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Assessing the Perceptibility of Prehistoric Monuments on their Landscape. An Exploratory Approach Using Agent-Based Modelling

Evaluación de la perceptibilidad en el paisaje de los monumentos prehistóricos. Un enfoque exploratorio por medio de la modelización basada en agentes

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Abstract

The perceptibility of a prehistoric monument (the property of being perceptible from its surrounding landscape) can be quite difficult to analyse by means of traditional static models. Such difficulty lies in the fact that perceptibility depends upon many other factors beyond simple topographical position, such as size, colour, contrast with the surroundings or even the specific circumstances of the audience, many such circumstances being of an immaterial nature. In this paper, we explore the potential use of Agent-Based Modelling for the analysis of archaeological perceptibility.

Keywords: Late Prehistory, NW Iberia, Rock Art, Mounds, Visibility.

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Resumen

La perceptibilidad de un monumento prehistórico (la propiedad que este tiene de ser divisado desde el paisaje circundante) puede resultar bastante difícil de analizar a partir de modelos estáticos tradicionales. Tal dificultad reside en el hecho de que la perceptibilidad depende de muchos otros factores además de la posición topográfica, como el tamaño, color, contraste con el entorno o incluso las circunstancias específicas de la audiencia, muchas de ellas de naturaleza inmaterial. En este trabajo, exploraremos el potencial uso del Modelado Basado en Agentes para el análisis de la perceptibilidad arqueológica.

Palabras clave: Prehistoria Reciente, NO de Iberia, arte rupestre, túmulos, visibilidad.

1. INTRODUCTION

Galicia –located in the Northwest of the Iberian Peninsula– is a territory of little more than 29500 km^2 where a rich archaeological heritage is preserved, including a minimum of 3400 open-air rock art sites (Rodríguez, Vázquez and Fábregas, 2018) and 3300 prehistoric mounds (Carrero-Pazos, 2019; Fig. 1). These monuments were mainly built/engraved between the Neolithic and the Early Bronze Age (second half of the 4th millennium and beginning of the 2nd millennium BC).

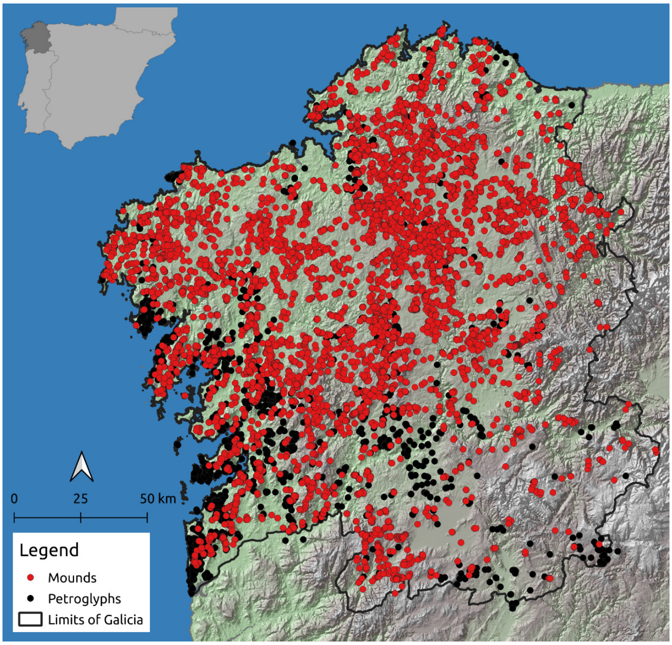

Figure 1. Location of Galicia and general distribution of mounds and rock art sites.

The relevance of Landscape Archaeology among Galician researchers (Criado, 1989; Criado and Villoch, 1998), combined with the huge impact of foreign scholars doing fieldwork there (Bradley, 1997; Bradley, Criado and Fábregas, 1994), has led to the production –from the 1980s onwards– of many studies exploring the distribution of mounds and petroglyphs across the region. In most of these approaches, prehistoric monuments have been interpreted as nodes connected to each other through routes retraceable by means of field work (Criado and Villoch, 2000), the analysis of mobility patterns of animals (Infante, Vaquero and Criado, 1992), the layout of historical routes (Parcero, Criado and Santos,1998) and –in recent years– through the calculation of least-cost paths using GIS tools (Carrero-Pazos, Bevan and Lake, 2019; Carrero-Pazos *et al.*, 2020; Fábrega-Álvarez and Parcero-Oubiña, 2007; Rodríguez and Fábregas, 2015; Rodríguez-Rellán and Fábregas, 2017).

The reasons behind this alleged connection between prehistoric monuments and what has sometimes been labeled as "geography of movement" (Criado and Villoch, 2000; Infante, Vaquero and Criado, 1992) derives from the fact that, within the theoretical framework of most of these studies, monuments are considered to act as a kind of normative mechanism of land tenure (Bradley, 1997). In addition to other purposes, mounds and petroglyphs would have allowed still quite itinerant farmer communities to negotiate their own identity and place in the world as well as to manage preferential and/or exclusive access to areas of economic and/or symbolic significance (Bradley, 1997; Casimir, 1992; Ingold, 1987).

The interaction between Galician monuments and the prehistoric landscape has been traditionally understood in terms of four specific variables: monumentality (usually equated to size), location (closeness/remoteness to a given spot), intensity (uneven density of monuments), and visual control (visual command over a specific place). Theoretically, the analysis of how these variables interact with each other would allow the archaeologists to understand how relevant a specific set of monuments was within the prehistoric landscape.

Another variable has received much less attention but is still essential for understanding the role of monuments in shaping the prehistoric landscapes, namely their perceptibility.

1.1. Visibility and perceptibility of archaeological features

From a semantic point of view, both visibility and perceptibility are almost synonymous, the former being defined as "the capacity of being seen" while the latter is "the state or property of being perceptible", that is "able to be seen or noticed" (Stevenson, 2010). However, in spatial analysis applied to Archaeology, visibility has gradually adopted a univocal meaning equivalent to the result of the viewshed analysis, which is generally carried out from an archaeological site towards its surroundings (Wheatley and Gillings, 2000).

This may cause some confusion on the very few occasions when this term has been used "in the opposite direction", that is, to define the area of the surrounding landscape from which a given site is noticeable. More importantly, visibility and perceptibility refer to two different dynamics that –if misunderstood– can lead to significant mistakes. Most readers have probably experienced during fieldwork that an archaeological site can be potentially visible (it is located within our field of vision), but still not be perceptible (we are not able to notice its presence). Taking these subtle but important differences into account, we have been advocating for the need to clarify when we intend to calculate visibility and when perceptibility, avoiding the interchangeable use of both terms (Rodríguez, 2016; Rodríguez-Rellán and Fábregas, 2017).

Back to Galician mounds and petroglyphs, the consideration of whether, how much and from where these monuments would have been perceived has been unevenly present in the literature. Being linked to the "geography of movement", it has been assumed –somewhat uncritically– that most mounds and rock art sites would be easily perceptible from the surrounding landscape and, more importantly, from the routes and paths along which prehistoric communities would have moved.

Regarding mounds, some authors have suggested that prehistoric communities would have sought to modulate the perceptibility of such monuments by choosing whether to build them in visually prominent areas which would make them conspicuous (by standing out against the horizon) or –conversely– restricting their noticeability to certain spaces (Llobera, 2015; Rodríguez, 2016; Rodríguez-Rellán and Fábregas, 2017). Other ways of enhancing perceptibility would have been, for example, the use of specific building materials (e.g., quartz cobbles and other shining stones) to increase the contrast between the monument and its background (Bradley *et al.*, 2000; Tilley, 1996). Alas, this would have implied some kind of "maintenance", since the vegetation would have quickly claimed its place over the monument, thereby decreasing its perceptibility.

Being in the open and easily accessible from the small fertile valleys and coastal platforms where most domestic sites would be located, Galician rock art has been considered a phenomenon whose contemplation would be little restricted, especially when compared to megalithic and schematic art (located in the walls of small burial chambers or in inaccessible caves, rock shelters and cliffs) (Bradley, 2002; 2009). This would have undoubtedly reflected the type of audience to which petroglyphs would have been intended. Since "these rock carvings were readily accessible and were created in places which more people would have been able to visit", then "they could have been visited by large numbers of people had they wished to do so" (Bradley, 2002: 239-240), including maybe (and this is quite important) the members of neighboring –and perhaps rival– communities. It would follow that petroglyphs, much like burial mounds, could have acted as "inter-group" references, therefore having the potential to become a significant player in the definition and negotiation of prehistoric territories.

Subsequent research has shown the need to qualify, at least partially, some of these conclusions. The discovery of petroglyphs inside small rock-shelters or *tafoni* where there is barely room for one or two people clearly shows that in Galician rock art too there seems to have been the wish to conceal specific sites from the public eye (Fábregas and Rodríguez, 2012b). The question then arises as to whether there were mechanisms that made it possible to modulate the perceptibility of rock art sites located outdoors, making them accessible or not to specific types of audiences.

R. Bradley –who has undoubtedly produced the most compelling reflections on the audience of Galician rock art– while claiming that the petroglyphs would be easily accessible to large numbers of people, also stated that "it is impossible to say whether everyone was allowed to view these pictures" (Bradley, 2002: 240), recognizing the possibility that there may have been physical and/or immaterial barriers that would have made it difficult for certain individuals or groups to access the engravings.

The first and perhaps most obvious of these barriers is remoteness, with the more distant petroglyphs being interpreted as those that would be intended for a more restricted audience, since it would have required significant knowledge of the terrain to be able to reach them (Bradley, 1997; 2002). The characteristics of the engraved rock were probably also important: the choice of large, conspicuous rocks or vertical panels has been understood as a desire to make the engravings more perceptible (de la Peña Santos and Rey García, 2001), whereas the selection of small, ground-level rocks or horizontal panels would have had the opposite effect.

Other variables, which would undoubtedly have affected the perceptibility of the engravings, have been systematically ignored. Leaving aside the –presently unproven– possibility of petroglyphs being also painted, carving a dark-colored rock (dark gray to black) would cause a sharp contrast with the freshly made grooves (white to light gray), making them much more perceptible. However, it would be necessary to refresh the grooves from time to time to prevent such contrast from fading. Conversely, the selection of light-toned rocks and shallow groves would have made it difficult to identify the carvings even from a few steps away.

The perception of the motifs may also have depended on light conditions. In those petroglyphs where there is little contrast between carvings and rock surface, perception is highly dependent on the incidence of sunlight. Thus, a petroglyph can be practically invisible when observed at noon and fully revealed in the light of dawn or dusk. Other atmospheric factors (i.e., rain) may have an influence as well (Fábregas and Rodríguez-Rellán, 2015). As such, knowing the optimal conditions for observing a petroglyph may have been as insurmountable a barrier to their perception as it was knowing their location.

Finally, it is important to keep in mind that the capacity of being noticed is not entirely (or even mainly) based on physical factors: the social or ritual significance of a specific monument might have multiplied its perceptibility, regardless of its remoteness or size (Rodríguez-Rellán and Fábregas, 2017).

1.2. GIS approaches to perceptibility of archaeological sites

Prior to the widespread use of computers, the perceptibility of prehistoric monuments was analyzed in a somewhat impressionistic manner, based mainly upon personal experience gained during fieldwork. However, since these assessments were extremely time-consuming, they were usually conducted in an unsystematic way. As such, the results were little more than a rule of thumb (a general threshold beyond which a specific set of monuments of a given region were no longer noticeable) and they could hardly be applied to other regions and sites.

With the generalization of Geographic Information Systems (GIS), this type of analysis became much easier to implement and, as a result, it began to increase in popularity. However, this brought a whole new set of problems. Most approaches used the standard tools available in GIS suites: line-of-sight and binary viewsheds. As other authors have already noted (Gaffney and Leusen, 1995; Gillings *et al.*, 2000), such tools only take into consideration as limiting factors for visibility the characteristics of the terrain and, optionally, the curvature of the Earth, atmospheric refraction, etc. However, they do not account for other, equally important aspects when determining whether a structure or object is perceptible from afar, such as its size, color, contrast with the background, etc.

Being aware of this problem, several studies have sought to address the limitations of the traditional viewshed computations in different ways. The first group of them are based on a similar concept: those areas more noticeable from the surroundings are more likely to have acted as landmarks and, therefore, might have played a significant role within the cognitive and symbolic geography of the human groups living nearby. A recurrent setting of archaeological sites in those conspicuous areas might imply that these were purposely built/engraved in those places so they might have had a higher chance of being noticed (Llobera, 2003; 2006). These simulations are based on the calculation of either a cumulative viewshed for a significant number of points distributed across the area of interest, or by the calculation of a total viewshed, in which a viewshed analysis is conducted for each of the cells in the study area.

In former studies (Rodríguez, 2016; Rodríguez-Rellán and Fábregas, 2017), we have conducted a variant of this approach based on the calculation of the cumulative viewsheds from corridors composed of several thousands of least-cost paths. The logic behind this is that, were the mounds and petroglyphs related to the "geography of movement", they would be primarily located at spots especially noticeable from the routes along which prehistoric communities would have moved.

The other family of GIS approaches to modeling perceptibility are those that consider the characteristics of objects or structures to be noticed, such as –for example– size. All these approximations are distance-dependent, focusing on defining the limits or ranges beyond which an object, despite being within our field of view, would cease to be noticeable. The first of these approaches is based on the works by T. Higuchi. The so-called "Higuchi viewshed" decomposes the traditional binary viewshed into three ranges (short-distance, middle-distance and long-distance view), calculated according to the average high of the trees existing in the area (for a more detailed description, see Wheatley and Gillings, 2000: 15-19).

D. Ogburn criticized the use of Higuchi's approach on the grounds that a method based on the characteristics of natural elements (trees) has little applicability to man-made structures (Ogburn, 2006). Instead, Ogburn proposed to apply a distance decay function to generate "Fuzzy viewsheds". These would represent the degree (ranging from 1 –clearly visible– to 0 –non visible–) to which an object is clearly perceptible from a given point. Ogburn also proposed a modified version of this method which takes into consideration the size of the target by calculating the distance from which the perceived size of a given item (measured in degrees, minutes, and seconds of the visual angle) is less than the limits of the human visual acuity (usually 1 arc minute for a perfect vision).

Also based on the visual angle occupied by a monument (in this case barrows), M. Llobera defined four different ranges around it: Not relevant (0.5 < VA < 0.1º); Background (0.1 < VA < 0.5º); Middle-ground (0.5 < VA < 15º) and Foreground (VA > 15º). Each of these areas would have the potential to serve as stage for different activities (communal processions, feasting…) (Llobera, 2007).

Finally, P. Fábrega and C. Parcero created both a regular and a fuzzy version of what they called an "Individual Distance Viewshed". This method was intended to calculate "the visible area from a given location that falls within a distance where the presence of a human being can be perceived and recognized in different ways" (Fábrega-Álvarez and Parcero-Oubiña, 2019: 64). What is genuinely novel about this approach is the fact that the thresholds were defined based on *ad hoc* experiments with real subjects, who were instructed to recognize other individuals walking towards their location.

As we have just seen, the solutions applied in GIS to model the perceptibility of archaeological features have become progressively more complex, overcoming some of the limitations of standard approaches. However, these solutions are still limited by their static nature and by the fact that they can handle only a small number of variables at a time (one of them being the distance between the target and the observer). In addition, GIS approaches to past landscapes have difficulties when handling immaterial aspects that undoubtedly would have affected the relationship of prehistoric communities with the landscape.

In this paper, we will explore the potential role of Agent-based Modelling (ABM) in tackling some of the aspects affecting the perceptibility of archaeological features that –due to their complexity– are difficult to handle by means of static models such as those built in GIS environments. For this, we have designed a simple ABM model aimed to observe the interaction between mobile agents pretending to be prehistoric people walking around the landscape (walkers) and specific monuments (mounds and petroglyphs). The main objectives are: a) to determine whether ABM can be a potentially interesting tool for analyzing the interaction between prehistoric monuments and people; b) trying to measure the intensity of such interaction and how different variables (both material and intangible) would have influenced it.

2. METHODOLOGY

2.1. Study area

The area chosen for carrying out the analyses shown in this article is the Barbanza Peninsula (A Coruña, Spain; Fig. 2). This is the northernmost of the peninsulas that make up the Rías Baixas, deep sea-inlets in the SW coast of Galicia (NW Spain). Following a NE-SW orientation, its main geographical feature is the Serra da Barbanza, a horst structure with an average altitude of 550 m.a.s.l. whose upper part is comprised of small plateaus separated by ridges and gentle hills and crossed by several small river valleys. The Serra is surrounded by a rather narrow coastal plain where settlement and farming areas are concentrated nowadays. The transition between these two areas (the Serra and the coastal plain) is composed of slopes that can reach very steep gradients.

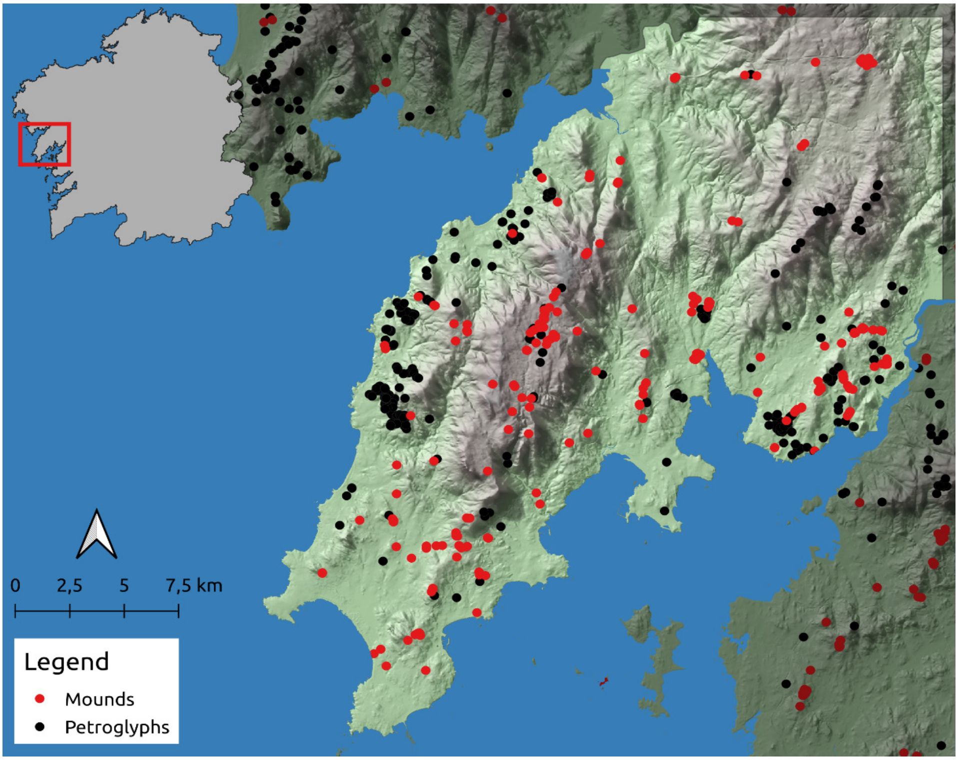

Figure 2. Barbanza Peninsula with the location of the catalogued mounds and petroglyphs.

The Barbanza Peninsula is known for the important presence of megalithic burial mounds. Nowadays, a total of 223 mounds are known, although it is quite possible that their original number has been reduced by the destruction due to agricultural intensification and urban development (Bustelo *et al.*, 2017; Rodríguez-Rellán and Fábregas, 2017).

As elsewhere in Galicia, the Barbanza mounds are relatively small, especially when compared to those of other European regions. Most monuments have a maximum diameter of between 12 and 25 meters, with extreme values reaching 8 and 32 meters. The height is usually ranging between 0.5 and 2.5 meters, again with extreme values reaching 0.3 and 3.5 meters. However, it should be noted that such numbers are greatly affected by erosion and other post-depositional alterations. Likewise, although it is very difficult to ascertain their exact number, it is very likely that a high percentage of mounds in this area had cuirasses, an external layer of stones –generally granite and quartz– covering the earthen mound.

Regarding the rock art sites, a total of 348 petroglyphs are known nowadays in the Barbanza Peninsula. These display mainly geometric motifs (cup-marks, cup and rings…), but the presence of naturalistic representations (deer and other animals, human figures, weapons…) is also relevant (Fábregas and Rodríguez, 2012a; Rodríguez, Vázquez and Fábregas, 2018). Images seldom exceed 0.3 m. in size, although there are some deer depictions as tall as 1.5 m. and cup and rings exceeding 0.6 m. in diameter. The average depth of these engravings is around 0.5 cm, with only very few examples exceeding 2 cm.

Nearly all the petroglyphs are found engraved on granite. Although we do not have information available for the whole Barbanza, the study we carried out on 164 petroglyphs in the North half of the Peninsula clearly showed that most engravings were located on flat, inconspicuous rocks that are barely visible a few meters away (Fábregas and Rodríguez, 2012a; Rodríguez, 2016). In the study area, the size of the engraved rocks rarely exceeds 4.5 meters.

2.2. An exploratory Agent-Based Modeling approach to perceptibility

Agent-Based Modeling (ABM) is a type of computational simulation that makes it possible to model complex systems. It focuses on the creation of a system composed of heterogeneous, autonomous individuals (agents) interacting with each other and with their virtual environment.

Agents can represent any type of entity –whether individual (persons, viruses, ants, petroglyphs, mounds…) or collective (households, settlements, cities…)– who can have specific properties (location, size, velocity, memory…). ABM models usually are spatially explicit: they have a structure that specifies the location of each agent within a virtual, heterogeneous environment. This can be an abstract rendering (i.e., a quadrangular, blank space) or a semi-realistic representation of a real-world space (i.e., a simplified representation of our study area). These virtual environments are made of patches, stationary agents which can have specific properties (i.e., land, sea, forest, productive capacity, altitude...). To some extent, one can think of patches as pixels in a raster map.

In addition to being spatially explicit, ABM models are dynamic. In other words, they can manage processes that unfold over time (Romanowska, Wren and Crabtree, 2021). Thus, the outcomes of the interactions taking place within a system at time x (tick), may impact the subsequent development of the model at time n (i.e., an agent can learn from its present interactions and modify its future behavior based on them). This feature allows us "to move beyond a static snapshot of the system" (what GIS approaches generally offer) towards "a dynamic understanding of the system's behavior" (Wilensky and Rand, 2015: 55).

The interactions between agents (or between agents and the environment) are governed by a set of behavioral rules that are established during the implementation of the model. These individual interactions within the system can lead to the emergence of complex, global patterns which –although generally intuitive– are rarely predictable (Romanowska, Wren and Crabtree, 2021; Wilensky and Rand, 2015).

To some extent, ABM models can be considered as *in silico* experiments that "provide a way to examine the contingencies of history, to test our assumptions about the dynamics that governed these systems, and to investigate how individual interactions lead to chains of consequences that produce observable facts" (Romanowska, Wren and Crabtree, 2021: 8). Within this theoretical framework, archaeologists can act as social scientists, testing and refuting hypotheses, examining alternative scenarios, and selecting the ones whose results are in better agreement with those detected in the archaeological record. To achieve the objectives established for this paper, we have designed an ABM model using NetLogo (Wilensky, 1999).

2.2.1. Designing the world

As an environment for the simulation, we created a semi-realistic version of the Barbanza Peninsula (Fig. 3) in which several features were included:

- Land and sea: since our study area is a peninsula surrounded by water, we have distinguished between "land" and "sea" patches, allowing the agents (walkers, petroglyphs, and mounds) to interact only on land.
- Least-cost path routes: since we have not considered altitude, slope, and other topographic features of our study area, we intended to maintain a certain degree of realism in the movement of the agents through the landscape. For this, we limited their movement to corridors created from the aggregation of least-cost paths (LCPs). Although there are approaches that show the potential of ABM for simulating the generation of LCPs (Gravel-Miguel and Wren, 2018), we chose to calculate them directly in GRASS GIS to keep the model as simple as possible and reduce the computational cost of the simulation.

Thus, we created a LCPs network composed of 250 paths linking different areas of the Barbanza Peninsula (Fig. 5). First, we used the module *r.walk* for calculating the anisotropic cumulative cost of moving along the landscape taking into consideration altitude, slope, and water accumulation (to hinder transit through rivers and wetlands). Subsequently, we calculated the routes using the module *r.drain* and establishing those places that the archaeological evidence has shown to be the most probable settlement areas as origin and destination. The coincidence of the LCPs with some of the historical routes that cross the Barbanza Peninsula (Fábregas Valcarce *et al.*, 2018) suggests that the simulated paths are representative of the actual mobility strategies developed by the communities who inhabited the study area in the past.

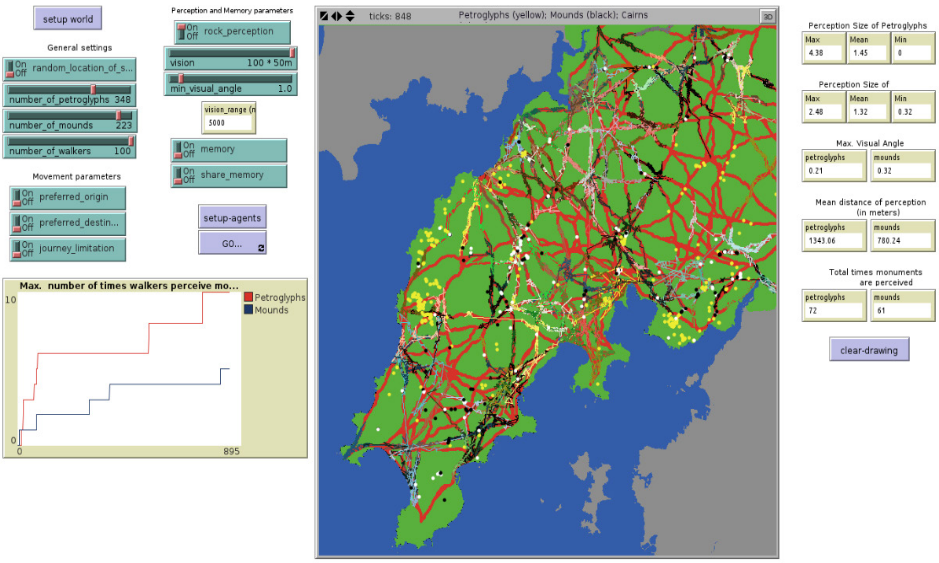

Figure 3. Interface of the Agent-based model implemented for this article.

2.2.2. Choosing the protagonists

Three different types of agents were created for this model: walkers, petroglyphs, and mounds.

As their name suggests, "walkers" are the only agents in the simulation with the ability to move. These are intended to simulate human individuals walking through the landscape. Some of their major characteristics are:

- Number: up to 150, defined by a slider on the interface of the model.
- Original location (yes/no): the places where the walkers start the simulation. They can be random or fixed in those areas especially suitable for prehistoric habitat (Fábregas and Rodríguez, 2012c).
- Homeland (yes/no): if activated, all walkers who start the simulation on the same original location become "fellow members" of the same group and

–if the "Cultural Transmission" option is enabled– they will share information among themselves (i.e., the location of new monuments they encounter as they move through the virtual world).

- Destination (yes/no): if enabled, walkers choose a specific area as target or destination. This option prevents random walking.
- Sight limit: up to 5km, defined by a slider on the interface of the model.
- Visual acuity: between 0.01 and 10 degrees, defined by a slider on the interface of the model. Establishes the minimum visual angle that the target must occupy in a walker's retina before it can be perceived.

Petroglyphs are immobile agents with some of the basic features of the rock art sites. Their major characteristics are:

- Number: up to 500, defined by a slider on the interface of the model. If the random location is not activated, the number is equivalent to that of the actual set of petroglyphs existing in the study area (348).
- Random Location (yes/no): if activated, petroglyphs are randomly distributed over the land area of the virtual world. Otherwise, they will be placed in their actual locations within the study area.
- Rock size: height in meters of the rock on which the engravings are located. For the purposes of this work, the size of the rock has been established randomly according to the minimum and maximum dimensions (0.20 to 4.50 meters) registered in some of the monuments of the study area.
- Panel size: height in meters of the panel (the part of the rock covered by engravings). For the purposes of this work, the size of the panel has been established to be a random percentage of the rock size varying from 20 to 70%.
- Inclination of the rock: established randomly between 0 and 90º to the horizontal.
- Contrast between the carvings and the surface of the rock: given the difficulties for simulating this variable, we have chosen to establish a random contrast that takes the form of a percentage. 0 means a null contrast while 1.0 (100%) equals a perfect contrast.
- Apparent size of the panel: a function of the three variables described above (panel size, inclination, and contrast) according to the following formula:

$$AS = (Size * sin(Inclination)) * Contrast$$

- Expertise (yes/no): if enabled, the variable "Contrast between the carvings and the surface of the rock" will be overwritten. Walkers will only need to perceive the rock to become aware of the existence of the petroglyph. The contrast of the grooves with the surface of the rock becomes perfect (100%).
- Times perceived: it records the total number of times a petroglyph has been perceived by walkers.
- Already perceived?: it records if a given petroglyph was previously perceived by a specific walker

Mounds are immobile agents with some of the basic features of these monuments. Some of their major characteristics are:

- Number: up to 250, defined by a slider on the interface of the model. If the random location is not activated, the number is equivalent to that of the actual set of mounds in the study area (223).
- Random Location (yes/no): as defined for petroglyphs.
- Height: height in meters of the mound. For the purposes of this work, the size of the monument has been established randomly according to the minimum and maximum height (0.50 to 2.50 meters) of most mounds in the area.
- Contrast between the mound and its background: as with petroglyphs, we have chosen to establish a random contrast that takes the form of a percentage. However, we have set the limits between 0.5 (50%) and 1.0 (100%), since the contrast between the mound and its background will never be so low as to impede its perception (unlike rock art, where a null contrast between engravings and the surface of the rock has been documented).
- Apparent size: a function of height and contrast according to the following formula:

$$AS = Size * Contrast$$

- Expertise (yes/no): if enabled, the variable "Contrast between the mound and its background" will be overwritten. Walkers will perceive the monument as if its contrast with the surrounding background were always perfect (100%).
- Times perceived: it records the total number of times a mound has been perceived by walkers.
- Already perceived?: it records if a given mound was previously perceived by a specific walker

2.2.3. Simulating perception

One of the biggest challenges during the implementation of this model was to create a simulation of the perception process simple enough so that it could be effectively managed by Netlogo but, at the same time, fairly realistic. Thus, for each walker, we created a procedure trying to simulate the basic characteristics of the human field of view. This is composed by a cone 180º wide (approx. the width of the human field of view with head rotation excluded and peripheral vision included) and a depth ranging from 0 up to 5000 meters (Fig. 4). Each petroglyph or mound inside this area is potentially perceptible by a walker.

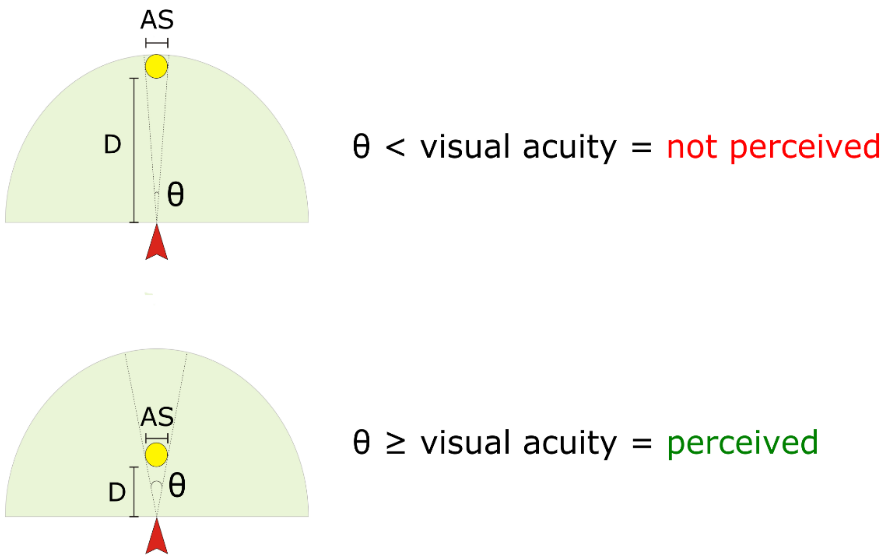

Figure 4. Diagram of the perception process implemented in the simulation. θ: Visual Angle; AS: Apparent Size of the monument; D: Euclidean distance between the walker and the target.

However, the final perception of a specific monument will depend on whether the perceived size of the target is greater than the threshold set for the walker's visual acuity. Following former approaches on this matter (Llobera, 2007; Ogburn, 2006), we have considered the perceived size to be equivalent to the visual angle it occupies on the walker's retina. This has been calculated according to the following formula:

$$\theta = 2arctan\left(\frac{AS}{2D}\right)$$

Where (θ) is Visual angle, (AS) the Apparent Size of the monument, and (D) the Euclidean distance between the walker and the target (for more details, see Swearer, 2011).

If the visual angle is higher than the threshold established for the visual acuity, then the target (either a petroglyph or a mound) will be perceived. Each monument records the identity of the specific walker who perceives it as well as the total number of times it has been perceived throughout the simulation.

As we have already noted, we have used the Apparent Size of the monuments for the calculations. This term defines the size at which the monument will be perceived. Let's see several examples of how it was calculated.

- Example 1: a petroglyph carved in a rock engraved on a vertical rock (90º), with a size of 1.20 meters and a very sharp contrast (90%) between the grooves and the surface of the rock. Its Apparent Size will be: (1.20 * sin (90)) * 0.9 = 1.08 meters.
- Example 2: a petroglyph carved in a rock engraved on a near-horizontal rock (10º), with a size of 1.20 meters and a very low contrast (10%) between the grooves and the surface of the rock. Its Apparent Size will be: (1.20 * sin (20)) * 0.1 = 0.04 meters.
- Example 3: a mound 2 meters high with a very sharp contrast (90%) with the background. Its Apparent Size will be: 2 * 0.9 = 1.80 meters
- Example 4: a mound 2 meters high with a low contrast (50%) which makes it difficult to distinguish from the background. Its Apparent Size will be: 2 * 0.5 = 1 meter.

Although we are aware that the option chosen to simulate the impact of contrast on how objects are perceived is quite abstract and simplistic, we consider it suitable for a first, exploratory approach. It will allow us to glimpse the impact that this variable has had on the perception of prehistoric monuments, something that has hardly been addressed before.

2.2.4. Simulating the impact of memory, experience, and cultural transmission

Given the ability of Agent-Based Modeling to simulate abstract concepts and dynamics, including the impact of agents' behavior in the virtual environment they inhabit, we decided to explore if and how specific characteristics of the audience would have affected the perceptibility of monuments. We have paid attention to how familiarity with the landscape and knowledge of the specific location of the monuments would have impacted the frequency with which burial mounds and petroglyphs would have been perceived.

This remains relevant in the context of some of the questions that have been raised about the target audience for the Galician tumuli and petroglyphs. As we have already stated, it has been assumed that most mounds and rock art sites would be easily perceptible for people passing by. Consequently, their intended audience would be very broad, as it would also include the members of communities other than the one who created the monument. It would be precisely this ability to reach "inter-group" audiences what would have allowed them to act as mechanisms of communication between communities still highly mobile (Bradley, 1997; Ingold, 1987; Casimir, 1992).

With this goal in mind, we designed the model so that we could test how petroglyphs and mounds would have been perceived by four different types of audiences:

- An extremely "naïve" audience whose members ignore the existence and location of the monuments and only become aware of their presence once/if they have eventually perceived them. In addition, they are unable to remember the location of monuments they have already seen, so they have to "rediscover" them each time they pass by.

- A "naïve" audience with the ability to learn, so they remember the location of a monument once they have seen it for the first time.
- A "naïve" audience who remembers the location of a monument once they have seen it and, in addition, are able to share this information with other members of their community.
- An expert audience who is already aware of the existence and location of all the monuments in the study area.

To try to understand how each of these audiences would have interacted with the monuments, we took advantage of the insights gained during more than 15 years working in the field along students and archaeologists with different levels of expertise.

Naïve audiences generally need more time and greater physical proximity to the monument to be able to perceive it and, therefore, to become aware of its existence. In extreme cases, such as low mounds or very inconspicuous petroglyphs, many naïve observers have been unable to notice them even from less than a couple of meters away. A significant percentage of inexperienced observers need to visit the monument several times before internalizing its location. Once this occurs, they no longer need to observe the engravings to become aware of its existence, since –for example– they can identify the rock from relatively large distances. In the case of burial mounds, naïve observers can remember the general location of the monument and perceive it from quite a distance after only a couple of visits. The transmission of knowledge about the existence of a monument (i.e., pointing out its location from afar) accelerates the process of perception by naïve observers.

In sharp contrast, expert audiences with a deep knowledge of the territory have a complete mental map composed of thousands of references that allows them to perfectly locate the monuments in space, regardless of their characteristics. In such cases, the perception of the monument is almost automatic once the area where it is located appears in their field of vision.

We have sought to incorporate these dynamics into our model by varying the threshold necessary for observers with different levels of expertise to be able to perceive a given monument.

For petroglyphs, naïve observers must first perceive the engravings to be aware of their existence. If the "Memory" option is activated, once walkers have perceived the engravings for the first time, they will recall the general location of the petroglyph, so that the next time they will only need to perceive the rock to remember the existence of engravings on its surface.

If the "Cultural transmission" option is enabled, a walker with a given origin at the beginning of the simulation ("Homeland") will transmit the knowledge regarding the location of the monuments he/she has seen with all the other walkers who share his/her same "Homeland". Enabling this option generates a kind of "collective memory" in which all members of the same "Homeland" will automatically have access to the knowledge generated by their peers. Consequently, if a walker passes near a petroglyph which has already been perceived by a fellow member of his/her "Homeland", he/she will only need to perceive the rock on which the petroglyph is located (and not the engravings themselves) to be aware of its existence. To speed up the process, we have decided that the transmission of information will be done automatically instead of requiring direct contact between agents (i.e., that they meet each other).

Finally, if the "Expertise" option is activated, all walkers will act as if they were already perfectly aware of the existence and location of the petroglyphs (they will only need to detect the rock to be aware of the existence of the petroglyph and they will see the engravings as if they were perfectly contrasted with the surface of the rock).

For burial mounds, naïve observers must perceive the monument to be aware of its existence. If the "Memory" option is activated, once walkers have perceived the mound for the first time, they will recall its general location, so that the next time they will be able to easily perceive the monument as if it had a perfect contrast with the surrounding environment. If "Cultural transmission" is enabled, a walker with a given "Homeland" will share with his/her peers the knowledge regarding the location of the monuments he/she has seen. Therefore, all the walkers of that same "Homeland" will automatically perceive those mounds perfectly contrasted against the landscape. If the "Expertise" option is activated, all walkers will act as if they were already perfectly aware of the existence and location of the mound (they all will perceive the mounds fully contrasted again the surrounding landscape).

Likewise, the possibility of simulating the random and targeted movement strategies makes it possible to verify if the knowledge of the terrain has an impact on the perception of the monument, since the targeted movement necessarily requires a sufficiently broad knowledge of the surroundings to know how to get from point a to point b (Fig. 5).

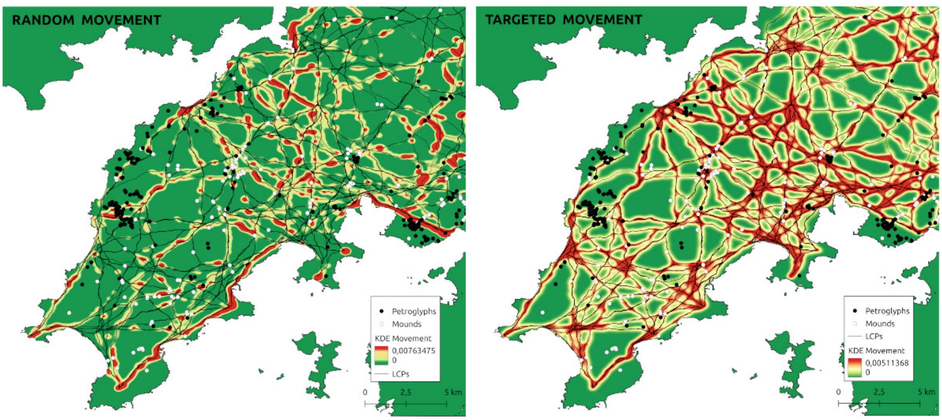

Figure 5. Kernel Density Estimation (KDE) of the movement made by 100 walkers during

the simulations (10 runs with the "Random Movement" option enabled, and 10 runs with the "Targeted Movement" option enabled. Duration: 1000 ticks each).

3. RESULTS

The results presented in this paper are derived from a total of 16 experiments, each of which was run 10 times (Table 1). Thus, a set of 160 simulations was created, with each simulation running for 1000 ticks. These have resulted in a virtual dataset consisting of 55520 petroglyphs and 34880 burial mounds (90400 virtual sites).

TABLE 1
Summary of the main characteristics of the experiments carried out for this paper

Experiment	Runs	Ticks	Walk	Location	Expertise	Memory	Cultural Transmission
1	10	1000	Random	Real	Yes	No	No
2	10	1000	Random	Real	No	No	No
3	10	1000	Random	Real	No	Yes	No
4	10	1000	Random	Real	No	Yes	Yes
5	10	1000	Random	Random	Yes	No	No
6	10	1000	Random	Random	No	No	No
7	10	1000	Random	Random	No	Yes	No
8	10	1000	Random	Random	No	Yes	Yes
9	10	1000	Targeted	Real	Yes	No	No
10	10	1000	Targeted	Real	No	No	No
11	10	1000	Targeted	Real	No	Yes	No
12	10	1000	Targeted	Real	No	Yes	Yes
13	10	1000	Targeted	Random	Yes	No	No
14	10	1000	Targeted	Random	No	No	No
15	10	1000	Targeted	Random	No	Yes	No
16	10	1000	Targeted	Random	No	Yes	Yes

The first striking aspect of the results is the small number of monuments that have been perceived by the walkers (Fig. 6). Thus, for the entire set of simulations, only 8.82% of mounds (3079) has been perceived at least once. This percentage drops to 2.24% (1244) in the case of petroglyphs. Moreover, the monuments that have been observed display an almost exponential distribution, with most of them being observed just once or twice and only a few more than five times. In absolute numbers, mounds have been perceived by walkers 5584 times, an average of 1.96 times per experiment. Petroglyphs, in turn, were seen almost half as many times: 2957 (an average of 1.74 times per simulation). Such difference between monuments in terms of number of perceptions is statistically significant (Mann-Whitney-Wilcoxon U Test. p-value: < 2.2e-16).

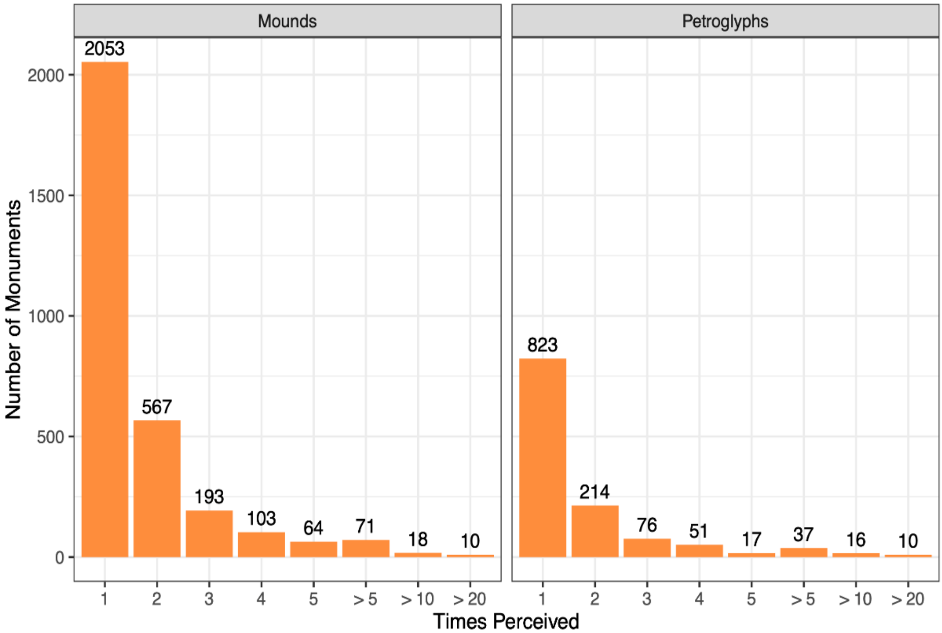

Figure 6. Number of times mounds and petroglyphs have been perceived during the simulations.

The reason for this small number of perceptions is most likely due to the extremely conservative approach we used when defining the threshold for walkers' visual acuity, which was set at 1° (approximately equivalent to the limits of Higuchi's short-distance view). As a reference, it should be noted that the limit that determines perfect vision (20/20) is set at much lower values: just between 1 and 5 arc minutes (between 0.01 and 0.08º). Therefore, if we reduce the threshold from 1º to 1 arc minute, the number of perceptions will increase significantly (Fig. 7).

Our option for such conservative limits derives from the fact that the use of a threshold equivalent to perfect vision yielded very unrealistic perceptual distances for the type of monuments analyzed in this paper. For example, a threshold of 1 arc minute resulted in petroglyphs and burial mounds being perceived at distances greater than four or even five kilometers, a span similar to that identified by D. Ogburn for this same threshold (Ogburn, 2006). In comparison, the average perceptual distances for the 1° threshold simulations have ranged from 20 to 2700 meters, numbers that (although they may be slightly low for some mounds) are much more realistic and closer to the perceptual limits of petroglyphs and burial mounds that we have detected in the field.

At the same time, these low levels of perceptibility suggested by the Agent-Based Models seem to support the conclusions reached by our previous studies using GIS tools, that had already pointed to a low conspicuity of these monuments, especially of rock art sites. For example, 59.1% of the petroglyphs in the north of the Barbanza Peninsula would not be visible (they are not located within the field of vision) of an individual walking along the main transit routes in the area (Rodríguez, 2016). Mounds, in turn, are located to a greater extent within the visual basins of the main transit routes; however, a significant percentage of them would also not be visible from such paths (Rodríguez-Rellán and Fábregas, 2017).

In the specific case of rock art, the results achieved by both ABM and GIS are in line with those gathered during our fieldwork in Northern Barbanza. There, we found that more than half of the petroglyphs were barely perceptible at more than 50 meters away (Fábregas and Rodríguez, 2012a).

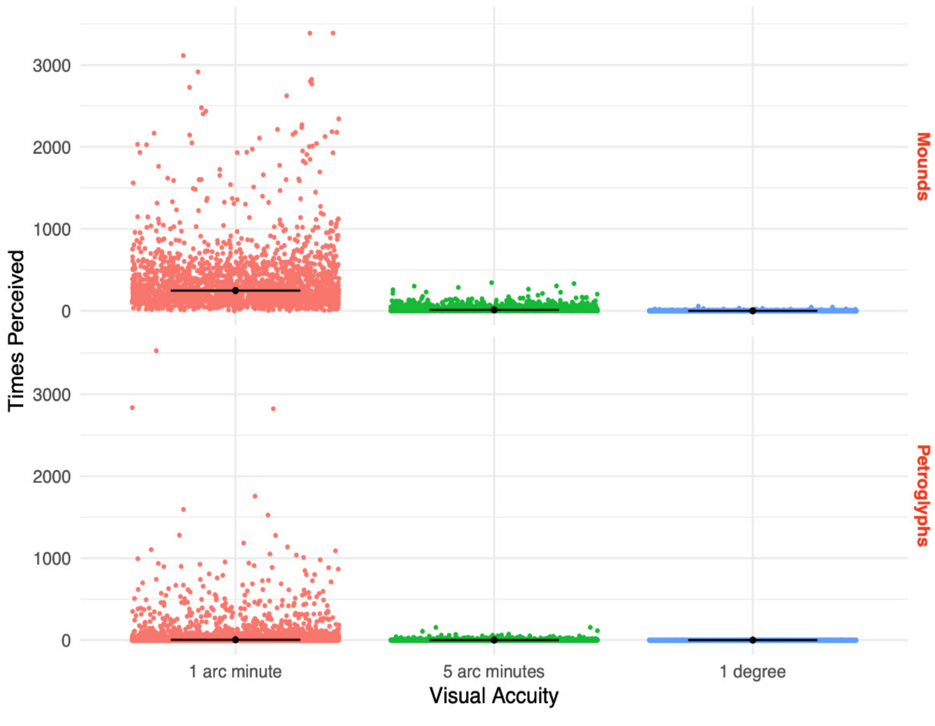

Figure 7. Number of times mounds and petroglyphs have been perceived during the simulation according to the walker's visual acuity (taken from 3 simulations of 10 runs each. Duration: 1000 ticks).

3.1. Impact of the characteristics of monuments on their perceptibility

As mentioned in section 2.2.2., we have simulated a series of physical, intrinsic characteristics of mounds and petroglyphs to try to determine and quantify, albeit theoretically, the hypothetical impact that these characteristics would have had on the perception of such monuments. For mounds, these variables were size (height in meters) and contrast with the background (percentage). For rock art, the variables were: rock size and panel size (height in meters), inclination of the panel (degrees to the vertical) and contrast between grooves and surface of the rock (percentage).

The statistical significance of these variables has been measured in two ways. On the one hand, a Generalized Linear Model (GLM) was calculated using perception as a dichotomous binary response variable (*i.e.*, Was monument *x* perceived at least once? yes/no) and the different characteristics mentioned above as explanatory variables (Table 2).

This test has allowed us to establish whether the explanatory variables have had a significant impact on the probability that a monument were perceived by walkers. On the other hand, Kendall's tau correlation was calculated to determine whether there was any association between the values of each of the explanatory variables considered and the number of times a given monument was perceived (Table 3) (*i.e.*, Does the number of times a monument was perceived depend on the value of the explanatory variable *y*?). We have chosen this test because it is relatively robust and suitable for measuring the association between continuous and discrete variables that do not meet normal distribution.

Both the GLM and the Kendall's tau correlation were applied only to those simulations (120) in which the "Expertise" option was disabled (Table 1). The reason behind this decision is that, as described in Section 2.2, such option overwrites the Contrast parameters of the monuments, increasing them to the maximum (100%), which would imply a logical overestimation of the importance of this variable.

The GLM results suggest that almost all the explanatory variables considered had a significant impact on the probability that a given monument would be noticed by walkers (Table 2). This is not surprising, given the weight assigned to these variables in the model design. However, what is relevant about the results is that they point out that not all variables considered have affected the likelihood of a monument to be perceived in the same way.

Table 2

Generalized Linear Model (GLM) calculated using perception as response variable and physical, intrinsic characteristics of monuments as explanatory variables (Results calculated over the 120 simulations in which the option "Expertise" was disabled)

Mounds				
Response variable: Perceived (No vs. Yes). AIC: 14665				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-5.053	0.1427	-35.41	< 2e-16 ***
Size (h)	1.1392	0.0423	26.9	< 2e-16 **
Contrast	1.0746	0.1520	7.07	1.55e-12 ***
Petroglyphs				
Response variable: Perceived (No vs. Yes). AIC: 3289.2				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-10.3057	0.2974	-34.650	<2e-16 ***
Rock Size	0.1045	0.0861	1.214	0.225
Panel Size	1.0723	0.1248	8.587	< 2e-16 ***
Inclination	0.0311	0.0025	12.456	< 2e-16 ***
Contrast	3.3016	0.2360	13.985	< 2e-16 ***

Signif. codes: 0 '***' 0.001 '**'

Thus, in the case of mounds, the likelihood of a monument being perceived rises almost equally (1.13 and 1.07) for each unit by which the value of "size" and "contrast" is increased. This suggests that –at least theoretically and always within the framework of the simulations– size and the contrast of the monument with its background might have a similar impact in terms of its probability of being perceived. For petroglyphs, all explanatory variables –apart from the rock size– had a statistically significant impact on the probability of perception. The variable "contrast" is noteworthy because by every unit it is raised, the probabilities of a petroglyph being perceived increase notably (3.30). A noticeable, although somewhat more discrete, impact was also observed for the variable "Panel size" (1.07). While statistically significant, "inclination" does not seem to have been such a decisive factor in increasing the likelihood of a rock site being perceived. This seems to contradict traditional remarks, linking verticality and perceptibility.

The results of the Akaike Information Criterion (AIC), or measure of the relative quality of the model, suggest a better fit of the model to petroglyphs than to mounds (a circumstance derived, in large part, from the fact that our model was originally devised for the analysis of the perceptibility of rock art).

Having analyzed the role of the explanatory variables on the probability of a given monument being perceived or not, we subsequently explored the impact of these same variables on the total number of perceptions of each monument. The results –analyzed by means of Kendall's tau correlation– again show a statistically significant impact of the variables on the number of times the monuments were perceived (Table 3). However, the measure of association (tau) shows that such correlation is very weak, ranging between 0.03 and 0.14 (-1 or 1 being the perfect association).

TABLE 3

Kendall's tau correlation of physical, intrinsic characteristics of monuments with the number of times these were perceived during the simulations (Results calculated over the 120 simulations in which the option "Expertise" was disabled)

Monument	Variable	Z	tau	p value
Mounds	Size (h)	28.164	0.1404	< 2.2e-16*
	Contrast	6.9261	0.0345	4.325e-12*
Petroglyphs	Rock size	12.985	0.0519	< 2.2e-16*
	Panel size	15.759	0.0630	< 2.2e-16*
	Inclination	13.003	0.0522	< 2.2e-16*
	Contrast	14.979	0.0598	< 2.2e-16*

This is also clearly seen in the scatterplots relating the number of perceptions and the different characteristics of the monuments considered in our simulations (Fig. 8).

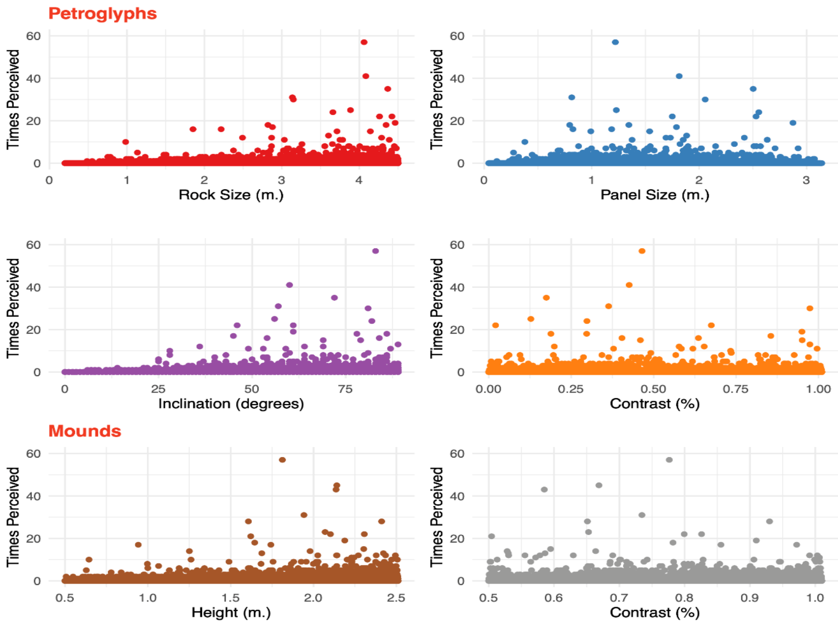

Figure 8. Number of times the monuments were perceived during the simulations as a function of the characteristics considered in this paper.

The results suggest that none of the explanatory variables, by themselves, satisfactorily explain the total number of times a monument has been perceived. Likewise, they highlight the complexity of the processes of perception of prehistoric monuments, where material as well as immaterial factors would have contributed to make a monument particularly conspicuous. However, the results again suggest that while size (of both mounds and engraved panels) is an important variable, other factors generally regarded as secondary would also have had an impact on both the likelihood of a monument being noticed and the number of times it would have been detected.

A further variable considered was the location of the monuments within the study area. Using a Monte Carlo-like approach, the perceptibility of mounds and petroglyphs located in their real location in the Barbanza Peninsula was compared with that of populations of identical size but randomly distributed. The effect that location may have had on the perceptibility of the monuments was then measured by means of a Generalized Linear Model in which the location –expressed as a dichotomous response variable (Random location vs. Real location)– was explored in relation to the number of times a given monument was perceived during the simulations (Times Perceived).

The GLM shows different outcomes depending on whether we focus on mounds or petroglyphs. Among the first we can observe a significant impact of the type of location on the probability of a monument being perceived to a greater degree, with the number of perceptions increasing very slightly (0.03) for the monuments in actual places (Table 4). Conversely, location does not seem to have played a statistically relevant role in the number of times the petroglyphs were perceived (Table 5).

These results underscore that perceptibility was more site-dependent for mounds than for rock art. The former would tend to be built in places with a greater prominence than the latter, so when the location of mounds in the model is the same as in the real world, their number of perceptions tend to increase compared to when randomly distributed. This trend had already been detected in previous approaches using predictive modelling and GIS platforms. In these studies, it was observed that visual prominence was a significant predictor for mounds in the Barbanza (Carrero-Pazos *et al.*, 2020), but not for rock art sites (Rodríguez and Fábregas, 2015).

3.2. Impact of the character of audiences on the perceptibility of monuments

As we mentioned earlier, one of the advantages of ABM over GIS when modeling the perception of prehistoric monuments is, in addition to its dynamic nature, the comparative ease with which ABM can manage intangible variables. These include specific characteristics of the audiences to whom these monuments would have been preferentially or exclusively addressed.

To test the possibilities of ABM in simulating if some of these immaterial aspects of the prehistoric observers might affect their ability to perceive the monuments, we designed a "virtual audience" (walkers) with capabilities such as "Expertise", "Memory", and "Cultural Transmission" (see section 2.2.4. for an explanation of these variables). Likewise, walkers were provided with the ability to develop two different types of mobility strategies: Random walking vs. Targeted walking (Fig. 5). The purpose of these variables was to simulate audiences with variable degrees of familiarity with both the study area and the monuments located there.

We applied a Generalized Linear Model in which the audience characteristics –expressed as dichotomous response variables– were analyzed in relation to the number of times the monuments were perceived during the simulations. The results suggest that, for mounds, only one of the four variables analyzed –"Walking strategy"– shows a statistically significant effect on the likelihood of these monuments being perceived more of less often (Table 4). However, the estimated value of this variable (-0.24) suggests that such effect would not have been particularly powerful.

Table 4

Generalized Linear Model (GLM) calculated using different characteristics of mounds and audiences as response variables and the number of perceptions as explanatory variable

Mounds				
Response variable: Location (Random vs. Real). AIC: 48350				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-0.0057	0.0109	-0.526	0.5991
Times Perceived	0.0361	0.0132	2.720	0.0065**
Response variable: Walking strategy (Random vs. Targeted). AIC: 48163				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	0.0353	0.0110	3.199	0.0013 **
Times Perceived	-0.2451	0.0200	-12.224	< 2e-16 ***
Response variable: Expertise (No vs. Yes). AIC: 39232				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-1.0981	0.0125	-87.370	<2e-16 ***
Times Perceived	-0.0029	0.0141	-0.209	0.834
Response variable: Memory (No vs. Yes). AIC: 33306				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	0.6915	0.0133	51.888	<2e-16 ***
Times Perceived	0.0101	0.0150	0.673	0.501
Response variable: Cultural Transmission (No vs. Yes). AIC: 33306				

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-0.6920	0.0133	-51.940	<2e-16 ***
Times Perceived	-0.0069	0.0147	-0.473	0.636

Signif. codes: 0 '***' 0.001 '**'

Regarding petroglyphs, only the variable "Expertise" seems to have played a statistically significant role in their perception (Table 5). In addition, such variable shows an important effect (1.38) on the probabilities of petroglyphs increasing or decreasing the number of times they would have been noticed.

Table 5

Generalized Linear Model (GLM) calculated using different characteristics of petroglyphs and audiences as response variables and the number of perceptions as explanatory variable

Petroglyphs				
Response variable: Location (Random vs. Real). AIC: 76969				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	0.0006	0.0085	0.078	0.938
Times Perceived	-0.0138	0.0138	-0.995	0.320
Response variable: Walk (Random vs. Targeted). AIC: 76971				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-3.216e-05	8.49e-03	-0.004	0.997
Times Perceived	6.042e-04	4.64e-03	0.130	0.896
Response variable: Expertise (No vs. Yes). AIC: 61213				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-1.1513	0.0100	-114.76	<2e-16 ***
Times Perceived	1.3851	0.0529	26.14	<2e-16 ***
Response variable: Memory (No vs. Yes). AIC: 53013				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	0.6929	0.0104	66.472	<2e-16 ***
Times Perceived	0.0176	0.0732	0.241	0.809
Response variable: Cultural Transmission (No vs. Yes). AIC: 53012				
Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-0.6923	0.0104	66.408	<2e-16 ***

Times Perceived	-0.0795	0.0770	-1.033	0.301

Signif. codes: 0 '***' 0.001 '**'

These GLM results suggest that the audience variables show a more varied and, to some extent, complex behavior than those analyzed in section 3.1. As far as the tumuli are concerned, it seems quite clear that none of the variables related to a more expert audience have a significant impact on their chances of being perceived more often. Neither the ability of walkers to remember and recognize the location of these monuments, nor the capability to transmit this information to other members of their community, nor a targeted mobility strategy have led to a significant increase in the number of times mounds were noticed.

This is not the case with petroglyphs. The fact that the variable "Expertise" does have a statistically significant effect on the perceptibility of rock art suggests that the existence of an audience with an important level of knowledge of the terrain may have been an important condition for these monuments to be noticeable. This can be clearly seen in the difference regarding the number of perceptions if the variable "Expertise" is enabled or not. When it was not activated, the petroglyphs were perceived 448 times (as opposed to 4203 times for the tumuli). Meanwhile, when "Expertise" was enabled, the number of perceptions rose to 2509, higher than the tumuli (1381).

The fact that neither the "Memory" nor the "Cultural Transmission" variables had a significant impact on the number of perceptions may suggest that the accumulation and transference of knowledge between walkers was not extensive enough in our model to generate a sufficiently familiar audience for this circumstance to be reflected in an increase of perceptions. Maybe longer simulations (10,000 or 20,000 ticks) would allow the emergence of audiences with a sufficiently broad and generalized knowledge of the environment to really impact the perception processes. This should be explored in future developments of this model.

4. DISCUSSION

The implementation of an Agent-Based Model aimed at simulating the process of perception of monuments (mounds and petroglyphs) by prehistoric audiences has demonstrated the potential of ABM to handle this kind of questions and overcome some of the limitations of static models built in GIS suites through which this problem had been usually handled.

To begin with, the analysis of physical properties intrinsic to the monuments (location, size, contrast...) has made it possible to show how some of the variables hitherto considered as secondary, would have had –at least in theory and in the framework of the simulations implemented in this paper– an equivalent impact on the perceptibility of the monuments to that of factors traditionally considered to be of much greater importance, such as size. This is the case with “Contrast”. For lack of a solution that allows a more realistic simulation of this variable, our model has clearly shown how the contrast of mounds with their surroundings or of engravings with the surface of the rock would have been of great importance in modulating the perceptibility of these monuments. Conversely, factors traditionally considered relevant, such as the inclination of the engraved panels, have proven to be of little relevance in our model.

As for the characteristics of the audiences considered in our model, these suggest that the existence of viewers with a deep knowledge of the landscape and the location of the monuments would have been a very important factor for the petroglyphs to successfully perform the role of landscape markers they have been traditionally assigned. This does not seem to be the case for the tumuli, whose perceptibility seems to have been quite independent of the level of experience of the audiences.

These results, although taken with the caution inherent to the merely exploratory nature of this approach, could suggest that the attribution to rock art of an “inter-group” communication role may not be too realistic (at least for a substantial part of petroglyphs). For such function to have been effective, it would have required from the viewers a deep knowledge of the territory of neighboring and perhaps rival communities, fact that we are far from knowing if it would have been feasible. Conversely, it might be suggested that Galician open-air rock art may have been more of an element of “self-consumption” aimed at audiences made up mainly of members of the very community responsible for the carvings, perhaps as a means of reinforcing the group’s identity and the link with its own territory. What does seem to be evident is that, in almost all the scenarios considered in our simulations, megaliths would have been a much more effective element in shaping prehistoric landscapes, being much more perceptible than petroglyphs.

In short, the results of this first, exploratory approach to modelling the perceptibility of prehistoric monuments using Agent-Based Modelling, suggest that ABM –in collaboration with GIS tools– could bring valuable insights into the analysis of complex processes in which material and immaterial variables may have contributed to make specific monuments more noticeable than others. ABM may, therefore, allow us to get a little closer to understanding the processes of shaping and transformation of cultural landscapes during prehistoric times.

5. ACKNOWLEDGMENTS

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