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RESEARCH ARTICLE

The elusive intertidal: Wave forms and coastal dynamics through architectural representation

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Abstract

Background

This study combines cartographic sources with the situated knowledge of the local surfing community to address the lack of information describing intertidal zones in coastal areas, using the mouth of the Douro River as a case study. It employs architectural representation as a means of integrating knowledge from different disciplines and exploring the relationships among wave action, currents, flooding, and shoreline evolution. The underlying hypothesis is that recurring coastal and seabed configurations reflect recurring maritime dynamics, and that the ways in which these dynamics are represented contribute to the social construction of facts.

Methods

The methodology involved the systematic archival collection of 75 documents (1634–2021), which were standardised to reveal long-term transformations of the sandspit. These historical records were compared with oral histories and personal archives from surfers who experienced the river mouth before the construction of the jetties. These disparate sources were integrated into original drawings using architectural conventions to represent dynamic processes within a static medium.

Results

Using the mouth of the Douro River in Porto, Portugal, as a case study, this research maps dynamic coastal systems and identifies the tensions between biophysical morphogenesis and competing human

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uses, such as port navigation and surfing. It identifies changing patterns within the intertidal zone through historical cartographic evidence, reconstructs vanished wave forms through surfers' counternarratives, and employs architectural representation to bridge the gap between terrestrial and marine modes of representation.

Conclusion

By applying critical cartography and the concept of *situated knowledges*, this study challenges the "view from nowhere" associated with conventional mapping. It demonstrates how the 2004 construction of the jetties privileged engineering interests over the situated expertise of surfers, whose world-class waves were erased from the official record. Ultimately, the paper reframes the intertidal as a site of "matters of concern," where biophysical and social agencies converge.

Keywords
Coastal Mapping; Architectural Representation; Situated Knowledges; Critical Cartography; Wave Morphogenesis

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Introduction

Coastal representation is a branch of cartography traditionally divided into two distinct disciplines: topography and bathymetry (Gesch & Wilson, 2002). The former concerns the terrestrial domain, while the latter focuses on the seabed. This division results in a lack of precision in the representation of the intertidal interface, owing both to the temporal asynchrony of surveys, a critical issue in environments characterised by continuous change, and to the discontinuity between the two systems of representation. As a result, the boundaries between the respective surveys are not always clearly defined, often leaving gaps in the representation of the intertidal zone.

Recent developments in bathymetric surveying have expanded seabed coverage and improved spatial resolution, exemplified by the Nippon Foundation–GEBCO Seabed 2030 project (Mayer et al., 2018). On land, advances include the widespread use of airborne LiDAR systems (Wang et al., 2023), enabling more detailed topographic mapping of coastlines. More recently, the Surface Water and Ocean Topography (SWOT) satellite altimetry mission has provided rapid, large-scale observations of coastal environments (Yeasmin et al., 2026). However, deriving intertidal topography from these data remains challenging, particularly because of the difficulty of automatically distinguishing water-covered pixels from exposed but still wet surfaces.

Although these technologies provide high-resolution information that helps resolve interface areas overlooked by previous surveys, they do not account for the variety of dynamic processes or the social and more-than-human interactions occurring within the intertidal zone.

Oceanic waves have long been studied for their physical properties (Loper, 2017) and, more recently, for their cultural and media dimensions (Helmreich, 2023). Dynamic maritime phenomena, such as currents and swell, are typically represented cartographically through numerical parameters, including intensity, direction, wave height, and wave period, and are made readily available through weather forecasting platforms. Nonetheless, the visual representation of water movement remains an unresolved challenge, creating further difficulties in accurately representing and understanding intertidal environments.

The mapping of dynamic systems has become an important area of experimental research (Aït-Touati, Arènes, & Grégoire, 2022; Zwer & Rekacewicz, 2021; Bremner, 2022), with promising approaches challenging conventional methods of representing the interplay between landscapes and ecological dynamics. In relation to water, authors such as Dilip da Cunha have argued that mapping, shaped by a colonial perspective, has historically overlooked the subtleties and variability of the fluid relationships that characterise riverine and coastal environments, often contributing to the dysfunctional organisation of urban settlements in relation to biophysical systems (da Cunha, 2018). Drawing on case studies of the Ganges River and the representation of the Mumbai estuary (Mathur & da Cunha, 2009), da Cunha and Mathur argue that coastal territorial representation should move beyond the binary distinction between land and water to reveal the different degrees of wetness that exist across the landscape. Their work, grounded in the analysis of historical cartography, provides an important reference for the present study.

Beyond the technical challenge of mapping the physical characteristics of dynamic coastal environments, intertidal representation also raises epistemological questions about the forms of knowledge that cartography can accommodate. Conventional mapping methods privilege measurable physical attributes while often overlooking the situated understandings developed through lived experience. These include forms of knowledge generated through navigation, fishing, surfing, and other practices that emerge from sustained engagement with the coastal environment (Ingold, 2000). Recognising these perspectives aligns with Haraway's (1988) concept of *situated knowledges*, which argues that objectivity does not arise from a detached "view from nowhere" but from specific, embodied, and context-dependent positions. Incorporating these situated perspectives into coastal mapping broadens our understanding of the intertidal zone beyond its measurable morphology, acknowledging it as a space constituted through the continuous interaction of physical processes, human practices, and more-than-human agencies.

Within this framework, this paper uses the mouth of the Douro River in Porto, Portugal, as a case study to explore the challenges of mapping dynamic coastal systems and to identify the tensions between biophysical dynamics and the competing human uses that shape this intertidal environment.

The Douro River is an international watercourse that rises in the Sierra de Urbión, Spain, and flows for approximately 897 km before reaching the Atlantic Ocean. Historically, it has been the primary source of fluvial sediment for the northwestern Portuguese coast, supplying the littoral drift that nourished beaches along much of the central Portuguese coastline (Dias et al., 2002). During episodic flood events, large volumes of sediment were discharged through the estuary and redistributed southwards by waves and longshore currents, playing a key role in shaping both the estuarine

morphology and the adjacent Atlantic coastline (Dias et al., 2002). Since the construction of a cascade of dams along the river throughout the twentieth century, however, sediment delivery has been drastically reduced, profoundly altering the estuary's morphodynamics and contributing to a chronic sediment deficit and widespread coastal erosion (Bastos et al., 2021).

Cabedelo do Douro is the name given to the sandspit, a semi-permanent landform created through the continuous redistribution of sediments by the competing processes of fluvial deposition and marine erosion, that forms within the intertidal zone at the mouth of the Douro River. Its morphology depends on a delicate balance between sediment supplied by the river and sediment removed and redistributed by waves, tides, and coastal sediment transport, a balance continually challenged by recurrent extreme weather events. This fragile equilibrium has been increasingly disrupted by anthropogenic interventions, particularly the construction of dams and harbour breakwaters. Consequently, the sandspit exists in a constant state of transformation, with its position, extent, and morphology changing over time.

This dynamic behaviour challenges conventional approaches to planning and management. The river mouth has long been the focus of competing interests: port authorities and developers seek to maximise navigability and economic activity; public authorities prioritise safety, flood protection, and the stabilisation of the river entrance; ecologists emphasise the importance of its habitats and sedimentary processes; while beach users, including surfers, value the very morphodynamic conditions that create recreational opportunities.

For centuries, major floods in the Douro estuary brought destruction: riverbank settlements were threatened by rising waters, debris-laden currents disrupted navigation, and harbour activities came to a halt. Yet it was not until the 1980s that surfers recognised another consequence of these events: the formation of world-class waves at the river mouth. Compared with the city's long-standing functional and cultural relationship with the river, this surfing era was relatively brief. It ended abruptly at the turn of the twenty-first century, when major harbour engineering works, including the construction of long jetties and breakwaters on both sides of the estuary, transformed the river mouth's hydrodynamic and sedimentary regime, causing the world-class waves to disappear.

From 2001 onwards, the planning and construction of the jetties coincided with the implementation of a systematic monitoring programme to document the evolution of the sandspit, supported by increasingly sophisticated surveying and remote-sensing techniques, such as those employed by M. Eduarda Jesus in 2003 (Martins, 2026a, Sequence no. 65). Yet neither the emergence nor the disappearance of these waves was ever recorded in cartographic documents. The wave forms and hydrodynamic processes that shaped the intertidal sandspit remained absent from these representations, effectively left blank on the map, together with the surfing activity they made possible.

Contemporary critical cartography is founded on the recognition that maps are not neutral representations but active agents in the production of reality. As Denis Wood famously argued, "maps construct, not reproduce, the world" (Wood, 1992). This understanding has inspired a growing body of research exploring alternative forms of cartographic representation that challenge the conventions of authoritative mapping and incorporate multiple ways of knowing (Harley, 1989; Crampton, 2001; Zwer & Rekacewicz, 2021).

This paper develops a repertoire of graphic conventions for producing and communicating knowledge about the intertidal at the mouth of the Douro River. By combining historical cartography with the experiential knowledge of surfers, both translated into architectural drawings, we propose a method for representing wave morphogenesis and intertidal dynamics cartographically. This approach provides a means of making dynamic maritime processes legible within the conventionally static medium of cartography.

Methods and materials

Case study

The research is based on the Cabedelo do Douro case study. Cabedelo is the sandspit located at the mouth of the Douro River in the city of Porto, Portugal. Its selection as a case study is justified by the intensity of the biophysical processes concentrated within its approximately 1 km-long extent.

The Douro River generally flows through a narrow valley bordered by steep granitic slopes, causing water levels to rise rapidly during flood events and generating exceptionally strong currents. Early twentieth-century sources (Machado Jr., 1917) report a maximum discharge of 30,000 m^3/s, exceeding that of both the Tagus (12,000 m^3/s) and the Danube (28,000 m^3/s), despite the latter two rivers being considerably longer than the Douro. More recent sources report a maximum discharge of over 13,000 m^3/s (Azevedo et al., 2010). Moreover, the river mouth is exceptionally narrow, further intensifying the influence of river currents on patterns of sediment accumulation.

Another distinctive feature of the Douro is the size of its hydrographic basin, which covers approximately 100,000 km^2, making it one of the largest on the Iberian Peninsula. Rainfall collected across this vast catchment transports sediments generated through erosion downstream. This explains why the Douro is the principal source of sediment that, carried southward by the dominant longshore currents, nourishes approximately 200 km of the Portuguese coastline, extending as far as the Nazaré Canyon. Beyond the river mouth, the advance and retreat of the Portuguese coastline are therefore closely influenced by these sedimentary dynamics.

Sandspit long-term transformation

Evidence of changes in the shape of the case study sandspit is documented through historical cartography. Records dating back to 1634 were collected from a variety of sources. However, only those produced from 1789 onwards can be rigorously compared, as they share the same projection system. Prior to 1855, relatively few records are available, with only ten maps covering a period of 66 years. Digital archives were consulted at the Municipal Historical Archive of Porto, the National Library of Portugal, the online catalogues of the National Library of France, the Austrian National Library, the Cartographic and Geological Institute of Catalonia, and the General Digital Library of the University of Coimbra (specifically the Nabais Conde Collection). In addition to the archive of the Hydrographic Institute of the Navy in Porto, the largest collection of unpublished material was obtained from the local port authority (APDL – *Administração dos Portos do Douro, Leixões e Viana do Castelo, S.A.*).

A total of 75 documents were identified and arranged chronologically (Martins, 2026a). These sources range from the earliest graphic representations of the port to city maps, topographic and bathymetric surveys, and photogrammetric and satellite imagery (Martins, 2026b). Each document was standardised to the same scale, orientation, and framing, creating a consistent basis for comparison despite the heterogeneous nature of the original sources. From these documents, 165 distinct sandspit contour positions were extracted, with each contour recorded on a separate layer identifying its original source. A contour line was then traced to approximate the boundary between sand and water. This process was carried out digitally using AutoCAD, a vector-based drawing software widely used in architectural practice.

Because the collected sources employed different map projections and representation methods, they were originally produced for a variety of purposes, ranging from navigation charts and technical surveys to political or institutional representations. Consequently, their accuracy and level of detail vary considerably. In many cases, it is not possible to determine whether a given drawing represents high or low tide. However, because the objective of this study was to reconstruct the long-term transformation of the sandspit, these limitations in the historical representations were considered acceptable.

The documents also made distinct contributions to the drawing series according to their origin and level of detail. Some, particularly those produced to support harbour engineering works, contained multiple superimposed shoreline outlines. In such cases, it was possible to distinguish successive shoreline configurations within a single source, while variations in line type and graphic conventions provided additional detail for interpreting the drawings.

The resulting dataset makes it possible to visualise the dynamics of the sandspit either as an animated sequence (Martins, 2026c) or as a chronological series arranged sequentially, similar to a comic strip (Figure 1).

Wave shape before 2004

As no archival documentation describes the shape of the waves, this information was gathered directly from surfers representing different generations of users of the site. Oral accounts, including filmed and transcribed interviews with three key participants, as well as informal conversations with other surfers and third-party accounts, provided an important source of information for reconstructing the site's hydrodynamic characteristics. These testimonies included qualitative observations, such as the large quantities of material transported by the river (in the most extreme and anecdotal cases, including reports of cars, trees, and even a cow), changes in water colour (from green to muddy), the sound of sand being carried by the current, and changes in buoyancy when moving from saltwater to fresh or brackish water.

Beyond the anecdotal nature of oral histories, these accounts proved valuable in describing the routes surfers used to reach the waves, whether by paddling or with the assistance of motorised boats, and the ways in which river currents either facilitated or hindered movement. These descriptions were consistently corroborated across the different sources.

It is important to note that surfing was only introduced to Porto in the early 1980s. Before then, direct experience of these waves was largely confined to fisherfolk and sailors, whose relationship with the water differed fundamentally from the embodied experience associated with surfing.

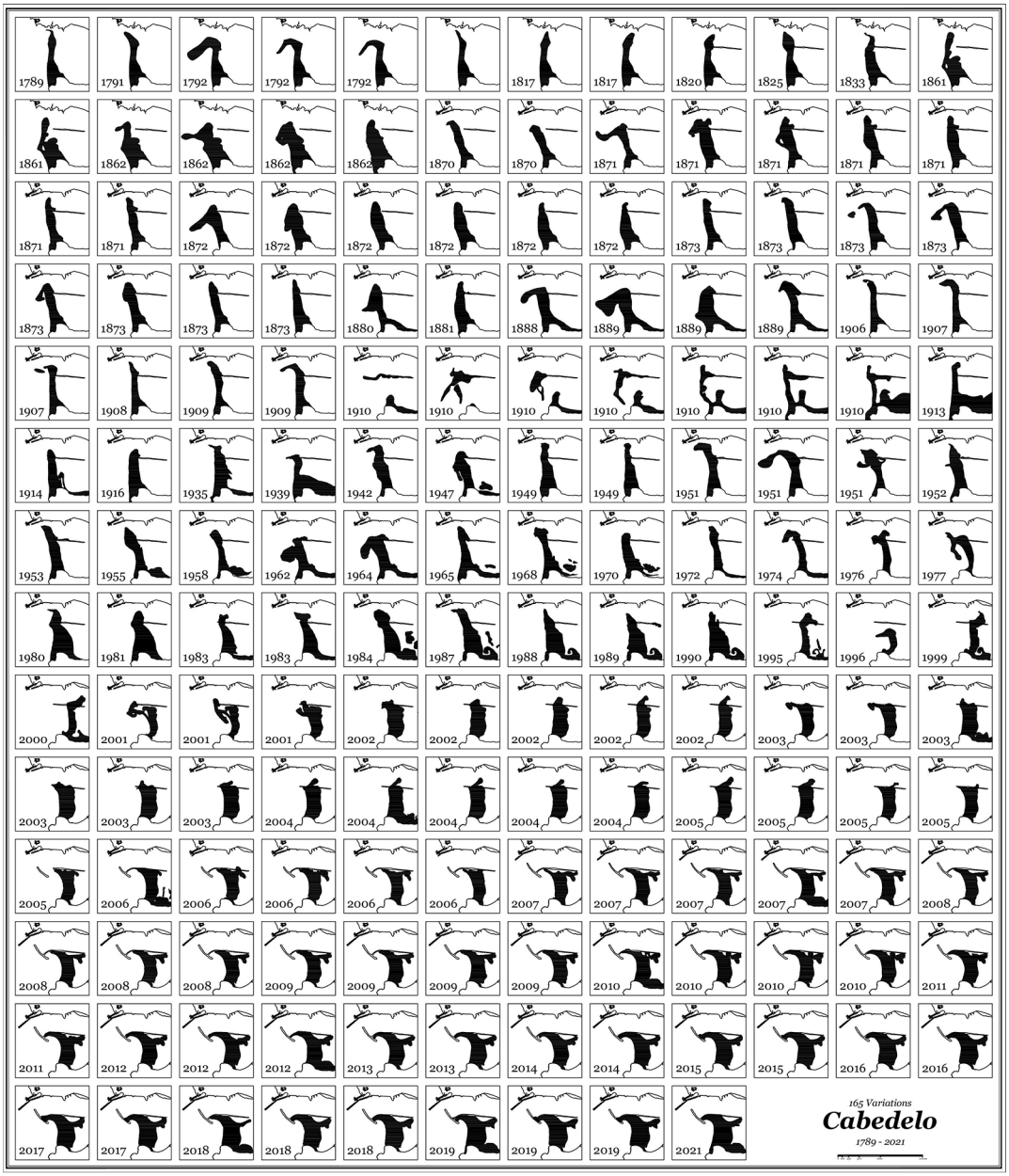


Figure 1. Chronological grid of 165 graphically standardised cartographic surveys of the Cabedelo (1789–2021), by Ivo Poças Martins, 2026.

The interviewees were selected on the basis of their shared experience of Cabedelo do Douro and their complementary expertise in surfing. One participant had surfed at Cabedelo since the early 1980s and had an outstanding competitive record, allowing the study to place local wave conditions within a broader historical context and to compare them with other internationally recognised surf breaks. A second participant was a surf photographer who had extensively documented the Cabedelo waves on film. The third was a surfer with formal training in architecture, whose expertise proved instrumental in representing wave dynamics and surfing phenomena through rigorous cartographic conventions.

The interviewees also provided access to a broader archive of personal, previously unpublished photographs and videos (Figure 2). These visual materials offered a retrospective record of the wave forms and, through detailed analysis, provided sufficient references to represent moving water as a stable architectural element. The scale of a surfer riding a wave offers a tangible reference for estimating wave dimensions, while moving images reveal the characteristic patterns of wave breaking.



Figure 2. A-frame wave breaking offshore at the mouth of the Douro River, Porto, Portugal. Photograph by Miguel Dolce, 1997.

The combination of oral histories and visual documentation made it possible to reconstruct the wave forms that existed during the late twentieth century, prior to the construction of the breakwaters. Together, these sources provided insights into the morphology of the waves and their evolution over time.

Designing the waves

The reconstruction of the vanished world-class surfing wave provided valuable insights into the dynamic transformation of the sandspit. Because the profile of the underwater sandbars has a significant influence on the shape of the surf break, the visual representation of the waves, combined with surfers' situated knowledge, made it possible to reconstruct short-term changes in the morphology of the sandspit. These processes were cyclical, occurring each year during the flood season. Floods and coastal storms were the principal drivers of these transformations, which can be summarised as a five-stage sequence:

Before the Flood – Under normal conditions, the river displayed a stable configuration, with substantial sand accumulation within the navigation channel and a consistent surf break.

The Flood – Flood events were characterised by rising water levels, darkening river waters, and increasingly powerful currents. As water levels rose, the exposed sandspit became submerged while the river transported large quantities of sediment and other debris at high velocity.

Receding Waters – As water levels gradually receded, river currents remained strong and the former sandspit became a shallow submerged platform, with small sand islands and shoals occasionally emerging offshore. At this stage, tall barrelling waves began to form at the river mouth, breaking to the left (northwards). It was common for a wave to begin breaking offshore and continue into the river channel before dissipating.

A-Frame Wave – As river discharge decreased, the waves continued to break to the left but also began breaking to the right, forming what surfers describe as an "A-frame," or triangular peak. This configuration is particularly valued because it allows rides in either direction.

After the Flood – As river discharge returned to normal, the newly formed underwater sandbar typically produced a right-breaking wave (southwards). These waves often retained their barrelling shape and considerable length, allowing for longer rides and, at times, enabling more than one surfer to ride the same wave simultaneously.

The five-stage sequence informed the production of four maps, each corresponding to a distinct wave configuration: Before the Flood, Left, A-Frame, and Right (Figures 3–6). The maps were produced in AutoCAD following a protocol inspired by historical cartographic materials, including military fortification maps, and were prepared at a printed scale of 1:2,500. They were based on surveys from three different dates, June 2001, December 2002, and March 2003, all produced by M. Eduarda Jesus (Martins, 2026a, Sequence no. 65). Although these source materials were not originally intended to represent wave dynamics, they provided a consistent cartographic framework for visualising the information derived from the interviews and surfers' personal archives.

The large map scale made it possible to develop a rich set of graphic conventions, including detailed symbols, legends, and annotations. Maintaining a consistent geographic frame made temporal changes readily apparent, while the graphic treatment of water highlighted the dynamic processes under investigation. Variations in linework were used to distinguish different swell conditions, wave intensity, river currents, and surf-break configurations. In addition, the maps incorporated the principal routes and movement patterns described by the surfers.

A deliberately restricted colour palette was used throughout: blue for bodies of water, black for all other elements, and, where necessary, red for annotations. This approach emphasised the development of graphic conventions, including linework, negative space, form, directionality, and hatching density, rather than colour. Variations were explored primarily through changes in line density. To reinforce the blurred boundary between land and water, this transition was intentionally not represented by a single, sharply defined line.

The first map, Before the Flood (Figure 3), is based on a survey conducted in June 2001 (Martins, 2026a, Sequence no. 65). This period is typically characterised by low rainfall and low river discharge. Accordingly, the water is rendered in a light, relatively uniform tone. In the northern part of the Cabedelo, a dense black mass represents the artificial mole constructed in the 1820s. The navigation channel is clearly defined, although substantially constrained by the distal head

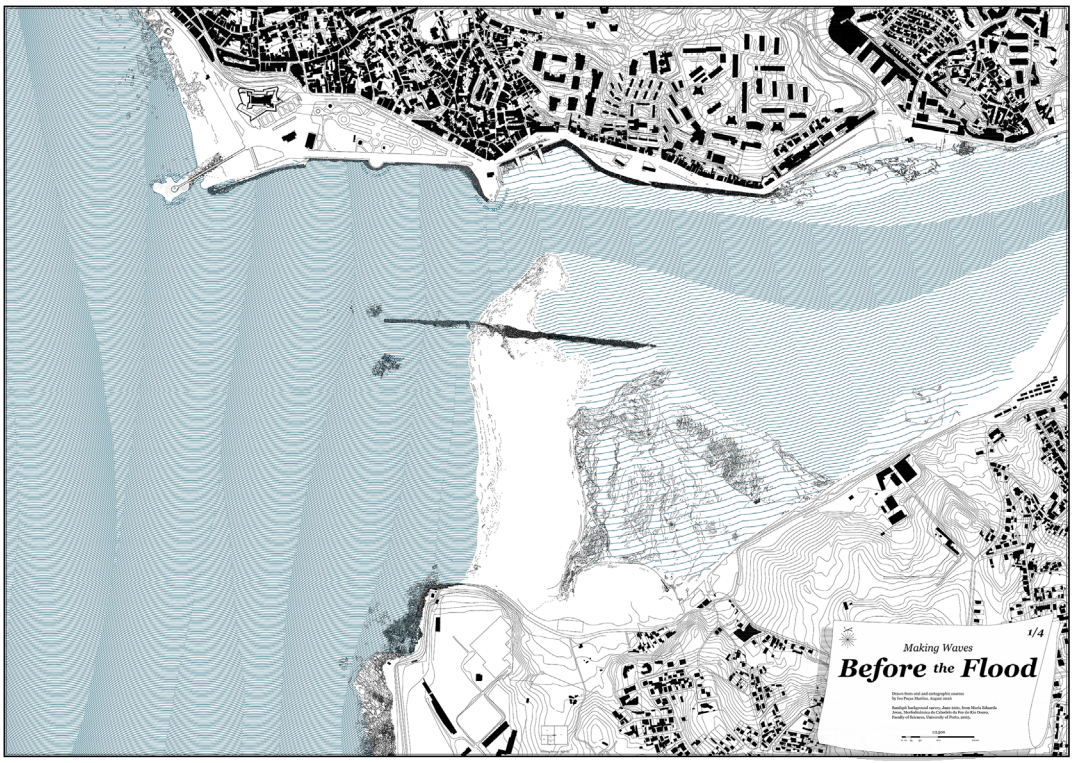


Figure 3. "Before the Flood" map, based on the June 2001 cartographic survey of the Douro sandspit (Cabedelo), by Ivo Poças Martins, 2026.

of the sandspit. On the seaward side, hatching is used to evoke the effect of a gentle swell with a long wave period, while additional hatching creates a subtle sense of relief. The river side is represented with a similar tonal intensity but a more regular wave pattern, suggesting a calmer water surface. The colour intensity gradually decreases towards the riverbanks to indicate the deeper navigation channel. On the southern side, the water hatching becomes more dispersed and is superimposed over a series of black lines representing a sandbar exposed at low tide. This pattern depicts both the texture of the sand and the delicate network of drainage channels revealed as the tide recedes.

The second map, Left (Figure 4), is based on a survey of the Cabedelo conducted in December 2002 (Martins, 2026a, Sequence no. 65), capturing the navigation channel following a flood, when it had been cleared of accumulated sand and was fully exposed to the surf break. On the seaward side, south of the old mole, an accumulation of sediment is visible. The sea is represented with a darker shade of blue, reflecting higher-energy conditions, shorter wave periods, and a rougher surface texture. In places, the wave crests are emphasised through unfilled areas representing breaking foam. This graphic convention is most evident within the navigation channel, highlighting the left-breaking waves that interfered with navigation.

A focal point, marked by a flag symbol, is located at the western end of the 1820s mole, where river-borne sediments tended to accumulate. This was the point at which the waves consistently peaked, making it the ideal location for surfers to catch the wave.

These conditions were characterised by exceptionally strong currents, and surfers often relied on small motorised boats, particularly those moored in a small harbour on the northern bank, to reach the take-off zone. These routes are represented by red lines, while a dotted blue line indicates the drift of surfers carried downstream by the current after completing a ride. When assisted by boats, surfers and boat operators followed a continuous shuttle route between the take-off zone, the breaking wave, and the offshore drift.

The plan makes the sequence of successive waves visible. As a wave set begins to break, the foam crest accentuates the face of the following wave, while the successive peaks advance towards the shore. A subtle arch suggests the barrel, and

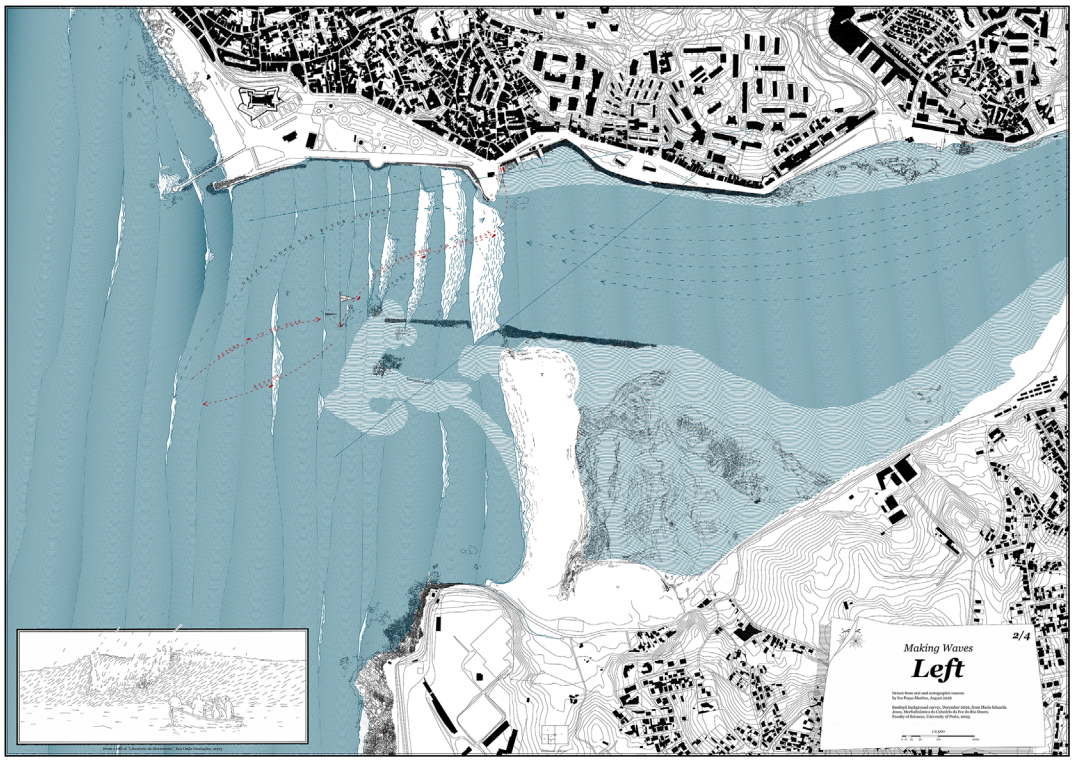


Figure 4. "Left" map, based on the December 2002 cartographic survey of the Douro sandspit (Cabedelo), by Ivo Poças Martins, 2026.

the area of breaking foam progressively increases until the final wave of the set, where it extends across the full width of the wave.

A vignette in the lower-left corner complements the plan with a low-angle perspective based on a film still. The image depicts a bodyboarder descending the wave after take-off and preparing to execute a bottom turn. Fine lines suggest spray rising from the wave crest, indicating a light offshore breeze. Although the prevailing local wind direction is from north to south, the deep river valley shelters the Cabedelo, creating the light offshore conditions illustrated in the drawing.

The third map, A-Frame (Figure 5), is based on the December 2002 survey of the Cabedelo (Martins, 2026a, Sequence no. 65). It follows the same graphic conventions established in the preceding maps. At this stage, surfers consistently described a small island to the west of the old mole, surrounded by shallow waters. These sand formations are represented by superimposing a water pattern over the earlier outline of the sandspit's distal head. As the waters gradually calmed, surfers no longer required the assistance of motorboats. Two flag symbols mark the wave peak, which had shifted westwards, and the sand island. The shallow waters enabled surfers to reach the take-off zone after a short walk across the sandspit followed by a brief paddle. Both the plan and the vignette depict the distinctive moment when the surf break formed an A-frame, allowing waves to break simultaneously to the left and the right.

The dashed lines indicate the most common access and return routes used by surfers from the northern bank, illustrating the broader movement patterns adopted in response to the river currents. An exceptional incident, in which a surfer failed to return and was carried several miles southwards by the coastal current, is highlighted in red.

The fourth and final map, Right (Figure 6), represents the remainder of the season, during which the sandspit maintained a relatively stable configuration. It is based on the March 2003 survey (Martins, 2026a, Sequence no. 65). The navigation channel is shown to be entirely clear, with sand accumulation extending south of the old mole and projecting slightly westwards. The resulting surf break formed long, barrelling right-hand waves. The blue tonal variations suggest a gentler transition between sea and river, with a more regular ocean swell forming a repetitive pattern as it progresses into the freshwater environment.



Figure 5. "A-Frame" map, based on the December 2002 cartographic survey of the Douro sandspit (Cabedelo), by Ivo Poças Martins, 2026.

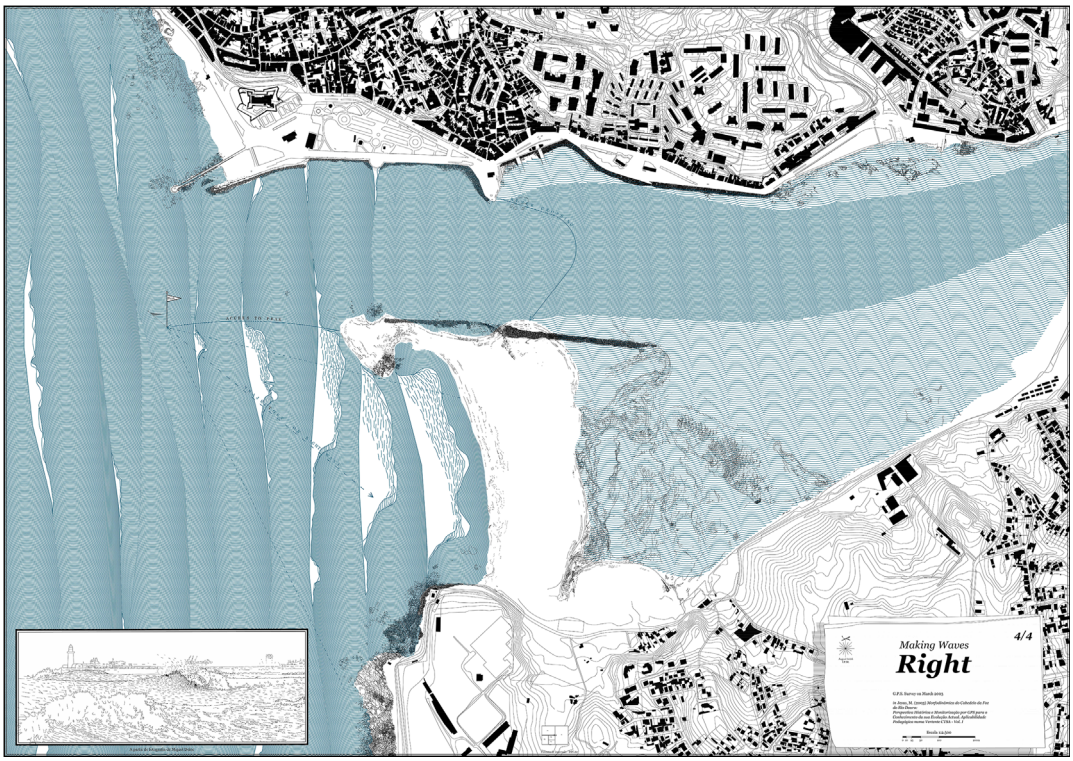


Figure 6. "Right" map, based on the March 2003 cartographic survey of the Douro sandspit (Cabedelo), by Ivo Poças Martins, 2026.

These four maps provide a situated visualisation of the relationship between the sandspit and the waves. Together, they depict the evolution of the intertidal zone, from an extreme hydrological event to its subsequent seasonal reconfiguration. The surf break evolves from a left-breaking wave to an A-Frame peak and, ultimately, to the expected right-breaking wave. Because the morphology of the surf break is directly linked to that of the sandspit, this sequence illustrates situated knowledge of water dynamics as a complement to conventional terrestrial representations. Through the experimental use of colour gradation, line density, hatching, perspective vignettes, graphic symbols, and annotations, the maps challenge the conventions of static cartography while capturing the complexity of hydrodynamic processes and human interactions within a conventionally static representational medium.

Discussion

The two sets of maps offer complementary perspectives. The chronological sequence of the sandspit outlines long-term geomorphological processes, whereas the wave drawings provide insight into short-term dynamics. Together, they represent complementary temporal scales of change within the intertidal zone. Although the mapping does not resolve the discontinuity between topographic and bathymetric surveys, it brings attention to an overlooked use of the site and draws on situated knowledge to represent the interactions among the various human and environmental agents operating within it.

Sand forms the link between the two systems of representation. As it accumulates offshore, it interacts continuously with coastal hydrodynamics. While winds and currents generate the swell, the morphology of the sand plays a crucial role in shaping the surf break (Bascom, 1964). Consequently, the morphology of the sandspit, both above and below mean tidal level, becomes a key factor in determining wave trajectories and the quality of the resulting surf.

Sandspit

Analysis of the long-term transformation of the sandspit indicates that Cabedelo has retained several fundamental characteristics over time. It remains connected to the river's southern bank and maintains an elongated form extending northwards. The connection between the river and the sea is therefore established through a channel along the northern bank, whose width varies inversely with sand accumulation. As noted by Luiz Gomes de Carvalho in his 1820s survey

(Martins, 2026a, Sequence no. 16), the "almost invariable part of the Cabedelo" is the open stretch between Porto's riverbank and the sandspit.

The principal variations in Cabedelo's morphology occur at its distal head, locally known as the *cabeço*. These variations are already evident in the earliest maps in the series, dating from 1634 and 1648 (Martins, 2026a, Sequence nos. 1 and 2). Because these maps were not produced using a conventional cartographic projection, they were not included in the silhouette time series. In the earlier map, the sandspit extends linearly towards the north, whereas in the latter the distal head projects westwards, forming an L-shaped configuration that extends towards the Atlantic. Over the long term, these variations reveal a recurring pattern characterised by a predominantly linear form punctuated by occasional L-shaped configurations. These interruptions can generally be attributed to flood events, during which the sand gradually accumulated along the sandspit is displaced seawards by exceptionally powerful river currents.

A major anthropogenic intervention that redefined the sandspit was the construction of a mole in 1820, designed by the engineer Luiz Gomes de Carvalho. It contributed to the consolidation of the navigation channel along the river's northern bank, a process that had already been supported by periodic dredging and the blasting of boulders and rocky outcrops on both the seabed and riverbed. Nevertheless, the long-term analysis suggests that neither the navigation channel nor the mole significantly altered the fundamental morphology or morphodynamics of the sandspit.

Between 1870 and 1873, the port authority conducted 23 detailed surveys (Martins, 2026a, Sequence no. 18, 19, 20 and 21). This intensive documentation was prompted by the recurring floods of the decade, whose severity is well documented in local historical records (Loureiro, 1910). These surveys reveal the progressive westward reconfiguration of the sandspit following the flood events of 1871, 1872, and 1873.

An exceptional flood occurred in 1909 (Vieira & Costa, 2017), representing the only documented instance in which the sandspit disappeared entirely. A monthly series of surveys conducted in 1910 documents its gradual reformation until it regained its characteristic morphology during the following winter (Martins, 2026a, Sequence no. 30 and 31).

The 1990s, the period during which the reconstructed wave existed, are characterised by a marked inland retreat of the sandspit. This represents the most pronounced retreat documented across the entire study period, with both the southern land connection and the distal head shifting eastwards. Although no exceptional floods comparable to the major historical flood events occurred during this decade, several episodes of intense rainfall and elevated river discharge significantly affected the hydrodynamics of the Douro estuary (Velhas, 1997).

On 4 March 2001, the Hintze Ribeiro Bridge at Entre-os-Rios, approximately 50 km upstream from the Douro estuary, tragically collapsed, resulting in the deaths of 59 people (Rocha, 2008). Subsequent investigations attributed the collapse to changes in the riverbed, caused by a substantial reduction in sediment transported by the river. This reduction has been linked both to the construction of dams upstream and to extensive sediment extraction for the construction industry. The resulting decline in sediment supply may also explain the observed retreat of the river-mouth sandspit and its consequences for navigation safety. It was this persistent retreat of the sandspit, together with expectations of increased economic returns from river navigation, that ultimately prompted the construction of the new moles, which fundamentally reshaped the sandspit and eliminated the world-class surfing wave.

The bridge collapse also highlights a fundamental limitation of the present research. By focusing on the intertidal zone, the chronological reconstruction documents the outcomes of sediment accumulation and dispersal rather than their underlying causes. Addressing these processes would require different methods and forms of expertise, calling for a substantially broader transdisciplinary research effort. This gap remains a significant lacuna in the existing literature.

The visual reconstruction of the sandspit provides sufficient evidence to identify long-term patterns of intertidal morphodynamics that have, until now, remained largely overlooked.

Wave

The wave maps demonstrate that the morphology of the surf break is a sensitive indicator of underwater sand profiles and sedimentary morphology, highlighting its potential to complement conventional cartographic representations. Moreover, they make visible, through mapping, perspectives that have traditionally been overlooked. We argue that this system of representation constitutes an original contribution to the emerging field of cartographies of everyday life and underrepresented spatial phenomena (Baxter et al., 2024). This contribution is particularly evident in the representation of the marine environment through architectural drawing, a rapidly expanding field of research (Fernandes, 2019; Tavares & Inglez de Souza, 2022; Couling & Hein, 2020; Siegert, 2024; Vianello, 2025). For the purposes of this study, architectural

drawing provided effective tools for translating multiple forms of knowledge, from technical documents to oral histories, into a shared visual language, bringing diverse sources into dialogue.

The drawing method intentionally explores ambiguity in the use of graphic conventions, employing familiar visual languages to represent underrepresented, and at times invisible, phenomena while conveying the subtle dynamics of the intertidal zone. The sources differ considerably in their degree of factual precision and reliability: a GPS survey differs fundamentally from oral accounts describing events that occurred more than twenty years ago. Nevertheless, by experimenting with visual representation and cartographic discourse, the proposed methodology offers a framework that can be adapted and further developed in other contexts.

In the specific case of the vanished wave, the drawings reveal the qualities valued by a community of users whose understanding of the intertidal was overlooked when the extension of the moles, completed in 2004, sought to stabilise the navigation channel and protect riverine areas. Their construction reflects the predominance of engineering priorities and navigation interests. Although coastal hydrodynamics remains a contested field, it was this body of knowledge that informed the design of the moles. The mapping presented here offers a counternarrative of the intertidal, making visible the subtle dynamics of the wave and the surf break that conventional cartography failed to capture. The surfers lost a place of exceptional value, and the world-class wave disappeared following the construction of the moles.

Conclusion

The terms *map* and *cartography* are often used interchangeably. Yet Svetlana Alpers's definition of a map as "a surface on which an assemblage of the world is set out" (Alpers, 1983) offers an important operational perspective. As a published artefact, the construction of a map involves a series of choices, including the selection of information, framing, orientation, and scale, as well as decisions regarding the use of specific visual conventions. Maps are typically organised around a theme or title and include information such as captions, dates, and authorship. Whether intentionally or not, maps are invested with authority, shaping both the perception and, ultimately, the transformation of reality.

A map is a site where different bodies of information converge, often through the negotiation and articulation of disparate sources. These bodies of information can be understood as distinct units of cartographic knowledge. Each possesses factual value, but it acquires intention and perspective through the process of mapmaking. Drawing on Bruno Latour's distinction between "matters of fact" and "matters of concern" (Latour, 2004), we argue that cartography primarily concerns the former, whereas maps give rise to the latter. It is through the act of combining matters of fact that maps transform them into matters of concern.

This paper functions simultaneously as both subject and method. It examines the waves generated by the Douro River's intertidal sandspit while challenging inherited modes of cartographic representation. Addressing the cartographic absence of the intertidal, it employs architectural representation to articulate and depict the convergence of environmental, cultural, and political tensions. In doing so, it animates the apparent stillness of the map, transforming absence into a shared space in which water, waves, sediment, infrastructure, memory, and embodied experience become simultaneously visible and available for collective interpretation and debate.

Ethics and consent

Ethical approval and informed consent were not required.

Data availability

The data supporting the findings of this study are openly available in the following Zenodo datasets and figures:

- Zenodo:*Cabedelo do Douro, Porto/Vila Nova de Gaia, Portugal: Cartography 1634–2021* (Martins, 2026a), https://doi.org/10.5281/zenodo.21833705;
- *Cabedelo do Douro, Porto/Vila Nova de Gaia, Portugal: A Cartographic Reel, 1789–2021* (Martins, 2026b), https://doi.org/10.5281/zenodo.21907323; and
- *Cabedelo do Douro, Porto/Vila Nova de Gaia, Portugal: A Standardised Cartographic Reel, 1789–2021* (Martins, 2026c), https://doi.org/10.5281/zenodo.21907916.

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

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The paper presents an original interdisciplinary approach to the study of coastal areas. The combination of historical cartography, surfers' experiential knowledge, and architectural drawing contributes to an understanding of coastal dynamics and the changes brought about by infrastructure development.
The methodology is generally appropriate to the research objectives. However, the reconstruction of historical wave forms relies heavily on retrospective accounts and privately held visual material, which vary in terms of accuracy and reliability. It would be useful to explain more clearly how data from interviews, photographs, and video recordings were selected, compared, and translated into graphic representations. It is not entirely clear whether the underlying materials are available for independent verification. The authors should clarify which source documents, interview materials, and visual records are publicly accessible and where they can be consulted. If disclosure is not possible due to copyright, privacy protection, or archival access restrictions, this should be explicitly stated.
The theoretical discussion of the concept of the map, drawing on Svetlana Alpers and Bruno Latour, would be more appropriately placed in the Introduction, while the Conclusion should focus on synthesising the main findings and highlighting the contribution of the research.
Overall, the paper is clearly structured, and its theoretical framework is relevant to the subject.

Is the work original in terms of material and argument?
Yes

Does it sufficiently engage with relevant methodologies and secondary literature on the topic?
Yes

Is the work clearly and cogently presented?
Yes

Is the argument persuasive and supported by evidence?
Yes

If any, are all the source data and materials underlying the results available?
Partly

Does the research article contribute to the cultural, historical, social understanding of the field?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Architectural History and Theory, Architectural Heritage, Tourism Architecture

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.