Ca' Foscari University of Venice

Master's Degree programme

in Digital and Public Humanities

Final thesis

Discovering and analysing the Roman landscape in the Aurisina area (Trieste Karst) through LiDAR

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Academic Year 2021 / 2022

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1. Introduction

Recent extensive and interdisciplinary studying of the ancient landscapes of the Trieste Karst (north-eastern Italy) allowed to significantly advance the knowledge about the archeological history and geomorphology of this territory. The surveys were mainly based on LiDAR combined with small-scale excavations and archeological surveys[1].

As for this research, high resolution Digital Terrain Models (DTMs) of a sector of the Trieste Karst, obtained through the Light Detection and Ranging (LiDAR) remote sensing technique, have been visualized and managed using QGIS to identify possible archaeological anomalies. The potential archaeological anomalies have been also studied and checked through field surveys, allowing to discover and to identify ancient structures and features, consequently allowing the improvement of the knowledge of the Roman landscape in the Aurisina area. Large and previously unknown rural buildings, segments of the road network and remains of the Karst centuriation (Roman land division system) have been identified.

To reconstruct part of the past Roman landscape in the Trieste Karst area, and to achieve such goal, LiDAR data have been processed to virtually remove the vegetation and obtain high-resolution topography of the surveyed area. The potential anomalies detected thanks to LiDAR-derived data have been verified and interpreted through a multidisciplinary approach, mainly based on the collection of associated materials (Roman shoe hobnails) and in-person field investigations to verify possible stratigraphic relations among landforms.

The interdisciplinary approach of the research in the investigated area has helped to understand the Karst's processes and environment, and their interactions and influence with human activities[2].

The study and the understanding of possible man-made landforms and associated archeological materials in the area, allowed us to understand whether some modern constructions and roads go over the ancient ones and which ones are to be considered earlier, sometimes dating

[1] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023), p. 1

[2] BERNARDINI, VINCI, FORTE, FURLANI, PIPAN, BIOLCHI, DE MIN, FRAGIACOMO, MICHELI, VENTURA, TUNIZ, Discovery of ancient Roman "highway" reveals geomorphic changes in karst environments during historic times (2018), p. 15

back to ancient times (some of these structures can be considered fossilized: built in ancient times, collapsed and never reused).

More specifically, this has been achieved by superimposing the high-resolution LiDAR-derived images and historical documents, such as the 1800's Cadastral Maps of the area, in order to establish which structures are probably ancient, which are modern and which ones have been modified and reused throughout the centuries.

The discoveries of the research have a considerable archaeological and historical significance.

According to the research results, the investigated area was crossed by an important Roman road and, next to it, large rural buildings have been identified. The road fits one of the main axes of the Roman land division grid (centuriation), which seems to be built starting from the road itself. The study of the centuriation has also led to the understanding of the fact that the famous Aurisina quarries were probably under the jurisdiction and authority of *Tergeste* (ancient Trieste), because they are included within the city's land division grid attributed to this city. At the same time, the centuriation traces suggest that the border between *Tergeste* and Aquileia was likely located west of Aurisina.

1.1 Historical background

Due to its geomorphological characteristics, the Karst plateau is a territory that, at first, seems to be only rocky and inhospitable, but hides, at the same time, beautiful landscapes. In this context, during the times, history has made its course through trade, people passing by and historical events that often did leave just elusive traces. However, some traces have been disclosed recently, and some historical events, such as the Istric Wars, that before were just passed on by the work of the Roman historian Titus Livius, are now starting to become more tangible. The identification of three military camps, ancient road structures and traces of centuriation of the land, led to an enriched understanding of a crucial and unstable period for the region, when, after the foundation of Aquileia, in 181 BC, Rome started to conquer the Karst region and Istria. Gradually, the conquest saw its conclusion only two centuries after, with the pacification of the region made by Octavian, later known as Augustus[3]. Under the administration of Augustus, in fact, the Istrian peninsula was entirely pacified. The development of the Istrian peninsula during those years was supported by the stability given by the colonization[4].

The majority of the information we have about the conflicts between Histri and Romans are reported and passed on by the already mentioned Roman historian Titus Livius in his work *Ab Urbe Condita*, that narrates the ancient history of Rome and its empire. Particularly, in the forty first (*XLI*) book of his literary work, he describes the siege on the city of *Nesactium* by Romans, and he talks about the clashes that took place and about the Roman consul Gaius Claudius Pulcher, who was in charge in 177 BC; he also precisely mentions in his text the years 178 and 177 BC.

In the last few years, thanks to the data produced by modern remote sensing techniques, archeological evidence has come to light: for instance, military camps, divisions of the land and roads structures. These findings are very important in the context of the conquest and romanization of the Karst, in the regions to the east from Aquileia[5]. The understanding of the Roman expansion in these areas and the origin of Trieste can become clearer thanks to the traces left by the conquerors. The available ancient literary sources and the archeological data are still not enough to recreate, in an accurate manner, the complex cultural picture of the Karst area in the second century BC, when the Romans started to conquer the regions to the east from Aquileia[6].

In the Trieste territory and nearby areas were also discovered Celtic material traces, mainly weapons. However, the ancient sources claim that, at the beginning of the second century BC, the Trieste coast and the Istrian peninsula, which before were under the Venetian influence, were supervised by the Histri[7]. The Greek geographer and historian Strabone describes the Histri as an ancient tribe that lived and named the Istrian peninsula, located south-east from Trieste. The Romans described them as a fierce and barbaric clan, even considering them sort of pirates, protected by the rocky coasts of the Istrian peninsula. The Histri used to build and live in fortified

[3] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 10

[4] MATIJAŠIĆ, L'Istria tra Epulone e Augusto: archeologia e storia della romanizzazione dell'Istria (II sec. a.C. - I sec. d.C.) (1991), pp. 238-239

[5] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 15

[6] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 19

[7] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 19

settlements known as *castellieri*[8]; one of which (Castelliere di Slivia, figure 1) was also visited during our research's fieldwork, to better understand the ancient landscape's structure. More in detail, a *castelliere* was a fortified settlement built with the rubble masonry (*muratura a sacco*) technique in an elevated location, which was vital for defensive purposes, approximately between the 1800 BC and the 400 AD.

Figure 1. Picture of the road going up to the Castelliere di Slivia's walls, taken during the research's field survey.

In this complex context, Roman expansionism takes place towards the end of the third century BC[9]. Because of its vicinity with the Roman territory, the Istrian peninsula was the first area of the present-day Croatia to be Romanized. According to the historians of those times, the first conflicts between Romans and Histri occurred in 221 BC. Further clashes took place, between Romans and Histri, in 181 BC, when the city of Aquileia was established. However, it was just after a few years, between 178 and 177 BC, that the Istrian peninsula was officially conquered[10]. After the establishment of the city of Aquileia in 181 BC, the increasing tension between Romans and the native population led to the start of a war. According to the famous Latin historian Titus Livius (59 BC - 17 AD), the Roman navy approached the first dock at the border with the Istrian territory and established a military camp at approximately 7.5 km from the seacoast[11]. The art of building military camps was highly likely a crucial element for the Roman army and its development and expansion for the most part of Western Europe and the Mediterranean[12].

"Eae naues ad proximum portum in Histriae fines cum onerariis et magno commeatu missae, secutusque cum legionibus consul quinque ferme milia a mari posuit castra. In portu emporium breui perfrequens factum, omniaque hinc in castra subportabantur."

(Titus Livius, *Ab Urbe Condita*, XLI book, part I)

[8] MARCHESETTI (1903); Mihovilić (2013); Borgna et al. 2018; BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 19
[9] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 19
[10] BANDELLI (2004); BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 19
[11] BANDELLI (2004); BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 24
[12] BERNARDINI et al (2015); BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 39

“This squadron was sent to the nearest port in the Istrian territory, with a number of transports and a large store of provisions; while the consul, following with the legions, encamped at the distance of about five miles from the coast. A plentiful market was soon established at the port, and everything conveyed thence to the camp.”[13]

In the first stage of the conflict, seemingly, the Histri managed to defeat the Roman military camp. It looks like this news was spreading quickly from Aquileia to Rome, generating a feeling of panic and hopelessness. However, in accordance with Titus Livius, it is highly likely that the Histri and Epulon, their king, rather than safeguarding the conquered camp, would have recklessly sacked it and celebrated foolishly with the supplies found until they got drunk.

“Praetorio deiecto direptisque, quae ibi fuerunt, ad quaestorium, forum quintanamque hostes peruenerunt. Ibi cum omnium rerum paratam expositamque copiam et stratos lectos in questorio inuenissent, regulus accubans epulari coepit. Mox idem ceteri omnes, armorum hostiumque obliti, faciunt; et, ut quibus insuetus liberalior uictus esset, auidius uino ciboque corpora onerant.”
(Titus Livius, *Ab Urbe Condita*, XLI book, part II)

“The enemy then, tearing down the general's tent, and seizing on all they could find, went on to the quaestor's quarters, and the adjoining forum, called Quintana. Thereupon, when they found all kinds of food dressed and laid out in the quaestor's tent, and the couches placed in order, their chieftain lay down and began to feast. Presently all the rest, thinking no more of fighting or of the enemy, did the same; and being unaccustomed to any sort of rich food, they greedily gorged themselves with meat and wine.”[14]

“L. Atius, tribunus primus secundae legionis, non hortabatur modo milites, sed docebat etiam, si uictores Histri, quibus armis cepissent castra, iisdem capta retinere in animo haberent, primum

[13] The English translations for the Latin texts were taken from http://www.perseus.tufts.edu
[14] The English translations for the Latin texts were taken from http://www.perseus.tufts.edu

exutum castris hostem ad mare persecuturos fuisse, deinde stationes certe pro uallo habituros: uino somnoque ueri simile esse mersos iacere."

(Titus Livius, *Ab Urbe Condita*, XLI book, part III)

"Lucius Atius, first tribune of the second legion, not only urged on his men, but informed them also, that "if the Istrians meant to retain the camp, which they had taken, by the same arms by which they took it, they would, in the first place, have pursued their enemy driven from his camp to the sea; and, in the next place, they would certainly have stationed guards outside the rampart; and that it was very likely that they were lying in sleep, or drowned in wine."[15]

Thanks to the Histri's failing behavior, the Romans were then able to conquer back the camp previously lost and defeat the enemies. On that occasion, the king, who was drunk himself, is reported to have been put on a horse by a member of the army and managed to save himself.

"Ad Histrotum pauci, qui modice uino usi erant, memores fuerant fugae, aliis somno mors continuata est; integraque sua omnia Romani, praeterquam quod uini cibique absumptum erat, receperunt. [...]

Rex tamen Historium temulentus ex conuiuio, raptim a suis in equum impositus, fugit."

(Titus Livius, *Ab Urbe Condita*, XLI book, part IV)

"Only a few of the Istrians, who had drunk in moderation, betook themselves to flight: death succeeded as the continuation of the sleep of the others; and the Romans recovered all their effects unimpaired, except the victuals and wine which had been consumed. [...]

The king of the Istrians, though drunk after his banquet, was hastily mounted on a horse by his people, and effected his escape."[16]

[15] The English translations for the Latin texts were taken from http://www.perseus.tufts.edu

[16] The English translations for the Latin texts were taken from http://www.perseus.tufts.edu

Later, in the following year, the military campaign started again and led the way to the conquest of *Nesactium*, capital of the Histri, close to the present-day Pola. As a consequence, the king Epulon committed suicide and the Istrian peninsula and its population were subjugated[17].

"Cuius capti tumultum ubi ex pauido clamore fugientium accepit rex, traiecit ferro pectus, ne uiuus caperetur; ceteri capti aut occisi."

(Titus Livius, *Ab Urbe Condita*, XLI book, part XI)

"As soon as the king heard the uproar of the captured city, from the cries of terror uttered by the flying inhabitants, he plunged his sword into his breast, that he might not be taken alive; the rest were either killed or taken prisoners."[18]

The events of the first year of War probably occurred in the area that corresponds to the territory of Trieste as we know it today. Few months after Aquileia was defeated, in 177 or 176 BC, a group of Latin alleys probably went to the Istria area, very likely in *Tergeste* (ancient name of Trieste) to control the local population and prevent any plausible attacks against Aquileia. The whole territory kept on being very unstable politically until the half of the first century BC[19].

Taking into account the literary sources that talk about the conquest of the area during the third Istric War (178-177 BC), the researchers that discovered the Roman military camp in San Rocco (near the homonymous hill, the site of Grociana Piccola and the Basovizza area), consider it to be possible to be referred to an episode of the third Istric War described by the Roman historian Titus Livius in his famous Ancient History of Rome (*Ab Urbe Condita*)[20].

The only literary source left about the establishment of the city of *Tergeste* is to be claimed to the Greek geographer and historian Strabone and his work named *Geography*. He described Tergeste as a border fortress first, and then a Carnic settlement[21], referring to the homonymous region of the oriental Alps. The majority of the scholars claim that Strabone obtained information even from older sources that date back to the second century BC. Consequently, the description of *Tergeste* as a

[17] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 24

[18] The English translations for the Latin texts were taken from http://www.perseus.tufts.edu

[19] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), pp. 19-21

[20] https://www.anvgd.it/sito-romano-sul-carso-lpotrebbe-averne-scritto-tito-livior-28gen13/ Il piccolo, Gennaio 2013

[21] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 22

border fortress could refer back to the clashes that happened in 178-177 BC, when Latin alleys were sent to the city. The definition of *Tergeste* as a Carnic settlement could suggest a time shortly after the War, when the city had gained a military trait and had accommodated a large number of Celtic people. As a matter of fact, a Celtic army was active during the 178-177 BC clashes as Roman allies[22].

Figure 2. Main locations mentioned.

Founded as a border garrison near the most accessible part of the Alps, the ancient *Tergeste* is for the most part hidden by the medieval and modern city of Trieste[23].

Considering some literary (especially Hirtius and Appian) and epigraphic documentation, the establishment of *Tergeste* is quite debated. Based on the VIII book of *De bello Gallico*, written by the Roman dictator Iulius Caesar, it might be deduced that *Tergeste* was a Roman town populated by Roman citizens before 52 BC, but it is not known what its status was: *municipium*, colony or other. *Municipia* were indigenous communities under the authority of Rome with a certain degree of administrative and political autonomy; while colonies consisted of new settlements established by the Romans in conquered areas or ceded to Rome by other populations. *Tergeste* surely became a Roman colony, but historians don't agree on the chronology of its acquisition, which could have taken place between the proconsulship of Caesar in Gaul (58-50 BC), his dictatorship (49-44 BC) or even during the second triumvirate (43-33 BC)[24].

The toponym of *Tergeste* has Venetic origins and dates back at least to the fourth century BC, when the coastal area of the Adriatic was populated by ancient Venetians, at west, and by Histri, at east. As it was previously mentioned, in 181 BC Romans founded the colony of Aquileia, in an area where the Alps were less safeguarded from the invasions of the neighboring local populations. *Tergeste*'s stronghold, probably already utilized by Romans against the Histri, was presumably populated for the most part by Carnic communities and its harbor had an important economic role, because it was the place where the commercial products and goods from the east part of the Adriatic were sorted out and distributed, especially the oil from Istria. Despite the advantageous

[22] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 22
[23] TRAINA, *Tergeste*. Storie della colonia romana (2015), p. 3
[24] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 23

geographical location, *Tergeste* was not as important as Aquileia, which maintained a leading role in the area during the centuries[25].

As reported above, the transformation of *Tergeste* from a Carnic settlement to an actual Roman colony happened both for economic and strategic reasons in the mid-to late first century BC. Caesar's aim was to strengthen the colony in order to conquer the neighboring populations. However, he died in 44 BC and his death led to a series of civil wars. Consequently, the process of reinforcement of the settlement was held back for some time, and later resumed by Octavian, who built monuments and infrastructures. A series of inscriptions (figure 3), conserved today at Tergeste's lapidary, allow to date the start of a large urbanization process back to the last decades of the Republican period[26].

Figure 3. Inscriptions of Octavian (33-32 BC), kept at the Trieste's lapidary in the Castello of San Giusto. Picture taken from I giorni di Trieste[27] .

The city maintained its administrative, economic and religious organization and structure of a colony also during the Imperial period. The population was mainly located in the villas and in the settlements of the territory, which not only included the Karstic plateau, but also the northern part of Istria[28].

An interesting and important role was played by the *Tergeste*'s senator Fabius Severus, who helped with the integration of indigenous population in the economic and political life of the colony[29].

During the Augustean period, the area of the colony was still considered as a border territory; and even after the pacification of the neighboring areas, the Romans never forgot the strategic role of *Tergeste*[30].

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25 TRAINA, *Tergeste*. Storie della colonia romana (2015), pp. 3-4
26 TRAINA, *Tergeste*. Storie della colonia romana (2015), p. 6
27 TRAINA, *Tergeste*. Storie della colonia romana (2015), p. 7
28 TRAINA, *Tergeste*. Storie della colonia romana (2015), pp. 7-8
29 TRAINA, *Tergeste*. Storie della colonia romana (2015), p. 20
30 TRAINA, *Tergeste*. Storie della colonia romana (2015), pp. 7-8

Figure 4. Schematic reconstruction of the city planning of Tergeste. Civic Museums of Art and History, Trieste. Picture taken from I giorni di Trieste[31] *.*

1.2 Karst centuriation

The expression "centuriation" describes the method by which the Romans used to split the common land into *centuriae*, regular square areas that measured around 710 m each side (20 x 20 *actus*). This operation was conducted in order to have the possibility to assign those plots of land to new colonies and the population with Latin or Roman citizenship. The so-called centuriation, the Roman land division system, was built on a grid based on *limites*, including perpendicular roadways called *decumani* and *cardines*. The major roads were denominated *decumanus maximus* and *cardo maximus*[32].

The *centuriae* were further divided into smaller portions and were generally not assigned to a single holder[33].

The centuriation was the typical land division in areas where the land was flat, but in some cases, it was implemented also in hilly terrains.

The regular and well-organized shape of the *centuriae*, positioned, in this research's case, in an irregular territory such as the Karst landscape, clearly indicate that they could have been created and shaped entirely by using a rather advanced and refined tool and technology, which is the so-called *groma*. The *groma* was a vertical pole which held up two perpendicular cross-pieces, with a plumb line hanging at both extremities; it was used by Romans to trace orthogonal alignments and mark out two road axes perpendicular to each other[34].

In the latest years, the research derived from the examination of terrain models obtained with laser scanning data and archeological inspections has disclosed that a large part of the Karst, corresponding to the area from Aurisina up to the coastal area adjacent to San Rocco, was organized

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[31] TRAINA, *Tergeste*. Storie della colonia romana (2015), p. 9

[32] BOSIO (1982, 1986); Franceschelli (2015)

[33] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2015), p. 83

[34] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2015), pp. 57-58

with a single centuriated system and probably only somewhat pointed out by stone walls. San Rocco's inner structures also have a matching orientation[35].

The orientation of the land division grid of the Karst area appears to be strongly affected by environmental characteristics, such as the geological layers' direction and the morphology of the terrain. The main axis of the centuriation, the *decumanus maximus*, seems to correspond to the road between Aurisina and Prosecco[36], which is part of the area investigated in this work.

The detection and interpretation of a centuriation system in the Trieste area, that could date to a quite early stage of the late Roman Republican period, set the base for a series of inquiries about the first establishment of an organized administrative institution responsible for the land division system and the assignment of the plots of land[37].

Figure 5. Satellite image from Google Earth of a locality around Vodnjan (Dignano d'Istria), whose outlook reflects even now the Roman division of the land in regular square plots, which measure around 710 m per side. Taken from Bernardini and Duiz, 2021.

1.3 The Roman road network in the Karst landscape and its reconstruction

Due to the peculiar morphology of the Trieste Karst, which is a plateau characterized by sinkholes, narrow valleys and hilly ranges that runs for the most part parallel to the coast, the mobility within this area has consistently been affected by geomorphological factors[38].

Simulating the road system in a particular time period requires the reconstructions of the nearby landscape, both physical and cultural, that led to the development of that specific route. Generally, the elements that influence the creation of the roads could be both cultural and environmental. Even though the social, economic and strategic reasons for creating such a road structure are important, those cannot work regardless of the orographic characteristics of the terrain,

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[35] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2015), p. 83
[36] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2015), p. 83
[37] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2015), p. 83
[38] BERNARDINI, VINCI, FORTE, FURLANI, PIPAN, BIOLCHI, DE MIN, FRAGIACOMO, MICHELI, VENTURA, TUNIZ, Discovery of ancient Roman "highway" reveals geomorphic changes in karst environments during historic times, p. 4

the presence of the vegetation, waterways and every element that can be seen through survey and research[39].

In the investigated area, thanks to LiDAR-derived digital terrain models and a meticulous survey with the subsequent collection of *caliga* hobnails (Roman shoe hobnails), it was possible to rebuild and pierce together portions of the Roman road network with high-quality and precision[40], obtaining significant results and information concerning the geomorphological and social development of the Karst environment and its population.

The road system, in the area of the Timavo springs, already identified and studied in the last decades, was based on two main routes (figure 6). The first one consisted of the road axis that crossed the area from north-west to south-east in the direction of Duino-Aurisina and that, once passed the bridge on the Locavaz river, used to divide into two ramifications: one used to run upstream between two elevations, and the other proceeded downstream to get back together with the previous one in a point at S. Giovanni near the Timavo river. The other road axis used to run in north-east and south-west direction, from the valley of Brestovizza-Madeazza-Gola Ograda, towards the area of the Timavo river's mouth. In this way, the connection between the coastal area and the Karst hinterland was guaranteed. Certainly, also other plausible halfway routes could have existed[41].

Figure 6. General map based on a portion of the CTRN (elements number 088152, 088163, 109031, 109044) with the detected ancient evidences and the reconstruction of the historical viability structure of the area. Elaboration by V. Degrassi and D. Riccobono, taken from Auriemma et al (2008)[42].

Taking into account the archaeological data at hand and the old itinerary information, the Trieste Karst was intersected by two primary Roman public roads, going from Aquileia to *Tergeste* (modern Trieste) and from there to Pola (in Croatia), in the southern part of the Istrian peninsula, and to *Tarsatica* (modern Rijeka) in the Kvarner bay in Croatia. In accordance with most scholars and

[39] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 145
[40] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2015), p. 77
[41] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 146
[42] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 145

archaeological data, the two routes stuck to the same road for approximately 15 km, from the *Fons Timavi* (Timavo springs) at the north-western border of the Karst (see the detailed description of the road network above) to the village of Prosecco, where it split into two forks. One fork descended to Trieste and went on towards the Istrian peninsula, while the other fork continued in the direction of Rijeka, behind Trieste, through the Karstic plateau. Other scholars have debated that the road division described above took place around 2 km south-east from the Timavo mouth, where the Duino village is located. However, this hypothesis is contested by most researchers. In addition, it is very likely that an additional route, probably following a pre-Roman road, branched off from the primary one in the area corresponding to Sistiana and run to the modern center of Slovenia, passing across the central Karst ridge, presumably between Monrupino and Zolla[43].

Figure 7. Localities mentioned above. Figure taken and modified from Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy)[44].

During the study of the Roman road network, the LiDAR-derived images were combined with the Roman shoe hobnails collected in the course of surface surveys. As a matter of fact, exceptionally handy and convenient for the reconstruction and interpretation of the ancient Roman road system is the methodology based on LiDAR-derived data integrated with the collection of Roman shoe hobnails gathered during surface examinations. LiDAR-derived images and visualizations, disposing a particular scale of elevation values, let to emphasize small-scale relief disparities, constituting an effective tool for the study of ancient road networks[45]. On the ground, these features belonging to ancient roads reveal themselves as topographic anomalies, such as depressions, ridges or bumps covered by vegetation and often also covered by modern-day land division walls. The attribution of the roadways to the Roman period, especially the Roman Republican period, is confirmed and verified by the presence of numerous *caliga* hobnails gathered[46].

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[43] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023), p. 4

[44] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023), p. 2

[45] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023), p. 5

[46] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023), p. 7

The surveys performed to find materials, in this case the Roman shoe hobnails, are especially effective after heavy rains. The purpose of the in-person field survey, in this research's case, was to retrieve archaeological artifacts, hopefully related to the detected roadways. The discovery of Roman shoe hobnails is really useful to locate and to examine Roman routes. Generally, because of the overall low sedimentation rates, most of the Karst area is considerably conservative and different ancient artifacts dating back to various periods can be recovered together on the ground surface[47].

From an historical perspective, the reforms established by Marius in 107 BC gradually transformed the Roman army into a more professional military corp. The soldiers were equipped by the state and the recruitment of the members of the troops was no longer connected to the census. Henceforth, all legionnaires were provided with the same equipment, that consist also of a *pilum*, a *gladius* and a *scutum*[48] (figure 8).

Figure 8. Roman legionnaire of the first century BC. Drawing by G. Zanettini, taken from Oltre Aquileia[49].

Roman legionnaires wore the so-called *caligae*, robust military sandals manufactured with a thick leather sole, on which were fixed conical-shaped hobnails that had a width of about 2 cm and ensured an outstanding grip even on the more arduous grounds[50].

The Spanish theologian, writer and archbishop Isidorus Hispalensis, in his work named *Origines*, dates the term "*caliga*" back to the *callus,* with which the leather of the sole was hardened[51].

Another interesting information is passed on us by the Roman historian and senator Publius Cornelius Tacitus, who talks, in his work *Historiae,* about a particular equipment called *clavarium,* which consisted in some amount of shoe hobnails given to the army members because, during the long marches, the hobnails often detached from the shoes[52].

Hobnails were, in fact, frequently lost during clashes and marches and now they are considered to be essential evidence for the identification of Roman military sites and for the study

[47] BERNARDINI, VINCI, FORTE, FURLANI, PIPAN, BIOLCHI, DE MIN, FRAGIACOMO, MICHELI, VENTURA, TUNIZ, Discovery of ancient Roman "highway" reveals geomorphic changes in karst environments during historic times (2018), p. 6
[48] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 27
[49] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 27
[50] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 77
[51] ISIDORO DI SIVIGLIA, *Etymologiae*, pp. 19, 34
[52] PUBLIUS CORNELIUS TACITUS, *Historiae*, book 50

of ancient Roman road networks. In fact, the underside of the hobnails, in most cases, shows marks in relief, which can be very helpful in order to distinguish between the discovered hobnails of Republican age or Imperial age and date both the hobnails themselves and the roads in which they were found[53].

Figure 9. Foot with sandal of a Roman statue preserved at the Archaeological Museum of Aquileia. Picture by M. Raccar, taken from Oltre Aquileia[54].

Figure 10. Sole of a caliga shoe beside the posterior part of a sandal, conserved at the Archaeological Museum of Aquileia. The circular marks and holes visible on the shoe are the results of the hobnails that were once attached to it. Photo by M. Raccar, taken from Oltre Aquileia[55].

The discoveries of Roman shoes' hobnails are more ancient in military contexts compared to the civil ones. In the first phases, around the first century BC, *caligae* with hobnails were exclusively used by soldiers. Later, the Romans, seeing the advantages that this type of shoe had, decided to extend its use to the civilian population, so the *caligae* were not anymore restricted only to the military world. The shoe hobnails were fixed mostly under the soles of the military shoes to increase their grip to the ground and improve their durability[56]. Typically, the shoe hobnails can be categorized depending on the type of marks they have on their underside: lines and circular marks. Such marks present on the underside of the Roman shoes are important to the research because archaeologists can, in some cases, determine, looking at the pattern represented, if they belong to the Republican or Imperial Roman period[57].

Figure 11. An example of Roman caliga hobnails retrieved on the ground. Picture shot during a field survey performed in the investigated area after it had rained.

[53] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 77
[54] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 78
[55] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 79
[56] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 65
[57] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023), p. 5

Various types of *caliga* hobnails existed and it is possible to distinguish between them thanks to the different patterns represented.

Firstly, hobnails without patterns on the underside were in use during the Roman period for a long time. Other types of hobnails have several linear marks, series of spaced large dots or both linear signs and dots. These three types of hobnails described belong to the Late Republican Roman period, between Caesar's campaigns in Gaul and the start of the Augustean period[58].

The *caliga* hobnails with a cross and four dots were peculiar to the first century BC. The ones in which are represented circular protuberances and cruciform patterns in relief, in fact, were abundantly widespread in military environments and camps that can be considered to date back to the period between the Gallic wars and the early Augustan period (58-15 BC)[59].

During the middle and late Augustean period, the dots of the type of hobnails that had a series of spaced points multiplied and became smaller[60]. In fact, the shoe hobnails with small dots were employed in the first century AD, so during the Roman Imperial period.

Figure 12. Roman shoe hobnails from the Grociana piccola archeological site, dating back to the half of the first century BC. Photo by M. Raccar, taken from Oltre Aquileia[61].

[58] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023), pp. 5-6

[59] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 65

[60] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023), p. 6

[61] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 63

1.4 The investigated area: geographic and geological background

The geographic section where the research took place is the Trieste Karst, in particular the Aurisina area (figure 13 and 14). Aurisina is a small town that is part of the Duino-Aurisina municipality. It is located 15 km north-west from Trieste, the capital city of the most north-eastern Italian region, Friuli-Venezia Giulia, that borders Slovenia. Aurisina was already known in the ancient Roman times for its limestone quarries. East of Aurisina lie the town of Prosecco and then Trieste. Going west from Aurisina we find Sistiana, the Timavo spring, Monfalcone and, before Grado, Aquileia.

Figure 13. Location of the investigated area and the main localities referred to in the paper.

Figure 14. Location of the investigated area and the main localities referred to in the paper.

Figure 15. Picture of the area shot from the Castelliere di Slivia, visited during the research's field survey.

Figure 16. Picture of the area shot from the Castelliere di Slivia, visited during the research's field survey.

The investigated area encloses a surface of about 55 km² and is part of the Classical Karst, a historically and geologically unique region that runs from Gorizia, through Trieste, to the Istria area. The area of the Karst plateau is dominated by caves, paths passing between the stony outcrops and dolines (also called sinkholes), which are natural depressions of the land in the Karst's landscape.

The average height of the plateau is around 380 meters above sea level and it is moderately tilted toward north-west; Mt. Cocusso is the highest elevation (674 m) and the south-western sector is characterized by steep slopes, in the direction of the gulf of Trieste[62]. In the investigated area the presence of limestone is predominant, but a thin belt of sandstones and marls outcrops along the coast; numerous quarries, many of them used by men since prehistoric times, are reported in the

[62] BERNARDINI, VINCI, FORTE, FURLANI, PIPAN, BIOLCHI, DE MIN, FRAGIACOMO, MICHELI, VENTURA, TUNIZ, Discovery of ancient Roman "highway" reveals geomorphic changes in karst environments during historic times (2018), pp. 6-7

Aurisina karstic area. The vegetation consists mainly of downy oak, black pine and hornbeam trees[63]; the trees are combined with wide areas covered by grassland and bushes. No rivers or surface water runs in the studied territory[64].

Figure 17. Geological map of the studied area, with the schematic representation of the main geological features.

The geological aspect of the area is really important for the distribution of archeological sites. The stone belt that runs parallel to the sea coast line consists of two main types of rocks, sandstone and marl (*formazione marnoso-arenacea*), and reaches its largest width in the Trieste area (6km), while it shrinks down completely after Aurisina. The stone belt is visible again nearby Canovelle/Srednje and Sistiana[65] (figure 17).

The area has seen the identification of some archaeological features mainly through surveys and archeological field examinations. This environment has also been one of the scenes of the First and Second World War, hence the fact that trenches from those conflicts characterize the landscape of the area[66]. For more details, refer to the chapter below about the archaeological background of the area.

1.5 Roman archeological sites in the investigated area

The aim of this section is to summarize the main archaeological evidence known in the area before the present study.

Going east from the Timavo river, the altitude of the seashore gradually increases and here, between the area of Duino/Sistiana and Grignano (where the famous Miramare castle is located),

[63] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023), pp. 3-4
[64] BERNARDINI, VINCI, FORTE, FURLANI, PIPAN, BIOLCHI, DE MIN, FRAGIACOMO, MICHELI, VENTURA, TUNIZ, Discovery of ancient Roman "highway" reveals geomorphic changes in karst environments during historic times (2018), p. 7
[65] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 108
[66] BERNARDINI, VINCI, FORTE, FURLANI, PIPAN, BIOLCHI, DE MIN, FRAGIACOMO, MICHELI, VENTURA, TUNIZ, Discovery of ancient Roman "highway" reveals geomorphic changes in karst environments during historic times (2018), p. 6

there are still the stone quarries that played a decisive role in the development and in the economic flourishing of this area during the Roman times. Some Roman buildings known in the area were probably connected to the limestone quarries. The landscape between Sistiana and Trieste, seen from the sea, was probably not so different compared to the current times: small settlements dissimulated by vegetation with nautical landing places[67].

The location of the archaeological features is tightly connected with the topographical characteristics of the territory. As a matter of facts, the area between Trieste and Duino appears to be a good location for human settlements, taking into account its features: the area is well sunlit and partially protected by the cold north-east wind (*bora*) in the steep part that goes down to the sea. More precisely, just the steep coastal area is protected by the wind and partially suitable for agriculture, due to the predominance of sandstones and marls. The Karst environment, except for the quarries' area, is not that inviting, with just few areas suitable for agriculture, for the most part at the bottom of the sinkholes.

Figure 18. Distribution of the main previous archeological discoveries in the studied area.

In the examined area, already during Roman times, a particular type of basin was employed, still partially used nowadays for the recovery of recreational boats (*imbarcazioni da riporto*) and fishing vessels. Sistiana's harbor (figure 19, n.1) is considered by some authors to be the place from where the lithic products extracted from the Aurisina quarries (figure 19, n. 7) were boarded[68]. Even though their presence is still debated, it is also recorded the possible presence of two slides not far from the Aurisina quarry that could have helped the materials being transported and managed, one in Sestrance (figure 19, n. 6) and one in Botanjek (figure 19, n. 4)[69]. Probably connected to Sistiana's harbor, it is also recorded the presence of a villa (figure 19, n. 2) located very close to the sea further down Sistiana's settlement and, based on the archaeological evidence, probably provided with a residential area.

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[67] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 108

[68] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 108

[69] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 119

In addition, as the Diplomatic Archive of Trieste records, in the Sistiana bay, a long structure perpendicular to the seacoast is reported as "*muro*". This feature continues in the Trieste direction and can be correlated with the existence of a dock, a building (*villa*) or other submerged structures connected with it. Furthermore, following the course of the Roman road from Aquileia to Trieste, in the Sistiana area a diverticulum probably reached the bay in correspondence with the modern dock. This could mean that the ancient Roman dock could be hidden from the current one[70].

Other settlements in the examined area were detected, both in the coastal belt facing the sea and in the karstic plateau: few structures in the Canovella area (figure 19, n. 10, 11, 12), some villas south-west from Santa Croce (figure 19, n. 13, 14, 15), a structure near the modern Piezometric tower (figure 19, n. 5), some villas in Aurisina (figure 19, n. 8, 9) and other buildings that showed remains of the processing of the limestone[71].

In the Canovella area were identified a *villa* (figure 19, n. 11), a tomb (figure 19, n. 10) and also a plausible dock (figure 19, n. 12) connected with the structures. The *villa* is located under Aurisina in the Srednje area and, based on archaeological evidence, can be dated back to the end of the first century BC[72].

South-west from Santa Croce were identified three *villas* (figure 19, n. 13, 14, 15) and the existence of a dock connected to the structures (figure 19, n. 16) can be deduced from the location of the villas themselves. Considering the archaeological traces, the *villa* n. 15 could date back to the Roman Imperial period[73].

The chronology of the structure close to the Piezometric tower (figure 19, n. 5), at first identified as a Roman *villa*, is now predated because of the building technique (limestone walls without bind), that recalls local traditions. The hypothesis seems to be accurate also for the

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[70] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), pp. 108-110

[71] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 118

[72] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 119

[73] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), pp. 117-118

chronology of the ceramic material retrieved on the site, that date back to the romanization period (first century BC)[74].

The excavations and the research performed in the Aurisina *villas'* area (figure 19, n. 8, 9), seem to confirm the presence of the residence of a quite wealthy family due to the discovery of bronze fragments and semi-finished stone products. It is very likely that the prosperity of the people that lived there was connected to the exploitation of the nearby quarries, which already started in the late Republican period. The dating of the structures can be set within the half of the first century AD. A pavement (figure 19, n. 8), thanks to fragments of ceramic and black slip pottery found in the foundations, can be referred also to the first century AD. The building was probably used for just a few years, if we consider the discovery of an Augustus coin, datable between 10 and 3 BC, in the collapsed layer[75].

However, these rural structures seem to be the only ones connected to the productive activities of limestone extraction. Considering the morphology and the characteristics of the area, suggest the idea that the villas located in the upper part of the coast belong to people who had administrative and political interests downtown; while the docks were probably used to easily transport manpower and supplies from and to Trieste (known at those times as *Tergeste*)[76].

Figure 19. Main previously discovered archeological structures mentioned and described, located in the investigated area.

Generally, also in this part of Europe, the roadways have mainly followed, until the eighteenth century, the previous blueprints of ancient road layouts. The variations in the mobility structure have to be connected to changes in waterways or landslides. In the Karst environment the routes are steady and often forced by geomorphological elements, such as sinkholes. Therefore, reasons for the variation of the paths do not exist, unless there's a demand for the traffic to changes or expansions, which in the majority of cases leave unchanged the general scheme of the roadways[77].

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[74] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 119

[75] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 119

[76] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 119

[77] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 65

The discovery of a road layout is considered possible when it goes over the calcareous layers that preserve the engraved route, due to the fact that they are less rough and more even[78].

For the most part, the real estate development in the Sistiana area made the detection of elements on the ground impossible. However, precisely in the Sistiana area, was visible an ancient path that used to run for about 80 meters on the bump on the left of the state highway and that used to tilt at about 30 degrees from the modern path[79]; this path was recently destroyed, but it is still visible in the LiDAR-derived data (figure 19, n. 3).

The numerous traces cut through very clearly and it is significant that they run on the bump of the upland of Sistiana, definitely standing out from the modern roadways. These characteristics would confirm the antiquity of the Roman path because one of the properties of the Roman roads in these kinds of territory was to be built in an elevated location, when possible. Immediately east of Sistiana, the area is characterized by a ridge parallel to the coast and the ancient road runs parallel to the inner side of the ridge itself[80] (figure 20).

It is only in the area of the Aurisina quarries, where lies the supposed continuation of the ancient path, that numerous Roman materials were found in correspondence with the Roman quarries in the area: amphorae and vase remains, roof tiles and iron scoriae. Here, in the summer of 1976, were brought to light the remains of a Roman civil building that can be dated back between the first century BC and the first century AD (figure 19, n. 8 and 9). However, in the whole route from Sistiana to Prosecco, Roman remains were found. Following this direction, the modest curves of the route present are due to the natural characteristics of the Karst landscape, such as the predominant sinkholes that partially became caves afterwards[81].

In the direction of Trieste, in the Santa Croce cadastral map dating 1822, is reported a road segment, of possible Roman origins, that joins the modern provincial one where there are two stone columns that advise the border between the territory of Trieste and that one of Duino-Aurisina. In nature, in the woodland is still detectable a feeble trace of some segments of wrecked furrows[82] (figure 20 and 21).

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[78] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), pp. 79-80

[79] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 69

[80] GRILLI, MENG, La strada romana sul carso triestino (1978-1979) , pp. 69

[81] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 70

[82] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 71

Moreover, it is verified that the border between the municipalities of Trieste, Duino-Aurisina and Sgonico still runs over the old Austrian postal road, which overlays the Roman one[83].

Figure 20. Map with the outline of the roads mentioned, taken from La strada romana sul carso triestino[84].

Figure 21. Map with the outline of the roads mentioned, taken from La strada romana sul carso triestino[85].

The Roman road between Sistiana and Prosecco was planned with a perfect military concept: the manufacturers abandoned the so-called *strada dei castellieri* (*castellieri*'s road) and they built a new roadway to be in a dominant position and better view and control the underlying slope and the hilly ridge on the inside, so to be in a safer place in case of attacks from the enemies. The so-called *strada dei castellieri* (*castellieri*'s road), in fact, used to run between the two internal hilly ridges, connecting the numerous *castellieri* that arose there, and it was considered too dangerous and vulnerable to the enemies' attacks[86] (figure 22).

Figure 22. The castellieri's road (strada dei castellieri) scheme, taken from La strada romana sul carso triestino[87].

[83] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 73
[84] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), pp. 80 e a seguire
[85] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), pp. 80 e a seguire
[86] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 74
[87] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 75

2. Materials and methods

One of the most important goals of archaeological research is acquiring information about features from remote sensing data (position, shape, structure, characteristics and so on)[88]. Scientific and technological advancement is transforming the way in which material traces of the past can be studied and investigated, and is providing archeology with progressively more sophisticated tools and methods. Laser remote sensing technologies, combined with aerial photography, historical maps and geophysical surveys, allow the detection and analysis of the ancient archaeological landscape[89].

Taking into account the fact that the investigated area, being part of the Karst plateau, is mostly covered by woods and bushes, Airborne Laser Scanning (ALS), also known as Light Detection and Ranging (LiDAR), was selected as the most promising and effective method in such a kind of environment. As a matter of fact, the canopy covering the area would have considerably limited the acquisition of data through other remote sensing techniques, such as UAV (Unmanned Aerial Vehicle), structure-from-motion (SfM) photogrammetry, satellite or aerial photography.

To briefly introduce the research process, data obtained through LiDAR technique were interpreted and presented with the aid of the GIS (Geographical Information System) software QGIS. These data were, then, further analyzed and examined in combination with previous archaeological discoveries' records in the area, the nineteenth's century cadastral maps, information and tangible material collected during in-person surveys. A more detailed and exhaustive description of the techniques employed and the research's approach will be presented throughout this chapter.

88 LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 22

89 BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 99

2.1 Airborne Laser Scanning (ALS) / Light Detection and Ranging (LiDAR)

2.1.1 Historical background

Archeological and Cultural Heritage (ACH) was one the fields that first used remote sensing from elevated points. First, there were kites and hot-air balloons, followed by aircrafts, rockets and finally satellites. Airborne and spaceborne remote sensing techniques are the most widely used in Archeological and Cultural Heritage research because of their advantages: fast imaging, large spatial coverage, high resolution and sensitivity to anomalies in the subsurface of the Earth.

Photography was invented in 1839, but it was around 1900 when airborne remote sensing was first used in the Archaeological and Cultural Heritage field. In 1906, a British military general utilized a hot-air balloon to photograph the Stonehenge site, both vertically and obliquely. Moreover, one of the first publications regarding the application of airborne remote sensing in ACH was about the use of aerial photography supporting military purposes in surveying an area for map production. Later, in 1959, the spy satellite CORONA was the first spaceborne platform ever launched.[90] Even though the limits of their use, the historical and aerial spy satellite images have benefited in revealing ACH sites for a long time now. Since then, remote sensing technology has developed incredibly, leading to the collection of big remote sensing data, allowing for more new discoveries.

Airborne LiDAR's applications commercially emerged in the mid-1990s, and in the last couple of decades, its growth has led to an improvement in flying heights and pulse rates, which permits mapping of large areas more easily[91].

At present, LiDAR-derived data are used in ACH applications to obtain terrain information and accurate surface models in order to detect archaeological structures or submerged sites even under vegetation or underwater. Airborne LiDAR has been successfully applied across the world to ACH to detect and analyze archeological features and their patterns. LiDAR-derived data are not only useful to accurately portray the topography of the investigated landscape, but also to understand and study the paleo-landscape and the characteristics of the social history and patterns of the area.

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[90] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), pp. 1-2

[91] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 17

2.1.2 LiDAR acquisition and visualization

Airborne Laser Scanning (ALS), also known as Light Detection and Ranging (LiDAR), is part of the so-called active remote sensing methods. Remote sensing is the name given to all the techniques that use non-direct contact devices to detect targets of interest on the subsurface and facet of the Earth, from the surface of the ground or from above it. This description includes different methods: geophysical (ground penetrating radar, electromagnetic methods and electrical resistivity tomography) and ground-based one (sound navigation and ranging). Remote sensing techniques are then divided into passive and active methods. Passive remote sensing methods include photography (mainly aerial), multispectral and hyperspectral imaging (that consist in a natural collection of radiations). By contrast, LiDAR and Synthetic Aperture Radar (SAR) are considered active remote sensing techniques. The main difference between the two types of methods is the fact that, while the passive remote sensing systems naturally capture occurring radiations (for instance, reflected solar radiations or thermal energy), active remote sensing systems produce their own radiations[92]. The latter remote sensing methods' type, in practice, produce its own radiations to send to the target that needs to be examined. The reflections of these radiations are connected to the remote sensing device, allowing to get information about the investigated target.

The technique used for this research's purposes, LiDAR, is a scanning and profiling system used in topographic applications, that determines three-dimensional (3D) data points by making use of a laser[93]. It is widely utilized for landscapes, large areas and environments covered by vegetation to detect variations on the ground related to the presence of archaeological features. Unlike other remote sensing methods, LiDAR, involving an active sensor that shoots out a beam of light, can be employed even at night or in circumstances when passive techniques wouldn't work, such as the above-mentioned canopy. Nevertheless, acquiring data at night could not be the best choice because the presence of possible clouds that could affect the quality of the investigation[94].

In basic terms, airborne LiDAR consists of an active laser beam being transmitted in pulses from a fixed aircraft and the reflection that returns being measured. LiDAR sensors can be installed on ground platforms (Terrestrial Laser Scanning, TLS), airborne platforms (Airborne Laser Scanning,

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[92] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), pp. 2-3

[93] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 1

[94] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 3

ALS) or satellites[95]; they can be employed from moving or static platforms, including vehicle-mounted detectors and aircrafts[96]. The accurate location of the sensor array is known in the aircraft due to the combination of the Inertial Measurement Unit (IMU) in the platform and the Global Positioning System (GPS)[97].

More in detail, LiDAR systems shoot out light pulses and measures how long it takes for their backscattered reflection to return and the intensity of the energy that comes back. LiDAR sensors are able to measure orientation and range, identifying target objects through position, reflection and backscattering characteristics[98]. Measuring how long it takes for a pulse of light to be shoot out to the target and then to bounce back, it is possible to record the location of points on the ground with a high degree of accuracy, generally from 100 to 150mm both in plan and height[99]. Moreover, in most cases, LiDAR uses eye-safe lasers within wavelengths in the infrared range (IR)[100].

LiDAR provides accurate locational and height data (point cloud), which enables the creation of a three-dimensional (3D) model of the land surface in a short period of time. This three-dimensional model can be examined and interpreted to identify archaeological features that display some form of topographic expression on the surface of the investigated area[101]; moreover, the 3D model surely facilitates the effective and detailed analysis of the site and the landscape. In fact, because of the information it can provide on forested areas, the three-dimensional digital model of the ground is considered to be the most useful outcome of LiDAR for archaeologists[102].

To further analyze the LiDAR process, when the laser is shot by the aircraft, it travels towards the ground and, if it hits anything while passing by, part of that beam of light is reflected back to the device, forming the so-called first return. The remainder of the beam goes on the way to the ground and might strike further features and could, consequently, produce other returns until it finally meets the ground. The final reflection of the land that reaches the sensor is denominated the last

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[95] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 16

[96] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 1

[97] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 24

[98] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 16

[99] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 24

[100] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 3

[101] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 4

[102] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 22

return (figure 23). While early-generation LiDAR sensors could generally collect up to four returns (a supplementary one or two returns, in addition to the first and last returns), their development expanded in the last few years. Now, instead of just collecting two to four returns, it is possible to digitize, through the new full waveform (FWF) system, the entire echo waveform for each laser beam emitted. Despite that, the very first and last returns have always been considered the most useful: the first corresponding to a Digital Surface Model (DSM), and the last being a way to calculate a Digital Terrain Model (DTM)[103].

Elevation data is an important part of LiDAR-derived data that presents information detected during data collection about morphological and topographic attributes of a landscape. In general, Digital Elevation Model (DEM) is a generic term that can refer both to Digital Surface Models (DSM) and Digital Terrain Models (DTM). The DEM is a form of raster image in which the value determined for each cell is an elevation (height) value[104]. DEMs contain height values that are part of different types of surfaces, such as built-up areas, forested terrains, or the bare ground.

Under the umbrella of DEM, DSM and DTM elevation models are mostly being produced and used for archeological research[105]. The DSM consists of the digital elevation model of the earth's surface, which records the highest points of it, including the vegetation and buildings; it represents all the features on it, comprehending also the manmade structures and water surface height. Therefore, the DSM can be defined as the representation of the information about the uppermost surface features detected by the sensor. On the other side, the DTM is the digital elevation model of the uncovered land, with buildings or other structures removed[106], showing topographic variability not only on the bare earth surface, but also on the seafloor. Ultimately, the DTM is the result of filtering operations where the only points left are the ones belonging to the very ground surface[107].

Figure 23. Graphic representation of the airborne laser data acquisition method. Taken and re-elaborated from Oltre Aquileia - La conquista romana del Carso[108].

[103] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 7
[104] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 21
[105] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 18
[106] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 7
[107] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 17
[108] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 97

The Digital Elevation Models (DEMs) are forms of raster images. Raster Digital Elevation Models, in many cases, are obtained from data acquisition techniques, such as LiDAR, by recording the 3D location of points in space. The raw dataset is then managed to transform the three-dimensional points obtained into a structured grid of cells, where a value is assigned to each pixel. In raw data single points are dispersed over the examined area precisely as they have been recorded, while in gridded data the points have been disposed in a regular way to form a spaced arrangement[109].

More in detail, raster data are arranged in an organized geodatabase management system to fulfill the goal of a particular project. Raster datasets contain a metadata description that define the characteristics of the data (date of acquisition, resolution, geographical location and so on). A raster dataset is composed of a matrix of cells (also known as pixels), arranged in a grid made of rows and columns. Each cell corresponds to a geographical region, and to each pixel is assigned a numeric value representing some characteristic of that area, which could be different phenomena, such as elevation, temperature and so on.

All DEMs raster files are composed of a grid of pixels in which an attribute expresses the height value, each with an *x*, *y* and *z* coordinates. Point clouds derived by the height data is, in fact, a collection of points measurements converted into the Cartesian (*x*, *y* and *z*) coordinates system, that describe the surface of a target with accurate detail and that shows its spatial distribution. It is important to take into account the fact that the points themselves have no correlation between them; however, analyzing their density helps to define features and objects on the surface[110].

The points correspond to the spots where the light pulse was reflected and they usually include both the reflection of the ground and the potential objects that the laser found on its way to the land. Consequently, there are two classes of points: the ones belonging to the ground, and the other ones corresponding to various features (vegetation, buildings, etc.).

However, points alone are not useful to create data in order to easily visualize archeological features. By creating a surface from the data, the archaeological elements detected can be visualized more easily and effectively, as it is possible to generate surface analyses with the use of lighting effects, and represent LiDAR-derived models in a number of ways[111]. Actually, the traditional methods for visualizing and post-processing the data employed by archaeologists include mostly

[109] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 13
[110] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 15
[111] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 41

hillshaded maps, slope analysis and local relief models. DEMs can be represented by the software showing elevation changes through a color gradient[112]. The most used and easy to interpret visualization method is the hillshaded map[113]. Like in all DEMs, through hillshade visualization, it is possible to handle the data lit from different positions. Combined with the opportunity to increase the vertical emphasis of features, this kind of visualization, allows to analyze also features that have just a slight surface mark on the land[114].

Usually, some techniques are used to erase surface elements, such as vegetation and buildings, to create a DTM. Mathematical algorithms are implemented to classify the characteristics of the different returned points. This classification is fundamental to be able to remove all those features that are identified to be above the bare ground surface, by comparing the single heights of the nearby detected points[115]. Depending on the characteristics of the investigated area, archeologists should choose the adequate filters to LiDAR raw point clouds to discriminate between ground and non-ground. This filtering and then classification of the points is crucial for the detection and then interpretation of archaeological features and the production of accurate DTMs[116]. In practice, in arable land the first and last returns are usually already suitable for the record of archaeological features; in open land the first and last returns could be exactly the same. On the other hand, LiDAR-derived data, especially in woodland, is made of numerous returns, which can be filtered through algorithms to remove above-ground points. This process is extremely useful for archeological research, because filtering out the vegetation allows it to detect features beneath the canopy[117].

From an archeological perspective, it is often easier to utilize a model that didn't go through the removal of buildings and other features, since it could help, in some cases, with the understanding and interpretation of features related to modern architecture and land usage. In fact, there might be some structures important for the comprehension of the ancient landscape that would be removed through the process, such as walls or gardens. Data processing also allows to create a DTM penetrating the canopy and smooth out specific archeological structures. Nevertheless,

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[112] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 47

[113] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 18

[114] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 41

[115] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 21

[116] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), pp. 17-18

[117] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 48

for disclosing features in forested areas, the DTM is not valuable. Indeed, the last return from woodland would get through some degree of canopy; while there would still be parts of the investigated area where the LiDAR beam would not reach the very ground surface, due to the return from the tree trunk. By managing the data with algorithms to create a DTM, an unmatched perspective of the forested area can be obtained[118]. LiDAR-derived DTM data can be applied to the analysis and reconstruction of ancient settlements in vegetated areas and to the discovery of still unknown archeological landscapes.

Generally, the height data are considered as the core outcome of the LiDAR survey, but they are not the only information collected. The reflection of the laser pulse has an intensity, which can also provide useful details about the investigated target. As it was mentioned above, the intensity of the reflected signal of the laser is recorded by the sensor, as well as the relative location (*x*, *y* and *z* coordinates) of the point on the ground. The results are determined by the wavelength of the laser pulse and the characteristics of the surface that reflects the beam of light. For instance, if the laser encounters an obstacle, the pulse would be partially absorbed, according to the nature of the land. Disparate surfaces have different absorption rates and, accordingly, produce different signal strengths reflected back, that can be examined to distinguish different surfaces and analyze the reflectivity of the land. Nevertheless, it must be taken into consideration the fact that LiDAR mostly works in the infrared spectrum (IR) and the reflection might not meet the expectations. In practice, roads' asphalt has a low return ability, while grass and plants have a higher return value; instead, solid and flat surfaces, such as stone, reflect most light in the visible spectrum, but it is not the same in the case of the infrared spectrum (IR)[119].

Once the information has been acquired, by utilizing GIS (Geographical Information System) software, it is possible to manipulate LiDAR-derived data and highlight specific features, in order to visualize the data in a way that enables their interpretation[120]. The visualization techniques primarily used by archaeologists, for post-processing the arranged data and to highlight the natural and manmade features on the ground, are hillshaded map, slope analysis and local relief model (figure 24). Generally, a slope is calculated by comparing a raster point with the height of its nearby points; slope analysis plays an important role in site planning, infrastructure implementation, conservation and predictive modeling. A local relief model, on the other hand, is employed to increase the

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118 CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), pp. 21-22
119 CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 10
120 CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 40

visibility of small-scale features on the surface by removing from the DEM wide-scale landforms. However, the easiest and more common method to view the data is considered to be the hill-shaded image, due to the fact that it allows a more straightforward interpretation of the data[121]. By handling the data virtually lit from different locations, it is possible to improve the vertical emphasis of features and analyze even elements on the ground that just have a slight surface mark on the terrain[122].

Figure 24. Roman rural building in the surveyed area shown by aerial data (bottom right) and DEM visualizations: hillshading (top left), slope (top right) and local relief model (bottom left).

2.1.3 Advantages of LiDAR

The LiDAR technique has revolutionized archeological research due to its capability to provide fast and high-resolution data of areas covered by vegetation; woodland is, indeed, the key area where LiDAR has substantial advantages over other forms of survey[123]. By contrast, other remote sensing methods and, especially, passive remote sensing techniques are not effective in forested areas. In fact, before the implementation of LiDAR surveys, the history and characteristics of many woodlands were generally poorly understood[124].

Other than the ability to penetrate the tree canopy, another advantage of LiDAR is the insensitivity to lighting conditions[125]. Comparing the visualization of LiDAR data with aerial photographs, it is clear that, in aerial photography, features on the ground do not create a shadow when they run parallel to the direction of the sun and they are, therefore, impossible to visualize. On the other hand, even though this situation can occur also in LiDAR-derived imagery, it is possible, in this case, to artificially produce multiple images. In fact, just one hillshade (the easiest to interpret visualization of LiDAR data) can be considered not enough; it is needed and useful to make

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[121] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 18

[122] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 41

[123] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 33

[124] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 56

[125] LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), p. 17

comparisons between images lit from different directions. By setting the altitude and the position of the light source, it is possible to enhance all those features perpendicular to the direction of the light and better detect and understand archaeological elements in the investigated area.

2.1.4 Limits of LiDAR

Although satellite imagery and LiDAR data can be considered an aerial revolution, since it offers archaeologists around the globe the opportunity to look for archaeological sites and examine the ground through high-resolution images, it is clear that this kind of data are merely tools. Images do not reveal sites by themselves; examinations of other types of data and the terrain are vital. Moreover, to correctly interpret remote sensing images, it's necessary to verify the possible features on the ground by fieldwork. LiDAR systems do not distinguish between the remains of nowadays agricultural practices and archeological features created by humans centuries ago. This is also why it is important to combine LiDAR-derived images with other data types, such as aerial photographs and in-field surveys, which can help to recognize the features previously detected and clarify uncertain areas[126]. In practice, since LiDAR is indiscriminate in what it detects, it is paramount to aid the interpretation of archeological remains with alternative sources of information, particularly in forested areas, because the creation of features is obtained by different processes that could be misleadingly interpreted as archaeological remains[127]. Skills and experience are certainly needed, but checking the plausible features on the land is absolutely necessary to avoid wrong identifications. In fact, ancient archaeological features are often collapsed and/or covered by vegetation; they are, at this point, part of the landscape and they can no longer be identifiable as human made structures without analyzing different data, both virtual and in-person. In this research's case, fieldwork inspections were successfully performed. For instance, during the study of the Roman road, the LiDAR-derived images were combined with the Roman shoe hobnails collected in the course of surface surveys. Shortly, the shoe hobnails were fixed mostly under the soles of the military shoes to increase their grip to the ground and improve their durability[128]. Typically, the shoe hobnails can be categorized depending on the type of marks they have on their surface: lines and circular

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[126] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), pp. 50-51
[127] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), pp. 56-57
[128] BERNARDINI, DUIZ, Oltre Aquileia - La conquista romana del Carso (II-I secolo a.C.) (2021), p. 65

ornaments[129]. Such marks present on the underside of the Roman shoes are important to the research because, firstly, they validate the existence of an ancient road or path, and consequently archeologists can determine, looking at the hobnails' typology, if they belong to the Republican or Imperial Roman period.

To summarize, LiDAR can be an extraordinarily useful tool when used in appropriate environments, also if it is used combined with other data sources[130]. Having analyzed its own advantages and limits, LiDAR's utility and benefits to archaeological research are incredible. The pros of utilizing such technology are way above its limits: fast and high-resolution imaging, the possibility to cover large areas, the accurate performance in different types of grounds and lightning.

2.2 GIS elaborations: QGIS

When there's the necessity to prepare to survey an area and to study the ancient landscape, it appears essential the employment of a territorial information system that is able to handle historical and archeological data in comparison with other territorial elements. The target of the research is multifaceted, not only for the type, but also for its distribution in time and space[131].

Generally, archaeological features can be extracted, in our case, from LiDAR-derived images as morphological and statistical data utilizing GIS-aided software. For the purpose of this research, the software chosen was QGIS (Quantum Geographical Information System), a free and open-source software that allows to visualize, analyze and edit geospatial information.

A Geographical Information System (GIS) can be described as a set of digital tools for collecting, analyzing, managing, manipulating and presenting information, that is spatially referenced in accordance with geographical coordinates displayed in a Cartesian space determined by *x* and *y* (and sometimes *z*). GISs have a well-established tradition in archeology and examples of their applications in archeological research are countless. In fact, by its nature, archeology is a field where the tangible manifestation of the past is examined in relation with the surrounding environment. Spatiality, then, becomes a paramount aspect for describing archaeological discoveries. Consequently, GIS platforms

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[129] BERNARDINI, Rediscovery of the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Division, Rural Buildings and New Hints on the *Avesica* Road Station (2023), p. 5

[130] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 64

[131] AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di Mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), p. 181

allow to manage various archaeological data and structure the information through a conceptual framework. Furthermore, they allow data processing and modeling, manipulating already existing data and creating new informative layers [132]. The main applications of GIS in archeology are landscape-scale analysis, site-scale and artifact-scale analysis, overlays and predictive modeling. Landscape-scale analysis is the interpretative range in which archeology works often and it represents an extremely useful comparative tool. Moreover, site-scale analysis allows to pick out patterns on pavements, inside urban layouts and in different stratigraphic sections. Lastly, predictive modeling is a way in which, considering the geomorphological aspects of an area, it is possible to predict where archeological features would be located[133].

From a historical perspective, GIS was developed during the so-called "processual" era of archeological study, when the "New Archeology" movement used to put strong emphasis on inferential and quantitative approaches[134]. As a matter of fact, from the 1960s New Archaeologists believed in the objectivity of observing, measuring and recording the data through quantitative methodologies. Processual Archeology researched in terms of process, of how changes in the economy and social systems happen. New archeology sought to explain instead of simply generating and describing new information, by testing hypotheses using valid scientific methods. In these circumstances, GIS provided archeologists with the possibility to represent and examine the data collected, and then contribute to the "explanatory" side of the discipline[135]. G.I. Systems were first developed in the 1960s, for instance the Canada Geographic Information System, that aimed to help manage natural resources with the aid of spatial data. The first applications in archeology took place only from the late 1980s, whereas nowadays GIS tools are widely used in a lot of disciplines. During the 1990s a large number of GIS models were developed to try to merge the study of environmental factors with the quantitative assessment of human elements that had been rejected in the processual era[136]. In this period an increasing number of archaeologists used these models to create maps of potential archeological risk. Through predictive modeling techniques they could define the areas that are more subject to the risk of destruction from new development and where they could more likely find archeological materials[137].

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[132] DELL'UNTO, LANDESCHI, Geographical Information Systems in Archaeology (2022), p. 5
[133] CONOLLY, LAKE, Geographical Information Systems in Archeology (2018), p. 181
[134] DELL'UNTO, LANDESCHI, Geographical Information Systems in Archaeology (2022), pp. 5-6
[135] DELL'UNTO, LANDESCHI, Geographical Information Systems in Archaeology (2022), p. 6
[136] CONOLLY, LAKE, Geographical Information Systems in Archeology (2018), pp. 7-9
[137] DELL'UNTO, LANDESCHI, Geographical Information Systems in Archaeology (2022), p. 6

Every GIS-based examination aims to foster the understanding of the past landscape reflecting the interactions between human actors and the natural ecosystem. Every landscape scrutiny turns out to be extremely complex. However, GIS-aided research allows archaeologists to build, with the modeling tools, multiple models and scenarios of the collected data, that can be used to produce new interpretations with an extraordinary number of instruments for managing spatial data and with a multi-vocal approach. Indeed, GIS cannot be considered a new technology as a whole, because it is itself a combination of already existing technologies, such as database techniques, computer-aided cartography, processing of remote sensing derived images, data visualization and spatial analysis.

The structure of GIS is composed by a data entry and storage, where the raw spatial data are translated, included and stocked in the project; then the data can be examined, transformed and modeled; as the last step, results can be returned by visualizing them in maps form and other graphics, often containing also text[138]. The aforementioned raster data models are often used in GIS applications because of the continuous field approach. As explained in the section above, this data type describes the world as a series of pixel values and it turns out to be much more suitable to visualize continuous surfaces, such as the elevation of an area, where the information represented changes gradually. The raster model appears to be the base format for DTMs because of its advantages: velocity of processing, good ability at mapping steadily changing phenomena (such as elevation) and their barriers (such as vegetation)[139]. In QGIS, the Relief Visualization Toolbox (RVT) plugin helps to visualize high resolution raster elevation model datasets derived from LiDAR, mostly hillshade maps, in order to identify small-scale features, such as roadways. The development of toolboxes, such as RVT, provide a considerably wider variety of options to visualize and examine the data[140].

2.3 Interpretation and analysis of the acquired data

Once the data have been obtained and adequately visualized, it was vital to establish an appropriate research approach and carry on the interpretation of the data, combining it with the

[138] CONOLLY, LAKE, Geographical Information Systems in Archeology (2018), pp. 11-13
[139] DELL'UNTO, LANDESCHI, Geographical Information Systems in Archaeology (2022), pp. 9-11, 13
[140] CRUTCHLEY, CROW, Using Airborne Lidar in Archaeological Survey (2018), p. 46

other available information. All the LiDAR-derived data were processed, managed and analyzed using the open-source GIS software QGIS and Relief Visualization Toolbox plugin to produce different visualizations, including combined shaded reliefs, local relief models, slope and other visualizations of LiDAR-derived data. Considering that slope, hillshading and local relief model are considered some of the best visualization techniques for the majority of circumstances[141], the identified features were illustrated by using these techniques in most images, associated with the superimposition of other data types. The incorporation of all this information has led to the interpretation of the complex scenery represented by the various structures and anomalies visible in the LiDAR-derived data. With the aid of this approach, it was possible to understand and study the state of conservation of the structures, the stratigraphic relationships among archeological features and the associated archeological material.

In addition to the data obtained through the LiDAR method and visualized in QGIS, referring to the already known archeological topography of the investigated area and to the nineteenth's century cadastral maps allowed to compare the modern historical structures with the archeological features detected during this research and define their stratigraphic and chronological relationships.

Historic cartography, in fact, represents an effective aid in the complex study of the evolution of the landscapes. It is not considered only as a mere image of the past, but also as an active research tool, due to the fact that the old cartography is a symbolic representation of an area in a specific time period, where every single graphic element was positioned following a precise geographical system. From it, then, it is possible to deduce important topographic and stratigraphic information in order to reconstruct the ancient landscape[142]. The Cadastral map from the 1800s taken into consideration here, can be considered a useful survey tool because, even considering some possible errors, it is a precise and meticulous work.

Combining and super-imposing the ALS-derived images with the historical cadastral maps and the previously discovered elements, let us not only detect archeological features in the investigated area, but also understand which traces are still visible in the modern landscape (as land divisions and roads tracing over pre-existing features with the same orientation) and which elements are to be considered fossilized. For this purpose, in-person field surveys of the examined area are also

141 LUO, X. WANG, GUO, LASAPONARA, ZONG, MASINI, G. WANG, SHI, KHATTELI, CHEN, TARIQ, SHAO, BACHAGHA, YANG, YAO, Airborne and spaceborne remote sensing for archeological and cultural heritage applications: A review of the century (1907-2017) (2019), pp. 17-18

142 AURIEMMA, DEGRASSI, DONAT, GADDI, MAURO, ORIOLO, RICCOBONO, Terre di Mare: paesaggi costieri dal Timavo alla penisola muggesana (2008), pp. 184-185

extremely important in order to verify the conservation state of the structures. If the features appear to be considerably deteriorated and covered by vegetation, there's a high chance for them to be ancient. Furthermore, in the case where these potentially fossilized structures coincide with the walls represented in the nineteenth's century cadastral maps, this research's method allows to understand the stratigraphic relationships and validate the hypothesis that they are features from the past.

For instance, the study of the Roman field division system (centuriation) and highway was carried out in the investigated area, firstly, through the analysis of the morphology of the land detected with the aid of LiDAR-derived images. This brought to the identification of linear fossil features buried under the canopy and detectable as moderate linear ridges. Subsequently, the investigation was expanded to the entire Istrian peninsula to confirm the presence of centuriation traces in areas that have been just slightly or never analyzed before. Thereby, to identify centuriation traces, a geometric reference grid was created and planned in a precise way. The grid has *cardines* with a module of 706.39 m and they are orientated 18 degrees east of the north. This operation allowed to double check the centuriation marks previously reported and disclose various still not reported relict traces that are visible in the modern landscape as roadways and territory divisions, often going over previously existing features having a similar orientation. Thanks to this grid, also built with the centuriation traces that are left and still visible, it was possible to verify the presence of structures where we would expect them, following the scheme of the grid and aligned with it. The geometric reference grid, corresponding to the main *limites* of the centuriation scheme, allowed to verify if the traces detected belong to this land division system. In fact, when the traces fit and line up with the grid, this means that they are all part of the same ancient land division[143].

Consequently, it was of paramount importance doing in-person field surveys to check on the ground the main features detected in LiDAR-derived images. Indeed, archeological investigations of the studied area are vital because they allow to double check the accuracy of the features detected through LiDAR analysis. This permits to demonstrate that the centuriation traces are ancient. Some of them surely go over the field division lines represented in the modern cadastral maps; additionally, in some locations these traces are detected as fossilized features. As we personally saw during this research's in-person field examination, these traces, other than by vegetation, can sometimes be covered by modern walls that transversely run over them.

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[143] BERNARDINI, VINCI, Archeological landscape in central northern Istria (Croatia) revealed by airborne LiDAR: from prehistoric sites to Roman centuriation (2020), pp. 3-4

Figure 25. Detection of a moderate linear ridge during a fieldwalking survey. This trace is covered by vegetation and by a modern wall that transversely runs over it, and it can be interpreted as a fossilized feature.

Figure 26. Indication of the direction of the ancient centuriation in figure 25.

Fieldwork, generally including even small-scale excavations and surveys, allow archeologists to recover more information about the sites and even tangible materials. The archeological excavations, when performed, allow to obtain direct material from the area. The material that can be found during fieldwork might be dated through the identification of the archeological typology; or it could be also possible to retrieve organic material, datable with the aid of the Carbon-14 dating technique. What is gathered during the field surveys can, then, be interpreted and analyzed in the context of the data already collected[144]. In this case, particularly useful for the comprehension and reconstruction of the road structure was the collection of Roman shoe hobnails during surface investigations. The identification of the shoe hobnails allowed not only to prove the structure of the Roman road detected, but also to understand with more precision when the road could have been built and used.

To sum up the research process, the investigation was carried out visualizing and elaborating the data obtained with the remote sensing LiDAR method through the QGIS software, which were then combined with the pre-existing data about the area (previous discoveries and nineteenth's century cadastral maps), and field surveys, with the subsequent collection of tangible materials.

[144] BERNARDINI, Rediscovery of the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Division, Rural Buildings and New Hints on the *Avesica* Road Station (2020), p. 1

3. Results

The elaboration of LiDAR-derived data with different visualizations, combined with archeological in-person field surveys, the collection of archeological material (Roman *caliga* hobnails) with the superimposition of modern and nineteenth's century cadastral maps, led to the improvement of the knowledge of the Roman landscape in the Aurisina area. More in detail, large and previously unknown rural buildings, segments of the Roman road network and remains of the Karst centuriation (Roman land division system) have been identified (figure 27 and 28) and will be accurately described in this chapter.

The discoveries of this research have both an archeological and historical importance. By analyzing and superimposing all the retrieved and available data mentioned above, it was possible to investigate and interpret features thanks to their stratigraphic relations, the state of preservation of the structures and associated archeological materials. Comparing the archeological anomalies detected through LiDAR-derived images with the cadastral maps allowed us to understand whether the modern structures run over the ancient ones, and which ones are to be considered dating back to the past, sometimes even to ancient times. In the first case, the structures have been reused during recent historical times and might correspond to modern walls or modern land division systems. By contrast, in the last case, the features can be considered fossilized: built in antiquity, collapsed and never used again.

Shortly, based on the studies and analyses performed, the investigated area was crossed by an important Roman road that fits one of the main axes of the Roman centuriation, which seems to be built starting from the road itself. The study of the centuriation has also led to a better understanding of the fact that numerous modern structures still fit the ancient land division system. Moreover, we could acknowledge the fact that the famous Aurisina quarries were under the jurisdiction and authority of *Tergeste* (ancient Trieste), because they are included within the city's land division grid.

To follow, LiDAR data will be shown and described in order to illustrate the detected structures' characteristics and interpretations more in detail. The description and analysis of the data will pay specific attention to the main features detected, in particular the ones that lie in areas where we have identified significant stratigraphic relations among features belonging to different periods.

Figure 27. *Distribution of the main Roman traces detected represented over satellite aerial imagery.*

Figure 28. *Main Roman traces detected visualized over the Digital Terrain Model (DTM) of the investigated area.*

3.1 Rural buildings

The main two previously unknown structures identified during the analysis of the data (figure 29) can be interpreted as rural Roman buildings and they are clearly located near the main road, leading from the Timavo springs to the nowadays Prosecco. The traces of the rural buildings appear as linear bumps on the ground generally covered by grassland.

Figure 29. *Location of the structures detected (**a** and **b**). Hillshading visualization.*

The structures have been studied through different types of visualization of the LiDAR-derived data. As shown in the following figures, now the structures lie under vegetation, meaning that they were probably not reused in recent times.

In particular, the structure **a** (figure 30) can be probably interpreted as a large rural Roman building. The building is rectangular in shape and measures 46 m x 26 m. It does not appear to follow the same orientation as the centuriation (figure 31). The construction has an oval fenced area attached about 263 m^2 large, presumably used for farm animals.

The structure **a** can be compared with the one detected in the Portole area (Croatia), especially for the fenced part next to the probable residential building (figure 32). Due to the copious concentration of Roman surface materials in the area, it was possible to identify the presence of the large complex probably as a Roman villa[145]. Also, the structure detected in the Portole area presents traces of an enclosed area for animals.

[145] BERNARDINI, VINCI, Archaeological landscape in central northern Istria (Croatia) revealed by airborne LiDAR: from prehistoric sites to Roman centuriation (2020), p. 10

*<u>Figure 30.</u> Rural building **a** detected in the surveyed area, shown by white lines over aerial data (top left) and DEM visualizations: hillshading (top right), slope (bottom left) and local relief model (bottom right).*

*<u>Figure 31.</u> Lines of the rural building **a** over satellite imagery combined with the centuriation grid reconstructed.*

*<u>Figure 32.</u> Comparison between our rural building **a** (on the left) and the structure detected in the Portole area, Croatia (on the right). Right image 1: main building, 2: enclosure, 3: corridor-like feature, 4: entrance to a large enclosure, 6: probable artificial pond. Right image taken from Archaeological landscape in central northern Istria (Croatia) revealed by airborne LiDAR: from prehistoric sites to Roman centuriation[146].*

The structure **b** (figure 33) can be also probably interpreted as a Roman building, quite smaller than the structure **a**. In fact, structure **b** measures about 23 m x 8 m.

*<u>Figure 33.</u> Rural building **b** detected in the surveyed area, shown by white lines over aerial data (top left) and DEM visualizations: hillshading (top right), slope (bottom left) and local relief model (bottom right).*

[146] BERNARDINI, VINCI, Archaeological landscape in central northern Istria (Croatia) revealed by airborne LiDAR: from prehistoric sites to Roman centuriation (2020), p. 10

3.2 Roman roadway network

Thanks to the retrieved LiDAR-derived data and a meticulous field survey and collection of Roman shoe hobnails (*caliga* hobnails), it was possible to pierce together and reconstruct segments of the Roman road network in the investigated area with precision and high quality (figure 34).

Generally, the features belonging to ancient roads reveal themselves on the ground as topographic anomalies, such as bumps, ridges or furrows, covered by vegetation and sometimes by modern land division walls[147].

The majority of the evidence of the road network can be attributed to the route previously identified by Grill and Meng, that used to run towards Prosecco[148] (figure 34, n. 3, 4 and 5). Then, the road, in correspondence with Prosecco, split into two roads: one going in the direction of Trieste, and the other one running to Basovizza and then Fiume.

The road network segment east of Sistiana (figure 34, n. 2), follows the route of the so-called *strada dei castellieri* (*castellieri*'s road), already mentioned by Grilli and Meng[149]. However, the presence of furrows and *caliga* hobnails, also dating back to the Roman Republican period, prove that the road had been readapted and reutilized also by the Romans, even if its origin is probably earlier.

Figure 34. Roman roadway traces detected represented over hillshading visualization. The main segments are numbered from 1 to 5.

The attribution of the roadways detected to the Roman period and in particular their use/construction already to the late Roman Republican period, is confirmed and verified by the presence of numerous *caliga* hobnails gathered (figure 35). In fact, the *caliga* hobnails retrieved in the investigated area, with a cross and four dots, were, as previously described, in use during the first century BC. This confirms the fact that the Roman route can be dated back to the Roman Republican period.

[147] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station, pp. 7

[148] GRILLI, MENG, La strada romana sul carso triestino, pp. 69

[149] GRILLI, MENG, La strada romana sul carso triestino, pp. 74

Figure 35. *Distribution of the caliga hobnails retrieved (white dots) near and along the Roman roadway traces detected in the investigated area. Hillshading visualization.*

Based on the evidence collected, the investigated area was crossed by an important Roman road that corresponds to one of the main axes of the Roman centuriation, which seems to be built starting from the road itself (figure 36 and 37).

Figure 36. *Roadway traces detected, combined with the centuriation grid (black dotted lines) reconstructed in the area based on the survived ancient limites (see below).*

Figure 37. *In particular, segments of the roadway that precisely follow the centuriation grid (figure 34, n. 3 at the top and 5 at the bottom). Hillshading visualization.*

Interestingly, also the modern road south from Aurisina overlaps with the ancient road and perfectly corresponds with one of the main axes of the centuriation (figure 38).

Figure 38. *Modern road south from Aurisina (red line), corresponding with the centuriation axis.*

The feature n. 1 of figure 34 shows a fossilized segment of the road network, located in Sistiana. As it can be seen in figure 39, the traces that can be seen through LiDAR-derived data do not correspond to any modern route and, instead, are located near a group of houses. In fact, this feature was recently destroyed.

Figure 39. *Different visualizations of the segment n. 1 (figure 34): not interpreted hillshading (top left), interpreted hillshading (top right), aerial data (bottom left) and local relief model (bottom right).*

As shown in figure 40, in the feature n. 3 of figure 34, part of the ancient road is partially covered by the modern one, but some of its traces are to be considered fossilized (the ones at the top and at the bottom).

Figure 40. Different visualizations of the segment n. 3 (figure 34): not interpreted hillshading (top left), interpreted hillshading (top right), aerial data (bottom left) and modern cadastral data (bottom right).

Stretches of the ancient road, not reported by Grill and Meng, have been identified just southwest of Aurisina, where the Roman road joins the modern one (figure 41).

From this point to Santa Croce village, the modern road runs over the ancient path, which is, again, preserved south of Santa Croce; and here it corresponds to the Austrian postal road, also mentioned by Grilli and Meng[150]. This is confirmed by the abundance of shoe hobnails found along the stretch (figure 43).

Going south from Aurisina, after the stone columns mentioned above, the route corresponds to the borders between the modern municipalities of Trieste, Duino-Aurisina and Sgonico. Moreover, one side of the above-mentioned border (the northernmost part dividing the Trieste and Aurisina municipalities) corresponds to one axis of the centuriation.

The segment n. 4 (figure 34) of the road network was also examined during an in-person field survey (figure 42). On the ground, this feature appears as a furrow with a difference in the height compared with the nearby portions of the land. The main and longer stretch of the trace measures about 470 m in length and is around 2 m wide.

Figure 41. Different visualizations of the segment n. 4 (figure 34): not interpreted local relief model (top left), interpreted local relief model (top right), aerial data (bottom left) and hillshading (bottom right).

Figure 42. Pictures of the segment n. 4 (figure 34), shot from both directions during an in-person field survey.

Figure 43. Feature n. 5 of figure 34 with the indication of the shoe hobnails (white dots).

The feature n. 2 of figure 34 also can be interpreted as a fossilized road section. As shown in figure 44, particularly in the interpreted aerial data, the road does not match any modern route.

[150] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 73

This segment of the roadway coincided with the so-called *strada dei castellieri* (*castellieri*'s road), which probably detached from the main route in correspondence with nowadays Sistiana.

Figure 44. Different visualizations of the segment n. 2 (figure 34): not interpreted hillshading (top left), interpreted hillshading (top right), aerial data (bottom left) and local relief model (bottom right).

3.3 Centuriation

Remains of the Roman land division system were found pretty much all over the investigated area. This is the area with the most centuriation traces preserved in the whole Trieste Karst. Due to the multidisciplinary approach of the research and the obtained information, it is possible to distinguish two classes of centuriation traces, demonstrating the ancient origin of such land division system: the fossilized centuriation segments (in green) and the ones corresponding to modern structures (in red) (figure 45). The areas where fossilized centuriation traces are located are particularly relevant and, there, the ancient traces are often crossed by modern structures. By contrast, the centuriation segments that correspond to modern structures are generally matching modern walls or modern land division systems.

Figure 45. Remains of the centuriation detected, visualized over the local relief model of the investigated area.

Considering all the available data, it is possible to state that most of the centuriation structures identified in the surveyed area perfectly fit the reconstructed Karst's centuriation grid based on all the main *limites* identified (figure 46).

Figure 46. Representation of the centuriation segments detected in the investigated area, superimposed on the reconstructed Karsts' Roman land division grid.

If we examine the area from a wider angle, it is also important to note that both the structures detected in this research's studied area and in other parts of the Italian and Slovenian Karst all have the same orientation and match with the same land division scheme (figure 47).

Figure 47. Representation of the traces detected both in this work's studied area and in the north-western part of the Slovenian Karst (purple lines), superimposed on the reconstructed Roman centuriation grid.

The traces of centuriation that are located in areas characterized by important stratigraphic relations will be further described below (figure 48).

Generally, the fossilized traces of the centuriation appear on the ground as linear bumps, usually covered by vegetation and grassland; or, in some cases, they show as low dry-stone walls (*muretti a secco*), collapsed for the most part and with a width of about 0.5 m to 0.8 m.

Figure 48. Segments of the centuriation that will be described in more detail below, numbered from 1 to 4.

The areas indicated will be described mainly using the local relief model visualization type, because it allows to enhance small-scale features. The cadastral available information, both modern and the nineteenth's century one, was also taken into account and combined with the LiDAR-derived images. The modern cadastral maps are very similar to the ninetheent's century ones, but easier to use to visualize stratigraphic relations, because they can be uploaded in QGIS as vector files.

Interestingly, analyzing the modern cadastral data available, it appears that numerous structures detected run over the ancient ones (figure 49).

Figure 49. View of part of the centuriation traces combined with the modern cadastral data.

The feature n. 1 of figure 48 is one of the main relevant traits of the centuriation detected. This structure is entirely fossilized as it doesn't correspond to any modern structure (figure 50). This part of the centuriation is particularly interesting because we can clearly see that the ancient land division line is being perpendicularly intersected by a modern land division wall (figure 53); and this can be confirmed also by consulting the cadastral data (figure 54).

Figure 50. Different visualizations of the centuriation segment n. 1 (figure 48): not interpreted local relief model (top left), interpreted local relief model (top right), hillshading (bottom left) and aerial data (bottom right).

Figure 51. Lines of the centuriation segment n. 1 (figure 48) over satellite imagery combined with the reconstructed centuriation grid. The white rectangle indicates the area that is described more in detail below.

Figure 52. Segments of the feature n. 1 (picture 48). Pictures taken during a field survey.

Figure 53. Detail of the centuriation segment n. 1 (figure 48), visualized in different ways: not interpreted local relief model (top left), interpreted local relief model (top right), hillshading (bottom left) and aerial data (bottom right).

Figure 54. Cadastral data of a detail (figure 53) of the centuriation segment n. 1 (figure 48).

This detail was also examined during an in-person field survey and it is clearly visible that the modern wall runs perpendicular to the ancient land division (figure 55). On the ground, this particular feature is detectable as a linear bump that runs for about 22 m on the examined land, and is 1.5 to 2 m large and less than 0.5 m high.

However, in other parts of this segment the traces are visible as low dry-stone walls (*muretti a secco*).

Figure 55. Pictures taken during a field survey: picture ***a*** indicates the ancient centuriation bump with the modern land division wall in background, picture ***b*** shows the orientation of the centuriation.

The feature n. 2 in figure 48 is peculiar because it is characterized by a mix of ancient and modern structures (figure 56 and 57).

Figure 56. Different visualizations of the centuriation segment n. 2 (figure 48): not interpreted local relief model (top left), interpreted local relief model (top right), hillshading (bottom left) and aerial data (bottom right).

Figure 57. Centuriation feature n. 2 (figure 48) over the cadastral data, with the grid of the centuriation on the right.

Figure 58. *Segments of the feature n. 2 (picture 48). Pictures taken during a field survey.*

The feature n. 3 in figure 48 has been identified near the *castelliere* of Slivia (picture 59).

Figure 59. *Different visualizations of the centuriation segment n. 3 (figure 48): not interpreted local relief model (top left), interpreted local relief model (top right), hillshading (bottom left) and aerial data (bottom right).*

Figure 60. *Segments of the feature n. 3 (picture 48). Pictures taken during a field survey.*

The feature n. 4 in figure 48 is interesting, again, because it is a mix of fossilized and modern structures (figure 61).

Figure 61. *Different visualizations of the centuriation segment n. 4 (figure 48): not interpreted local relief model (top left), interpreted local relief model (top right), hillshading (bottom left) and aerial data (bottom right).*

Figure 62. *Segments of the feature n. 4 (picture 48). Pictures taken during a field survey.*

4. Conclusions

The study of high-resolution LiDAR-derived terrain models, combined with the geomorphological and stratigraphic examination of the investigated area, the superimposition of already available sources (such as the cadastral maps), field surveys and the collection of archeological material, allowed to disclose further information and details about the still largely unknown Roman landscape in the Aurisina area, which is part of the Trieste's Karst environment. Two main previously unknown rural buildings, segments of the Roman road network and remains of the Karst centuriation have been identified.

The outcomes of the research are both archeologically and historically significant. By combining all the data mentioned above and described through the chapters, it was possible to detect and interpret features in the surveyed area, especially considering their state of conservation, the stratigraphic relationships and the related archeological material. Moreover, comparing the archeological anomalies detected through airborne LiDAR with the cadastral maps has allowed us to distinguish between fossilized ancient features, modern structures and modern structures that follow pre-existing ancient features.

Based on the results of the research, the two main previously unknown constructions, located near the main road leading from the Timavo springs to the present-day Prosecco, can be interpreted as Roman rural buildings, whose precise chronology could be established only through archeological excavations. They don't share the same orientation as the centuriation and they can be compared with other archeological features detected in Croatia (Portole)[151]. These new data show, together with the already available archeological ones, a concentration of Roman structures close to the famous Aurisina limestone quarries. Especially the larger building identified, close to the Roman road, could be hypothetically related to the Aurisina limestone exploitation but, again, further research is needed to verify its chronology and function.

Furthermore, the study of the Roman road network allowed us to understand that the investigated area was crossed by an important Roman road fitting one of the primary axes of the centuriation. The majority of the traces are to be attributed to the route previously described by Grilli and Meng[152], that runs towards Prosecco and, there, splits into two other roads: one running

[151] BERNARDINI, VINCI, Archaeological landscape in central northern Istria (Croatia) revealed by airborne LiDAR: from prehistoric sites to Roman centuriation (2020), pp. 8-9
[152] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 69

to Trieste, and the other one going in the direction of Basovizza and then Fiume. The road evidence detected east of Sistiana can be, instead, referred to as part of the so-called *strada dei castellieri* (*castellieri*'s road), already supposed by Grilli and Meng[153]. Thanks to the significant presence of *caliga* hobnails across this segment of the road, it is possible to state that the road was for sure reused by the Romans. The collection of Roman shoe hobnails confirmed the presence of the road and allowed to date its early Roman use to the late Republican period. The typology of the collected Roman shoe hobnails, characterized by different signs on the underside, but including also those with an embossed cross associated with four dots, place its first Roman use at least in the first century BC. The same applies to the main route from the Timavo springs to present-day Prosecco, where hobnails of the same type have been found. This confirms the interpretation of Grilli and Meng, who proposed that this road was built by the Romans for military purposes soon after the foundation of Aquileia in 181 BC.

Moreover, the accurate study of the putative centuriation features has allowed us to clearly establish their ancient origin. This has been demonstrated by 1) the stratigraphic relationships that have been identified by comparing different data sources (i.e., historical cadastral maps vs. detected linear archeological anomalies) and 2) the perfect correspondence of the identified features both in the Italian and Slovenian sides of the Karst with a regular grid with squares about 710 m large (20 *actus*). Additionally, the present study would confirm the hypothesis[154] that such a Roman land division system could have been developed starting from the main road crossing the Karst and connecting The Timavo springs to Prosecco. One of its axes fits perfectly the Roman road between the villages of Aurisina and Santa Croce.

As already pointed out by Bernardini et al[155], the origin of the Karst centuriation may date back to the late Republican period, probably somewhere between the end of the second and the first decades of the first century BC. This is suggested by the chronology of the second military camp of San Rocco[156], whose structures show the same orientation.

From an historical point of view, it is worth noting that the famous Aurisina quarries fall within the Karst centuriated area, probably connected to *Tergeste*. This could suggest that the exploitation

[153] GRILLI, MENG, La strada romana sul carso triestino (1978-1979), p. 74

[154] BERNARDINI, DUIZ, Oltre Aquileia – la conquista romana del Carso (II-I sec. a.C.) (2021)

[155] BERNARDINI, Rediscovering the Lost Roman Landscape in the Southern Trieste Karst (North-Eastern Italy): Road Network, Land Divisions, Rural Buildings and New Hints on the *Avesica* Road Station (2023)

[156] BERNARDINI, HORVAT, VINCI, San Rocco/Koromačnik military camps (2nd-1st centuries BC) (2023), p. 46

of such relevant economic resources was, perhaps, controlled by *Tergeste* and not Aquileia, as previously believed.

If the Karst centuriation area was really related to *Tergeste*, the border between the latter and Aquileia should be placed west of nowadays Sistiana.

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