Latin American Antiquity (2026), 1–16
doi:10.1017/laq.2025.10168

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ARTICLE

Ancient Amazonian Earthwork Roads: Unveiling Ceremonial, Livelihood, and Networking Significances

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(Received 27 February 2025; revised 17 December 2025; accepted 17 December 2025)

Abstract

By using satellite images, this study confirms 350 km of ancient roads, comprising 634 wide and 321 narrow roads, in southwestern Amazonia's earthwork-rich landscape. The roads were straight, mostly under 500 m long, but with some extending several kilometers. They occurred most prevalently in areas of dense earthwork. Nested earthworks were more road-rich than simple ones, and roads were more common in structures with quadrilateral rather than roundish shapes. Geoglyphs typically featured wide ceremonial roads with start widths ranging from 15 to 40 m, sometimes wider, and gradual narrowing toward their distal ends. Mound settlements had narrow, short roads pointing in various directions, which may have been for everyday travel. They also presented narrow but long roads leading to distant destinations, occasionally spanning many earthworks. When the endpoint was observable, 39.7% of roads led to a riverine environment indicating access, 10.6% connected to other earthworks reflecting integration, and 49.7% faded into currently open terrain. Many roads starting from geoglyphs aligned with the cardinal directions suggesting a possible awareness of astronomical alignments in the construction of the ditched ceremonial enclosures. This study confirms that ancient roads provide key insights into past civilizations and are essential to the region's archaeological heritage.

Resumo

Usando imagens de satélite, confirmamos 350 km de estradas antigas, que são 634 estradas largas e 321 estreitas, na paisagem rica em estruturas de terra da Amazônia Ocidental com alto interesse científico. As estradas eram retas, na sua maioria com menos de 500 m de comprimento, embora algumas se estendessem por vários quilômetros. Elas ocorriam predominantemente em áreas com alta densidade de estruturas de terra. Estruturas de terra complexas apresentavam mais estradas do que as simples, e as estradas eram mais comuns em estruturas de formato em quadrilátero do que nas arredondadas. Os geoglifos geralmente apresentavam largas estradas cerimoniais com larguras iniciais variando geralmente entre 10 m e 40 m, com um estreitamento gradual. Os assentamentos em montículos possuíam estradas estreitas e curtas apontando em várias direções, provavelmente para a movimentação cotidiana. Eles também apresentavam estradas estreitas, porém longas, levando a destinos distantes. Entre as estradas, 39.7% levavam a ambientes ribeirinhos, indicando acesso; 10.6% conectavam-se a outras estruturas de terra, refletindo integração, e 49.7% desapareciam em terrenos abertos. Muitas estradas que partiam dos geoglifos estavam alinhadas com os pontos cardeais, sugerindo a importância das observações astronômicas. O estudo confirma que estradas antigas oferecem perspectivas fundamentais sobre civilizações passadas e patrimônio arqueológico da região.

Keywords: Amazônia; Acre; earthwork; geoglyph; mound village

Palavras chave: Amazônia; Acre; estruturas de terra; geoglifo; assentamento em montículos

Ancient road systems represent a widely recognized archaeological phenomenon with a global presence (Snead et al. 2009). In anthropological and archaeological literature, their construction has frequently been associated with the formation of states and empires (Isbell and Schreiber 1978; Johnson 1973:18; Wright and Johnson 1975). Even in various chiefdoms, a concept created by Kalervo Oberg (1955), constructed roads were common (Heckenberger 2004; Heckenberger et al. 2003; Schwarz 2016; Sever and Wagner 1991; Spencer and Redmond 1992). Studying roads can therefore contribute to our understanding of the emergence of civilizations with complex economic, political, and belief frameworks (Virtanen and Saunaluoma 2017).

In South America, the ancient Inka road system allowed high-capacity logistics involving the movement of the army, people, goods, and messages in the Andean mountains in the fifteenth and sixteenth centuries (Garrido 2016; Hyslop 1984). Also in the Amazon region, early travelers of the sixteenth and seventeenth centuries noted ancient roads, but their observations gained little recognition (e.g., Cieza de León 1991 [1553]; De Almesto 2012 [1562]:78; De Carvajal 1992 [1541–1543]; De Limpias 1906 [1635]; Recio de León 1906 [1623]). Centuries later, following the archaeological research conducted in 1916 by Erland Nordenskiöld in the Bolivian Mojos (Nordenskiöld and Denevan 2009), a subsequent generation of researchers began to focus more closely on these structures (e.g., Denevan 1963, 1966). Examples of this include studies in the Bolivian Mojos (Erickson and Walker 2009; Prümers et al. 2022), Venezuelan Llanos (Redmond et al. 1999; Spencer and Redmond 1992), and Brazilian Xingú (Heckenberger 2004). Rostain and others (2024) announced the discovery of a dense system of ancient urban centers and roads in the Upano Valley of Ecuadorian Amazonia. Covering an area of 300 km^2, the network is one of the largest and oldest known in Amazonia, originating between around 500 BC and ending around AD 600.

The expansive, gently rolling plains of the Brazilian state of Acre and its neighboring areas have revealed an advanced civilization in the lowlands of southwestern Amazonia (Pärssinen et al. 2003, 2009). This ancient cultural landscape encompasses numerous archaeological sites with geometric earthworks, which are often associated with roads featuring subtle earthen banks (De Souza 2022; Pärssinen et al. 2009; Rampanelli et al. 2017; Ranzi 2003; Riris 2020; Saunaluoma et al. 2018, Schaan et al. 2012; Watling et al. 2018). A preliminary study of 306 Acrean earthwork sites, based on field observations and a limited number of remotely sensed images, revealed that a quarter of these earthworks were associated with one or more roads (Pärssinen and Ranzi 2020; Ranzi and Pärssinen 2021). In a later study of 289 earthworks, 206 were associated with roads or paths leading to other structures, springs, or streams (De Souza 2022). Some of these roads were wide at their junctions and narrow at the distal ends, while other roads were narrow all the way (Iriarte et al. 2021; Saunaluoma et al. 2021). A few notably long narrow roads extended for distances up to 5 km.

Despite the abundance and variety of ancient roads in the region and the area's study accessibility, the insights they may offer into earlier times is not fully recognized. Hence, we implemented in this study a landscape archaeological approach to systematically inventory, classify, and interpret these features in the high-density earthwork area of southwestern Amazonia. We adopted, as our working hypothesis, that the roads of this region may reveal overlooked perceptions into comprehending the cultural conventions of the people who built and utilized them across different periods. Adopting this view, we use a structured analytical approach with consistent methodology across the entire area to explore the following specific questions: (1) How do the characteristics of ancient roads vary across the designated geographical area? (2) Is there an association between certain types of earthworks and specific road characteristics? (3) What insights do ancient road characteristics provide about the societies that designed them?

Materials and Methods

We conducted a visual satellite image-based inventory of ancient roads across a 134,400 km^2 region in southwestern Amazonia, in a zone that includes Rio Branco among other municipalities (Figure 1). The landscape comprises gently undulating lowland plains (100–350 m asl) covered with tropical rainforest. As exposed land surfaces show where ancient roads can be detected, and this exposure is limited to areas where trees have been felled, the surveyed deforested landscape represents 20.5% (27,569 km^2) of the entire study area.

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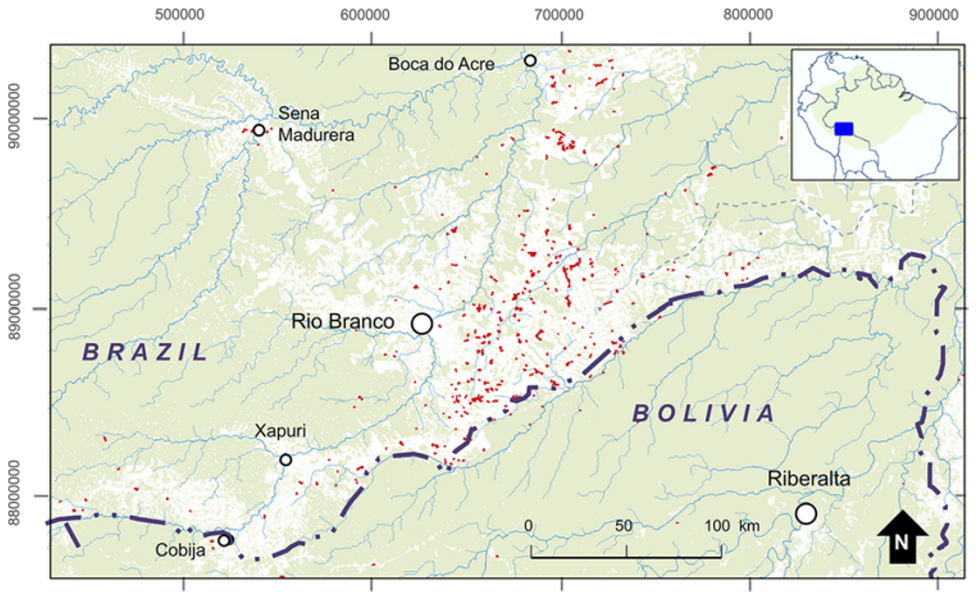

Figure 1. Map of the study area with forests in light green and deforested areas in white. Red lines show ancient roads at their correct lengths with widths exaggerated to one kilometer for visibility at a map scale. The inset map shows the location of the study area, and the side-markers show the WGS84 UTM Zone 19S projected coordinates. (Color online)

In this study, we used online satellite imagery available during 2021 to 2023, primarily Google Earth Base Map, Bing Satellite Maps, and Esri World Imagery Base Map. Although optical satellite data has limited capabilities compared to lidar (Iriarte et al. 2020), it possesses an unchallenged advantage in its extensive availability and broad spatial coverage. For further details of the data sources and image analysis methods, we refer to a previous publication (Kalliola et al. 2024). The following sections will therefore focus on issues pertaining specifically to the interpretation of ancient roads.

In remotely sensed images, ancient roads are primarily identifiable as straight ditch-like lines with raised backfill on both sides. In some cases, they may appear indistinct, posing challenges for tracing, but even in these instances, ancient roads differ from modern landscape lineages such as highways, dirt roads, off-road vehicle tracks, cattle trails, or pasture fences. It was advantageous that we could use our team's extensive research experience in the region. This includes on-site visits and archaeological investigations at numerous locations as well as oblique-view aerial observations and photographs at various structures (e.g., Pärssinen et al. 2020; Ranzi and Pärssinen 2021; Ranzi et al. 2007). Before transferring the interpreted results to QGIS, Pärssinen and Kalliola collaborated to maintain uniformity in the analytical data.

We examined each road individually and digitized narrow roads as single vectors and wide roads as double vectors (Figure 2). In most cases, the distinction was clear when based on the width between side banks. Narrow roads had starting widths below 15 m and featured low, inconspicuous banks, whereas wide roads were broader with characteristically prominent banks. Despite this, the two categories may not represent entirely distinct road types, as intermediate cases existed—such as roads that started wide and narrowed to a single path along their course or cases where a bank on one side of a wide road disappeared while the other continued.

To ensure methodological consistency, we used the vector representing the right side of the wide roads, as seen from the earthwork, to define the road length, even if the left side extended further. Where obstructions such as a small river, remnant forest, a farmhouse, or a highway intersected an ancient road that continued in the same direction on the other side, we combined consecutive sectors on a case-by-case basis to represent a seamless and uniform road. The final dataset contains 39 unified road vectors generated in this manner.

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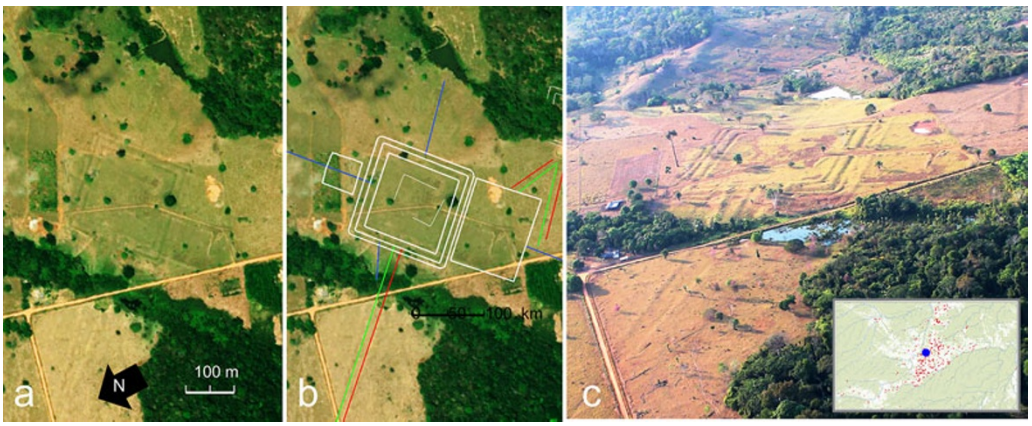

Figure 2. (a) Example of an earthwork complex (site: Tequinho) in satellite imagery; and (b) its interpreted ancient earthworks (white), wide roads (the right side is green and the left side is red) and narrow roads (blue). The photograph in (c) is an aerial view taken from a low-flying plane (photo: Martti Pärssinen). (Color online)

We classified each road on four baseline characteristics (Table 1; Figure 3). With respect to roads with an earthwork connection, we categorized their junction positions (i.e., if the earthwork contained a straight side) and its openness as well as the start width of the road (only wide roads). The operational road attributes included the character of the road's association with the earthwork, if any, and the perceived context of their endpoints. Finally, relying on the criteria described by Kalliola and others (2024), we identified the functional earthwork types related to the roads. Geoglyphs are open or closed geometric structures with a ditch and a ridge. Embankments, despite having similar shapes, lack a ditch and were further classified into associated and solitary embankment types. Mound sites consist of accumulated mounds framing a central space with no continuous ditch or embankment.

We employed various processing tools interactively in QGIS and Excel for selecting, processing, visualizing, and calculating data. We employed a 10 × 10 km grid of 1,344 cells, each representing 100 km^2, to illustrate geographical variations in local road lengths across the study area. Due to the varying proportions of open landscape between different cells, roads were only detectable in their cleared parts. We estimated the bias introduced by this limitation using linear regression analysis. For the analysis of directional variations in roads relative to their associated earthworks, we utilized a QGIS Line Direction Histogram Plugin and divided rose diagrams into 32 bin sectors to depict the frequency of roads oriented in specific directions without applying weighting by length.

Results

In the study area, we identified 955 ancient roads (94.6% straight) with a total length of 350 km (Table 2). The average lengths of both narrow and wide roads were almost identical (364 m and 373 m), but as narrow roads accounted for two-thirds of the total (66.4%), their combined length in the study area doubled that of the wide roads. The longest road was a narrow one that reached 5.5 km. Further details revealed by the road length histogram showed a constant decline in roads exceeding 200 m, and those over 1 km were individual cases (Figure 4a). There was little to no correlation between the variations in road length and their start width (R^2 = 0.0216). However, a geographical pattern was evident with 12 roads above 50 m occurring northeast of Rio Branco with many near Boca do Acre (Figure 4b).

From an aerial perspective, wide roads commonly appeared to gradually taper as they extended to their distal ends (Figure 5a). In contrast, narrow roads exhibited two main patterns. Some were short, appearing in various settings and pointing in nearby directions, while others stretched over considerable distances and extended across river valleys (Figure 5b). Sometimes, consecutive road segments

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Table 1. Attributes Assigned to Each Road Vector in the GIS Data.

Column/Feature	Classes/Characters	Explanation
Baseline characteristics		
Integrity	single road	continuous section of a road
	unified road	apparently continuous road (partly broken)
Road type	narrow road	width <15 m, digitized as one vector line
	wide road, right	width >15 m, digitized right side
	wide road, left	width >15 m, digitized left side
Straightness	straight	the road is a straight line
	moderate	the road has slight directional changes
	bending	the road has notable directional changes
Earthwork connection	yes	the road has connection to an earthwork
	no	the road has no detectable connection to any earthwork
Road's relationship with an earthwork		
Junction position at earthwork´s side	not determinable	unclear or irrelevant (roundish earthworks)
	corner or tip	corner or tip of an earthwork's side
	other part of side	outside middle of a straight side
	middle of side	middle of a straight side
Junction openness at earthwork's side	unclear	unclear to see or interpret
	closed	no opening at earthwork's side
	open	opening at earthwork's side
Start width	in meters	wide road width (from satellite imagery)
Operational road attributes		
Earthwork connectivity	leading away	from earthwork to environment
	leading to another	from earthwork to another earthwork
	passing through	earthwork passed through, no junction
	not relevant	not relevant to determine
Perceived context of the endpoint	open terrain	gradual fade into currently open and featureless terrain
	modern obstacle	visibility halted by a modern obstacle
	another earthwork	connects to another earthwork
	riverine	near river or rivulet (ca. 150 m)
Functional earthwork types		
Geoglyph	geoglyph	earthwork is delineated by a ditch and ridge
Embankment	associated embankment	a ridge form within a cluster of earthworks
	solitary embankment	a ridge >100 m away from another earthwork
Mound site	mound site	cluster of mounds with a central open space

between earthworks provided long-distance connectivity with the longest such arrangement, despite interruptions by patches of standing forest, extending to 28.9 km (Figure 5c).

The total length of roads within grid cells showed marked geographic distribution across the study area (Figure 6a). While peripheral regions contained less than 1 km of road length, the central cells along

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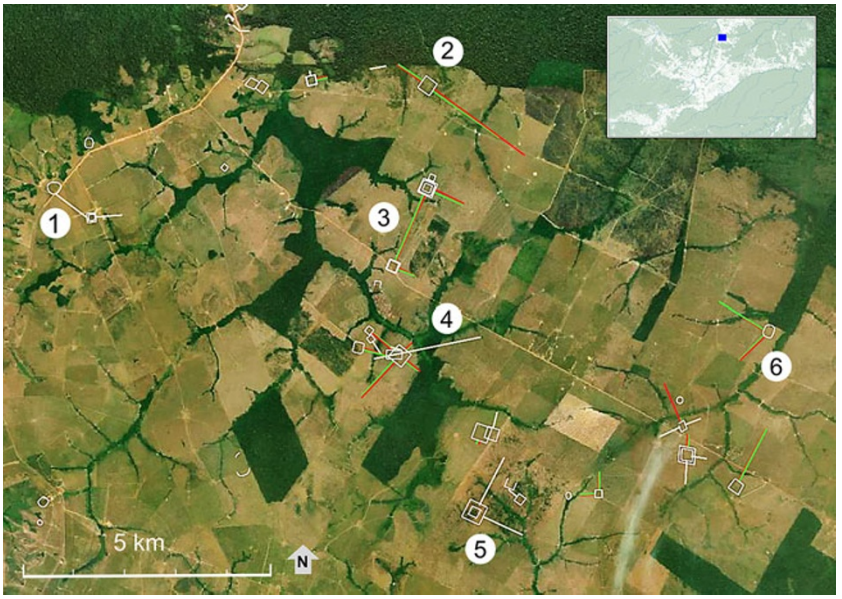

Figure 3. Example of an area featuring diverse earthworks and roads. The background is a satellite image. The interpreted earthworks and narrow roads are white, while wide roads are green (right side) and red (left side). For improved visibility at this scale, the lines are wider than these structures. Numbers indicate selected examples: (1) a narrow road connecting adjacent earthworks; (2) an earthwork with two wide roads in the middle of its opposite sides with one ending to forest and the other one fading into open terrain; (3) a wide road connecting adjacent earthworks; (4) a narrow road passing through two earthworks; (5) a narrow road ending in riverine context; and (6) a wide road beginning from a soft-edged corner of an earthwork. (Color online)

Table 2. Numbers and Lengths of Ancient Roads in the Study Area and by Road Type.

		Width Categories	
Characteristic	All Roads	Narrow	Wide
All roads			
total number	955	634	321
% of all roads	100	66.4	33.6
Straight roads			
number	903	588	315
% of all roads	94.6	61.6	33.0
Road lengths			
total, km	350	230	120
average, m	367	364	373
median, m	245	232	260
minimum, m	10	10	16
maximum, km	5.5	5.5	1.8

the southwest-northeast axis exhibited higher values, with 18 cells containing more than 5 km of road. According to the scatterplots (Figure 6b and c), deforestation accounted for only about a quarter of the variation in both road numbers and total road length (R^2 = 0.2521 and 0.2383, respectively) because many road-poor cells were also heavily deforested. In contrast, the number of earthworks (Figure 6d and e) provided a much stronger predictor of both road counts and total road lengths within grid cells (R^2 = 0.6998 and 0.5921, respectively). Across the 10 × 10 km grid, both road types—classified by the positions of their starting points—were broadly distributed (Figure 7). However, wide roads numbered

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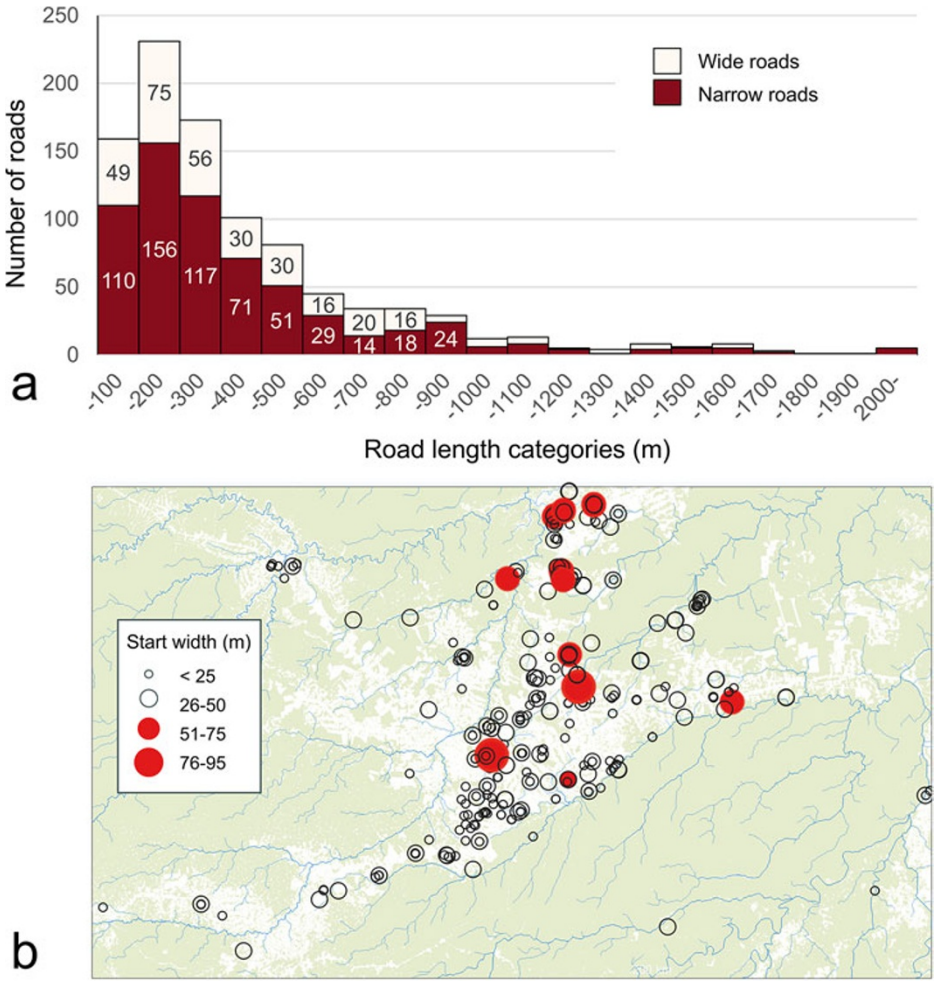

Figure 4. (a) Histogram of the length distribution of narrow and wide roads in the study area (only the upper limit of each length class is shown). Data labels indicate the number of roads in each category (values below 10 are not shown); (b) map of road start-width categories in the study area. (Color online)

fewer than five in most cells and were most common in a few cells of the northwestern survey area, whereas narrow roads exceeded 10—and often 15—in numerous cells in the central part of the study area.

Among all earthworks, 38.9% linked to one ancient road and 16.0% connected to two or more (Table 3). Earthworks with nested structures increased the likeliness of having roads. Half (49.9%) of roundish earthworks (circular, oval, drop-shaped, or D-shaped) were connected with roads, compared with 60.2% of quadrilateral ones (square, rectangular, rhombus, or trapezoid). A vast majority of the roads in the latter category (81.7%) had their junction positioned in the middle of a straight side, with wide roads showing an open junction in 66% of cases, excluding junctions too unclear to determine (Figures 8a and b). The perceived context of road endpoints also exposed some preferences (Figure 8c). Excluding roads that disappeared beneath modern obstacles, 10.6% connected to another earthwork, while 39.7% led to riverine environments and 49.7% faded into a currently open landscape. These proportions were nearly the same for both road types.

The prevalence of roads varied between the functional types of earthworks with geoglyphs having the lowest proportion of roads and mound sites having the highest (Figure 9a). This pattern was almost identical in both narrow and wide roads, but mound sites were an exception, as they commonly featured

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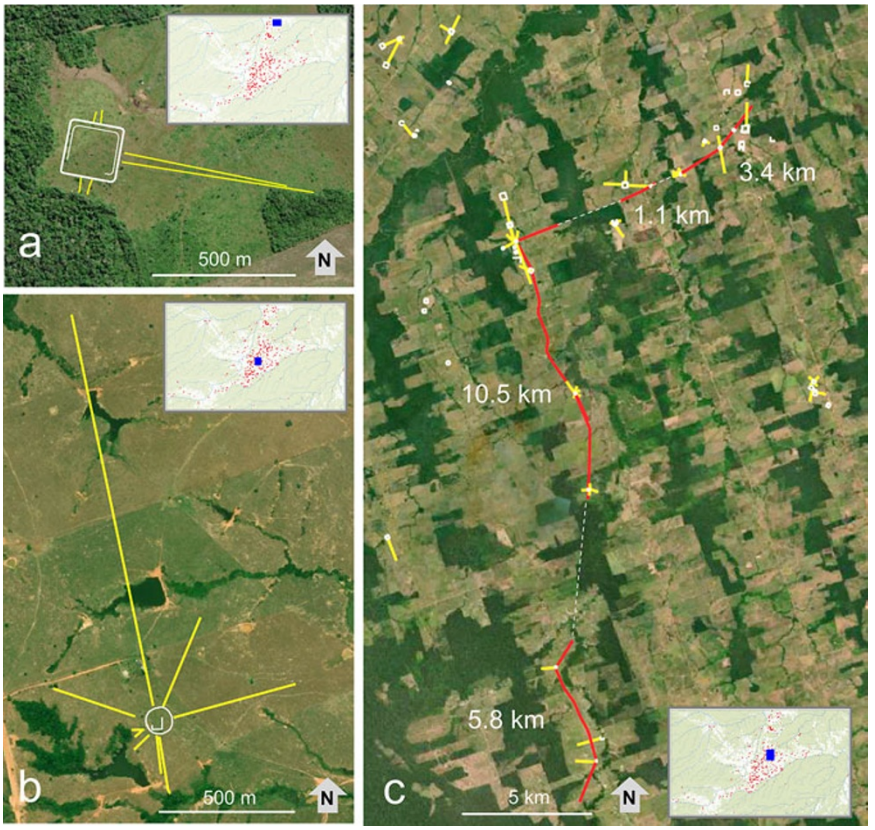

Figure 5. (a) A quadrilateral nested geoglyph (Boca do Acre) with three wide roads (both sides shown in yellow), one of which shows narrowing toward its distal end; (b) a mound site (MP.Ac.3) with a radial arrangement of narrow roads of varying length; and (c) four interconnected road segments in the central study area (red) total 20.8 km. The inclusion of forest-covered interpreted segments (gray dashed lines) increases the total length to 28.9 km. (Color online)

three to six narrow roads but hardly any wide roads (Figure 9b). Data showed no differences in average road lengths across the compared groups (Figure 9c), yet roads exceeding 1 km occurred only in geoglyphs and mound sites. In the study area, both associated and solitary embankments had shorter total road lengths than geoglyphs and mound sites (Figure 9d).

The compass orientation of road directions varied but with some preferences according to earthwork type (Figure 10). Roads connected to geoglyphs, whether wide or narrow, were often oriented approximately along the four cardinal points: north, east, south, and west. The southeastern orientation was also pronounced; however, when there was an open junction at earthwork's side, western directions were scarce. In associated embankments, the preferred directions in wide roads were east and west, whereas in solitary embankments, southeast and northwest directions were more typical. These same directions characterized mound sites with narrow roads, but in the few cases when these roads were wide, they aligned with the east or northwest.

Discussion

Early reports documenting the presence of road structures in the Amazonian lowlands during the sixteenth century by early explorers and chroniclers, such as Francisco de Orellana and Gaspar de Carvajal, described roads that connected settlements and established links between parallel river corridors (for further details, see Saunaluoma et al. 2021). Although later researchers may have overlooked the significance of these remarks, perhaps viewing them as informal and ephemeral routes facilitating general movements of people, recent investigations in the Amazon Basin have shed light on the diversity and

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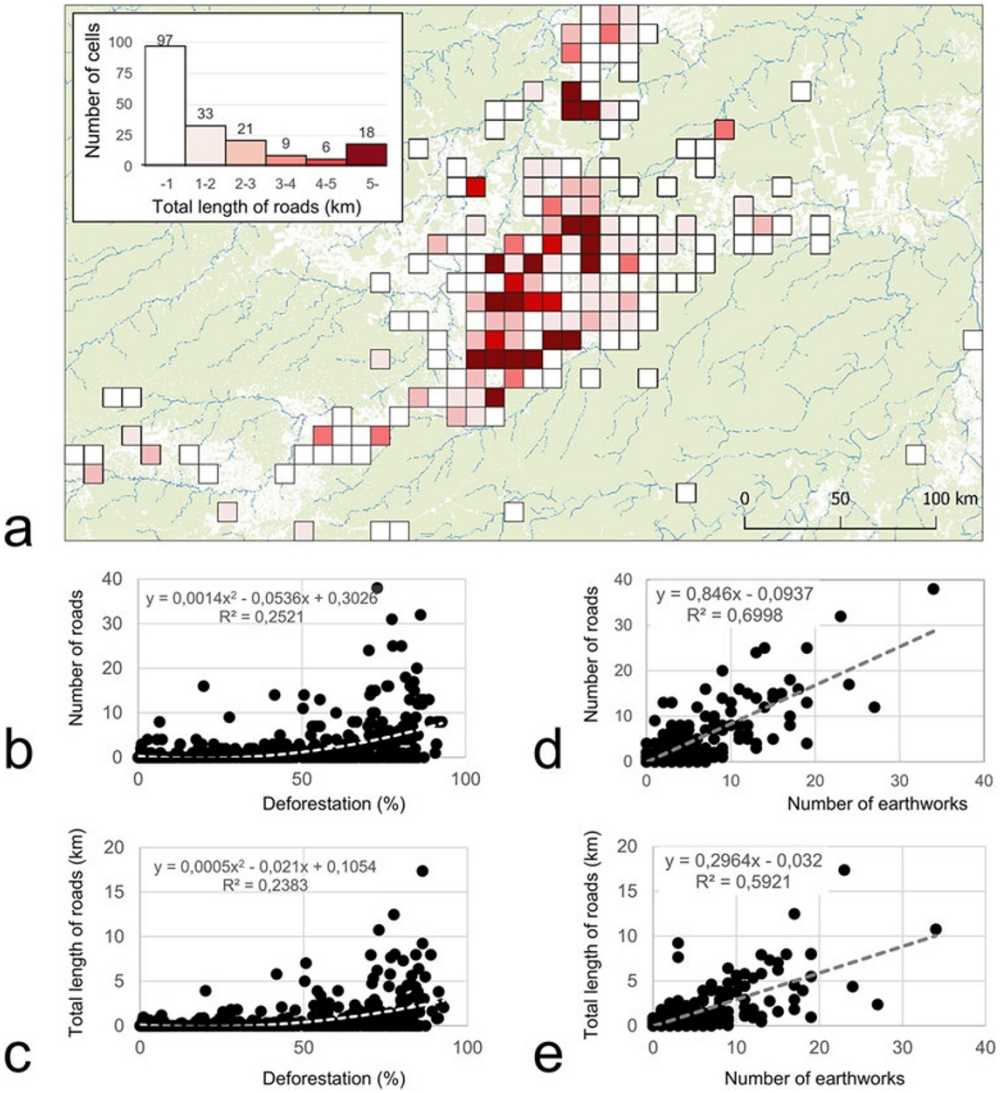

Figure 6. (a) Distribution of total road lengths in grid cells within the study area, with an inset showing the lengths using bar colors matching the map; (b) relation between deforestation and the number of roads in the grid cells; (c) relation between deforestation and the total length of roads in the grid cells; (d) relation between the number of earthworks and the number of roads in the grid cells; and (e) relation between the number of earthworks and the total length of roads in the grid cells. Second-order polynomial fits in (b) and (c); first-order in (d) and (e). (Color online)

intricate nature of the ancient road, causeway, and trail systems (Erickson 2001, 2008; Prümers 2022; Rampanelli et al. 2017; Saunaluoma et al. 2021; Schmidt 2012). Roads crisscrossing interfluvial areas played an important role in facilitating human mobility and information exchange (Schmidt et al. 2014; Snead et al. 2009; Virtanen 2015).

This study provides evidence that the 955 ancient roads in the area were both remarkably straight and carefully planned, suggesting the involvement of complex societies. Despite their generally short individual lengths—most often under 500 m—the combined total of 350 km, along with the presence of carved profiles and elevated edges testify to a significant undertaking. These characteristics attest to deliberate design and skilled engineering. However, not all roads were contemporaneous, as the roads originated and functioned in different temporal and cultural contexts. Radiocarbon dating suggests that road building started in the Brazilian Acre between 763 and 399 cal BC, and extended to the Brazilian

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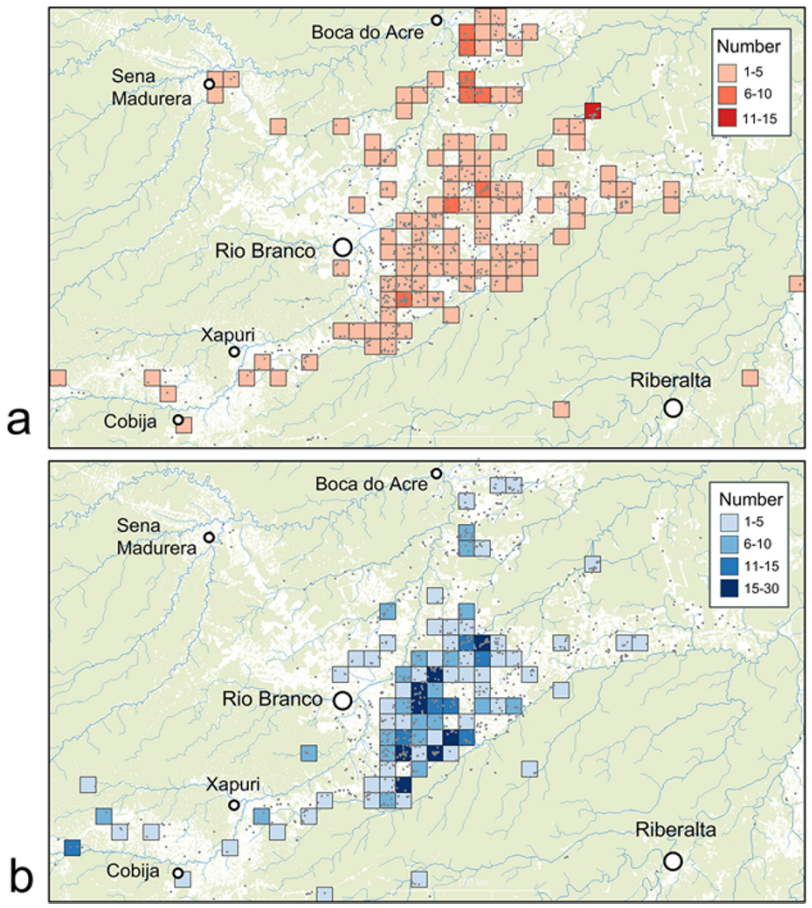

Figure 7. Total number of road start points within each 10 × 10 km grid cell in the study area categorized by (a) wide roads and (b) narrow roads. (Color online)

Table 3. The prevalence of ancient roads across different types of earthworks. Percentages (%) refer to the first number in each road.

		0 roads		1 road		>1 roads	
Structure	Total	*N*	%	*N*	%	*N*	%
All structures	1,300	586	45.1	506	38.9	208	16.0
of which nested	152	34	22.4	78	51.3	40	26.3
Roundish	503	252	50.1	174	34.6	77	15.3
of which nested	32	13	43.8	12	37.5	6	18.7
Quadrilateral	721	287	39.8	307	42.6	127	17.6
of which nested	111	11	9.9	65	58.6	35	31.5

states of Amazonas and Rondônia, as well as Pando and Beni in Northern Bolivia, occurring in an area of at least approximately 60,000 km^2 of recently deforested lands (Pärssinen 2021). The oldest roads were associated with a geoglyph-building civilization called Aquiry until around AD 950. Later, from around AD 1200 onward, a new mound settlement tradition emerged in the same area, characterized by patterned mound villages often associated with radiant road systems (Saunaluoma et al. 2018, 2021). At places, the pattern of these sites somewhat resemble the well-known Andean ceremonial walking lines known as *ceques* (e.g., Bauer 1998; Zuidema 1962).

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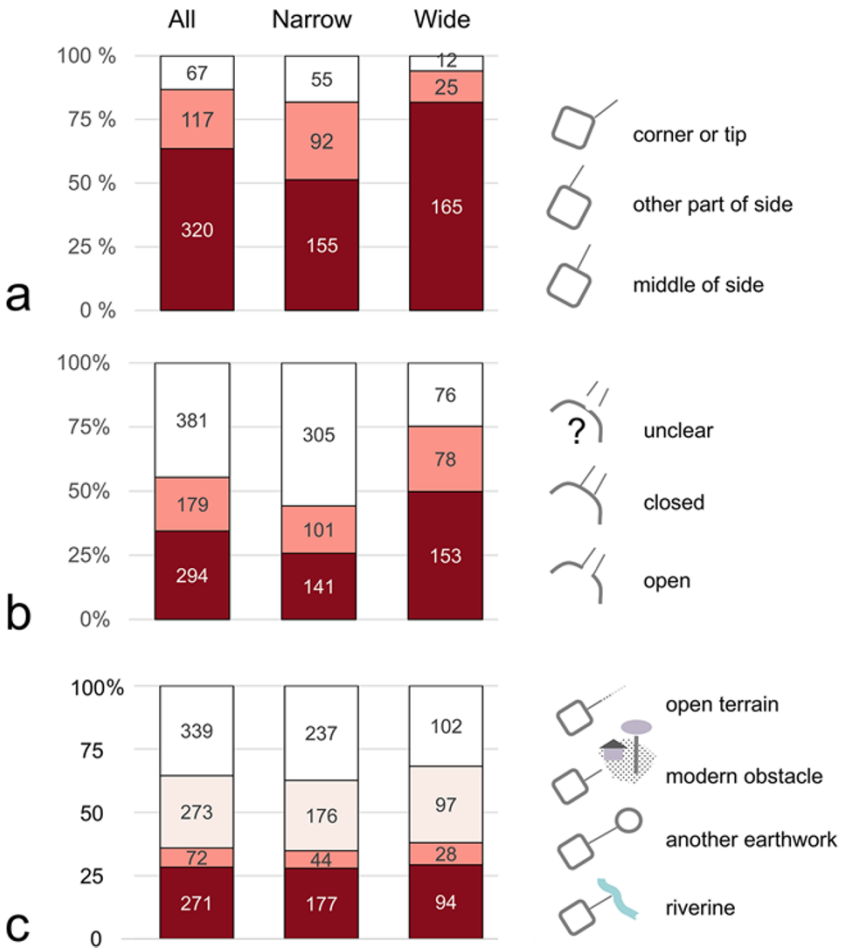

Figure 8. Classifications defining the features of ancient roads and their relationships to earthworks: (a) junction position at the earthwork's side (*n* = 504, excluded roads where this characteristic was not relevant to determine); (b) junction openness at the earthwork's side (*n* = 854, only roads with earthwork connection); and (c) perceived context of the endpoint (*n* = 944, all roads included). (Color online)

The making of long, straight roads across gently undulating terrain necessitated unobstructed visibility to achieve the kind of technical perfection as it appears to be. The view of an open landscape is supported by stable carbon isotope ($\delta^{13}C$) values from various geoglyph sites, suggesting selective burning of small grassland patches, but there is no evidence suggesting that the region's general vegetation resembled an open savannah grassland approximately 2,700 to 500 years ago (Pärssinen et al. 2020). Similar findings emerge from Fazenda Colorada and Jaco Sá sites during the late Holocene (Watling et al. 2017, 2018). Local inhabitants possibly created open landscape patches by setting fires opportunistically to available spaces, such as bamboo thickets following their flowering and dieback, when ample dry biomass was available (Ferreira et al. 2020).

In our study, pragmatically, the road classification was divided into two primary road types—wide roads and narrow roads, though there were occasional intermediate road types. Wide roads are exclusively associated with the ceremonial landscapes of the Aquiry civilization (Kalliola et al. 2024). Although present in most parts of the study area, geoglyphs were less likely to have roads than either associated or solitary embankments. As many roads were narrowest at their distal ends and widened toward the earthwork, they created a wedge-like configuration that enhanced the site's monumental

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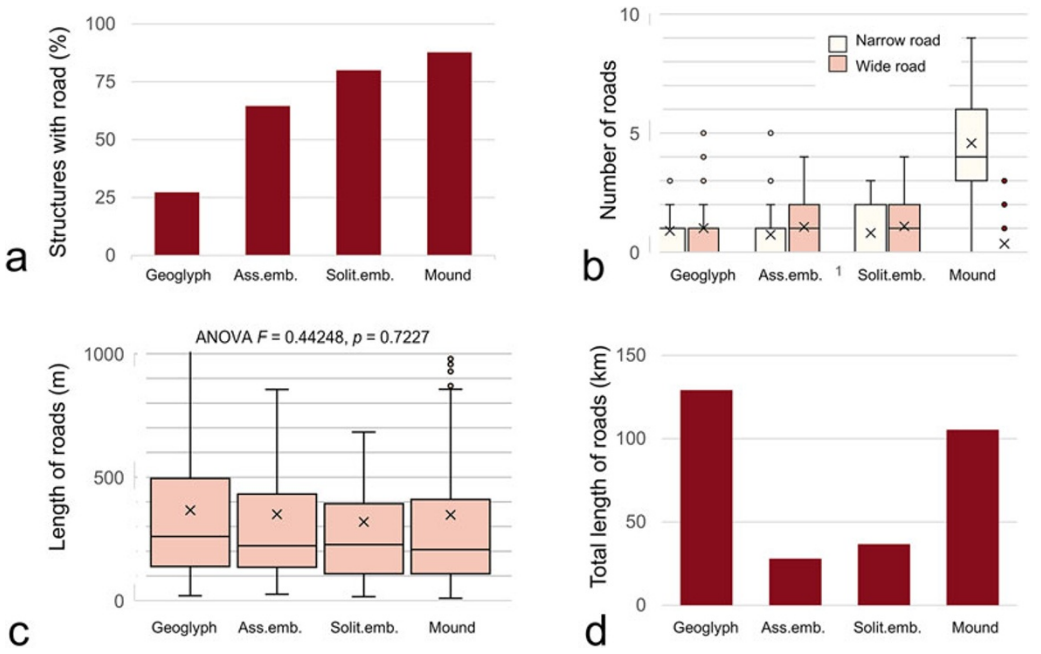

Figure 9. Roads examined related to their associated functional earthwork types: (a) proportion of earthworks with associated roads; (b) boxplots of the numbers of roads in different earthworks; (c) boxplot of the total lengths of roads in different earthworks; and (d) total length of roads in different earthworks. Note that the vertical axes in both boxplots are truncated. (Color online)

appearance. As these roads were seldom more than a few hundred meters long, their primary function was hardly to support everyday movements; rather, they helped to frame specific cultural meanings with symbols of power and prestige. A broad junction point in the middle of the earthwork's straight side further emphasized its symmetrical appearance and the prestigious configuration of the site. These attributes could have supported engagements between human and nonhuman subjects by facilitating movements between the visible and spiritual realities (Pärssinen and Ranzi 2020; Virtanen and Saunaluoma 2017). A noteworthy detail is that the entry point varied between being open and closed, although the reasons for this remain unclear. It raises the question of whether some of the latter may have been intentionally sealed to keep the interiors undisturbed.

Narrow roads were geographically more concentrated in the central regions of the study area. In line with earlier research (e.g., Saunaluoma et al. 2021), our data revealed two distinct forms and both associated with mound sites that mainly date back to the last millennium (e.g., Iriarte et al. 2021). The most common pattern featured numerous straight, short, and narrow roads radiating from a central plaza and passing between the mounds to connect with the surrounding lands. Their short lengths, uniform widths, and radial extension from the village center point to purpose for livelihood needs. Different societal groups may have utilized distinct entrances or radiating trails might signify routes to various activity zones, such as hunting grounds, cultivated lands, or water sources. The second category of narrow roads established long-distance connections between nearby settlements and other important locations promoting efficient movement of people and transport of goods. The longest sequence of interconnected roads we found (Figure 5c) spanned nearly 30 km and connected four mound villages, some of which were part of a complex featuring several earthworks, including ceremonial geoglyphs.

Road endpoint features offer additional cultural insights (Rampanelli et al. 2017). The most apparent interpretation is that the roads linking nearby earthworks affirmed the interconnectedness of their spaces (Virtanen 2023). While those roads accounted for one tenth of the roads with visible endpoints (10.6%), those terminating in riverine environments comprised 39.7% and facilitated access to and from

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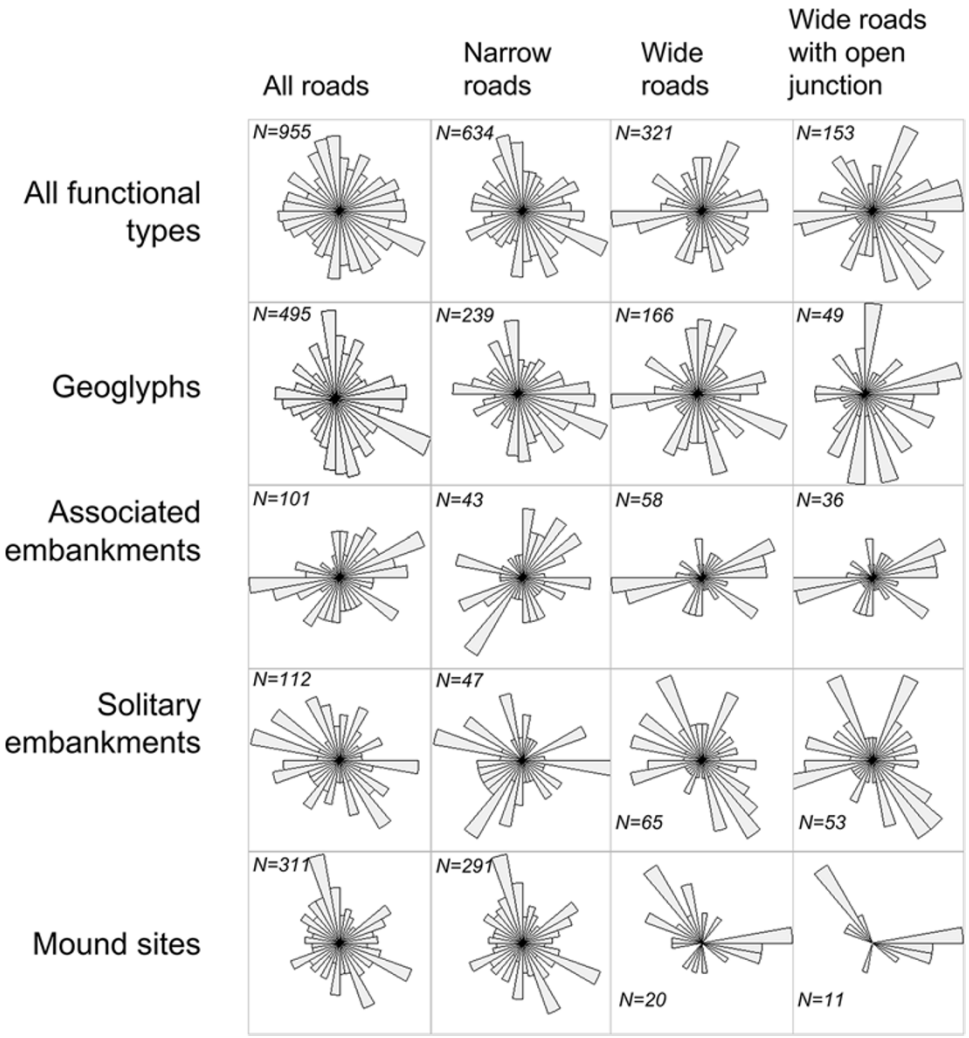

Figure 10. Road direction histograms grouped by road types, roads with open junctions at an earthwork's side, and the earthwork functional types. Note that these diagrams appear approximately the same size; therefore, the lengths of the plotted sectors are not directly comparable in quantitative terms.

the river (Saunaluoma et al. 2018). Despite the passage of time, we posit that the predominantly small headwater river valleys in this erosional landscape have generally maintained their stability during the past centuries and even millennia. The most enigmatic group were the roads that seemed to terminate in an open landscape without any distinctive features. These roads may once have provided access to locations associated with routine daily activities, such as plantations or particular types of forests, or they may have just vanished into the forest facilitating people's transition in and out of settings where multispecies relationships, spirits, and other nonhuman entities existed (Virtanen 2025).

The frequent alignment of roads with the cardinal directions in many geoglyphs suggests that astronomical observations may have played a role in the construction of these ditched ceremonial enclosures. Even in contemporary American cultures, celestial figures like the Sun and the Moon hold a significant importance in shaping interactions between beings (Virtanen and Saunaluoma 2017). The roads of associated embankments and mound sites also exhibited some asymmetric road orientations that may warrant further attention in future studies.

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The exposure of ancient roads in the deforested landscape of the southwestern Amazonian lowlands poses issues akin to the idiom of Damocles' sword. The good visibility of ancient road structures in open landscape offers valuable opportunities for archaeological science. While the other edge emphasizes the peril of losing an irreplaceable cultural heritage, as the modern landscape is dynamic and undergoing powerful changes. Highways, offline driving tracks, and cattle paths crisscross over millennia-old roadways; large areas are ploughed to support cash crops; and tree cover no longer mitigates landscape erosion caused by rainfall. The risk of a disappearing unique archaeological heritage is immediate unless swift and definitive protection measures are implemented (UNESCO 2015).

Conclusions

Answers to the three study questions are as follows:

(1) How do the characteristics of ancient roads vary across the designated geographical area? The 955 ancient roads in the region are remarkably straight and mainly extend from a few tens to a few hundred meters. Both wide and narrow road types are widespread in the study area, with the latter particularly abundant in its central parts, while roads with especially large start widths (more than 50 m) concentrate to its northeastern sector.

(2) Is there an association between certain types of earthworks and specific road characteristics? Roads were less prevalent in roundish earthwork shapes than in quadrilateral ones, where their starting position was most commonly in the middle of the side. About a quarter of the geoglyphs and more than half of both associated and solitary embankments were connected to one or more wide roads, narrow roads, or both. Mound settlements predominantly featured narrow roads, both short and radially distributed and wide spanning.

(3) What insights do ancient road characteristics provide about the societies that designed them? We interpret that the configuration of wide, avenue-like roads leading to geoglyphs or geometrically shaped embankments emphasized their ceremonial significance. As many roads aligned with cardinal directions, observations of celestial phenomena may have played a role in their design. Roads leading to nearby earthworks suggest interconnectedness of their spaces. Short narrow roads leading to surrounding lands or a river likely served everyday needs. Narrow roads spanning greater distances between locations indicate a higher degree of interaction across the region.

Acknowledgments. We thank the numerous discoverers of ancient earthworks and roads in the study area who have shared their findings. We appreciate the open-access register *Hundreds of Geoglyphs Discovered in the Amazon* by James J. Jacobs. Special thanks to Pirjo K. Virtanen for her critical reading of our manuscript, and the three anonymous referees for their constructive and insightful feedback.

Funding Statement. This work was supported by the Academy of Finland research grants 296406 (RK) and 297161 (MP).

Data Availability Statement. A KML file containing vectors that show the ancient roads is available at https://doi.org/10.23729/050fb4f0-6966-4c89-adfb-b6cddc646377.

Competing Interests. The authors declare none.

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Cite this article: Kalliola, Risto, Martti Pärssinen, Alceu Ranzi, and Antonia Damasceno Barbosa. 2026. Ancient Amazonian Earthwork Roads: Unveiling Ceremonial, Livelihood, and Networking Significances. *Latin American Antiquity.* https://doi.org/10.1017/laq.2025.10168.