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Space Analysis in Palaeolithic Cave Art: Towards a Multidisciplinary and Integrated Approach

Olga Spaey^{1,2,3} · Diego Garate^{1,4} · Aritz Irurtzun³

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Abstract

We present a revision of the concept of space in Palaeolithic cave art. Previous research attempting to approach this notion encounters several gaps, which surface on multiple levels: subjectivity, vagueness, restrictions on its conceptualisation, its illustration (two-dimensional description and representation), among others. We reassess the key elements at play, interpretative attempts, and theoretical concepts to gain a better understanding of the notion of space as applied to cave art. This is achieved by examining the historiography not only in pre-history but also in related disciplines, integrating new theoretical approaches and insights from ethnoarchaeology, linguistics, cognitive science, and analytic philosophy. Following this analysis of the existing research, we propose a new method to address the aforementioned issues. This method relies on digital quantitative tools for spatial analysis and three-dimensional representation, such as geographic information systems (GIS) and 3D visualisation. Through the application of these advanced technological tools, we aim to offer a more comprehensive and precise representation of the spatial aspects in Palaeolithic cave art, enabling researchers to analyse and comprehend the complexities of spatial distribution in a systematic and quantitative manner.

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Introduction

Palaeolithic cave art is now considered one of the most valuable sources for approaching the societies of hunters-gatherers from that era (Upper Palaeolithic (40.000–12.000 cal. BP) in Western Europe). Art, reflecting the thoughts of these groups, is thus a cornerstone of prehistoric research.

These artistic manifestations are not located at random but are rather distributed in particular places, which can teach us a lot about their logic, meaning, and purpose.

But what is a place? How far does the word ‘space’ lead us? Can we set about defining it, or at least offering an overview of the concepts it can mobilise? From Leroi-Gourhan’s *caverne participante* (1965) to Pigeaud’s *caverne organisatrice* (2013), what are the researchers’ proposals, and what can its analysis bring?

In this article, we propose to revisit the key elements at play, the interpretative attempts, and the pitfalls that the prehistorian must confront.

Indeed, as we will see, the existing literature highlights a number of difficulties that have been addressed with the tools available to date. These include the question of representing three-dimensional spaces on supports that only offer two, the subjectivity of the researcher when characterizing space and its divisions and the many facets of this notion. Indeed, until very recently, the only means available to represent space were limited to photography, plans, cross-sections, and verbal description, the latter involving nontrivial degrees of subjectivity, which is extremely critical when evoking places as complex as underground cavities.

The very vocabulary used to address this spatial issue quickly reveals its limitations. For if we try to use everyday words to study the space in cave art, we realise that they are bounded by our cultural frame of reference. Terms, seen in many publications, such as ‘corridor’, ‘background’, ‘ceiling’, or ‘room’ reveal their limited ability to represent the complex reality of the cave.

The term ‘space’ is, as we will see, pulled in all directions: from the location of a motif on the wall to the physical perception of narrowness, passing through the notions of visibility, acoustics, appropriation, and structuring of the motifs. Faced with such multiplicity and technical constraints of representation, traditional analysis methods have shown serious limitations. In this text, we propose to open the classical vision to a new spectrum of possibilities, allowing us to conceive the concept of space in a more nuanced way and to determine which tools would be best adapted for its study. Indeed, the discipline now offers the possibility of reconsidering the question with new analytical instruments: geographic information systems (GIS) and three-dimensional visualisation, which put together provide quantitative data that pave the way for better informed cross-site comparisons and inferential arguments.

Historical Background

Archaeology of Cave Art

First, let us examine what has been proposed by prehistorians and archaeologists in the research on space, particularly in the case of Upper Palaeolithic decorated caves.

Proposed Structural Frameworks

In the study of cave art, historically, the cave space has typically received little attention. This is evident at the scale of the wall, where works like Breuil (1952) abstract from the support and space between motifs altogether, as well as at a broader scale of the entire cavity. Thus, as Groenen (2013, 2019) comments, the works of Raphaël (pioneering in the field in the 1940s and early 1950s, only published posthumously in 1986), followed by Laming-Emperaire (1962) and Leroi-Gourhan (1965), were innovative on the matter in their time. However, the arbitrary and vague definition of sectors, the particular focus on iconography, and the search for an ideal model applicable to all caves (a sort of an archetype) relegated the role of space itself to a secondary position in their works. Caves as complex as El Castillo, Pech-Merle, or even Les Trois-Frères (Fig. 1) were consequently reduced to a general structure, whereas their layout and architectural characteristics offered the possibility of a broad and comprehensive spatial study.

After these major structuring models, other researchers have explored their own ways of analysing space. They have proposed numerous notions to categorise, direct, and proportion the space.

For instance, the concept of ‘panel’ proposed by Leroi-Gourhan (1972) was translated into ‘graphical ensemble’ by Sauvet (1993). It has long prevailed and continues to occupy a significant place in the division of space despite the many criticisms that have been made (Leroi-Gourhan, 1972), and the caves and shelters where this concept becomes completely arbitrary, as at Combarelles or Fuente del Trucho, for example.

For his part, Vialou (1986, 2009) suggested dividing the description of space into two categories: (i) topographic situation, at the scale of the cave, and (ii) parietal position, at a more local level. In the former, he considers spaces such as the entrance porch, galleries, dead-end spaces, ends, chambers, or rooms, as well as cracks and diverticules. He also introduces new concepts, such as ‘stop and backtrack’, ‘mandatory return’, or ‘mandatory circulation’, which go beyond describing places to what they impose in terms of pathways and behaviours of their visitors. In the latter, he proposes categories involving terms like ‘vertical’, ‘ceiling’, ‘concave’, ‘dièdre’, or ‘entablement’.

Among other authors, such as Garate (2010), one finds the notions of ‘topographic unit’, ‘composition unit’, and ‘graphic unit’, which align with the concepts of sector, panel, and figure. These are the same categories used by Ochoa

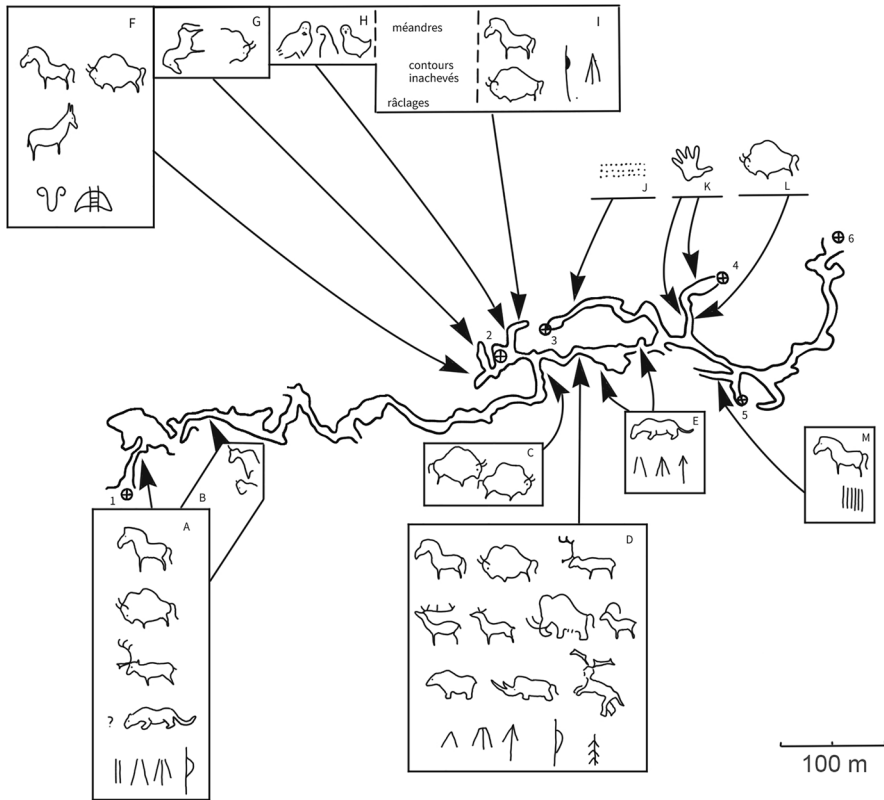


Fig. 1 Structure of the cave of Les Trois-Frères following Leroi-Gourhan (1965)

and García-Diez (2018). For topographic units, these authors consider classifications proposed in speleology (passage, niche, corridor, hall, ...).

In a similar vein, Fritz (2020) proposes the terms ‘environmental space’, ‘cave space’, and ‘space of decorated surfaces’. She also incorporates human experience in the taxonomy of space notions with her distinction between what she terms ‘non-immersive spaces’, meant to be viewed frontally, and ‘immersive spaces’, intended to be observed from a distance, where the progression itself is an integral part of the experience.

The distribution of the decorated area within the development of the underground network is questioned by Vialou (1986, 2009). In his view, various types of ensembles can be distinguished, from simple model where the decoration is concentrated at one point to multiple models, which can be continuous (with uninterrupted ornamentation) or discontinuous (with an ornate space separated into different zones).

This idea is then taken up and further developed by Garate (2010), who proposes the following types: ‘linear space with wide dispersion’, ‘closed space’ (motifs gathered at one point), and ‘restricted zones’ (with decoration located in easily accessible yet distant areas or closer to the main path but difficult to reach).

In the works of González García (2001), the concepts of ‘active support’, ‘inactive support’, or ‘indeterminate support’ emerge, based on their alleged influence (active, inactive, or both) on the surrounding space. These terms, considering the effect of the ornate areas, are based on the concept of ‘panel’, which aligns with Leroi-Gourhan’s (1965) proposal.

Finally, Groenen (2012, 2013, 2016, 2017, 2019) has proposed separating cave spaces into two main types: ‘transit zones’, which connect main spaces and are minimally or not decorated, and ‘stationary zones’, which contain motifs and structure the layout.

All in all, what this brief overview of the literature reveals is a wide variety of conceptions regarding space, space partitions, taxonomies, and human experiential implications that even if they help approaching the complex nature of the relationship between space and cave art are often too impressionistic and vague. As a consequence, the taxonomic systems proposed in those works fall short in attaining descriptive and explanatory adequacy.

Symbolism and Attempts at Interpretation

Beyond these systems of categories, which aim to organise not only the figures but also the scientist’s thought, researchers have endeavoured to approach interpretation in relation to space. The main proposals, of which here is a brief overview, continue to exert influence on current research.

Types of Space A question commonly encountered in works addressing space in subterranean networks pertains to visibility, specifically the distinction between ‘public’ and ‘private’ spaces. Indeed, this notion is prevalent among numerous authors (Laming-Empeaire, 1962; Sauvet & Sauvet, 1979; Raphaël, 1986; Vialou, 1986, 2009; Bradley, 1991, 1995; Foucher, 1991; de Beaune, 1995; Clottes, 1997; Baffier & Girard, 1998; Gamble, 1998; Lorblanchet, 2001; Bahn, 2003; Villeneuve & Hayden, 2007; Utrilla & Martínez-Bea, 2008; Villeneuve, 2008; Lewis-Williams, 2002; Pastoors & Weniger, 2011; Groenen, 2016, 2017; Ochoa Fraile, 2016; Bourdier *et al.*, 2017; Ochoa & García-Diez, 2018; Jouteau, 2021); yet, a few other works argue that ‘Il n’est donc guère possible, dans ces conditions, de spéculer [...] sur une opposition entre images “publiques” et “privées”’ [It is therefore hardly possible, under these conditions, to speculate [...] on an opposition between ‘public’ and ‘private’ images] (Le Quellec, 2022).

While a majority seems to converge on a general separation, important differences in terminology and associated concepts do exist.

According to some of them, ‘private’ spaces are characterised by a lack of polychromy, featuring ‘raw’ or expedited images that required less production effort. The areas hosting these images would be less accessible and more restricted, lacking an overall view. Such spaces would also be limited in capacity (ranging from one to three individuals). The potential public of this art, thus, would be more limited, due to restricted access conditions or to the small size of the area (Foucher, 1991). Utrilla and Martínez-Bea (2008) suggest the concept of a ‘small cave within the cave’. Jouteau (2021) observes that this type of space could be divided into two

subspaces: individual (single person) or restricted (a few individuals), as proposed by certain authors (Gamble, 1998; Villeneuve, 2008; Bourdier *et al.*, 2017). Laming-Emperaire discusses ‘panels intended to be hidden’ (1962), and Vialou (1986, 2009) extends this notion of concealment, stating that such places are not immediately noticeable and are more likely to be found within what he terms ‘the derived network’. Bahn (2003) provides examples of spaces he considers hidden, such as some sections of Combarelles II, Fronsac, Pech-Merle, or Bernifal. This concept of private space is taken to an extreme in places like the Pergouset cave, where a figure’s position, implying it was drawn blindly, raises questions about the purpose of this type of representation: is the observation significant, or is the act of creation more important than the result itself (Lorblanchet, 2010)? Does it lean more towards the act of making rather than the act of seeing, as proposed by Villeneuve (2008)? Indeed, according to authors like Lewis-Williams (2002), the act of creation itself can have a performative symbolic value that goes beyond the visual result. In this case, the work may not be the painting itself, but rather the act of its creation. He argues that this applies to hand stencils, which result from a ritualistic act of immersion into the wall.

At the opposite end of the spectrum would be ‘public’ spaces. This notion is already found in the work of Laming-Emperaire (1962), who mentions ‘panels intended to be seen’. These are places where a monumental decoration can be found, with an emphasis on staging and the use of visible techniques, such as polychrome painting. Foucher (1991) goes further by proposing that the decoration in these spaces, which he characterises as ‘profane’, aims to evoke emotional reactions in their viewers. According to Villeneuve (2008), this type of public space, oriented towards groups, is larger and contains more elaborate images. Vialou (1986, 2009) nuances this idea by suggesting that the works in these spaces are not always spectacular, but they are immediately noticeable and easily accessible. Bahn supports this proposition, adding that certain adorned sites have been modified in prehistoric times to make them accessible to the public, such as the Cougnac or Peña de Candamo caves (Bahn, 2003). Jouteau (2021) expands on this thought, asserting that they were designed to accommodate groups of over twenty people, following Gamble’s proposal (1998). Finally, Groenen (2017) notes that these sites, remarkable as they may be, do not constitute the majority of Palaeolithic cave art.

Configuration and Organisation of the Motifs In addition to this significant dichotomy, there have been other proposals analysing the symbolism that can be attributed to the cave, some more daring than others. While Vialou agnostically asserts that the structuring of motifs is simply impossible to interpret, and Sauvet *et al.* (1977) vaguely propose that the cave was probably imbued with some sort of symbolism, with certain particularly significant spaces, other authors delve deeper into interpretation, making more precise proposals.

Structuralist models by Leroi-Gourhan (Fig. 2) and Laming-Emperaire, for example, offer an interpretation of the animal associations based on a prevalent horse-bovid duality, and a distribution of animal figures in different areas of the cavity according to species types and the significance attributed to them. Djindjian (2003, 2015) later proposed a revision of these models with the original hypothesis that the

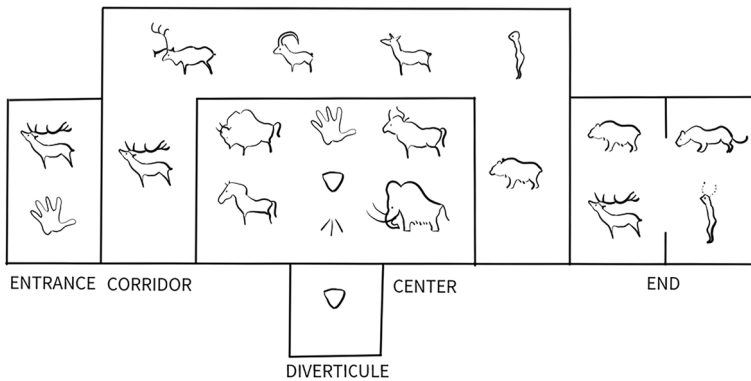


Fig. 2 'Ideal layout for a Palaeolithic sanctuary' following A. Leroi-Gourhan (1965)

placement of motifs reflects the actual territory of Upper Palaeolithic populations, varying across the distinct major periods of this time span (Aurignacian and Gravettian/Solutrean/Magdalenian). He thus distinguishes central compositions, peripheries, and areas of depth/diverticules and passage. However, this model, which aspires to be universal, as those of the previous generation does not properly capture the diversity of existing underground structures.

Motif Functionality—Spatial Indicators Another theory proposed by several authors (Groenen, 1990, 2011, 2013; Foucher, 1991; Pigeaud, 2005; Collado Giraldo, 2018) suggests that certain motifs, such as punctuations or hand stencils, might have served as topographical markers. These indicators would highlight specific segments of the network, such as introductory, transit, articulation, or terminal and closure spaces. They could also signal hazardous areas, stopping zones, or even function as way-points for navigating a specific route within the cavity, like a designated pathway. In a similar vein, some triangular symbols are interpreted by Groenen as markers, denoting relationships between different spaces (Groenen, 2012). This author also points out the presence of broken and displaced speleothems in the El Castillo cave that might have equally served as topographical markers, possibly associated with hand stencils (Groenen, 2013, 2017).

From Theoretical to Social Spaces

Modern archaeology has become essentially interdisciplinary, involving multiple fields of study. We have been stuck in narrow thinking for too long, focusing solely on one discipline. It is time to expand our viewpoint and embrace a broader approach.

As archaeology is now inherently interdisciplinary and as we have been stuck in narrow thinking for too long, focusing solely on one discipline, we now suggest broadening our perspective. To comprehend the boundaries of our system, let us attempt an overview of diverse ways of conceiving space.

Theoretical Frameworks: Exploring Conceptual Approaches

In Western culture, it is common to regard space as an empty and absolute medium, dating back to the advent of Cartesian thought which suggests viewing it as an expanse, a container indifferent of its contents. In a similar vein, Lefèbvre (1974) highlights various types of mathematical spaces (Euclidean space, curved spaces, *etc.*), which are by definition external to our field of perception. Within this shared representation of space, this author also notes that it is separated from the concept of time, as if the two evolve within separate systems, without intersecting.

As E. Hall *et al.* also note ‘space and time are conceptions that are culture-specific. However, they tend to be considered as “universally valid” by each culture’ (Hall and al., 1968), which can be illustrated sometimes in the everyday vocabulary.

Contrasting this would be the concept of ‘relative space’, aligned with the philosophy of centrality, which considers it solely in relation to a subject and a situation (Moles & Rohmer, 1998). It is in this idea that Berthoz (2005) suggests that space is always conceived, perceived, and experienced as a function of our own frame of reference. This perspective, which reintroduces the human and their perception into the equation, has been evoked in the context of prehistoric art studies, notably by Groenen (2013) and subsequently by Fritz (2020). The latter also highlights, citing the works of Merleau-Ponty (1945, 1964), Gibson (1950), Guillaume (1979), and Berthoz (2005), the connection between space and movement. She thus defines three types of spaces: the space of the body (which stops at the limits of our direct grasp), the space of the immediate environment, and the space of the distant environment. In caves with narrow or difficult passages, such as those of Aizpitarte (aka Aitzbitarte), Nerja, or Arenaza, for example, this notion of subjective experience and the link between space and movement are abundantly illustrated. We find this perspective based on the individual’s viewpoint in the works of Hall (1959), who proposes the notion that since space and territoriality are intrinsically linked to our culture, spatial behaviours can metaphorically be seen as a sort of ‘silent language’ as they employ a code. For instance, the physical distance between individuals during interactions is a result of social norms, which vary from one culture to another (cf. *e.g.* Lomranz, 1976; Kreuz & Roberts, 2017). Following Sapir (1929), some aspects of the culture are taken for granted and operated by the members of an ethnic community ‘... in accordance with an elaborate and secret code that is written nowhere, known by none, and understood by all’.

This connection between space and our perception of it has also been explored by Moles and Rohmer (1998), who consider the question of appropriation: ‘dominating space rather than being dominated by it’. This process, in stages, is achieved first through exploration and then by putting down roots. This type of vision is also echoed by researchers like Pigeaud (2005) and Groenen (2013). The former addresses what he terms the ‘phases of cave occupancy’, which he divides into three levels: ‘exploration’, ‘appropriation’, and ‘utilisation’. The latter, on the other hand, suggests that the use of suggestive relief features to create certain parietal images is a clue to this process, as it allegedly requires prior familiarity with the cavity.

Continuing along the lines of this spatial relationship, Moles and Rohmer (1998) identify three degrees of space valuation, based on our relationship with it: ‘space

with which we have no connection', 'places that hold significance for us', and 'spaces we have made our own'.

Another thought-provoking concept is presented by Lefèbvre (1974), suggesting that space should be viewed as a 'product', both created and creative. According to him, space and time are not 'facts of nature, more or less modified', but cultural products: they represent aspects of a 'second nature', an effect of societies' actions on sensory data, materials, and energies. Beyond just being products, they also play a role in production by organising productive work, movements, product distribution networks, *etc.* In relation to cave art, this perspective seems relevant, as we observe that space directly influences motif distribution, in terms of the general structure of the networks, as well as directly on the walls themselves. Space itself plays a part in the creation of art; it biases and partakes the artistic creation, which in turn ends up affecting the space itself.

Likewise, regarding what the environment offers, Gibson (1977) builds up the concept of affordances: 'The affordance of anything is a specific combination of its substance and its surfaces taken with reference to an animal'. In other words, it is what the environment provides, 'for good or ill'. Following him, some place can be 'sit-on-able', 'bum-into-able', or 'fall-off-able'. In this view, caves, as any environment, offer many possibilities, and restrain others.

Another valuable contribution, particularly relevant in the study of cave art, is the proposal by Moles and Rohmer (1998) to identify certain specific types of spaces such as 'island' or 'cave'. According to these authors, what they term 'archetypes' are particular forms of space in that they involve a concrete decision: they are spaces where one decides to go, 'where one goes'. They are not traversed by chance and visiting them requires preparation that can be significant. Here, we encounter the transition from 'space' to 'place'. This concept is indeed fully applicable to cave art, which requires preparation, material resources (light, carving, drawing and painting tools, potential scaffolding and ropes, *etc.*), physical condition, and specific training.

Related to this, it is interesting to observe that typically, humans can make reference—linguistically, or by pointing—to what they conceive as *places*, but not that easily to *spaces*, which tend to lack clear conceptual demarcations. Linguistically, *places* can be referred to with demonstratives+common nouns such as *that cave*, or with toponym rigid designators—proper names—such as *Aizpitate*. On the contrary, *spaces* tend to be vague entities lacking names and deictic reference can only be done by actual demarcation.

In a similar manner, Moles and Rohmer (1998) suggest that certain spaces can be conducive to specific types of use. An example of this is sacred space, which can be associated with peculiar physical characteristics such as verticality, to name just one. Verticality has indeed held significant importance in Christian asceticism for instance, and it is also found in other traditions (cf. the particular height of Christian gothic cathedrals such as Ulm Minster or Cologne, the Buddhist pagodas of Tiānníng or Tō-ji, or the Muslim mosques of Al-Nour or Isfahan). Certain locations that were occupied by prehistoric individuals, with imposing dimensions, such as the Great Hall of Pech Merle for instance or the Cataclysm of Nerja (Fig. 3), raise the question of how these features might have influenced the nature and positioning of the figures.

Fig. 3 Nerja cave (Málaga, Spain), Cataclysm chamber (© A. J. Torres Riesgo)



All these examples and approaches, while pointing in various directions, highlight the fact that it would be imprudent to regard our contemporary and *WEIRD* conception of space as universal; it entails significant complexity.

Comparative Ethnoarchaeological Approach

Let us now explore what ethnoarchaeology can contribute to our reflection. This approach provides us with a range of significant perspectives concerning the concept of space, as highlighted by Domingo *et al.* (2020), enabling us to emphasise the social and cultural variations occurring diachronically and diatopically.

In their article on the Aboriginal rock art sites in the Barunga region of Australia, these authors challenge the commonly held notion among archaeologists that easily accessible sites are associated with a type of ‘public’ or secular art, while less accessible sites are linked to a more private or sacred form of art. They provide the example of the rock art site Doria Gudaluk, with varying degrees of accessibility depending on the time of year and context, which aptly illustrates the complexity that can be present in hunter-gatherer cultures.

The ceremonies held there partly take place on-site but also partly off-site (including locations from which the rock art is not visible at all). In general, anthropologists have for a long time observed that certain sites are generally open but subject to access regulations during ceremonies. This cultural control—just like certain ceremonial actions like dances, gestures, and speeches—leaves no archaeological traces.

Similar differential treatments of space can be observed among basically all human groups. For instance, the Nukak of the Amazonian tropical rainforest (Politis, 2007) conceive the space around them as a juxtaposition of five dimensions through which they perceive and use the landscape and where they display different behavioural patterns (the *band territory*, the *territory of the regional group*, the *distance*

space that is known about but is rarely visited, the territory that is known but that is not visited, and the mythic space of Nukak cosmology).

As we said, such differential emic conceptions of space are well attested across human populations, and very often they imply a different ritualistic treatment: For instance, among the Garifunas (Coelho, 1955), the rite of calling down the spirits (*arairaguni*) can be performed in public, or in private spaces, depending on the practitioner. If held in private, the public can just hear the practitioner's performance, but if held in public, they observe all the ritual practices and the officiant's acts, by which they gain a much higher prestige in the community.

Likewise, mystic and ritual conceptions of space can be observed in the particular linguistic behaviour of some cultures: the Burus, for instance, employ different lexical items at home and in hunting expeditions, as a way of avoiding evil spirits and guaranteeing a good hunt (Grimes & Maryott, 1994), similar to what do the Kewa, the Mbongu, and the Gawigl when in the pandanus area (Franklin, 1972; Franklin & Stefaniw, 1992). And analogous 'everyday language taboos' are observed among the Marshallese, when they travel to the 'Bird Island' (Tobin, 1952), or among the Rosel Island islanders on the island of Loa (Armstrong, 2011).

Last, differential treatment of space and their corresponding linguistic practices are widely attested in initiation rites from Western Africa to Australia, where typically the children to be initiated are extracted from the community, secluded out of their normal living area, and often taught a particular language for the initiation period.

Ethnology can also shed light on the issue of the audience by opening us up to perspectives that may have been overlooked until now. Indeed, as noted by Carlson (2018): 'Performance is always performance for someone, some audience that recognizes and validates it as a performance even when, as is occasionally the case, the audience is the self'. Spirits or other metaphysical entities can also be considered the audience for these performances, entities that may not be confined to the occupation criteria traditionally observed by archaeologists (Witelson, 2023).

Similarly, we must broaden our understanding of the visibility question in general. Archaeology has commonly attempted to address the thorny issue of the target audience by calculating the maximum capacity of a site or area. However, while it is difficult to increase the physical capacity of a place, it is possible to restrict it in numerous ways. As indeed suggested by some authors (Domingo *et al.*, 2020), there is no deterministic relationship between the size of the site and the size of the audience. Cultural restrictions, involving potential dangers (punishment by spirits or traditional lawmen), could have been in effect. Certain places might be considered so powerful that it could be dangerous for non-initiates or individuals of a certain gender to approach (say, the Garbhagriha of Hindu temples, rarely accessible to anyone beyond the 'pūjari' temple priests (Bharne & Krusche, 2014); the inner shrine (Kōtai-jingu) of Naikū at Ise, which is the holiest of the shinto shrines in Japan, only accessible to the imperial family and the highest priestess, traditionally, a daughter of the Emperor herself (Tange & Kawazoe,

1965); The Holy of Holies in the Temple of Jerusalem, which in ancient Jewish tradition was believed to be the dwelling place of God, with access restricted only to the High Priest, and only on Yom Kippur (Barker, 1998); or the Chapel of the Tablet of the Axum Cathedral of the Ethiopian Orthodox Tewahedo Church, which is claimed to shelter the Ark of the Covenant and is tended by a single monk who is appointed for life (Heldman, 1992)).

This idea is consistent with the observations of Guy on Palaeolithic inequalities. Against the popular idea of some sort of communalism, this author argues that social and economic inequalities already existed during that time, and that ‘L’occupation humaine avérée de sites ornés et/ou riches en œuvres mobilières mérite d’être soulignée. Elle suggère en effet, là encore, que des individus à l’exclusion des autres vivaient au contact des représentations dont le caractère sacré paraît peu contestable. L’occupation des grottes ornées pourrait donc constituer un signe supplémentaire de discrimination sociale, comme semble déjà l’être l’inhumation ou le dépôt de défunts dans les cavités décorées. On a distinctement le sentiment ici d’une forme d’appropriation du sacré par une minorité’ [The demonstrated human occupation of decorated sites and/or sites rich in portable art deserves to be highlighted. In this case, it also suggests that people excluded from others lived in contact with representations whose sacred character seems unquestionable. Therefore, the occupation of ornamented caves could constitute an additional sign of social discrimination, as seems to be the burial or deposition of the deceased in the decorated cavities. Here there is clearly the feeling of a form of appropriation of the sacred by a minority] (Guy, 2017).

Another form of access limitation is the secrecy surrounding the meaning of the figures. Thus, the same motif may have different levels of meaning, revealed according to the age, gender, and personal qualities of the potential observer. Patterns can thus be hidden in plain sight through information restriction.

This diversity of meanings is illustrated for instance in the ethnoarchaeological work of Moore (1977) on Aboriginal stencils in Australia. This author identifies ten different functions for these motifs:

- (i) As an individual signature of an artist or to record a visit
- (ii) As a memorial, to be mourned over after death
- (iii) As a message to the spirit ancestors
- (iv) As a secular message to other Aborigines
- (v) As a record of a historical event
- (vi) As a story-telling device to record the myths at sacred sites
- (vii) As a means of using the power of a sorcery site
- (viii) Hand prints left by the totemic ancestors of the dreaming and obviously especially sacred
- (ix) Hand prints made in sacred places to derive spiritual strength from the ancestors
- (x) Stencilled representations of parts (or the whole) of totemic species for mythic or magical purposes

Besides, knowledge related to imagery, much like its location, can be a source of power, as observed by Nash and Smiseth (2015) when studying various rock art sites of Norwegian hunter-gatherer/fisher cultures. These sites concealed their locations to maintain or reinforce social hierarchies, and the meaning of the images was also subject to secrecy.

Ethnology can similarly shed light on the possibilities of space and landscape perception in general. For instance, Luig and Von Oppen (1997) suggest that the landscape is more of a historical process than a finished result, and Thomas (1993) proposes that the landscape, instead of being seen as an object from the observer's perspective, should be understood from within. This aligns with the perspective of performance theory, which offers a fresh research angle. According to Witelson (2023), traditional questions asked by archaeologists about rock art, such as 'What does it represent?' 'Who made it?' 'When was it made?' 'How was it made?' 'What does it mean?' restrict the scope of art interpretation. This author suggests focusing on the processes involved in the creation, visualisation, and utilisation of rock art. This encourages us, within the context of space, to adopt a different viewpoint, considering space from the perspective of the very creation of cave art.

In relation to the selection of locations or the systematic reuse of the same walls or shelters, ethnology shows us that there are numerous possible answers to why these choices were made. As some authors assert (Domingo *et al.*, 2020), the recurring use of the same shelters indicates that what really mattered was the location and the surrounding landscape, more than the paintings themselves. Taçon (1990) takes it a step further, claiming that certain sites are visually imposing and can 'invoke common responses in human beings – feelings of awe, power, majestic beauty, respect'. Bahn (2003) suggests the idea that there might be 'universally unpleasant areas' in the cave, while others may be more conducive to creating a decor. This aligns with the notion put forth by Moles and Rohmer, mentioned earlier, that certain physical dispositions would call for a specific use of space. Some authors even propose that the cave's space and its specific environmental conditions can induce particular effects on human behaviour, which would have implications for art creation (such as the hypothesis based on hypoxia of Kedar *et al.*, 2021).

We also find the concept of 'imbued territories' in the cosmology of Australian Aboriginal peoples, which recounts how during *Dreamtime*, the *Ancient Beings* shaped the landscape through intentional and unintentional actions that imprinted spiritual forces into the territory (Mather, 2003).

In conclusion, the integration of ethnology into archaeological research allows us to broaden our perspective to numerous conceptions of space. However, while parallels with cave art are enticing, Domingo *et al.* (2020) rightly remind us that 'Ethnoarchaeology has been misused in the past, through the enthusiastic but misguided application of Australian Aboriginal totemism to Palaeolithic cave art (e.g. Breuil & Lantier, 1950), across thousands of years and thousands of kilometres'. Let us therefore use it as a source of challenge to our preconceptions, without falling into the attractive pitfall of anachronistic comparison.

Method: Reflective Evaluation, Constraints, and Concepts to Consider

As we have seen, space is a complex concept, endowed with a multitude of facets, compounded by the inherent interests and constraints of the research. Indeed, the objectives and tools sometimes seem to bias researchers to make certain methodological decisions, whether consciously or unconsciously.

This particular theme is subject to a series of advantages and constraints.

Advantages

- The (relative) *immobility of the walls*: apart from the general evolution of the caves and major geological events (collapses, *etc.*), the figures are now in the same place where the Palaeolithic people chose to place them (with the exception of a couple of extractions [*e.g.* in the Abri de Laussel]). Unlike portable art, we thus have access to valuable context for studying the traces left by humans.
- The *preservative nature* of caves, as highlighted by Clottes (1993), has the advantage of recording even some of the gestures of the cave's occupants by allowing us to see traces of their passage and actions (footprints, bonfires, structures, broken elements,...). Movement and space thus come together to provide us with clues about their perception.
- The unique conditions of this inherently hostile environment for humans (Rouzaud, 1978) mean that the question of chance in the choice of location can be outright refuted: caves are, as Moles and Rohmer (1998) pointed out, a place one goes to, requiring *intentionality, planning, and expertise*. We are not dealing with an adorned site chosen incidentally along a natural path, by default.

Constraints

- *Taphonomy*, along with *changes in the cave's form* due to geological evolution and environmental conditions, or due to human actions of visitation and/or destruction. This implies that today we only have access to a fraction of the information available during the Palaeolithic era. Certain pieces of information, such as the location of the Palaeolithic entrance, crucial when considering the conception of a site, are often difficult to find. Additionally, as noted by Bahn (2003), there is what he calls the 'non-empirical environment', referring to data related to taboos or myths, that have disappeared today.
- The *clustering of figures* is also significant for analysing space and the distribution of depictions. Indeed, the deliberate accumulation of motifs within a work implies an artist's perspective on their visual field. This takes on different expressions in cave art across the world (see the case of Chauvet (Gély & Azéma, 2005) vs. Christol Cave (Le Quellec *et al.*, 2009), or the cave of Tito Bustillo (Fig. 4). However, different systems overlap in many caves, and these are often quite difficult to disentangle.

Fig. 4 Tito Bustillo cave (Asturias, Spain), accumulation of figures of the Main Panel (© P. Saura)



Researchers' Choices

Beyond these characteristics specific to spatial analysis, a series of choices confront the researcher, often remaining unseen.

For example, the *choice of a relevant corpus*, which arises when attempting to interpret the dispersion of a parietal arrangement. Which criterion to choose, from style to iconography, or technical characteristics? Even motifs that appear categorised and distinct merit subtlety in their selection. The depiction of the hand, well-known mainly through hundreds of existing hand stencils, serves as a good example. When studying these, should positive handprints, sometimes present in the same caves, be included? Should complete hand stencils be separated from those with missing fingers? Different types of missing fingers exist, with the same finger consistently absent or varying combinations. Should these distinctions be made? What about the 'rubbed' hands, digital tracings, or even finger flutings? Should the 'points' or 'disks' performed with a similar technique be included? Swiftly, choices arise, which fall to the researcher to undertake.

This is where two major problems arise: *ethnocentrism* and *subjectivity*. Several authors alert us to this danger: Lewis-Williams (1990) presents the expression 'Contexts are made of contexts', which illustrates this well. This idea is echoed by Conkey (1997) and Brouwer Burg (2017), to name a few. Gero (1996) shares this notion and asserts that our 'discoveries' as researchers are actually the result of a blend of our context and interpretation.

Indeed, in palaeolithic cave art research, the overwhelming presence of *WEIRD* thinking is striking and we have to be well aware that the concept that we employ today to refer to a set of different entities may be inappropriate for other cultures, as they may have had a more nuanced partition of the elements, which may not even conform a coherent set.

For example, through language study, one can observe that the categories of one culture or language do not necessarily fit well into another. What is

encompassed within a single term in one language might require two or more in another. In other words, what is included today in a language as *tokens* of a (macro) category might, in another language or at another time, be differentiated into more categories (and vice versa). For instance, in French, different species of oak trees (*Quercus robur*, *Quercus pyrenaica*, *Quercus ilex*) all fall under the single category and are all themed ‘chêne’, whereas Basque differentiates between them as different types of trees: ‘haritz’, ‘l’ametz’, and ‘arte’. In a nutshell, categorisation itself is mediated by culture, and we should be aware of this fact when driving conclusions about any complex artistic representation.

Thus, as noted by Groenen (2016), the very notion of an ‘animal figure’ restricts and directs our thinking. Similarly, the concept of ‘thematic associations’ in the analysis of spatial organisation restricts figures to an essence derived from our own perspective. Writing ‘animal type: horse’ or ‘figure type: sign’ implies establishing our system entirely upon a particular interpretation (not to mention more specific terms like ‘tectiform’ or ‘rugolean finger flutting’).

What if, rather than interpreting a motif as embodying an ‘essence of a horse’, it represented an individual of a certain breed, male gender, at a certain time of year, in a particular pose or activity? Or if it represented the activity itself, rather than the individual? That is, the interpretation of motifs immediately brings up a well-known problem in analytic philosophy: the ‘indeterminacy of reference’, as first discussed by Quine (1960). Moreover, how can we determine whether this depiction of a drinking reindeer of Combarelles, for example, has anything to do with another representation of the ‘jumping’ reindeer of Las Monedas? They might be poles apart symbolically, and the drinking reindeer might be closer in symbolism to a threatened bison or a falling horse, even though they are separated into different animal categories.

How do we distance ourselves from the lenses of contemporary thought and cultural baggage in order to think about this space while trying to approach the mindset of Palaeolithic people? Let us not lose hope. What fascinates us about these ancient times is their distant mystery. Yet, they are both far away and near enough for us to dare to take a step, to bridge the gap. Let us first admit that we might be mistaken. Then strive to distance ourselves from this peril as much as possible, while keeping it constantly in mind. Close enough to avoid getting lost, far enough to prevent it from discouraging us.

Let us try to move forward with clear-sightedness, then. But what about subjectivity? Even worse, false objectivity? Establishing criteria, categories, and attempts to objectify studies often result in findings that seem falsely removed from arbitrariness and subjectivity. Statistics, among other methods, transforming observed phenomena into numbers and graphs, can be a slippery slope, as they obscure an important part of the work involved: categorisation. Whether qualitative or quantitative categories, there’s always an element of choice in defining their characteristics or the numerical ranges that bound them.

The ‘*physical partitioning*’ of caves into different zones exemplifies this categorisation. Anyone who’s entered a cave would quickly notice that it is a physical entity that resists clear demarcation. Caves indeed form a rocky universe that removes us from the outside world, and while sharing this specificity, each one

is unique. How can we refer to a ‘room’ when the ceiling transforms into a wall, then a corridor and a pit, without providing any clear limit? How can we talk about categories of space when cave-corridors coexist with caves alternating between restricted and immense spaces?

If we adopt certain proposed categories to study a corpus, such as ‘sectors’, ‘panels’ or ‘graphic sets’, we rapidly confront our own subjectivity, as the categorisation itself begs for a justification *a priori*. This extends to demarcate the graphical unit: What are the criteria for its definition? Where does it end?

The same question arises regarding the *difference between a cave and a rock shelter*. This distinction, proposed by several authors (Laming-Emperaire, 1962; Leroi-Gourhan, 1965; Fortea Pérez, 1994; Vialou, 2009; Ochoa Fraile, 2016; Groenen & Groenen, 2019), some of whom assert that it also corresponds to a chronological difference, is it the fruit of our system of thought, of our own categories?

This subjectivity may indeed originate beyond our gaze, in our very knowledge of networks, in *the way we represent them*. Interestingly, research on Palaeolithic cave art generally employs two-dimensional plans to depict cave spaces, which, even if interesting, fail to do justice to their underground layout and provide information that may be unreliable. As Jaillet (2014, 2016) presents, our method of representing space, implying a way of thinking about space itself, shapes our perception and reflections. When attempting to map a cave, its physical characteristics cry out its irreducibility to the plan: What to choose between the wall as it is on the ground and as it is a meter higher, or three, when it narrows with a steep incline? How should the different levels be represented?

Some researchers, as noted by Sauvet (1993), have proposed solving this issue by adding cross-sections and photos to the traditional plan (Fig. 5). However, while these images provide a slightly more concrete understanding of the development of certain areas, they still fall short in fully capturing the extreme complexity of underground spaces.

Results: Trying to Find a Consensus

We have examined the advantages, challenges, and the stakes of choices associated with the study of space. Let us now attempt to propose an approach, a way of addressing the issue, in order to investigate the conception of space within the context of Palaeolithic cave art.

Our proposal is structured through a framework divided into different scales. Following in the footsteps of several authors, we suggest considering three scales: global, macro, and micro.

Global Scale

The first scale is a *general overview*, not only of the cave itself but also of its context, at the geographical level (Monney, 2012; Genuite *et al.*, 2018, 2022). This allows us

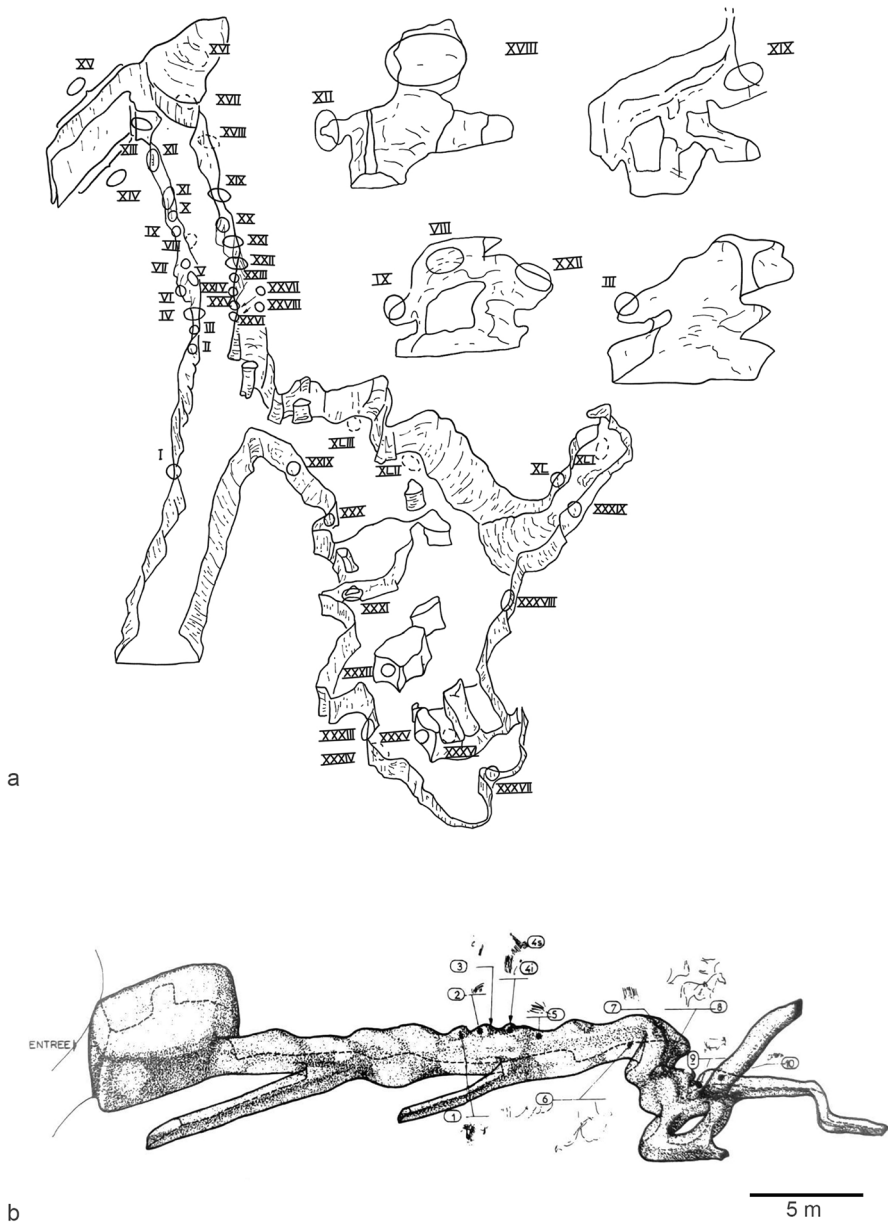


Fig. 5 Examples of proposals for representations trying to go beyond 2D presented by Sauvet (1993). **a** View in elevation of La Pasiega Cave (Cantabria, Spain) (following González García, 1987). **b** Axonometric perspective of La Croze-à-Gontrand (Dordogne, France) (following Delluc *et al.*, 1983)

to discuss, for example, the presence or absence of karst and decorated caves in a region, or to consider the relationship of a cave with its nearby environment (sources of raw materials, *etc.*) (Magnin, 2013; Salomon *et al.*, 2021). Caves could also serve

as important reference points in the landscape (Vialou, 2005; Pigeaud, 2013). It is at this scale that the ‘symbolic territory’ proposed by Pigeaud (2005) would unfold.

Macro Scale

The second scale we propose is that of a level we refer to as *macro*, which considers the cave itself in isolation of its surrounding area. It is at this scale that it becomes possible to examine the development of various parietal arrangements. Several factors must be considered when addressing the macro scale:

Process of Place Selection

The selection of certain areas at the expense of others, despite their suitability for decoration (smooth and accessible walls, visible locations, *etc.*), is an observation that resonates with numerous authors (Laming-Emperaire, 1962; Leroi-Gourhan, 1965, 1972, 1992; Sauvet & Sauvet, 1979; Vialou, 1986; Foucher, 1991; Clottes & Courtin, 1994; Gély & Porte, 1996; Bosinski & Schiller, 1998; Freeman & González Echegaray, 2001; Gély, 2001; González García, 2001; Pigeaud, 2004, 2013; Clottes *et al.*, 2005; Delluc, 2006; Robert Bégouën *et al.*, 2009; Groenen, 2011, 2013; Jousteau, 2021). Clear examples of this can be found in the Hall of the Bulls in Chauvet or certain walls within the Rouffignac Cave, which are richly decorated in the vicinity of other *prima facie* equally (or more) apt surfaces.

These observable choices can be illustrated in several ways.

Firstly, it should be noted that a particular wall (left or right) might be preferred, as observed by Groenen (2013) in the cave of El Castillo, for the striated deer, the cloisonné quadrangles, and the hand stencils. The distribution of motifs has also varied over different periods, leading to the challenge we mentioned earlier in distinguishing the presence of decorative schemes. Certain areas appear to have maintained significance over extended periods, being adorned with depictions separated by thousands of years (Garate *et al.*, 2021). According to González García (2001), this specific focus on particular walls indicates a hierarchical conception of space.

Furthermore, certain types of spaces seem to have particularly attracted the attention of Palaeolithic people. Here, we refer to corners, niches, and diverticules (González García, 2001; Delluc, 2006), as well as hazardous zones, such as the nineteen-meter-deep well in Cosquer (Clottes, 2008), or the daring art of Etxeberri (Fig. 6) or Santimamiñe (Intxaurbe *et al.*, 2022). Some of these hard-to-reach locations were chosen as sites for representation (Stone, 1995; Bahn, 2003; Groenen, 2013), as were particularly unique spaces like the *Sanctuary of Hands* in Gargas (Barrière, 1976; Foucher *et al.*, 2007; Clottes, 2008).

Space Modifications

Beyond participating passively within the structure of the artwork as a support, space was also subject to manipulation by the Palaeolithic people. This occurred firstly in terms of altering the spatial structure itself, involving the breaking and/or

Fig. 6 Etxeberri cave (Pyrénées-Atlantiques, France), graphic reconstruction of the cornice with a black horse and red stains, a high-risk area (© D. Garate & M. Medina-Alcaide)



Fig. 7 Structures in the sector IV of La Garma cave (Cantabria, Spain) (© P. Saura)



displacement of speleothems (as in Las Monedas, Las Chimeneas, El Castillo, Villars, Bernifal, Carriot, or le Combel) or blocks (as in La Garma (Fig. 7), Les Trois-Frères, Domme, Le Tuc d'Audoubert, Ardales, Tito Bustillo, La Pasiega A, Chauvet, Enlène, or Erberua), and even excavating passages directly into the rock surface (as in Pech-Merle or Cougnac) (Groenen, 2016). Secondly, direct manipulation of the material was performed to create the artwork, as seen with clay bas-reliefs of the Pyrenees (Tuc d'Audoubert, Aizpitarte, Labouiche, Bédeilhac, Erberua). In these

cases, instead of adapting to the existing space, the artist altered the volume of the space, essentially crafting the artistic space itself.

Mobility

The shape of the cave also influences our movement within it. It is therefore relevant, in the context of research, to examine the potential connections between movement within the cavity and Palaeolithic decoration, as suggested by Rouzaud (1978), Delluc (1979a), Le Guillou (2005), Pastoors and Weniger (2011), Groenen (2013), Ochoa and García-Diez (2018), and Intxaurbe *et al.* (2021). This can be explored on several levels.

Indeed, to see all the artworks in a cave, the viewer must move around, and this journey is conditioned by the natural structure of the cavity. It is therefore interesting to question the logic of movement. Rouzaud (1978) proposes that the most coherent approach is to choose the easiest path.

Accessibility is now quantifiable through experiments and analyses using geographic information systems (GIS), as demonstrated by the pioneering work of Intxaurbe *et al.* (2021), which adds a degree of objectivity and measurability to this complex parameter.

Another hypothesis put forward by Rouzaud (1978) involves the use of a *guiding wall to facilitate movement within the cavity*. In this regard, M. Groenen and M. C. Groenen (2015) observe no fewer than 732 charcoal marks distributed continuously along the walls of El Castillo cave. According to this study, these might not be random torch marks but potentially intentional marks serving as topographical markers. This interpretation is based on the composition of these marks: while the majority consists of pine charcoal, others contain, in addition to it, manganese dioxide sometimes mixed with iron oxide. On this subject, we must also mention the study of the parietal context, particularly the work of Medina-Alcaide *et al.* (2012, 2015, 2018, 2021, 2023) on charcoal remains found on the cave floors. They propose an interpretation of the occupation of several caves based on the observation of charcoal deposits on the floors, which indicate artificial illumination—and thus human presence—in these areas.

Beyond the notion of the guiding wall, other authors address the issue of finding your way within underground networks (Jouteau, 2021). Ideas such as the presence of signalling panels, with the example of Niaux cave (Robert, 2007, 2012; Clottes, 2010), grease lamps placed on the floor (*e.g.* in Gabillou cave) (de Beaune, 2000), and even, as previously mentioned, displaced speleothems or certain particular motifs on the walls have been proposed.

Public

Speaking about space also leads us to consider the position of the Palaeolithic individuals within these locations, both as creators and recipients of these motifs. We can question, in relation to the creators, what their positioning was like—whether it was convenient, (un)comfortable, or even dangerous—and whether the artworks

Fig. 8 Experimental torch use in a laboratory cave by the *Before Art Project* team (© A. J. Torres Riesgo)



could be produced by an individual alone or required assistance, or even the setting up of a structure.

As for the viewer, different questions arise. The type of audience, whether private or public, as discussed earlier, is one such consideration. This is linked to a range of parameters that can now be measured using recent techniques and technologies.

The question of occupancy capacity has been explored by Neufert (1951), Villeneuve (2008), Pastoors and Weniger (2011), as well as Ochoa and García-Diez (2018). Similarly, the angle of visibility is a topic addressed by Le Guillou with the notion of the *visual field* (2005), Garate (2010), Villeneuve (2008), Ortega Martínez (2014), Ochoa and García-Diez (2016, 2018), Intxaurbe *et al.* (2022), and by Vialou (2009), who discusses the concept of *concealment* through technique or motif placement.

Visibility

The visibility of motifs can also be measured in relation to the main space. In this manner, Groenen (2013) observes that the ornamented areas of El Castillo, Las Monedas, or La Pasiega caves are scarcely or not visible from the main spaces of the cavities. Furthermore, he proposes the idea of viewpoints imposed by certain elements that compel a specific gaze (Groenen, 2016). The confinement of a space, discreet technique, or anamorphosis are features that guide the viewer's perspective, potentially offering new insights into the representation goals of cave art.

Other authors have engaged with the intricate issue of motif visibility, as we have seen, employing various methodologies (Le Guillou, 2005; Villeneuve, 2008; Vialou, 2009; Garate, 2010; Pastoors & Weniger, 2011; Ortega Martínez, 2014; Ochoa Fraile, 2016; Ochoa & García-Diez, 2018; Intxaurbe *et al.*, 2022).

This question naturally also involves lighting issues. Several authors have worked on the way illumination conditions our perception of space, particularly through the analysis and experimental reproduction of fixed lights, grease lamps and torches (de Beaune, 2000; Medina-Alcaide *et al.*, 2021) (Fig. 8).

Micro Scale

The third scale that we propose to consider is the *micro* scale, which is situated directly at the level of the wall. This scale allows us to address questions of figure orientation (horizontality, verticality, facing), their relationships with each other, and their interaction with the wall.

Influence of the Walls

Indeed, it is known that Palaeolithic individuals carefully selected the walls that would host their artworks, often incorporating features of the rock's shape that contribute to the creation of their figures (Sauvet & Sauvet, 1979).

Consequently, within the framework of studying space, one might wonder if this motivation was paramount, potentially rendering the idea of studying the dispersion of motifs obsolete (since the mere presence of suggestive reliefs, in a random manner, would guide this dispersion).

However, it is important to note that while the form and material of the support undoubtedly had an impact when choosing the arrangement of the figures (Sauvet & Tosello, 1998; Wisher *et al.*, 2023), it is not the sole factor in this decision. Indeed, the reliefs could evoke a multitude of different interpretations: a crack could become the leg of a bovid, an equid, or a feline. Moreover, some evocative reliefs were ignored, and when suggestive reliefs were absent, Palaeolithic people simply went without. Furthermore, we would like to note that reliefs have been amply exploited to create some types of motifs, but not others (think for instance of the hands, which are never designed employing wall reliefs or fissures as lines), which may give us some clues as to their nature and purpose. It is reasonable to believe, therefore, that the pursuit of a logic of dispersion is meaningful despite the objective of integrating the reliefs. This notion is shared by Leroi-Gourhan (1972), who asserts that a precedence of the 'rule of place' can be observed over that of the integrated motif's relief.

Interaction Between Motifs

The presence of various motifs scattered across the walls then prompts the question of their interaction or connection. As we have seen with pioneers like Raphaël (1986), Laming-Emperaire (1962), and Leroi-Gourhan (1965), initial attempts were made to decipher these associations (primarily focused on animal depictions). Other hypotheses, such as the connection between the motif of the hand stencil and the briefly mentioned points or discs, are shared by a range of authors (Breuil, 1952; Leroi-Gourhan, 1965, 1967, 1992; Sauvet *et al.*, 1977; Groenen, 1990; González García, 2001; Collado Giraldo, 2018).

The concepts of 'juxtaposition' and 'superposition' ('interlocking', for Vialou (2009), were proposed by various authors for the different combinations of figures, in order to make it possible to capture their situation. Terms like 'integration' or 'fusion' (Sauvet *et al.*, 1977), as well as the varying degrees of separation (Leroi-Gourhan, 1965), seem to rely on the sensitivity of each researcher and may consequently be less relevant.

Sensorial Aspects

Lastly, it appears interesting to broaden our perspective to consider often overlooked elements such as our senses, as well as certain physical elements of the cavity. As noted by Jouteau (2021), in an environment like a cave where complete darkness can prevail, our other senses become heightened and hyper-receptive.

Pigeaud (2013) underscores the importance of *touch* in this unique atmosphere, whereas, on the contrary, Nowell and Van Gelder (2020) contend that ‘while navigating challenging, slippery, wet, bear-pitted, and boulder-strewn floors, Upper Palaeolithic people likely could not see their feet and yet they appear to have refrained from touching the walls or ceilings’. However, it is worth noting that the use of torches rather than grease lamps allows for broader illumination (Medina-Alcaide *et al.*, 2021), which mitigates this assertion.

Pigeaud (2013) also emphasises the sensation of *confinement*. The cave, a finite space, is a markedly different environment from the boundless outside world. Entering it involves a pervasive risk of getting stuck there, having an accident, and simply not getting out.

Other senses, such as *vision*, particularly in relation to light, have been explored by numerous authors (Delluc & Delluc, 1979b; de Beaune, 1987b; Beaune, 1987a, 1995, 2000; Arias, 2009; Lorblanchet, 2010; Pastoors & Weniger, 2011; Medina-Alcaide *et al.*, 2012, 2015, 2018, 2021; Groenen, 2017; Ochoa & García-Diez, 2018; Intxaurbe *et al.*, 2020; Jouteau, 2021). Light also interacts with visibility parameters and influences motif perception, shaping their staging and presentation, as argued by Groenen (2013).

Hearing, in turn, is a sense that could have had a significant impact on the selection of surfaces for ornamentation, especially where resonance is pronounced. Different researchers have explored or highlighted this (Reznikoff, 1987; Reznikoff & Dauvois, 1988; Waller, 1993a, b; Dauvois, 1994; Bahn, 2003; Arias, 2009; Groenen, 2016; Fazenda *et al.*, 2017; Miyagawa *et al.*, 2018; Diaz-Andreu & Mattioli, 2018; Till, 2019; Jouteau, 2021).

The question of sound creation in caves can be linked to various types of instruments discovered in Palaeolithic sites (Absolon, 1935; Bibikov, 1975; Fages & Mourer-Chauviré, 1983; Buisson, 1990; Dauvois, 2005a; Conard *et al.*, 2009), as well as the possible use of lithophones, which are parietal concretions themselves (Glory, 1964a, b; Glory *et al.*, 1965; Dauvois, 1996, 2005b; de Balbín Behrmann *et al.*, 2002; Lorblanchet, 2010).

The significance of natural elements such as *water* should also be considered in the context of space study. Its impact has been noted in some cases of Palaeolithic art (Foz Côa, Tito Bustillo, Pergouset), as well as in other more recent rock art sites, such as those from the Scandinavian Bronze Age. The possibility of acknowledging its presence (visible, audible, tactile, or even tastable (Lorblanchet, 2010; Groenen, 2016)) in the cave’s environment and its potential influence on the distribution of parietal devices should be examined. Additionally, it should be noted that other natural resources, such as iron minerals (pigment source) or clay (raw material source for modelling), could have also played a role in spatial choices.

Finally, let us address the question of *time* perception. As Pigeaud (2013) points out, its perception in caves is very peculiar. Time appears to stand still when we move underground, as demonstrated by experiments on circadian rhythms (Siffre, 1963; Aschoff, 1985, 1988). As we lose access to familiar markers like daylight and external noises, measuring time becomes more challenging. The unique context of this environment can also give us the sense of a change in era, of temporal travel, an impression amplified by the parietal motifs or traces of those who came before us. Time is also present and palpable in the presence of these different generations of motifs on the walls, bearing witness to passages over thousands of years. The temporality of the motifs themselves, with iconography occasionally reflecting the seasonality in which the animal is depicted (Crémades & Bonissent, 1993; Dubourg, 1994; Feruglio, 2006; Azéma, 2009, 2010), represents another form. Lastly, the ‘domesticated’ time of the journey through the cavity, distended by the differences in progress through certain zones, is another factor that interacts with space. As proposed by Lefèbvre (1974), as we have seen, the separation between time and space, commonly found in Western culture, could give way to a perspective where these two fundamental concepts, intertwined, become entwined.

This question of perception is also a focus point where the search for connections between modern humans and the Palaeolithics enters, with researchers like Clottes and Lewis-Williams (1996), who rely on neuroscience to analyse the functioning of our human brains. Bahn (2003), Taçon (1990), Groenen (2013), and Fritz (2020) also align with this perspective on the perception of parietal and cave art, along with the works of Salagnon, d’Errico, Mellet, and colleagues (cf. i.a. Mellet *et al.*, 2019).

Discussion: Beyond the Limits, Combining 3D and GIS as a Methodological Revolution

New Possibilities

We have seen the methodological and conceptual issues that need to be taken into account, and we have proposed a structure for attempting to study the question of space in prehistoric cave art. More than that, we want to propose a new way of dealing with this thorny issue.

This approach, combining several new technologies, has the advantage of addressing with agility the central problems raised in these lines (the subjectivity of the researcher and the challenges of illustration). Our proposal provides us with an empirical, reproducible and quantifiable way of overcoming these problems.

Indeed, if two-dimensional representation and description falls short for capturing space, why not explore 3D imagery and the analytical methods it enables (Fig. 9)? Three-dimensional representation through computer software, utilising techniques like photogrammetry or laser scanning, has been a form of illustration already adopted by some archaeology researches in recent years, including the very discipline of cave art study (González-Aguilera *et al.*, 2009; Azéma *et al.*, 2010, 2012; Fritz *et al.*, 2010; Beraldin *et al.*, 2011; Angás *et al.*, 2013, 2014; Galeazzi

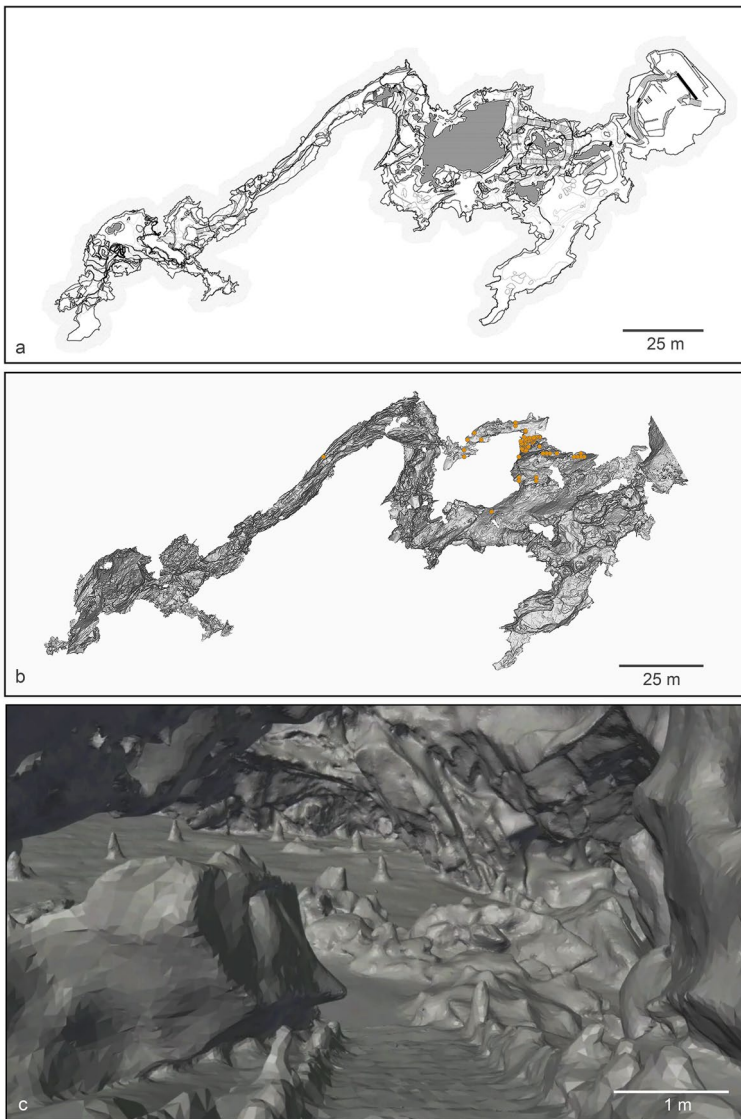


Fig. 9 Comparison of plan and 3D images of El Castillo (Cantabria, Spain). **a** Plan. **b** Orthogonal view of the 3D model. **c** 3D view (© Consejería de Educación, Cultura y Deporte del Gobierno de Cantabria)

et al., 2014; Cassen *et al.*, 2014; Alexander *et al.*, 2015; Cortón Noya *et al.*, 2015; Rivero *et al.*, 2019).

In addition to illustrating, the use of 3D also enables the study to go beyond the famous categorisations proposed in previous study methods: space is seen and conceived as a whole without subdivisions or lexical descriptions.

On the basis of these three-dimensional structures, it becomes possible to take the research one step further, using software such as GIS (geographic information

systems), which facilitate the measurement of a range of geospatial data. These systems are today widely embraced in archaeology in general, particularly in the field of landscape archaeology, with studies relating to analyses of visual and auditory fields of sites, their geographical distribution or their proximity to surrounding resources (Wheatley & Gillings, 2000, 2002; Wheatley, 2004; Llobera, 2007, 2012; Magnin, 2013; Gillings, 2015, 2017; Wienhold & Robinson, 2017; Díaz-Andreu *et al.*, 2017; Wernke *et al.*, 2017; Landeschi, 2019; Dell'Unto & Landeschi, 2022). GIS has also proven its effectiveness in underground environments (Moyes, 2002; Herrmann, 2002; Ortega Martínez, 2012, 2014; Landeschi *et al.*, 2019; Louman, 2022; Intxaurbe *et al.*, 2022) and rock shelters (Bourdier *et al.*, 2017). We note, however, that the combination of the two, *i.e.* the application of GIS to decorated caves as three-dimensional objects (and not just as planar surfaces), is not straightforward, as these tools were designed for a two-dimensional universe. The idea that we bring, following the innovative work of Intxaurbe and its team (Intxaurbe *et al.*, 2020, 2022) is to navigate in a hybrid environment combining GIS and the three-dimensional nature of the caves, thereby creating new possibilities to combine their capabilities. Primarily applied to the study of rock motifs, these recent studies have focused on issues on questions of accessibility, visibility, capacity, and optimal passage routes. To these lines of research, we propose to add, via the GIS, a special focus on themes such as ease of execution, use of the available surfaces, dangerousness, and clustering of figures.

This method, aimed at quantitatively describing and characterizing underground spaces, combines three-dimensional capture tools, geomorphological analysis, and GIS tools. This process encompasses a series of working steps.

(i) Laser Scanning

First of all, we begin by acquiring three-dimensional models of the caves using laser scanning techniques (employing devices like the *Terrestrial Laser Scanner 3D*).

Laser scanning is a method that employs laser beams to replicate the surfaces of a site by capturing millions of geolocated points (point cloud) through multiple scans. These scans are subsequently triangulated to construct a mesh, forming a unified 3D object. This process generates a file with .obj extension, which is compatible with 3D software such as *Blender*.¹

This collection of three-dimensional data, allowing for the rapid capture of extensive spaces, can be coupled with the recording of wall textures (visual appearance), although nowadays the precision of texture mapping is relatively limited.

The resulting 3D models, at both relative and global scales, provide a millimetre-precise representations of the current shape of the cave, with a negligible degree

¹ Blender is a free and open-source software tool, currently at its 4.2.0 version (URL: <https://projects.blender.org/>).

of error (for instance, in the case of Atxurra, Intxaurbe *et al.* estimate an error of around 1 mm per 25 m, with 90% reflectance (Intxaurbe *et al.*, 2020)).

(ii) Geomorphological Characterisation of the Cave

In order to analyse the caves housing Palaeolithic cave art and how these spaces influence the execution process of such art, it is crucial to understand the original state of these spaces at the time when the graphic manifestations were created. This requires identifying and excluding any processes that might have occurred within the caves, including those related to endokarstic dynamics, taphonomic processes, and the anthropic alterations. Thus, the geomorphological study of the cave becomes imperative. It entails identifying distinct morphological features and sedimentary bodies, establishing the overall stratigraphy of different sectors within the cave, and ultimately defining the evolution of the subterranean landscape over time (Palmer, 2007; Lacanette & Malaurent, 2010; Aranburu *et al.*, 2015; Arriolabengoa *et al.*, 2018a; Arriolabengoa *et al.*, 2018b, 2020). It is worth noting that obtaining a preliminary 3D representation of the cave beforehand facilitates the geomorphological study of the site.

(iii) Photogrammetry

As mentioned, the three-dimensional model obtained through laser scanning, which is more focused on reliefs than on nuances of the walls, does not provide precise information about the wall motifs. Therefore, we subsequently employ photogrammetric techniques to obtain three-dimensional models of the studied wall motifs. This second documentation technique allows us to overcome the limitations of the former. By combining with the 3D model, photogrammetry enables the creation of a photorealistic textured reproduction of the wall, providing us with detailed information about the state of the figures and facilitating their thorough analysis.

(iv) Geolocation of Graphic Units

The graphic units, the subject of our study, must then be geolocated in order to be accurately placed on the three-dimensional model. This operation can be accomplished using various sources of information. Firstly, photogrammetry, when geolocated and positioned on the 3D model, provides a precise definition of the motif's location. Additionally, the use of a total station is a reliable method for recording motif locations. For more inaccessible areas, portable devices like DISTOX2 can also serve this purpose. This process of geolocating wall motifs is necessary for the subsequent application of mathematical algorithms related to GIS.

(v) Reconstruction of Prehistoric Subterranean Space

Once all this data is acquired, we need to reconstruct the subterranean space to achieve the most faithful reproduction of the space at the time of the execution of the artwork. In addition to the data from the geomorphological study, we rely on the study of documentation, archives, and historical publications to enhance our understanding of recent cave evolutions (Ochoa *et al.*, 2017).

We then proceed to process the three-dimensional model to recreate the subterranean spaces as they were at the time of the execution of the motifs. Using a three-dimensional graphic editing software like *Blender*, we eliminate or reconstruct the required formations, modify the space and remove anthropogenic additions.

(vi) GIS Analysis

With the reconstructed subterranean environment and the precisely geolocated figures within the 3D model, we can perform a series of measurements using GIS. Indeed, as previously mentioned, our goal is to obtain new quantitative data to better understand the distribution of motifs within the network. Following the approach of Intxaurbe (2020, 2021, 2022), a Python script describing a workflow (a list of analyses that the program will perform one by one) is applied in a data processing and analysis software such as ArcGIS©.² This script enables calculations of accessibility, visibility, capacity, dangerousness, and optimal path. We propose to complete it, as we mentioned, with questions such as ease of execution (for specific figures, like hand stencils), use of the available surfaces, dangerousness, and clustering of figures.

(vii) Statistical Analyses

Finally, the last step involves the statistical analyses of the data to conduct correspondence studies of various factors (such as chronological or geographical contexts of rock art, or the location characteristics of the figures) to identify distinct patterns in the selection of specific sites within decorated caves. For this purpose, all documentation is input into a database for organisation and information management. The formal characteristics of the sample are individually analysed using tests such as Shapiro-Wilk normality tests (Royston, 1982a, b, 1995), for instance, using R³ (R Core Team, 2022), and multivariate analyses are not conducted without prior acceptable results. Once this step is completed, we proceed with factor analyses using the R FactoMineR package (Lê *et al.*, 2008).

Limits

We are prompted to question whether the possibilities offered by new technologies such as 3D and GIS are truly suited for the study of cave art. Let us examine the constraints and advantages of this novel approach.

An important feature of such methods is that they require preliminary questions. Thus, analysis axes such as the location of patterns in relation to each other, in relation to dangerous or difficult-to-access areas, their position in the network in general or their visibility have already been considered with promising results (Intxaurbe *et al.*, 2022).

² ArcGIS Pro is a privative GIS software developed by Esri, currently at its 3.2.1 version (<https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview>).

³ R is a free software environment for statistical computing, currently in its 4.3.3. version (<https://www.r-project.org/>).

These technologies and programs, combined with statistical analysis methods, offer a fresh perspective that distances us from traditional methods, which rely on description and measurement means that may seem subjective. However, as mentioned, the problem of false objectivity must be monitored, as it is never far away. Similar to statistics, GIS also have limitations, as pointed out by Brouwer-Burg (2017), who highlights the non-representativeness of certain data (linked to researcher bias and taphonomy).

While it allows a compelling illustration of an underground network, 3D representation also has its limits: it does not capture all the sensations or challenges experienced during the journey, potential feelings of danger, or the spatial fragmentation that might be felt along the way. A small corridor on a screen can differ greatly from the experience of having to crawl through a tight passage, just as a picture of a cliff compared to the sensation of falling off a precipice. Therefore, caution is necessary, even though immersive virtual reality now offers a way to reduce such pitfalls (Torres *et al.*, *under review*).

The question of lighting might draw similar observations. However, recent technological advancements alleviate this concern, as it is now possible to replicate lighting conditions similar to those of the era. Rather than observing that 3D might disconnect us from the physical sensations of being in the cave, as asserted earlier, it can actually bring us closer to its actual appearance. This is complemented by the potential for morphological studies of underground networks, which allow researchers to recreate the cave space as it was in the Palaeolithic era, shedding light on the potential of these innovative methods. As noted by Jouteau (2021), the advantage of numerical simulations lies primarily in their capacity to reconstruct physically lost conditions, creating reproducible results, which is invaluable in the field of research.

Conclusion: Challenges and Opportunities

Faced with the perils that research on spatial aspects of Palaeolithic cave art has encountered, such as the arbitrary nature of spatial categorisations, the inaccurate representation of these spaces, or the lack of objective data, the method we propose appears promising in its aspiration to be as systematic, reproducible, and objective as possible by measuring quantitative data. It also holds the advantage of potential extension to other environments, motifs, and a broader geographic and chronological scale.

It is worth adding that this type of digital format, in line with the principles of *open science*, allows for the democratisation of scientific research, making it accessible to a wider audience, thereby promoting multidisciplinary and ensuring openness at all levels of society, while allowing at the same time proper conservation of such a precious heritage.

Throughout these pages, we have witnessed the varying degrees of complexity brought about by the exploration of space. These, added to the specificities of the study of Upper Palaeolithic cave art, make this area of research a delicate and labyrinthine one.

However, the perspectives offered by a multidisciplinary approach to research enable us to view it through a different lens. Emerging technologies, in particular, are now opening up doors previously inaccessible to researchers, holding great promise (exhaustiveness, objectivity, illustration/description, quantification of data, *etc.*). Despite the numerous challenges, their impact is too significant to be dismissed.

In conclusion, we wish to underscore that, throughout this synthesis essay on the concept of space, we have refrained from attempting to provide a definitive definition of this term. Indeed, the vastness of its scope led us to avoid the risk of cutting short all the possibilities of thoughts gravitating around it. Its multiplicity is an integral part of its essence, and that is how we wanted to present it.

Lastly, let us acknowledge that all these notions, ideas, and attempts to comprehend spatial management through diverse interpretations are interesting in their efforts to take a step closer to the meaning of cave art. More than mere observation, they strive to interpret and approach sense. Step by step, within these unique spaces, we endeavour to move forward in the direction of the creators from millennia ago. This is a hope that is well worth the effort.

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Declarations

Competing Interests The authors declare no competing interests.

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