (Sear, 2006).

In this study, the large Roman theatre of Gortyn, placed on the slopes of the acropolis, have been analyzed as pilot object to explain the procedure and its potentialities, but this methodology can be used to know the characteristics of all those buildings dedicated to public performances, such as odeon, amphitheatres, stadiums and circuses.

To sum up, 3D visibility analysis can be a powerful tool to understand the architectural structure of buildings, but it is important that it is used together with traditional archaeological techniques in order to achieve reliable results.

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