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DIPLOMA THESIS

«The castle of Androusa: Characterization of mortars and application of the Geographical Information Systems (GIS)»

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Abstract

The purpose of this research is the study of the castle of Androusa through the use of new technologies and archaeometric analytical techniques. The research focuses mainly on the fortification of the castle, the mortars used for its construction and the relation of the castle with its landscape. The study is divided into two parts.

The first is the theoretical part. It includes a bibliographic overview of the medieval Frankish castles with main focus on the history and fortification of the castle of Androusa. In this part, there is also information about the building mortar materials.

The second is the practical part of the study. It presents the implementation of the new GIS information systems in the study of the castle of Androusa and its interaction with the landscape. A representation of the fortification of the castle and the geophysical relief of Androusa is made with the use of ArcMap10 program. This process led to some important remarks about the castle and some interesting assumptions.

In the practical part, the sampling process, the analytical techniques and the methodology followed for the analysis of 11 mortar samples collected from the castle of Androusa is also being described, providing detailed information on their materials and their manufacturing technology. By examining the composition of the mortar samples, an attempt to associate and determine the different building phases observed in the castle is made. The techniques applied for the study of mortars are Optical Digital Microscopy LED, Electronic Scanning Microscopy (SEM) equipped with X-ray Microanalyzer (EDX), X-ray Fluorescence (XRF) and Granulometric Analysis.

At the end of the study there is an overview and evaluation of all the results of the techniques applied. Finally, there is a discussion about the conclusions and some suggestions for future research.

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1. Introduction

The turbulent medieval history of Greece is attested by the still standing ruins of its greater region. Probably, the castles are among of the most characteristic structures of this period. They are considered symbols of strength and power of a different era. Today, apart from their importance as cultural heritage treasures, they constitute a valuable source of information and an excellent starting point for the study of history.

The foreigners, who settled in Greece, built new or repaired older castles. These fortified structures were used for long periods, receiving major transformations and alterations through the ages. Usually, it is very difficult to distinguish the different building phases of a castle or its initial form and shape. Moreover, the majority of the castles in the country are usually preserved in bad condition, with parts of their fortifications missing or lying in ruins. As a result, big arguments are being created among the archeologists and historians who study them and are focused mainly in their architecture, history and dating. The castle of Androusa is a nice example of such source of arguments (Molin, 2001). Although the castle is considered to be Frankish, it contains many elements that have different origin or belong to different chronological periods. In addition, many parts of the fortification of the castle are not preserved, either due to anthropological or environmental factors, giving an unrepresentative image about its actual form.

As in most of the castles in Greece, the masonry of the castle of Androusa consists of a mixture of small uncut stones quarried locally, shards of pottery and other recycled fragments found at the site connected with the use of mortars. While such characteristics are considered quite common, a deeper examination of the materials used can give important information. Nowadays, the study of historic mortars has become a center of interest for many scientists for historical and technological reasons. The research focuses mainly on aspects that have to do with the characterization of the materials and with the technology used. The resulting information can be very useful for the preservation of architectural heritage, as it gives a deep knowledge of the materials used, construction techniques, possible repairs and degradation processes, dating etc. (Adriano et al., 2008)

Archaeological science has also been greatly enhanced by the application of scientific approaches and digital technologies that provide fast and reasonably accurate information. One of the most versatile and comprehensive analytical tools in archaeology in terms of handling archaeological data and exploring the human space are the Geographic Information Systems (GIS) (Tsiafakis & Evagelidis, 2006).

It can be said that the castles have become an interdisciplinary field where sciences complement each other with ultimate goal the better knowledge about history. This essay will focus on the history of the castle of Androusa, on the morphological aspects of its fortification and on the characterization of the mortars used for its construction. Under this scope, an attempt will be made to extract some important conclusions about the castle and also provide some suggestions for future work.

2. Theoretical part

2.1. The Frankish castles in Greece

2.1.1. The medieval castles

The castle is considered to be one of the basic features of medieval feudal society (Smail, 1951). The medieval castles were more or less the same as the ancient ones since the war tactics had not changed significantly. A typical medieval castle consisted of the curtain wall forming an enceinte, with towers to strengthen it at regular intervals and at its corners (Hetherington, 1991)[1]. The walls, the towers and the gates were the elements that mainly constituted a fortification work giving form to it. Other elements like the wall-walk[2] and the battlements were features of secondary importance, designed to strengthen the defenses and improve the effectiveness of the walls (9th Ephorate of Byzantine Antiquities, 2001).

The walls were vertical and the towers were taller than the walls and were projecting on the outside. Over the gates and at the most vulnerable points of the walls were smashers or furriers, from where the defendants threw hot water or oil to their enemies (Δεληγιάννη-Δωρή, 1993)[3]. The nature of the terrain, the developments in the field of military technology, and the financial ability to build at any given time were the defining factors of height, form and shape of the fortification works (9th Ephorate of Byzantine Antiquities, 2001). For these reasons, there is also a great architectural diversity in the fortification design (Κατσαφάνας, 2003).

The basic role of a castle was to stop invasion forces and defend an area. However, not all castles acted the same way. Some smaller castles could be used just to delay or intimidate invaders rather than stopping them. Most of the time, strongholds were built in order to protect the people from localized raids or enemy attacks, acting as places of refuge (Molin, 2001). The areas where castles were built

[1] The curtain wall includes the wall-walk and the gates. The height of the curtain wall was depended on its thickness (Breuillot, 2005).
[2] Other terms used for wall-walk is *sentry-walk* (Hetherington, 1991) or the French term *chemin de ronde* (9th Ephorate of Byzantine Antiquities, 2001).
[3] This simple arrangement of the medieval forts was replaced by the asteromorphic shape of the new Venetian fortresses which was based on strict mathematical calculations and measurements (Δεληγιάννη-Δωρή, 1993).

soon became cores of new settlements (Μητρόπουλος, 2014; Κατσαφάνας, 2003)[4]. The security a newly-built castle offered to its district could result to the development of the area and to the prosperity of its inhabitants (Smail, 1951).

Castles and fortifications were part of the daily life of the inhabitants. The walls marked the borders of the settlement and also divided the life intra and extra muros. They separated the urban environment from the countryside and the gates dictated the points where the main axes of communication within the area were linked to the main urban streets. Inside the walls, the civilian life was mainly focused on craft and commercial activities, while outside the walls on the agricultural production (9th Ephorate of Byzantine Antiquities, 2001; Κοντογιάννης, 2012).

2.1.2. The significance of Frankish fortifications in Greece

In 1204, the capture of Constantinople by the Franks[5] of the Fourth Crusade and the breakdown of the Byzantine state, led to political fragmentation. Byzantium was replaced by small political units (Athanasopoulos, 2010)[6]. For a period of time the Greek East was turned to a Latin East, an "Orient Latin" (Κατσαφάνας, 2003).

The Latin conquest in Greece could be better described as an "armed colonization", since the crusaders remained in the regions they captured for a long time (Κατσαφάνας, 2003). As a result, the newcomers had to secure themselves from threats that had to do with internal violence or rebellions and needed places of shelter to protect them against potential rebels (Molin, 2001). The Franks introduced the feudal system and controlled dependent villages through dense networks of towers and castles, residences of the knights or the estate managers (Bintliff, 2015)[7]. These structures functioned as control and tax collection points of depending neighboring

[44] Despite the fact that most of the castles attracted people around them, in some cases this did not happened, as in Navarino and the unknown castle of Archangelos in Messenia (Λοκ, 1998).
[5] The term *Franks* was given by the Byzantines to the Westerners (Λοκ, 1998; Κατσαφάνας, 2003).
[6] The main political units were the Latin Empire of Constantinople, the Principality of Achaia in the Peloponnese, several Venetian colonies in coastal areas (Coron, Modon, Crete, Euboea, some Aegean Islands, and the Ionian Islands), the Despotate of Epirus, the Empire of Nicaea and the Empire of Trebizond (Athanasopoulos, 2010).
[7] The base of the feudal system was the fief. It was the economic and social unit of the countryside. An administrative association of many fiefs consisted the barony (*baronia*). The seat of the fief was the castle (Μητρόπουλος, 2014).

villages (Vionis, 2008), prisons[8] (Nevell, 2014-15), storage centers of agricultural products, control points of passages and communication routes, and protectors of the rural hinterland (Vionis, 2014; Smail, 1951). In addition, their prominence, served as a benchmark for the region and as a reminder of the power of feudal lords. The decision about the location, development and function of these imposing structures was usually influenced by the landscape, while in the same time the landscape was altered because of their presence (Van Doesburg, 2010).

The construction of a castle represented a major financial commitment. Only the barons and the feudal lords had the right to build a castle (Μητρόπουλος, 2014)[9]. It is believed that, the need of showing the wealth and the prestige was a more important factor in the construction of a castle than its strategic importance (Λοκ, 1998)[10]. In the earliest days, after the Latin conquest, the most common fortification pattern was the enclosure castle, which was subsequently converted into a motte and bailey castle (Kennedy, 1994)[11].

The castles were a symbol of power for the lords and a symbol of fear for their enemies (Breuillot, 2005). The Greeks generally didn't have the necessary equipment to siege castles. So, as soon as a castle was conquered or was built by the crusaders, the Greeks tended to stop fighting or came to terms with the Latin conquerors, since any attempt of resistance was meaningless[12]. Despite that, the Latins were in constant alert, since they were always considered as invaders by the local people. Internal violence and rebellions were typical threats during Frankish occupation. For this reason, castles were always properly defended by loyal soldiers, even during peace periods (Molin, 2001)[13]. Special care was also given to the supply of food and weapons as well as the maintenance of the castles for the same reason (Μητρόπουλος, 2014).

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[8] This was a common practice in modern era, when most of the castles that remained in use converted into prisons (Nevell, 2014-15).

[9] During the Carolingian period, only the king had the right to build a fortification. However, since the barbarian invasion and the fragmentation of public power, this right escaped royal control and was exercised by individuals (Smail, 1951).

[10] Historical sources make very limited references to the strategic role of the castles (Λοκ, 1998).

[11] Motte: an artificial mound of earth - Bailey: the adjacent enclosure (Liddiard, 2010).

[12] For example, in Messenia Franks couldn't impose their authority over the local Greeks, until they captured the strategic castle of Kalamata (Molin, 2001).

[13] According to the *Assizes of Romania*, liegemen who performed their annual service to their lord should spend at least four months a year guarding a castle (Molin, 2001; Ντούρου-Ηλιοπούλου, 2005).

Rebellions from local people were not the only threat for the conquerors. A possible revolution could also happen by Latin vassals. Therefore, the strength of the ruler, compared to his subordinates was a matter of primary importance and was also reflected on their castles (Smail, 1951). “Nor all castles were important enough nor all lords” (Nevell, 2014-15). The castles didn’t share the same significance and importance, nor were they equally strong. Typically, the strongest castles belonged to the actual rulers of the Crusader states and not to their barons. There were many cases of baronial disloyalty during Frankish occupation, so it was easier for the Latin rulers to maintain their defenses while having in their hands powerful castles at key points (Molin, 2001)[14].

In general, the castles and the fortifications were part of the feudal system, combining the fragmentation of the power, the defense and the fear of rebellions (Μητρόπουλος, 2014)[15]. The Latins were feeling reassured by the presence of castles, towers and fortified farmhouses, regardless if they were living inside them or not. These structures helped them to establish and maintain their power and minimize the possibility of a local rebellion. The more castles there were in an area, the fewer the chances of a revolt. The sense of safety they offered to the Frankish nobles encouraged them to stay in Greece and consolidate their new baronies (Molin, 2001)[16]. The whole image of a castle was giving the impression that conquerors were here to stay (Κατσαφάνας, 2003).

2.1.3. The characteristics of Frankish fortifications in Greece

Most of the Franks in Greece applied new ways of castle building, drawing knowledge from both East and West. The crusaders had experienced the military value of Byzantine fortifications through the battles[17]. This led them to adopt many of the architectural elements used by the Byzantines and from the Eastern architecture in general (Kennedy, 1994). All the fortifications that were built by the crusaders can be

[14] For example, the strategic castle of Androusa, as well as other significant castles of the Principality of Achaea (like the fortresses of Corinth, Kalamata, Chlemoutsi, Glarentza) belonged to the actual rulers of the state.

[15] Although the castles were essentially built for defensive purposes, ironically their presence usually attracted invaders, since valuable supplies were stored inside them (Λοκ, 1998).

[16] Usually, the fortresses were given the names of the lords who built them (Molin, 2001).

[17] The contact of the Franks with Byzantine fortifications had already begun from the 11th century during the period of the first crusades (Ευγενίδου, 2003).

summarized into three distinguished categories. Those that were totally built by them in areas with very little or no previews occupation, those that were built in areas were existed older Byzantine or classical structures by incorporating them, and those that were already in good condition at the time of the Fourth Crusade and were simply reoccupied (Hetherington, 1991).

Despite of who built them, it can be said that the Frankish fortifications in Greece were usually poorly constructed, using a combination of recycled older materials and uncut stones, rubble or mortar and ceramic fragments (Hetherington, 1991; Bon, 1969)[18]. In cases when ceramics were used, they mainly constituted building materials and not elements of decoration like in byzantine architecture (Breuillot, 2005)[19]. The Franks wanted to build their castles quickly to stabilize their power, so attention to the architectural aesthetic was not within their priorities.

Most of the castles in Greece were constructed by relatively unskilled local craftsmen, and not by experienced builders working in a Western European style. The crusaders didn't have the time to bring architects and builders from the West to build their castles, so they employed the locals who used the techniques and the materials they were familiar with. On this basis, it can be explained why the same type of stone work matches in many different fortifications, even if they were built after long periods of time (Hetherington, 1991; Breuillot, 2005; Curcic, 2010)[20].

It is surprisingly that even the royal strongholds were badly constructed[21]. Although there are some exceptions, it can be said that the Frankish fortresses were built by relatively poor lords, compared to the impressive castles of their western counterparts[22]. In the early years of the conquest, due to economic reasons, the Franks preferred just to add donjon towers (keeps) in former Byzantine castles they captured,

[18] The reuse of old materials was a common practice in the construction of castles. However, most of the building materials were usually from quarries for which little is known (Λοκ, 1998).

[19] Ceramics were usually inserted between the stones to fill the gaps in the masonry (Breuillot, 2005; Bon, 1969).

[20] Unfortunately, there is little information about the builders involved in the castle construction process (Λοκ, 1998).

[21] As sources indicate, Androusa belonged to the princes of Achaia throughout the medieval period. Despite that, the fortification was poorly built, using a slapdash mixture of broken pottery, bricks and uncut stones (Molin, 2001).

[22] The majority of the crusaders were merely adventurers or humble lords seeking for a better future. For example, a little is known about William's ancestry in Europe (Molin, 2001).

rather than building a new castle (see Appendix A) (Molin, 2001)[23]. However, in the late 13th and early 14th century, after the stabilization of the Frankish rule, there was an increase in the construction of new castles (Λοκ, 1998)[24].

It can be assumed that big and impressive castles were unnecessary in Greece. The terrain of the country could most of the times be used as a mean of defense. There was no need for big impressive walls like in West. Steep hill tops could act better than a well-built wall for discouraging aspiring invaders. The warfare in most regions in Greece (like in the Peloponnese) probably involved much smaller armies with far less experience in castle sieging. Frankish lords had to do mostly with raider bands or pirates rather than organized armies equipped with siege engines. For this reason, walls as thick as ninety centimeters or one meter were perfectly adequate for a secure defense (Molin, 2001)[25]. It is easy to understand that the Frankish castles in Greece were not built to meet the same priorities as the castles of the rest of Europe, since thin walls couldn't withstand a prolonged or intensive siege (Hetherington, 1991)[26].

As Hugh Kennedy points out, "there is a model which suggests that, in cultural matters, people only borrow from others when there are on the verge of inventing themselves". Based on that, Franks borrowed from Byzantine eastern military technology what they believed it was useful and served their immediate purposes (Kennedy, 1994).

2.1.4. Factors determining the location of Frankish castles

In Western Europe, the castles were usually in the countryside (Κατσαφάνας, 2003). The fortifications were mostly built to protect and defend a comparatively large number of people, thus they can be considered group or public strongholds. Big walls were encircling many cities of that time. The newer fortifications in Eastern

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[23] It is quite possible that when the *Chronicle of Morea* mentions new fortifications built by the Franks, it is actually referring to the addition of donjons in already existing Byzantine or ancient fortifications (Molin, 2001).

[24] The *Chronicle of Morea* mentions that there are about 20 castles belonging to the 13th century in the Peloponnese. A catalogue of the fiefs written in 1377, mentions 51 castles. A comparison of the numbers in these two documents shows a rapid spread of castles during this period (Λοκ, 1998).

[25] There are several examples of castles with walls of average thickness of 0,90m, such as Aetos and Kato Melpeia (Breuillot, 2005).

[26] A castle was more likely to be conquered through bribery or stealth than by siege (Molin, 2001). Most of the Frankish castles were conquered by the Greeks in the end of the 14th century after negotiations or betrayal and rarely after attacks against them (Λοκ, 1998).

Europe, like in Greece, were more or less promontory forts. They were usually located on coast sides, in areas overlooking valleys or rivers or on hillsides (Kennedy, 1994).

The most important factor for choosing the ideal place to build a castle was the natural landscape. It was critical not only for the position of the castle but also for its shape, size and design. The majority of the castles were trying to take advantage of the natural terrain. Hence, their form and ground plan was often rather irregular (Breuillot, 2005; Δεληγιάννη-Δωρή, 1993). They were built on carefully chosen sites, usually inaccessible in order to be difficult to be approached, with at least one of their sides guarded by a major natural feature. Cliffs and ravines or the sea were integral parts of the defense of a castle (Hetherington, 1991; Kennedy, 1994; Λοκ, 1998; Bon, 1969)[27].

Visibility offered by elevated sites was also an extremely important factor for selecting the right place for a castle. Castles should have visibility at all four points of the horizon or at least three of them. For this reason, mountains, hills, slopes, high peaks were ideal places to build one (Breuillot, 2005). The defenders of a castle could spot the invaders from several miles distance and warn people living nearby to get inside the castle in time and prepare themselves or launch an unexpected attack against the enemy (Λοκ, 1998; Molin, 2001)[28].

The need for fresh water in castles was not negligible, especially in Mediterranean countries where there is a shortage of natural water sources. Hence, proximity to lakes and rivers was a crucial parameter for choosing a place to build a castle. Water, beyond its necessity as a natural good for the preservation of life, was also a necessary element during the construction of a castle mainly for making mortars (Breuillot, 2005)[29].

Other factors determining the place of the castle had to do with the surveillance of areas of strategic importance, like passage zones, trade routes, borders, crossroads etc. In these cases, the most efficient way was to establish a network of castles, since it was really necessary for the castles to be able to communicate with

[27] Like the castles of Karytaina, Passavas, Geraki, Kyparissia and Mystras (Hetherington, 1991).

[28] At the highest point of a castle there was usually an observatory to supervise the surrounding area (Λοκ, 1998).

[29] The importance of water is also reflected on the cisterns that existed inside all castles. The construction of a cistern was among the first priorities of castle building since they provided the necessary water for the inhabitants. Usually, these cisterns were feeding with rainwater through special channels (Hetherington, 1991).

each other in case of emergency (Breuillot, 2005)[30]. In the countryside, the fortifications were used as observatories and military stations. They were mainly built at the entrance and exit passages of an area as well as near important key points of the roads (Μητρόπουλος, 2014).

The availability of local resources could also affect the choice of the location of a castle as well as its final design and size (Creighton, 2002; Bon, 1969). The proximity to necessary building materials for castle construction (e.g. stones, wood, lime etc.) was also a defining factor for the selection of an area. However, the long-distance transport of building materials was a common practice when required.

Choosing a site where it used to be an earlier fortification was also a good option. During the medieval period it was common to reuse the masonry from previous buildings (Breuillot, 2005; Bon, 1969). In these cases, the medieval builders used the old existing masonry and simply extended it upwards, without showing any particular interest in the uniformity of their work. The new masonry was mixed with the old one in an irregular manner and with the application of new mortars (Hetherington, 1991)[31]. It was more efficient in terms of money and time to repair or alter an old fortress than building an entire new one from the beginning (Molin, 2001). In addition, usually, the earlier fortifications fulfilled most of the criteria that were already mentioned in the above paragraphs.

[30] This could be achieved through a system of encoded signals exchanged between the castles. Messages could be transported quickly and easily through a network of castles and towers that controlled an area (Breuillot, 2005).

[31] The older masonry can easily be distinguished based on the stones used. Usually, in earlier periods the masonry was more refined and the stones used were better cut and much larger than those used in the medieval period (Hetherington, 1991).

2.2. The castle of Androusa

2.2.1. The origins of the name Androusa

The name Androusa, according to the tradition, derives from the Greek verb *ἀνδρόω – ἀνδρῶ* (*ἀνδρῶν – ἀνδροῦσα – ἀνδροῦν*) meaning making someone a man. Additionally, the words *Ἀνδρείοι*, *Ἀνδρέουσα*, *Ἀνδροῦσα* derive from the same theme *άνδρες*, meaning the city of the brave men (Νταμάτης, 2007; Θεοχάρης, 1948).

Another theory supports that the name of the city is associated with the Emperor Andronikos II Palaiologos, who built the city walls, the aqueduct, the monastery of the Transfiguration of the Savior (known as Andromonastiro) and the female monastery of Zoodochos Pigi Samarinas in the region (Νταμάτης, 2007; Θεοδώριτος, 2005; Λύρας, 2010). However, this theory lacks historical evidence and is considered a local myth dated after the 19th century.

The most prevalent scientific theory states that the name comes from the ancient Greek word *ἄνδηρον* (άνδηρο), meaning the mound/ditch, created by the rapids of the torrents (streams). Therefore, Androusa was most likely named after its location, since it is built on an *ἄνδηρον* (Θεοχάρης, 1948; Νταμάτης, 2007).

However, the name of the city underwent minor changes throughout the history. In the medieval period, during the Frankish occupation of the Peloponnese, Androusa was mentioned as *Druges*, *Druses* or *Druse*. This was probably because during this period Androusa was a military station, a place where nobles and knights lived. The name *Druges* is associated with the word *Drungus* or *Droungos*, which was a late roman and byzantine term used for military units guarding a place (guards). Moreover, it was really common for the Latin rulers to slightly change the name of the Greek cities. For this reason, in Latin sources it is also referred with the names *Terra Drusi*, *Drussi*, *Drusie*, *Druxie*, *Drisi*, *Druza*, *Drizi* (Νταμάτης, 2007; Θεοχάρης, 1948; Μητρόπουλος, 2014; Bon, 1969).

2.2.2. The history of the castle of Androusa

The castle of Androusa is located within the homonymous local community of the Municipality of Messenia in the Peloponnese. It occupies the northeastern edge of a low flat plateau (128m. height) at the western slopes of the plain of Messenia.

Today it is surrounded by cypress trees, offering a beautiful image from afar (Καρποδίνη-Δημητριάδη, 1993).

Figure 1: The main toponyms of the Principality of Achaea in the Peloponnese. The location of Androusa is indicated with a red frame (Ντούρου-Ηλιοπούλου, 2005)

According to the Aragonese version of the *Chronicle of Morea*[32], the erection of the castle dates back to the middle of the 13th century and is attributed to the renowned Frankish ruler William Villehardouin (Σφηκόπουλος, 1987; Molin, 2001; Bouza, 2002; Fernández de Heredia & Morel-Fatio, 1885)[33]. During the Frankish occupation, Androusa was one of the most important towns of the Peloponnese. In documents from the period of the Principality of Achaea[34], mainly the *Assizes of Romania*[35], Androusa is referred as the seat of the military commander (*castellan*) of the castellany of Kalamata (Κοντογιάννης, 2012; Bouza, 2002). Androusa was also

[32] The *Chronicle of Morea* is a long history text that contains a great amount of information about the Frankish conquest of mainland Greece. It was probably first written in French, but there are also versions in Greek, Italian and Aragonese, all of which have slight differences (Hetherington, 1991; Λοκ, 1998).

[33] The Aragonese version of the *Chronicle of Morea* mentions in the paragraph 216: «*…et en la castelania de Calamata fizo fer el castiello de Druges…*» (meaning the castle of Androusa) (Fernández de Heredia & Morel-Fatio, 1885).

[34] The Principality of Achaea (*Principatus Achaie*) was called *Nova Francia* and the Franks tried to bring to it the customs of their own country, such as the organization of games, horse races, jousting tournaments, knighthood, coats-of-arms etc. The principal language of the Principality was the French (Μητρόπουλος, 2014).

[35] *Assizes of Romania* (*Assizes de Romanie*) is a medieval legal text comprised of 219 articles defining the way of government, the relations of rulers, and the obligations of the barons to the *Prince* (Μητρόπουλος, 2014; Ντούρου-Ηλιοπούλου, 2005; Λοκ, 1998).

one of the frontier customs of the Principality in which the Peloponnesian products were imported and exported to Venetian territories (Μητρόπουλος, 2014)[36].

In 1308, during the reign of the Andronikos II Palaiologos, Androusa became a bishopric seat with a golden bull (*chrysobull*[37]) of the emperor (Θεοχάρης, 1948; Λύρας, 2010; Σφηκόπουλος, 1987; Κάππας, 2007)[38]. During the 14th and 15th century Messenia was the actual capital of the Principality of Achaia and the Court seat (Θεοχάρης, 1981; Καρποδίνη-Δημητριάδη, 1993).

By the end of the 14th century the castle of Androusa became a stronghold of the Navarrese mercenary company in Messenia (Bouza, 2002; Κάππας, 2007). It was conquered by the mercenaries in 1381 and in the following year a treaty of peace was signed in the city between them and the Venetians of Methoni and Coroni (Νταμάτης, 2007; Παπαδόπουλος, 1969). The mercenaries stayed in Androusa until 1383 (Θεοχάρης, 1981)[39]. During their rule, the population of city grew and became the capital of the region (Μητρόπουλος, 2014)[40].

During May of 1417, the castle of Androusa was sieged by Theodore II Palaiologos and his brother John VIII Palaiologos and eventually came under the control of the Despots of Mystra. After 1428, Constantine XI Dragases Palaiologos became the ruler of the castle, who will soon become the last Byzantine emperor (Καρποδίνη-Δημητριάδη, 1993; Νταμάτης, 2007; Bon, 1969).

However, the Byzantine reign was short. After the fall of Constantinople to the Ottomans on 29 May 1453, Sultan Mehmet II began his invasion to the other Byzantine territories. Most of them came to his hands in a short period of time. The city of Androusa came under the Ottoman control in 1460, following the fate of the

[36] On June 1209 a treaty was signed between Geoffrey Villearduin and Venice, known as *Sapientza Treaty*. The Peloponnese was granted as a fief to Goeffrey, while Venice was given Coroni and Methoni as well as the freedom of commercial activities (Athanasoulis, 2002; Κάππας, 2007).

[37] This chrysobull of Andronikos II Palaiologos constitutes the first mention of Androusa as a bishopric seat and dates back to 1292 (Κάππας, 2010).

[38] Androusa originally belonged to the Monemvasia Metropolis and included a total of 76 villages in the provinces of Messenia, Triphilia, Pilia, Arcadia and Navarino (Θεοχάρης, 1948). According to several written sources (Σφηκόπουλος, 1987; Λύρας, 2010; Νταμάτης, 2007; Corpus Scriptorum Historiae Byzantine (Bonnae), 1838), Androusa was the birthplace of Patriarch Athanasius and this helped to become a bishopric seat. However, this theory does not seem to be true, since Athanasius (formerly known as Alexios) was actually born in Adrianoupolis (Edirne) in Thrace (Σαββίδης, 1996; Kazhdan, 1991). In addition, the declaration of Androusa to a bishopric seat is really questionable since the Franks did not allowed orthodox bishops to settle in their territories (Κάππας, 2007).

[39] The Navarrese mercenaries left after selling most of the territories they had conquered, including Androusa (Θεοχάρης, 1948).

[40] In the feudal lists of 1391 it is reported that Androusa had 300 households, the same number as Kalamata (Νταμάτης, 2007).

rest of the Peloponnese (Θεοχάρης, 1981)[41]. During the period of First Ottoman Occupation, Androusa became an important commercial center in Messenia, that controlled the trade of all products coming from the Messenian gulf and from the Ionian ports (Θεοχάρης, 1948).

In September 1479, a Greek military leader from Mani named Krokodeilos Kladas (1425-1490) conquered Androusa and kept it free from the Ottomans until April 1480 (Νταμάτης, 2007).

In 1533, the Spaniards with the help of rebellious Greeks conquered the west coast of the Peloponnese and attacked Androusa under the commands of the Spanish General Masikao. However, only a few months later the Ottoman army recaptured the city (Νταμάτης, 2007; Θεοχάρης, 1981).

In 1684, the hostilities between Venetians and Ottoman began in the Peloponnese. Eventually, the Venetian Morosini conquered the Peloponnese and Attica, establishing a new period of Venetian rule. As a result, Androusa came under the Venetian control. During these years of the Second Venetian Rule (1685-1715), Androusa became a *territorio* of Messenia with 9,000 inhabitants, making it the largest city in the region of Messenia (Νταμάτης, 2007; Bouza, 2002; Bon, 1969)[42].

After 1715 the Ottomans regained their power in the Peloponnese establishing a Second period of Ottoman Occupation (1715-1821). The Peloponnese was divided into 24 administrative divisions, known as *kazades* (plural of *kazas*) with Androusa being one of them (Νταμάτης, 2007)[43]. However, Androusa steadily started to lose its importance. The downfall of the formerly glorious city was completed after the transfer of the seat of the local bishop to the neighboring Nisi, today's Messene (Ephorate of Antiquities of Messenia, 2016)[44]. According to the British colonel William Martin Leake who visited Androusa during 1805, the city had already begun to shrink. As he mentions, only about 250-300 Turkish families and 3-4 Greek

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[41] Only the Venetian territories of the Peloponnese were left out of Ottoman control (Μητρόπουλος, 2014).

[42] The Venetians divided the Peloponnese into four provincial districts: the province of Romania (capital Nafplio), the province of Achaia (capital Patras), the province of Messenia (capital New Navarino) and the province of Laconia (capital Monemvasia) (Νταμάτης, 2007).

[43] The 24 *kazades* of the Peloponnese during the Second Ottoman Occupation were: Nafplio, Argos, Corinth, Kalavryta, Vostitsa, Patra, Gastouni, Fanari, Arcadia, Leontari, Tripolitsa, Agios Petros, Monemvasia, Mistras, Eastern Mani, Western Mani, Vardounia, Nisi, Methoni , Koroni, Androusa, Kalamata, Karitena (Νταμάτης, 2007).

[44] The settlement of Messene was on the banks of Pamisos River and was surrounded by a tributary giving the image of an island. As a result the city was named *Nisi* (meaning *island* in Greek) (Μητρόπουλος, 2014).

families were left in the city (Θεοχάρης, 1981). The castle of Androusa in the early 18th century was already lying in ruins (Bouza, 2002; Bon, 1969).

Synopsis of historical events related to Androusa

1204	The Christian forces of the Fourth Crusade capture Constantinople. The Doge of Venice becomes lord of the Byzantine Empire.
1205	William Champlite marches into the Morea[45] and founds the Frankish principality of Achaia.
Mid-13th c.	The Frankish ruler William Villehardouin builds the castle of Androusa.
1259	Battle of Pelagonia. Defeat and capture of William Villehardouin by the Greeks of Nicea.
1261	Michael VIII Palaiologos recovers the Constantinople from the Latins and restores the Byzantine Empire.
1308	Androusa becomes a bishopric seat during the reign of the Emperor Andronikos II Palaiologos.
1381	The Navarrese mercenary company conquers the castle of Androusa.
1382	A peace treatment is signed in Androusa between Navarrese mercenary company and the Venetians.
1383	The Navarrese mercenary company leaves Androusa.
1417	Theodore II Palaiologos and his brother John VIII Palaiologos conquer the castle of Androusa.
1428	Constantine XI Dragases Palaiologos becomes ruler of Androusa.
1453	Capture of Constantinople by the Ottomans of Sultan Mehmet.
1460	The Peloponnese comes under Ottoman control.
1479	The Greek military leader Krokodeilos Kladas frees Androusa from the Ottomans.
1480	Androusa returns to Ottoman control.
1533	The Spanish General Masikao conquers the west coast of the Peloponnese including Androusa. Ottoman army recaptures the city a few months later.
1685	Francesco Morosini conquers the Peloponnese and Attica. Androusa becomes a Venetian *territorio.*

[45] The name of the *Morea* was applied to the whole of the Peloponnese from this period, while previously had been used just of Elis to the west (Hetherington, 1991). The origin of the name *Morea* is not clearly defined (Tozer, 1883).

1715	Ottomans regain their power in the Peloponnese. Androusa becomes a *kazas*.
1805	The British colonel William Martin Leake visits Androusa. The castle lies in ruins.
1821	Greek War of Independence. Androusa is released from the Ottoman occupation.

Table 1: Historical events associated with the castle of Androusa

2.2.3. The fortification of the castle of Androusa

The castle of Androusa is one of the most important examples of medieval fortifications in the Peloponnese, with interesting morphological features[46]. Its initial design, given its large scale, suggests that it operated as a fortified city rather than an independent fort, aiming at more effective surveillance of the area and commercial streets (Ephorate of Antiquities of Messenia, 2016)[47].

The castle is built on a low hill top, exploiting the natural features of the landscape. As most of the medieval castles, the ground plan of the curtain wall is trapezoidal and generally follows the contours of the terrain. Unfortunately, only a small part of it remains today, mainly due to the creation of the modern village of Androusa in the northern and western sides of the castle. Its initial size will have been around 20.000m^2 (Bouza, 2002). Much of the building material of the castle was probably reused by the inhabitants for the construction of their houses[48]. Despite that, the existing parts of the fortification are maintained in relatively good condition.

Generally, all the fortification is well constructed with mortars of good quality and with the use of mainly medium and small-sized stones. Between the stones there are many pieces of ceramic fragments and tiles. The fortification is founded on loose soils rather than a rocky ground. For the aforementioned reason, both the walls and the towers are built on an extended stone-made foundation, which nowadays is visible

[46] The most important Frankish castles in Messenia were the castle of Androusa, the castle of Kalamata and the castle of Arkadia. These cities had a central tower were the lord lived. The peasants (*βιλλάνοι*) lived inside city walls (Μητρόπουλος, 2014).

[47] Androusa despite being considered a fortified city, it has only one fortified enclosure rather than multiple, as is usually the case (Κοντογιάννης, 2012).

[48] This information came from oral testimonies of local inhabitants of Androusa.

in many areas due to soil erosion. Such a well-built stone foundation deep on the ground was not only important for static reasons, but also for defensive purposes[49].

The outside image of the castle is simple and unobtrusive, but at the same time impressive and imposing (see Appendix B, photo 1). It has not particular morphological features, with the exception of perhaps the many holes on the walls for securing the scaffolds at different levels[50]. The castle walls are reinforced by towers of various shapes that are placed in unequal intervals. The inner face of the walls has a series of blind relieving arches on which the wall-walk of the castle is housed. The use of relieving arches was a common practice in castle building that aimed to economize building material, mainly stones (Bon, 1969; Bouza, 2002)[51]. Special care has been given to the arches of the eastern wall which are pointed and have various motifs of decorative brickwork that either surround the arch or form isolated decorative elements (see Appendix B, photos 2-3). The arches of the southern wall are rounded and less carefully constructed without decorative motifs. The wall-walk was protected by ramparts, only a few traces of which remain today. There are no visible buildings inside the castle, except for a dilapidated stone-built structure built during the previous century. The many buildings that once existed in the castle are now covered by an accumulation of soil of large thickness. In addition, it remains unknown if the castle had more than one fortification enclosures or where was the location of its main gate.

The only parts of the castle that are preserved are the Eastern Wall, parts of the Southern and Northern Wall and six towers(see Appendix B, photos 4-12). The first tower is located in the middle of the eastern curtain wall and it is an open gorge tower (Eastern Tower). The second one is a circular tower, located on the northeastern corner of the castle (Northeastern Tower). At the western end of the Northern Wall stands a quadrilateral tower (Northern Tower). The foundations of a fourth tower lie on the western side of the Southern Wall (Southern Tower). There is also a fifth tower isolated in the northwestern side of the castle (Northwestern Tower).

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[49] A known tactic of castle sieging was to undermine the castle walls or the towers (Δεληγιάννη-Δωρή, 1993; Kennedy, 1994).

[50] These holes were used to stabilize the scaffolding during the construction of a fortification and were usually left open upon its complexion (Breuillot, 2005).

[51] The castle of Androusa is not built in a rocky or mountainous area, where stones are in abundance. In fact, they probably needed to be transported from other areas from the greater region.

All the above towers are integrated into the curtain wall, with only exception a quadrilateral tower located on the southeastern side of the castle (Southeastern Tower). It is the biggest and the most impressive tower of the castle and probably served as a donjon/keep, a common element of western fortifications[52]. This tower constitutes the oldest fortification structure of the castle, indicated by the fact that the eastern and southern walls -to which it is attached- were added at a later period. In fact, parts of the corners of the tower were removed, so it could be better connected to the curtain walls.

The following figure demonstrates the fortification of the castle of Androusa and the exact location of the towers and the curtain walls.

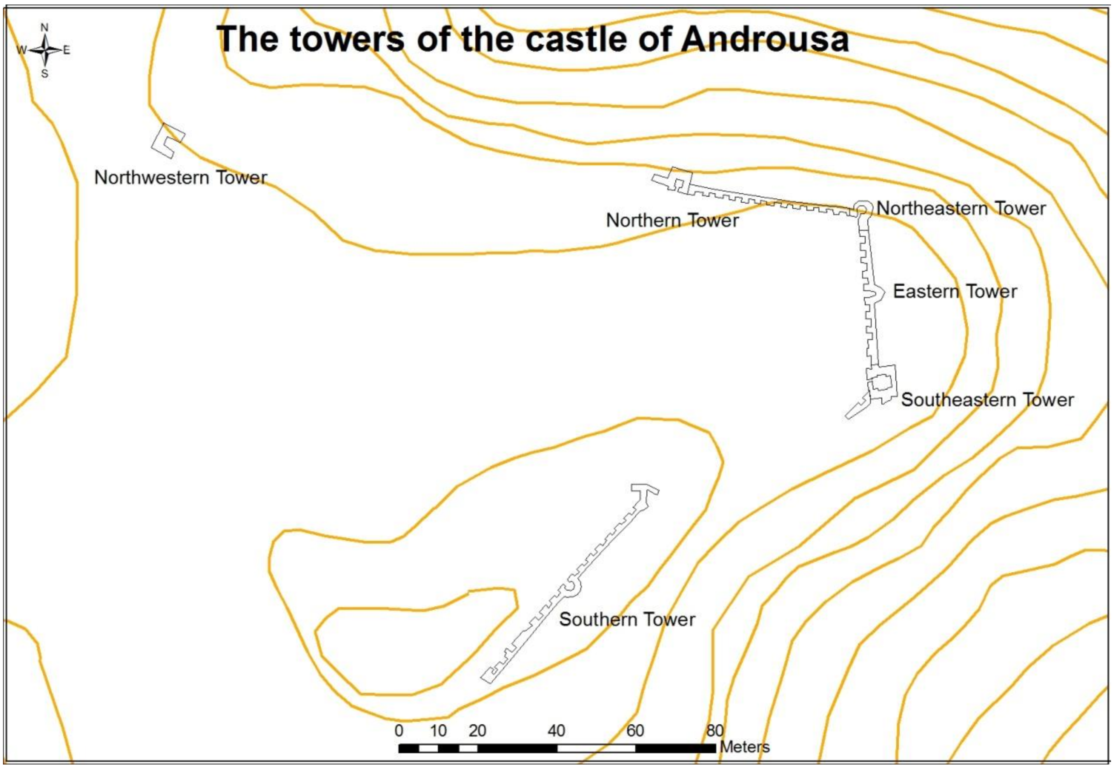

Figure 2: The ground plan of the castle of Androusa created with GIS (see chpt. 3.1). The locations of the towers are indicated.

2.2.4. The restoration works at the castle of Androusa

The castle of Androusa has undergone a series of restoration works during the last years aiming to its preservation. According to archival documents of the Ephorate

[52] The Southeastern tower also has an underground cistern, a feature of the donjon towers.

of Antiquities of Messenia[53], the first restoration works took place in the summer of 1969. During this year were restored the foundations of the Northeastern Tower and its two remaining floors[54]. Other small scale works included the restoration of the top floor of the Northern Tower. In both cases cement was used to seal the floors of the towers to protect them from the rain.

On April 2012 commenced a project for the restoration of the eastern section of the Androusa castle that lasted until October 2015. The budget of this project was 550,000€ and was implemented by the Ephorate of Antiquities of Messenia via direct labor. The project included a series of works, such as excavations in order to uncover the curtain walls and towers, stabilization actions, reconstruction of ruined sections of masonry, injections of cement and pointing. In addition, the walls and towers received waterproofing treatment, a part of the fallen southern wall was reconstructed, and retaining walls were built at the northern and southern sides to contain the slopes. Finally, a metal shelter covered with polycarbonate sheets was placed at the top of the Southeastern Tower to further protect it from the environmental conditions (Ephorate of Antiquities of Messenia, 2016)(see Appendix B, photos 13-14).

2.2.5. The building phases of the castle of Androusa

The medieval fortifications in Greece are very similar in appearance. Therefore, they cannot be easily attributed to Greeks or to foreign rulers, especially in cases where there is also a lack of written sources. This is mainly due to the fact that they were built by local craftsmen who used the same local materials and similar building techniques[55]. Often, older fortifications were demolished, rebuilt or altered in order to cope with the evolving tactics of the war. Distinguishing the different building phases of their construction is usually a really difficult task (Molin, 2001).

The castle of Androusa presents architectural features included in the Medieval, Byzantine and Ottoman architecture. Its origin, chronology and constructive evolution are controversial among authors (26th Ephorate of Byzantine Antiquities, 2013; Bon, 1969; Molin, 2001; Κοντογιάννης, 2012; Bouza, 2002). As

[53] Former 26th Ephorate of Byzantine Antiquities.

[54] The tower was in danger of collapsing because its foundations were in a severely bad condition.

[55] The Latins also used Greek craftsmen for building or repairing churches. These craftsmen incorporated the Greek style to their works (Molin, 2001; Κάππας, 2007).

already mentioned in the introduction, according to the Aragonese version of the *Chronicle of Morea* the construction of the castle is attributed to the William II of Villehardouin and it is dated to the 13th century (Fernández de Heredia & Morel-Fatio, 1885)[56]. The famous French expeditor Antoine Bon dated the castle to the mid-13th century, with possible additions in the 14th century (Bon, 1969). In 2015, a new approach about the different building phases of the castle was made by the Ephorate of Antiquities of Messenia, and was based on new archaeological evidence that derived after the restoration project of the castle during 2013-2015. According to the new theory, the fortification of the castle was probably built in three different building phases (26th Ephorate of Byzantine Antiquities, 2013; Ephorate of Antiquities of Messenia, 2016)[57]:

1st Building phase – Frankish Period: Northeastern Tower

The Northeastern Tower has many typical characteristics of a Frankish donjon tower, such as big dimensions and an underground cistern. In addition, the Eastern and Southern walls -to which the tower is attached- are not structurally connected with the tower indicating that were probably added at a later period.

2nd Building phase – Byzantine Period: Eastern Wall, Eastern Tower, Southern Wall, Southern Tower

The Eastern Wall (except from a small part of its southern edge), the Southern Wall and the Southern Tower have some characteristics that can be considered byzantine. The decorative brickworks found in the inner side of the Eastern Wall are very similar to those found in byzantine churches of this period and are characteristic of the byzantine military architecture in the middle of the 14th century and beyond (Breuillot, 2005; 9th Ephorate of Byzantine Antiquities, 2001; Curcic, 2010)[58]. In

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[56] Generally, the *Chronicle of Morea* must be examined with caution on the events of the 13th century as it was written in the first half of the 14th century and can lead to erroneous conclusions (Ντούρου-Ηλιοπούλου, 2005).

[57] In this study were included only the building phases of the fortification and not other structures from previous or later periods found in the castle.

[58] There are some examples of Byzantine fortification buildings in the Balkans with ceramic decorations in their masonry, such as the Tower of Mariana (Olynthos), the tower of Orestes (Serres), and the fortified capital on the Danube-Smederevo (Serbia) (Curcic, 2010). Ornaments like crosses made out of bricks on byzantine castle walls proclaimed the faith of the inhabitants and their intense emotional relationship with the fortifications that protected them (9th Ephorate of Byzantine Antiquities, 2001).

addition, polygonal towers projecting boldly from their respective curtain walls, like the Eastern Tower and the Southern Tower, are also a common element of byzantine fortifications (Kennedy, 1994).

3rd Building phase – Ottoman Period: Northern Wall, Northeastern Tower, Northeastern Tower, Northwestern Tower

The northern part of the Eastern Wall, the Northeastern Tower, the Northern Wall, the Northern Tower, and the Northwestern Tower are considered to have been built during Ottoman period. They present structural and morphological differences in comparison with the rest of the castle, mainly in the way the relieving arches of the Northern Wall are built. In addition, the three towers have cannon embrasures, indicating that they were built after the 15th century and the invention of gunpowder artillery. This section of the fortification was probably built when Androusa was under Ottoman occupation[59].

The following figure depicts the three building phases of the castle (26th Ephorate of Byzantine Antiquities, 2013):

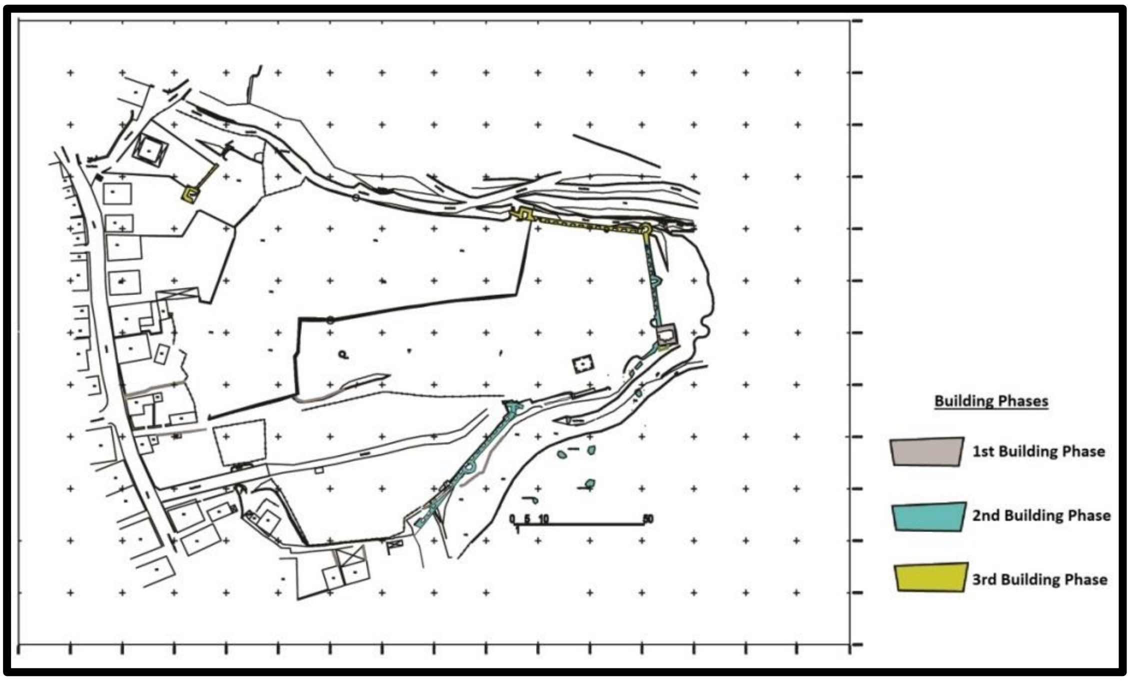

Figure 3: Plan of the castle of Androusa depicting the building phases of its fortification

[59] Most of the Byzantine fortifications were not modernized in time to cope with the new era of firearms. The Ottoman conquest stopped their development within a short time (Ευγενίδου, 2003).

2.3. Building mortars

2.3.1. Mortars

Mortar[60] is one of the first building materials and has been in use for thousands of years[61]. Due to its significance in construction, many ancient writers have been interested in the study of the technology and application of the mortars (Pachta et al., 2014).

The term *mortar* is really ambiguous with more than one definition (Hughes & Valek, 2003). In general, mortar is a material resulting from the mixing of organic and inorganic binders, aggregates, water, as well as various organic or inorganic additives[62]. When this mixture is ready, it forms slurry, which at a certain time is hardened progressively, depending on the type, composition and environmental conditions. This mixture provides to the mortars workability, good mechanical and physical behavior and great durability (Μπακόλας-Καραγιάννης, 2002; Κυροπούλου, 2016; Sanjurjo-Sanchez et al., 2010).

The function of the mortars within the structure is determined by their use (Hughes & Valek, 2003). Generally, the use of mortars as building materials is really extensive. Their basic role is to connect the building elements of structures in order to ensure a strong and durable architectural construction. In addition, they have been used as mudguards, as binders for architectural parts, as masonry coatings and as roofing materials. Mortars have also been used as decorative elements in building monuments such as frescoes and mosaics. Moreover, mortars also find use in restoration and preservation works in antiquities for the maintenance of structure and their decorative elements (Κυροπούλου, 2016; Papayianni et al., 2013).

[60] Mortars are also found in literature as *emplecton, titanos, cocciopesto opus cementitium, stucco, courasani, lykium* (Papayianni et al., 2008).

[61] The first use of mud-mortars has been documented in rubble and adobe masonry in the Mesopotamia and Babylonia during the 8th century BC (Pachta et al., 2014).

[62] Mortars can also be made just by the mixing of water and binder without the addition of aggregates (Μπακόλας-Καραγιάννης, 2002).

2.3.2. Aggregates

In general, aggregates are solid granular materials (sand, gravel, pumice etc.) that derive from the physical fragmentation or artificial fracturing of natural rocks[63]. They are generally inorganic, because most of them do not react with the binders. According to their origin, aggregates can be distinguished in natural, artificial (crushed) and industrial and are found in various natural sources (e.g. rivers, sea shores, mines, quarries). In antiquity, ceramic fragments or pumice were also used as aggregates in the preparation of mortars, aiming to the production of lightweight mortars with greater elasticity than conventional sand mortars (Μπακόλας-Καραγιάννης, 2002; Stefanidou, 2016).

Aggregates replace a significant proportion of the binders, which are relatively vulnerable to environmental conditions (Μπακόλας-Καραγιάννης, 2002). The addition of aggregates ensures technical advantages since they contribute to volume stability, durability and structural performance of a binding system. However, the correct proportion of aggregates is important during the mixing of the materials. Their volume content, maximum size and gradation influence the structure of the mortar mixture (Stefanidou & Papayianni, 2005). Furthermore, they can have a significant impact on workability, flow ability and segregation resistance of the final mortar (Hu & Wang, 2005).

Based on their grain size distribution, aggregates can be categorized as coarse aggregates (aggregates held in a 5mm diameter sieve) and as fine aggregates or sands (aggregates passing through a 5mm diameter sieve). Very fine aggregates offer mortars of better quality in terms of workability and cohesion, while mortars made of very coarse aggregates need less water for setting (Μπακόλας-Καραγιάννης, 2002). In mortars from historic buildings, aggregates are being found in different sizes, such as 0-4mm, 0-12mm, 0-16mm and 0-40mm (Stefanidou & Papayianni, 2005). Regarding the structural mortars, the most often gradation is 0-6mm and 0-8mm (Pachta et al., 2014). The following table shows the granulometry of mortars of different historic periods.

[63] In industrial era, aggregates can also derive from industrial residues (Μπακόλας-Καραγιάννης, 2002).

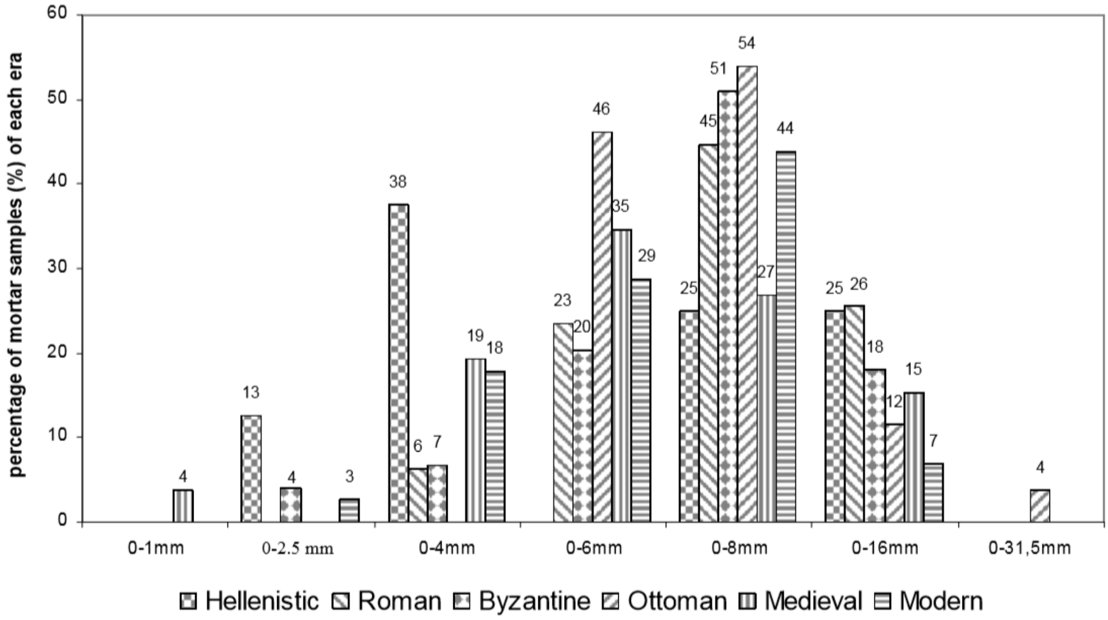

Figure 4: Granulometry of the aggregates from structural mortars of different historic periods (Pachta et al., 2014)

2.3.3. Binders

Mortars are mainly distinguished by the nature of the binder (e.g. lime, pozzolanic materials, hydraulic binders, gypsum, clay binders, organic binders or combinations of them) (Hughes & Valek, 2003). Binders are materials which, when mixed with water, form a pulp that thickens and hardens. According to their setting and hardening processes, there are two main categories of binders (Μπακόλας-Καραγιάννης, 2002; Van Balen et al., 1999):

- *Non-hydraulic binders:* set and harden with the influence of atmospheric air (e.g. air lime, gypsum).
- *Hydraulic binders:* set and harden with the influence of water (e.g. hydraulic lime, cement).

The hydraulic properties of the binder play an important role on the physical and chemical properties of the mortars. Moreover, the nature of the binder can also categorize the type of mortar (Hughes & Valek, 2003):

- Mortar based on Portland cement
- Mortar based on clay/mud
- Mortar based on several binders
- Mortar based on lime

- Mortar based on gypsum
- Mortar based on organic/synthetic binder

2.3.4. Additives

Additives are used as a mean to improve the properties of the mortars. Their use has been reported in written sources from different historical periods. Nevertheless, they are rarely mentioned in scientific papers of conservation science or history of technology (Rampazzi et al., 2015; Μπακόλας-Καραγιάννης, 2002).

Research has proved that the use of additives in mortars can offer increased mechanical properties, water resistance, different setting speeds (faster carbonization of lime), different textures, good performance with reference to caking property, weatherability, etc. The main considerations about the use of additives to the mortars are their cost and availability. In past, builders in order to better understand the properties and the results of additives had to rely on their experience and tradition. According to literature, the use of additives aims to (Rampazzi et al., 2015):

- Improve the durability and harness
- Reduce the drying shrinkage
- Increase the resistance to traction
- Delay/accelerate the setting time
- Facilitate adhesion on to the surface
- Stabilize any emulsion (if present)
- Increase resistance to decay caused by freeze/thaw cycles
- Increase plasticity and workability

Pozzolanic materials

Pozzolans are among the main additives used in historic mortars. They can be mainly categorized based on their origin as natural (materials of volcanic action) or artificial (materials made by human action). They are used as additives in lime mortars to give them hydraulic properties. Although there are many types of pozzolanic materials, their common property is to react and to harden when mixed with lime and water (Μπακόλας-Καραγιάννης, 2002). The addition of pozzolan enhances the durability of the mortar. Based on the type of pozzolanic material, it can offer increased comprehensive strength, density and reduced porosity (Acharya et al., 2017)[64].

Organic additives

There are a large number of organic additives that have been used throughout history in historic mortars. Some of them that have been documented in mortars of historic buildings are: blood, egg, olive oil, sugar, cheese, manure, gum, animal glue, blood, milk, flour, fruit and tree juices, fat, etc. (Μπακόλας-Καραγιάννης, 2002; Acharya et al., 2017; Πάχτα, 2011). The following table presents the known organic additives that were used in various time periods.

	150 b. C. Egypt	46 b. C. Vitruvius Era)	23 a. D. Pliny	800	1200	1500	1653 Plat	1703 Neve, Moxon	Mid-1700	1837 Vicat, Smith	1850 Burnel & periodicals
Egg albumen	X										
Animal glue	X							X			X
Barley			X						X		
Beer					X	X			X		
Bee wax					X	X		X	X		X
Blood	X	X	X	X		X	X	X	X		X
Butter										X	
Butter milk									X		
Casein	X										
Cheese								X	X	X	X
Cotton											X
Curd		X							X	X	
Manure									X		
Eggs	X				X	X		X	X		X
Egg white	X	X			X	X	X	X		X	X
Elm bark			X								
Fibers			X								
Fig milk	X	X	X						X		
Fruit juice					X	X			X		
Starch glue					X	X			X		
Arabic gum	X					X	X				X
Hairs			X								
Pork fat		X	X					X			X

[64] The porosity of the mortars plays an important role in terms of moisture transport, mechanical properties, durability and compatibility of the masonry as a whole (Caspar et al., 2007).

Keratin	**X**										
Malt					**X**	**X**					
Milk			**X**					**X**	**X**	**X**	**X**
Molasses		**X**								**X**	
Oil			**X**							**X**	**X**
Resin								**X**			
Rice					**X**	**X**					
Rye dough		**X**							**X**		
Saffron			**X**								
Shellac											**X**
Glue			**X**		**X**	**X**					
Bull fat			**X**								
Sugar					**X**	**X**				**X**	
Tannin			**X**								
Urines					**X**	**X**					
Vegetable juice									**X**		
Wine			**X**								
Herbs					**X**				**X**		

Table 2: Use of organic additives in different time periods (Μπακόλας-Καραγιάννης, 2002)

2.3.5. Historic mortars

The term *historic mortar* (or *original mortar*) is used in order to describe the original mortars of historic buildings (including mortars used in later repairs) and to differentiate them from modern/new mortars used in recent conservation and restoration works (Hughes & Valek, 2003).

Historic mortars can be divided into categories according to their use. As a result, there are rendering mortars (coatings), structural mortars, decorative mortars (for application in frescoes and mosaics), floor mortars, roof mortars and mortars for supporting and strengthening architectural elements (Κυροπούλου, 2016; Πάχτα, 2011). According to RILEM (TC 203-RHM (Main author: John J. Hughes), 2012), historic mortars -based on their functional role in construction- are distinguished in the following categories:

Main functions of mortars	
Bedding mortar	Setting units, adhesion bearing load
Pointing mortar	Water penetration protection and for aesthetics
Exterior render	Water penetration protection and for aesthetics
Interior plaster	Aesthetic covering, a substrate for decoration

Surface repair	Replace and repair missing sections of masonry
Grout	Material filling of cavities in masonry to improve monolithic behavior
Flooring mortar	Supporting layer, leveling screed, a substrate for tiles and mosaics
In-fill mortar	Filling mass between masonry faces (in certain types of masonry constructions) binding irregular masonry units that are part of the in-fill

Table 3: Main function of mortars in construction

In order to determine the characteristics of a historic mortar, a number of factors must be taken into account such as: the nature of the binder and the aggregates, the ratio between binder/aggregate, the presence of other organic or inorganic additives, the preparation and execution techniques (usually unknown today), and the impact of natural and environmental factors (Μπακόλας-Καραγιάννης, 2002).

There is a variety of historic mortar types used over time depending on the technological consciousness of each era and the local availability of raw materials (Papayianni et al., 2008; Sanjurjo-Sanchez et al., 2010). The main constituents of mortars found in ancient buildings are:

- *Clay*: Also referred as mud (Elsen, 2006). It is considered as the first material used in construction by human. Clay in its pure form is called kaolin and it is a silicate aluminum consisting mainly of SiO_2 and Al_2O_3 (Weems, 1903)[65]. During prehistoric times it was extensively used, mainly because of its abundance as a raw material and its easy preparation and application (Κυροπούλου, 2016)[66].
- *Lime (CaO)*: It is probably the most widespread and commonly used building material. It is produced through the calcination of limestone at a temperature of about 900-950°C (Van Balen, 2003). Limestones are often found in the form of magnesium carbonate ($MgCO_3$) or in the form of dolomite ($CaMg\ (CO_3)_2$) and may also contain impurities in varying amounts like aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), organic substances, etc. (Μπακόλας-Καραγιάννης, 2002). Lime produced from limestone with less than 5% of magnesium is referred as high-calcium

[65] Pure clay (like kaolin) has the formula $Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$ (Si02: 47.1%, Al_20: 39.2%, H_2O: 13.7%). Impure clays may contain impurities in form of other oxides (such as K_2O, NaO_2) (Weems, 1903).

[66] The first applications of clay as building material are witnessed during Neolithic era for the manufacturing of mud-mortars and mud-bricks (Κυροπούλου, 2016).

lime, whereas lime with magnesium above 20% is referred as dolomitic lime (Acharya et al., 2017). In antiquity, lime was mainly used for the production of plasters for the covering of walls, floors and roofs, since it protected them from the humidity and the rainwater (Papayianni et al., 2008).

- *Gypsum*: It is usually applied in masonries of lime-based mortars and renderings due to its ability to increase specific properties, like good heat insulation, acoustic insulation, fire resistance, workability and plasticity (Papayianni et al., 2008; Karni & Karni, 1995). In nature is found in two mineral phases, in dehydrated form as calcium sulphate ($CaSO_4.2H_2O$, selenite), and in anhydrous form as anhydrite ($CaSO_4$) (Μπακόλας-Καραγιάννης, 2002).
- *Pozzolana*[67]: Although it is considered a roman achievement, its use has been identified from prehistoric times (Papayianni et al., 2008). The term is used for pyroclastic rocks, particularly glassy and sometimes zeolite as well as for inorganic materials, natural or artificial, which harden with the presence of water when mixed with lime (Μπακόλας-Καραγιάννης, 2002)[68].
- *Brick dust*: It was the main binding agent during byzantine times. Its use was really important, since it increased the hydraulic properties of the mixture, reinforced the lime mortars, colored the mixtures and helped to their preservation against the negative effects of humidity (Papayianni et al., 2008).

Despite the variety of available binders, lime was the most used in the majority of historical buildings. The non-hydraulic lime-based mortars were the most common in the architectural history. Hydraulic lime-based mortars had been widely used during the roman and byzantine times, until the end of 19th century, when cement-based mortars replaced them (Hughes & Valek, 2003; Πάχτα, 2011)[69].

[67] The name Pozzolana derives from the name of the Italian city Pozzuoly near Naples (Κυροπούλου, 2016).
[68] Pozzalanic materials, based on their provenance, can be either natural (volcanic ash) or artificial. The artificial pozzolans used in ancient times were fine fragments of ceramics (tiles, bricks, pots, etc.) (Μπακόλας-Καραγιάννης, 2002).
[69] During the Roman and Byzantine times the use of brick dust and crushed ceramics in the mixtures for the construction of hydraulic mortars was systematized (Πάχτα, 2011).

Generally, historic mortars are really composite materials that are usually studied for specific conservation and repair related investigations or for academic purposes (Hughes & Valek, 2003). The three fields that are mostly focused in the study of historic mortars are the conservation field, the archaeology field and the academic material research field. Until 1970-1980 the traditional way to characterize mortars was mainly through wet chemical analyses (Elsen, 2006)[70]. Nowadays, there is a plethora of techniques that can help for the characterization of the compositional and mechanical properties of historic mortars. The choice of each technique is based on the research questions, the amount of the material available and the available resources. The basic techniques used as well as their main applications are:

1. *Macroscopic Observation (Visual examination by naked eye and with magnifying lens)*

This is considered a preliminary examination that precedes any microstructure study. It helps in the selection of the samples and of the investigation techniques that need to be used (Martinet & Quenee, 1999).

2. *Optical Microscopy in reflected light*

It helps the identification of hydraulic binders, of anhydrous clinker particles and of mineral admixtures and opaque mineral types (Martinet & Quenee, 1999)[71].

3. *Optical Microscopy in transmitted polarized light*

It helps in the mineralogical and petrographical identification of the mortar constituents, the qualitative distribution between binder and aggregate (including anhydrous clinker) and the observation of the different mineral phases in the matrix (Moropoulou et al., 2000; Martinet & Quenee, 1999). It can also help in the determination of physical problems such as cracking etc. (Caspar et al., 2007)

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[70] Despite their use, wet chemical analysis methods cannot provide a wide range of information on mortars. It is therefore important to precede mineral-petrographic analysis before chemical analysis (Caspar et al., 2007).

[71] A limitation of Optical Microscopy is the fact that it has a resolution of approximately 1 micron providing a two dimensional cross-sectional view. As a result, there can be doubts about the representativeness of the images it offers (Caspar et al., 2007).

4. *Scanning Electron Microscopy (SEM)*

It helps the characterization of carbonates and hydrates of the matrix (nature, form, structure etc.) and the identification of the alteration phases (Caspar et al., 2007).

5. *Scanning Electron Microscopy coupled with Energy Dispersive X-ray Microanalysis (SEM-EDS)*

It helps in the local qualitative and quantitative elementary composition of the observed phases. In addition, stoichiometric mineral types can be computed for comparative purposes (Caspar et al., 2007).

6. *X-ray diffraction analysis (XRD)*

It helps to the determination of the mineralogical nature of the binder, as well as of the detection of crystalized alteration products (Martinet & Quenee, 1999).

7. *Thermal analysis (DTA and TGA[72])*

It helps the identification and quantification of particular minerals in mortars (Hughes & Valek, 2003; Middendorf et al., 2005)[73].

8. *Luminescence dating technique*

It helps the determination of the chronology of historical mortars, offering an absolute dating (Zacharias et al., 2002).

[72] Differential Thermal Analyses (DTA) and Differential Scanning Calorimetry (DSC) techniques are also known as Thermogravimetry (TG) (Hughes & Valek, 2003).

[73] Endothermic and exothermic transitions are characteristic of particular elements.TG calculates the changes in the weight of a sample during its heating at a controlled rate from ambient temperature to 1000°C (Κυροπούλου, 2016; Hughes & Valek, 2003).

3. Practical part

3.1. Geographical Information System (GIS)

A Geographical Information System (GIS) is a computer-based technology that is used to produce, organize and analyze spatial information. The capabilities of GIS include database management, mapping, image processing and statistical analysis (Box, 1999).

GIS has a vital role on broadening the understanding of the relationship of space, place, and culture. For over 40 years GIS has been used in various sciences[74]. The archeology science was one of the first to exploit the potential of its use in landscape studies and cultural heritage management[75]. Today, GIS has turned to be one of the most versatile and comprehensive analytical tools in archaeology in terms of handling archaeological data and exploring the human space (Tsiafakis & Evagelidis, 2006; Petrescu, 2007).

It is widely accepted that GIS has drastically changed the way of processing and interpreting the archaeological information. It enabled the archaeologists to record, convert, analyze and represent big amounts of complex data in a homogenous way. According to Tsiafakis D. and Evagelidis V., by utilizing the inherent functions of GIS, archaeologists were allowed to (Tsiafakis & Evagelidis, 2006):

- *Develop an adequate concept of landscape and encourage a multiperspective envision of the past*
- *Deconstruct the traditional archaeological categories (like site) and define alternatives to the ones found lacking*
- *Define an analytical path that will relate individual scale to patterns observed in larger scales*
- *Devise a way to present the historical sequence of scale.*

Through the testing of different questions and approaches, GIS can give a better image of the past. As a result, it changed the way of viewing, analyzing and approaching the history (Tsiafakis & Evagelidis, 2006). Undoubtedly, GIS is

[74] Initially GIS systems were used by Geographers as resource management tools (Mejuto et al., 2012).

[75] The introduction of GIS in archaeology can be dated from the end of the 80's (Djindjian, 1998). Archaeologists are often considered as frontrunners within the social sciences and humanities in employing GIS (Gupta & Devillers, 2016).

something more of just a mapping or graphing service. It is a tool that allows the fast comparing of complex datasets and the support of new forms of analysis (González-Tennant, 2016; Gupta & Devillers, 2016; Sarris & Déderix, 2012; Malaperdas & Zacharias, 2018)[76]. The variability of GIS applications can be seen in the following table (Barceló & Pallarés, 1998):

GOALS	SCALE	DATA	TECHNIQUES
Centuriation	Intersite	Site coordinates; Remote Sensing; Satellite Imagery	Gridding, hypothesis testing
Erosion Modeling	Intersite Intrasite	Sites (surveyed field data); topographic data; geological data	Mapping, Digital Elevation Models (DEM)
Heritage Management	Intersite Intrasite	Sites (surveyed field data); historical record; archaeological data; ancient buildings	Mapping and database query; quantification and descriptive statistics; Risk Maps
Hydrological Modeling	Intersite	Sites (surveyed field data); historical record; topographic, geographic and hydrologic data; aerial photography	Mapping: Digital Elevation Models (DEM); Image Processing
Landscape Analysis – Diachronic	Intersite	Sites (surveyed field data); artifacts, environmental data; aerial photography	Mapping: thematic distribution maps; Nonlinear modeling, statistics
Landscape Analysis – Synchronic	Intersite	Sites (surveyed field data); artifacts; environmental data	Mapping: Digital Elevation Models (DEM), cost surface, friction surfaces, statistics
Location	Intersite Intrasite	Field survey data: sites, rock-art, burials, pottery, lithic, metal items, metal items, grinding equipment, etc.	Mapping: thematic distribution maps
Predictive Location Model	Intersite	Site coordinates; burials; land use data; topographic data; geological data	Logit/Probit; ring analyses; stepwise linear regression
Roads and communication networks	Intersite	Historical information data (written, oral, archaeological)	Mathematical calculation of the "difficulty" of different alternative roads

[76] GIS projects usually contain satellite images, topographic contour maps, site locations, hydrological maps etc. all of which are georeferenced to the same world. In addition, GIS packages contain special programs that can analyze spatial data. Examples of such programs can determine the sites that are close to a water source, the most energy efficient movement paths on a landscape, the visibility from certain areas and much more. These programs enhance the ability of the archaeologists to extract a meaning from cultural and environmental data (Tartaron et al., 2003).

Urban/Rural relationships	Intersite	Site types; pottery types; metal detector finds; aerial photography	Mapping: thematic distribution maps, multivariate statistical analysis; cost surfaces, Digital Elevation Model (DEM)
Visibility	Intersite	Environmental data (elevation topography); land use (historical record); archaeological sites (field survey data); ritual monuments, rock-art, burials	Mapping: Digital Elevation Model (DEM), QuickTimeVR, External statistics
Excavation Documentation	Intrasite	Artifacts; features, sediments, micro-stratigraphy	Mapping: Thematic distribution maps
Identification of activity areas	Intrasite	Pottery, bones, archaeological features, buildings etc.	Mapping: Thematic distribution maps
Site formation processes and spatio-temporal relationships	Intrasite	Pottery, bones, features, degree of fragmentation, geomorphological and micro-stratigraphic data, vertical and horizontal stratigraphy	Mapping: Thematic distribution maps, three-dimensional maps

Table 4: The variability of GIS applications in archaeology (Barceló & Pallarés, 1998)

3.1.1 Application of GIS in the castle of Androusa

The castle of Androusa is not preserved intact. Large parts of the northern and southern sides of its fortification are missing. However, the biggest problem is located on the western side of the castle, where there are no visible traces of the fortification, except from the Northwestern Tower. As a result, the whole image of the castle looks quite fragmented, providing only little information about it. The size and shape of the castle, its defensive arrangement, the extent of its supervision and its relation with the landscape are some questions that remain unanswered. To answer them, the use of GIS was implemented. The advanced visualization methods this system offers can lead to important conclusions and the creation of new knowledge (Gupta & Devillers, 2016).

A common way of using GIS is to organize information at a number of levels, or better known as "layers"[77] in GIS, that are relevant to a same geographical area.

[77] Each layer can be described as a transparent overlay that contains one type of information (Box, 1999).

Each of these layers includes either data in their original format (e.g. satellite images, maps, orthophotos etc.) or processed thematic information (e.g. type of soil, geophysical relief and orientation, archaeological site locations etc.). The layers are georeferenced to a common reference system making possible to overlay them (Figure 5). By overlaying all the different layers, a geographic database can be created (Box, 1999). For the creation of maps using GIS three main steps should be followed (Λυριτζής, 2007):

1. *Analysis:* the identification of the unique elements constituting the archaeological or immediate surrounding archaeological site (context).
2. *Synthesis:* the production of archaeological structures, meaning searching for some regularity or a logical order hidden in the existing data set. The synthesis is based on the analysis and is formed either by mathematical formulas or in a simply way.
3. *Interpretation:* the process of explaining the multidimensional digital image, the formation of a reference model and the process of correlating the archaeological with the environmental data.

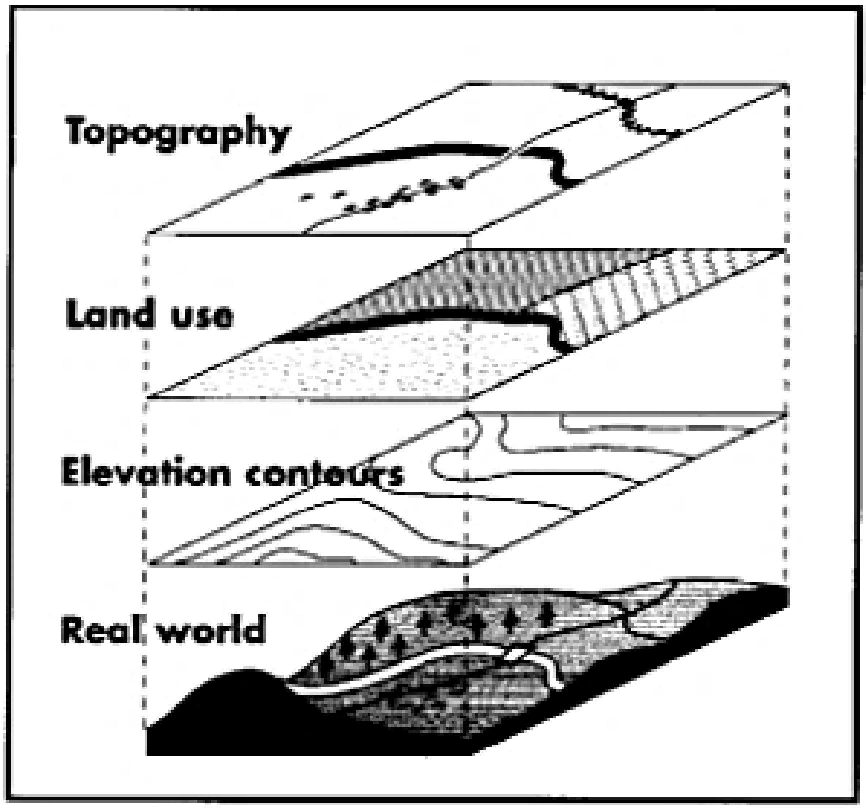


Figure 5: GIS layer structure (Box, 1999)

3.1.2. Representation of the fortification

An attempt to represent the castle of Androusa was made by employing the GIS ArcMap10 program and various maps as well as satellite and aerial photos of the region. The idea was to use these data and the geomorphology of the landscape as guidelines to make a hypothetical representation of the actual form and shape of its fortification ground plan. The data sets contained different type of information had to be digitized in different layers in the GIS program in order to be used in the process.

Georeferencing is the initial step when using GIS. It is basically the procedure of transforming a map image to a reference coordinate system in order to be used by GIS software (Cajthaml & Pacina, 2015). All the maps and the photos of the castle were georeferenced on the EGSA '87 coordinate system that is used in Greece and were inserted as layers in the GIS program.

Maps and map-forms can make the interaction and identification of unknown spatial patterns and relationships in complex data easier (Gupta & Devillers, 2016). An excerpt map of the region of Androusa was obtained from the LandSat (2007) and was used as the basic reference map (Figure 6).

Figure 6: Excerpt map of the region of Androusa (LandSat 2007)

The next step was to make a model of the natural landscape of the area. A topographical map of Androusa with scale 1:100.000 was provided by the Hellenic Military Geographical Service, depicting the contouring curves of the terrain (Figure 7). All the contours of the map were digitized with the use of polylines resulting to the creation of Digital Elevation Model (DEM) of the landscape (Figures 8-9).

Figure 7: Topographical map of Androusa (1:100.000) (Hellenic Military Geographical Service)

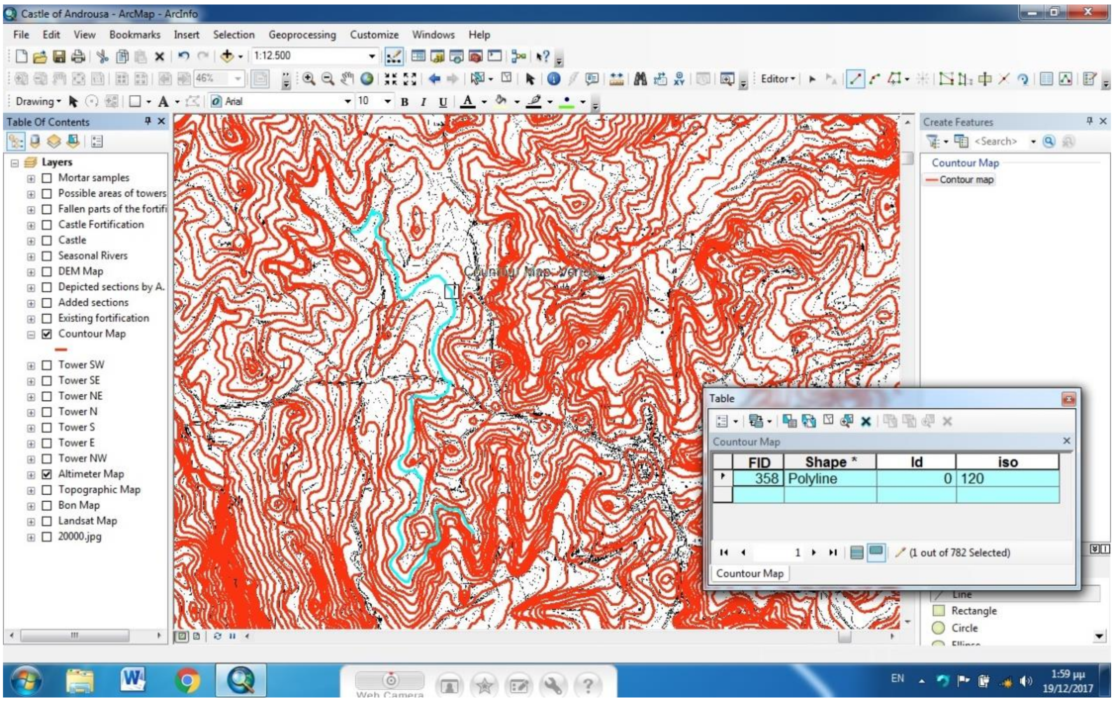


Figure 8: Digitization process of the topographical map of Androusa in GIS

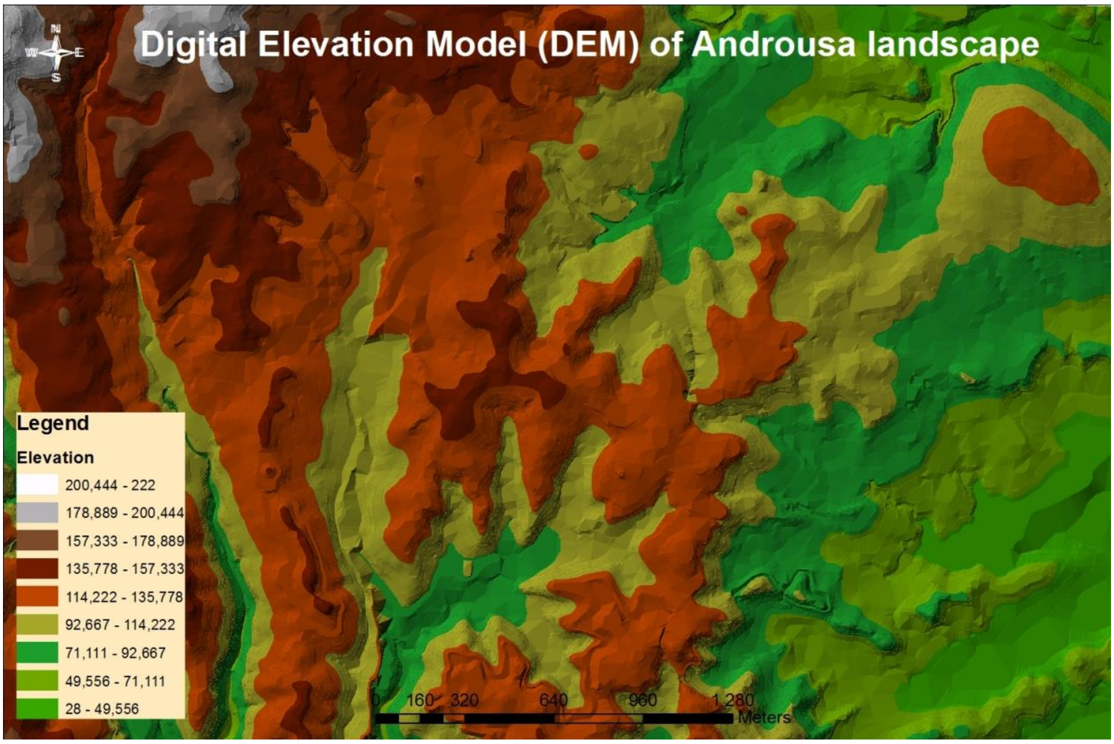


Figure 9: Digital Elevation Model (DEM) of the landscape of Androusa created in GIS

After the completion of the DEM model of the natural landscape of Androusa, the study was focused on the digitization of the ground plan of the castle. Two maps of the castle were used, a topographical map provided from the Ephorate of Antiquities of Messenia and an old map[78] made by A. Bon during his visit in Androusa published in 1969.

The topographical map depicted the fortification preserved today, including parts that were revealed during the recent restoration works of the castle. This map provided also an accurately coordinated ground plan of the fortification, since it had been created with the use of new GPS systems (Figures 10-11).

The old map made by A. Bon proved to be a very important source of information. It depicted remnants of the western, southern and northern fortification that today are not visible or preserved, including a tower at southwestern side of the castle, close to the Southern Tower (for the purpose of this study this tower received the name Southwestern Tower) (Figures 12-13).

[78] Old maps constitute a valuable source of information regarding the historical landscape. In recent years, they are widely used in archaeology, mainly due to the rapid increase of the use of GIS and the potentials it offers (Cajthaml & Pacina, 2015).

Figure 10: Topographical map of the castle of Androusa (26th Ephorate of Byzantine Antiquities, 2013)

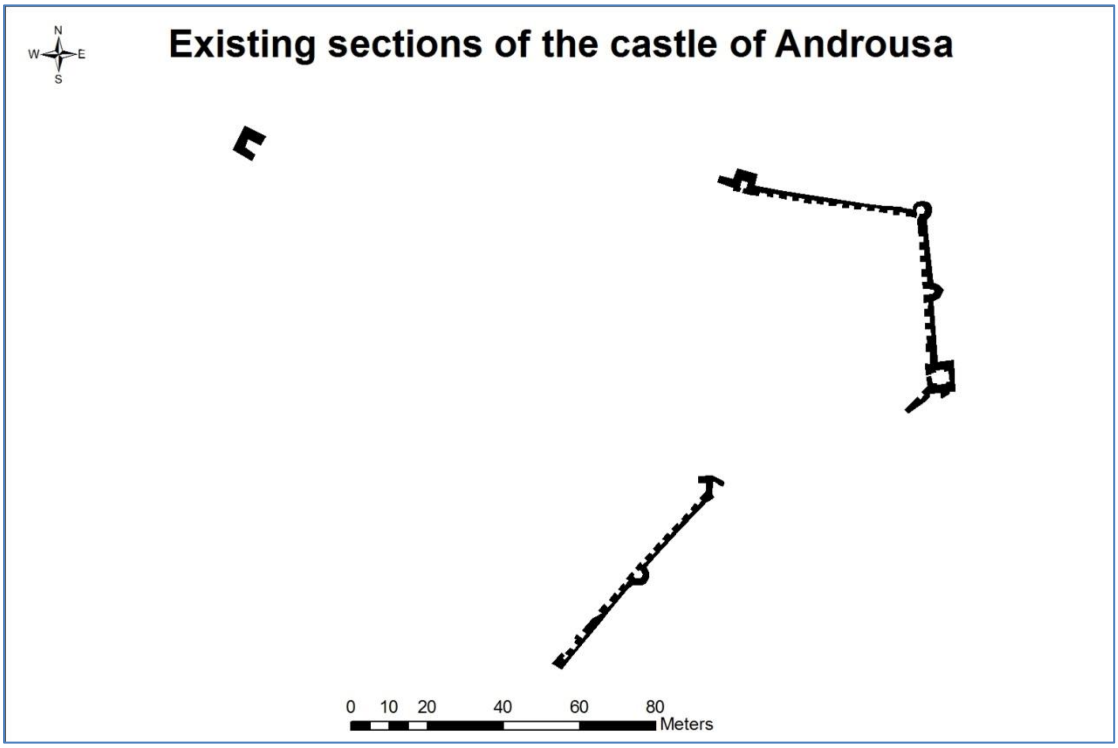


Figure 11 Digitization of the fortification depicted in the topographical map of the castle of Androusa with GIS

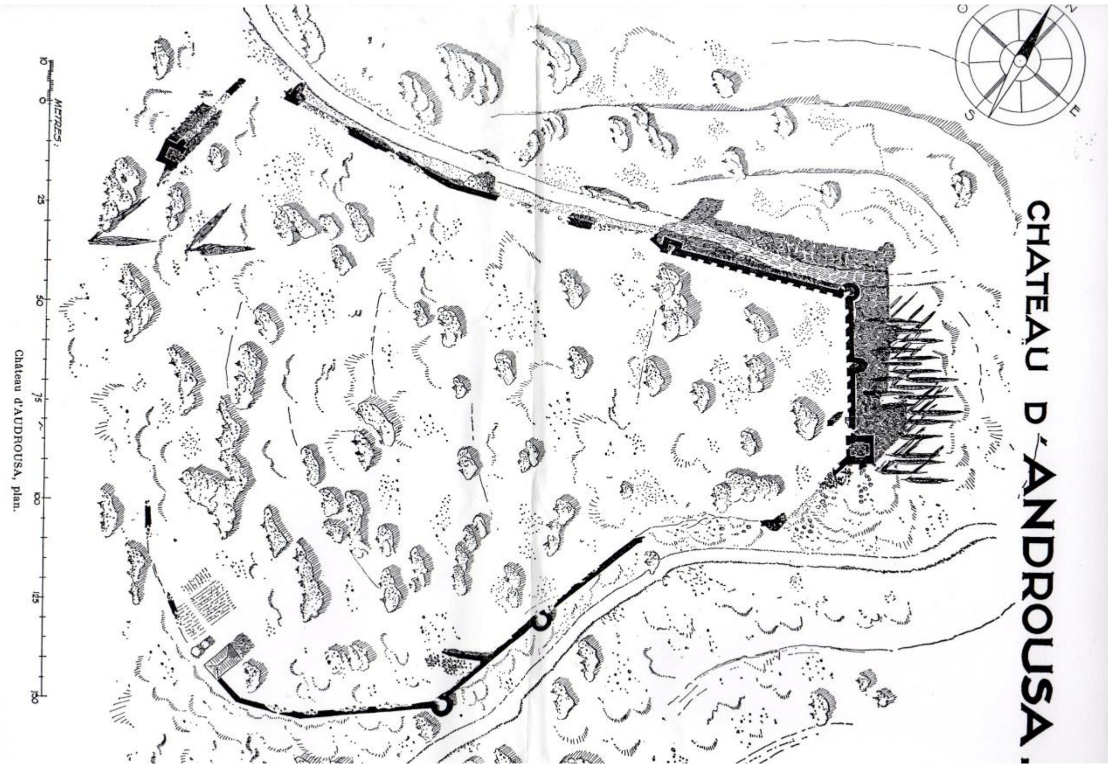


Figure 12: Depiction of the castle of Androusa according to A. Bon (Bon, 1969)

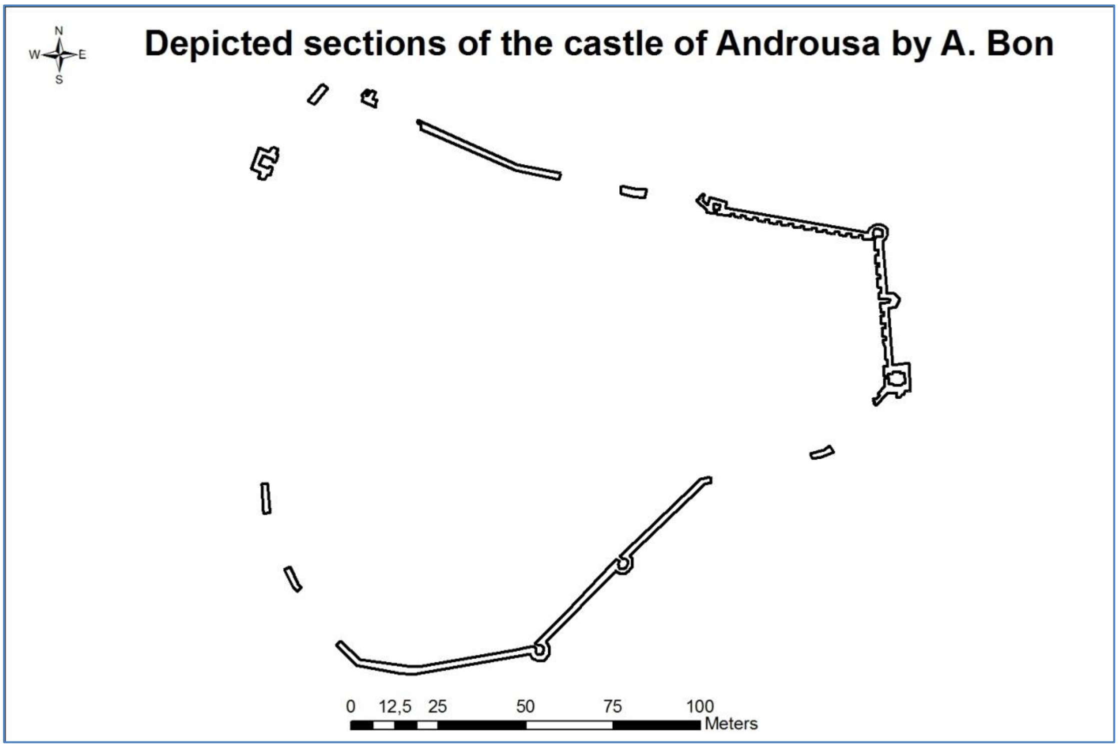


Figure 13: Digitization the A. Bon’s depiction of the castle of Androusa with GIS

The ground plan of the castle of each map was digitized in a different layer and then both maps were overlaid and correlated resulting to more complete image of the castle[79].

The final step was to connect the parts of the castle using polylines, thus completing the missing sections. This process was based on the geomorphology of the terrain and the orientation of the already digitized fortification parts. The result was a hypothetical representation of the castle, which seems to cover an area of approximately 20.000m^2 (Figure 14)[80].

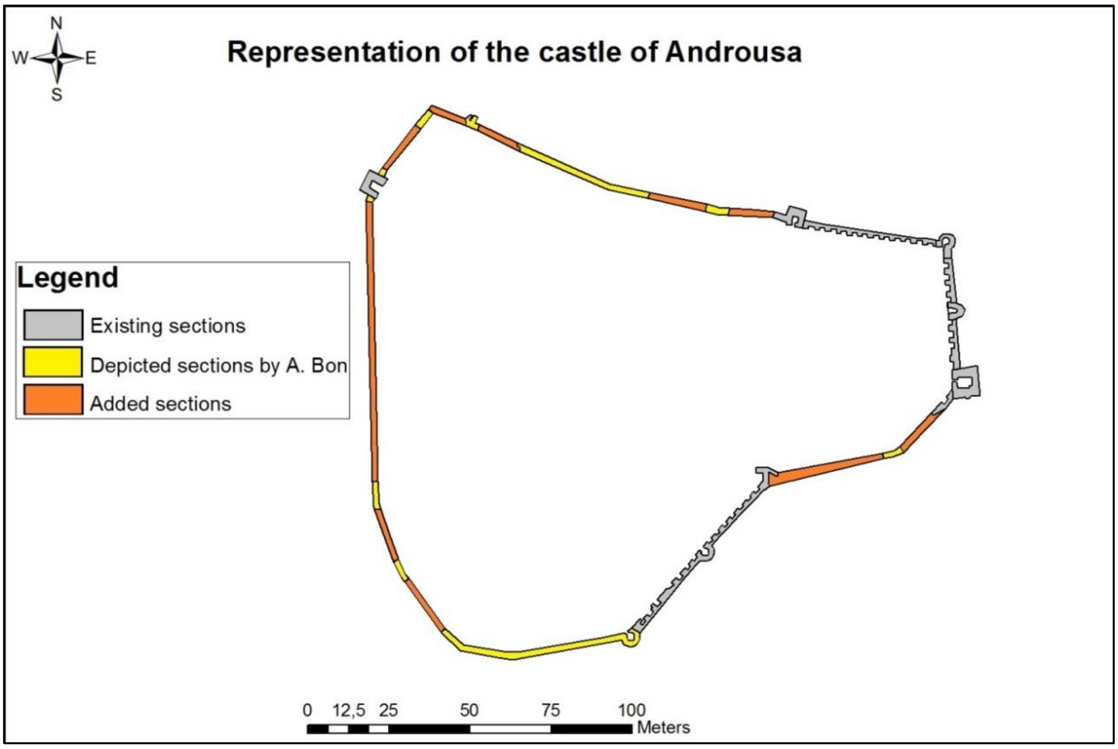


Figure 14: Representation of the castle of Androusa with the use of GIS.

3.1.3. Landscape analysis of the castle

Scientific research concerning castles is usually focused on the castle itself: the history of the castle, its architecture, its building phases or the archaeology of the main castle. However, to understand better the way a castle functioned in the past, it is necessary to place it into its geographical context. That means to investigate the castle in correlation with the landscape surrounding it (Wagener et al., 2016). In order to

[79] The correlation of the maps was based on the coordinates of the digitized fortification plan of the topographical map, provided by Ephorate of Antiquities of Messenia since it was more accurate.
[80] The calculation of the area of the castle was done with the use of GIS.

extract more information about the castle of Androusa, the fortification ground plan was overlaid on the DEM model of its landscape (Figure 15). This helped to make some interesting assumptions according to the landscape surrounding the castle[81].

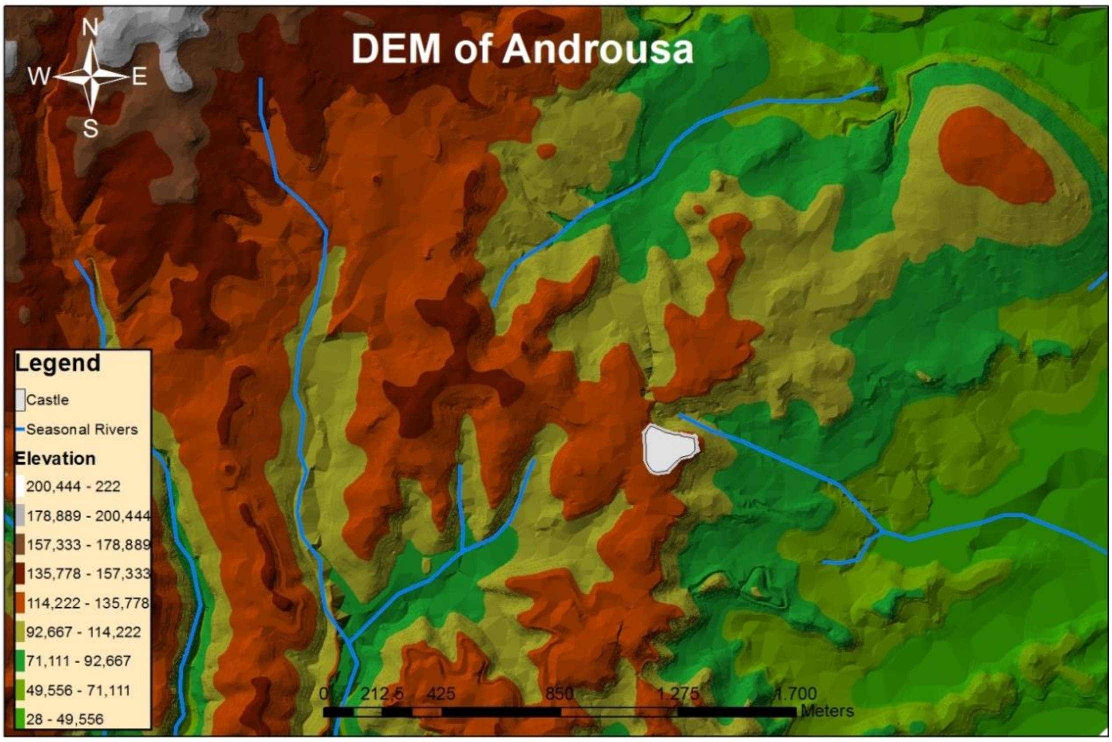


Figure 15: DEM with the landscape of Androusa and the location of the castle

As it is observed in the DEM model, the castle of Androusa is indeed built on a hill top, following the geomorphology of the terrain and exploiting mainly the height for defensive purposes and for better visibility, like most of the medieval castles (Breuillot, 2005; Δεληγιάννη-Δωρή, 1993). The eastern, northern and southern sides seem to be the most inaccessible areas of the castle, as they are surrounded by slopes offering natural protection to it. Although it is just a hypothesis, it can be assumed that the main gate of the castle was on the western side which is the most accessible. Probably, on this side was also the core of the medieval settlement, since the area seems to be flat and in the same time well protected by slopes. In addition, the fields where the peasants worked were probably in the lower eastern side of the castle. It can be easily understood that, the location of the castle had been carefully selected in order to be well protected and also to have proximity to fertile lands. For the purposes of this research, the seasonal rivers (torrents) of the area were also depicted in the DEM model (see chpt. 4.5).

[81] For the purpose of this study it was considered a necessary condition that the natural landscape has remained the same since medieval period.

3.1.4. Viewshed analysis of the castle

Based on the DEM model of Androusa, a Viewshed analysis[82] was carried out to determine the supervision range of the castle. In order to get more representative results, the level of all the documented towers was raised to altitude 135 taking into account the original height of the structures and not their current preservation state[83]. Visibility parameters were set from -90^{o} to 90^{o} for the vertical field of view and to 0^{o} to 180^{o} for the horizontal field of view, defining visibility control at all directions (Topouzi et al., 2000). A Viewshed analysis was made for each tower separately as well as a total for the castle (see Appendix C). As it can be seen in the following map, the castle despite being built at a relatively low altitude was overlooking a very large area of land expanding several kilometers around it (Figure 17). Probably, this could be considered the region of authority for Androusa.

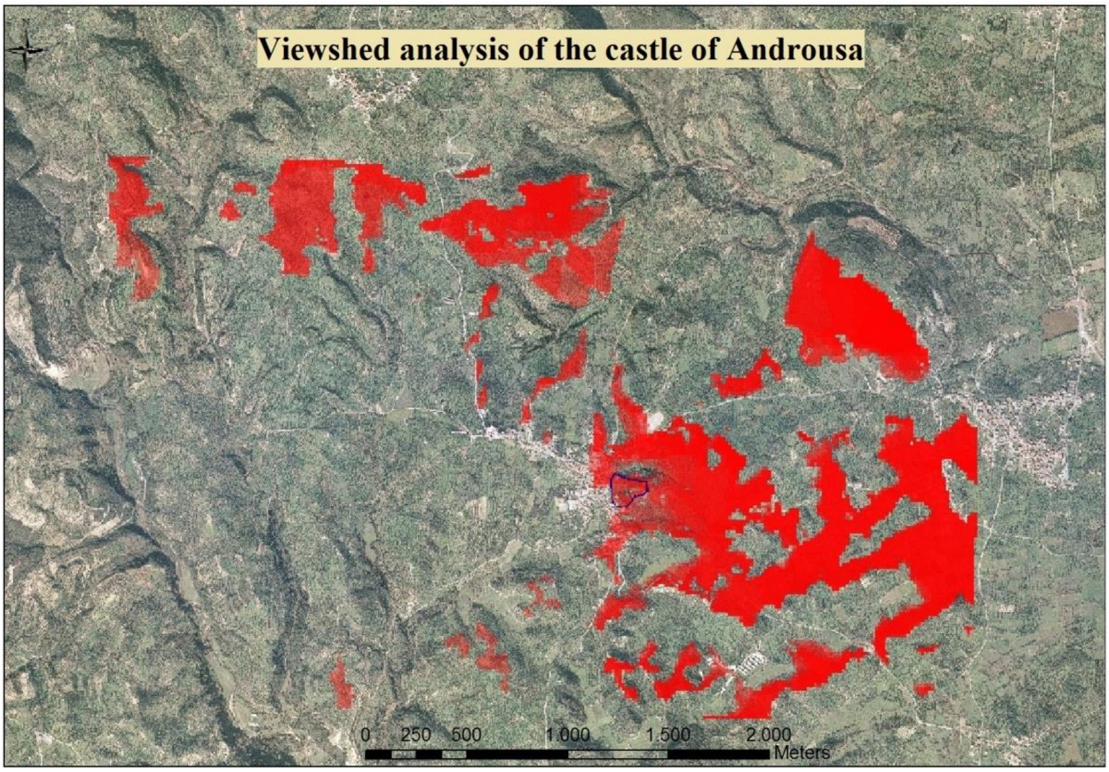


Figure 16: Viewshed analysis of the castle of Androusa

[82] Viewshed analysis is one of the most useful applications of GIS in archeology. It is extensively used in spatial modeling and reconstruction of landscapes of ancient environmental settings. It is particularly effective in modeling spatial patterns on an uneven terrain (Topouzi et al., 2000). It offers information like the depth at which objects may be seen or hidden from a viewpoint, mapping of visual horizon and analysis of intervisibility networks (Cuckovic, 2016).

[83] The Northwestern Tower was used as the basis for determining the height of the towers, as it is the only tower of the castle that is maintained at its full height.

Viewshed analysis can be employed as a cognitive tool for the revealing of habitation patterns like the inter-visibility between sites (Tsiafakis & Evagelidis, 2006). Visual contact was of primary importance between sites that apparently belonged to an interdependent network, like in case of castles (Breuillot, 2005). Based on that, the Viewshed analysis of the castle of Androusa compared with the other castles of the Peloponnese could result in the creation of a map of the potential defensive area of Principality of Achaia, indicating potential gaps or candidate archaeological sites that may have been used to complete the defense system of the region. However, this work is beyond the scope of this study.

3.1.5. Possible locations of towers

A further analysis of the fortification of the castle involved the creation of a model of spatial relations that could be used to indicate the location of towers that are not currently identified. The basic principle upon this analysis was based on is that the location of the towers was not random, but it followed some specific norms. As it is well known, the walls of the castles were strengthened with towers in regular intervals for better protection. The distance between the towers was usually determined by the visibility they offered and by the developments in the art of war (e.g. hitting range of the arches). The guardians of a castle had to be able to oversee and protect the curtain walls while resting inside the towers.

The towers of the castle of Androusa are located in unequal intervals, with only few of them existing nowadays. Taking into account the distances separating the towers in the areas where the curtain walls were intact, an assumption could be made about the possible locations of other towers that today don’t exist. In order to calculate the average distance between the towers, the following simple mathematical equation was used:

$$\boldsymbol{D_{average} = \frac{D_{total}}{D_{number}}}$$

$D_{average}$: The average distance between the towers

D_{total}: The sum of the distances between towers linked by intact curtain walls

D_{number}: The number of distances between towers linked by intact curtain walls

The possible distance between the towers was calculated based on the average of the distances between the Southeastern and Northeastern Tower, the Northeastern and Northern Tower, the Southern and Southwestern Tower, the Northeastern and Eastern Tower, and the Easter and Southeastern Tower. The following table presents the calculated distances with GIS program, as well as the average distance.

Towers linked with curtain walls	Distance between towers	Average distance
Southeastern Tower - Northeastern Tower	43,6m	**33,18m**
Northeastern Tower - Northern Tower	44,5m	
Southern Tower - Southwestern Tower	33,8m	
Northeastern Tower - Eastern Tower	21,4m	
Eastern Tower - Southeastern Tower	22,6m	

Table 5: Calculation of distances between towers

The resulted map showing the possible areas were towers existed is presented below (Figure 17). Although this analysis seems to be arbitrary, a closer look at the map can prove that in two of the indicated areas were remains of unidentified building structures. The first is east of the Northwestern Tower and the second east of the Southern Tower. Based on their ground plan and size, these structures don't seem to be just parts of curtain wall. An in-situ investigation could prove whether towers actually existed in these areas.

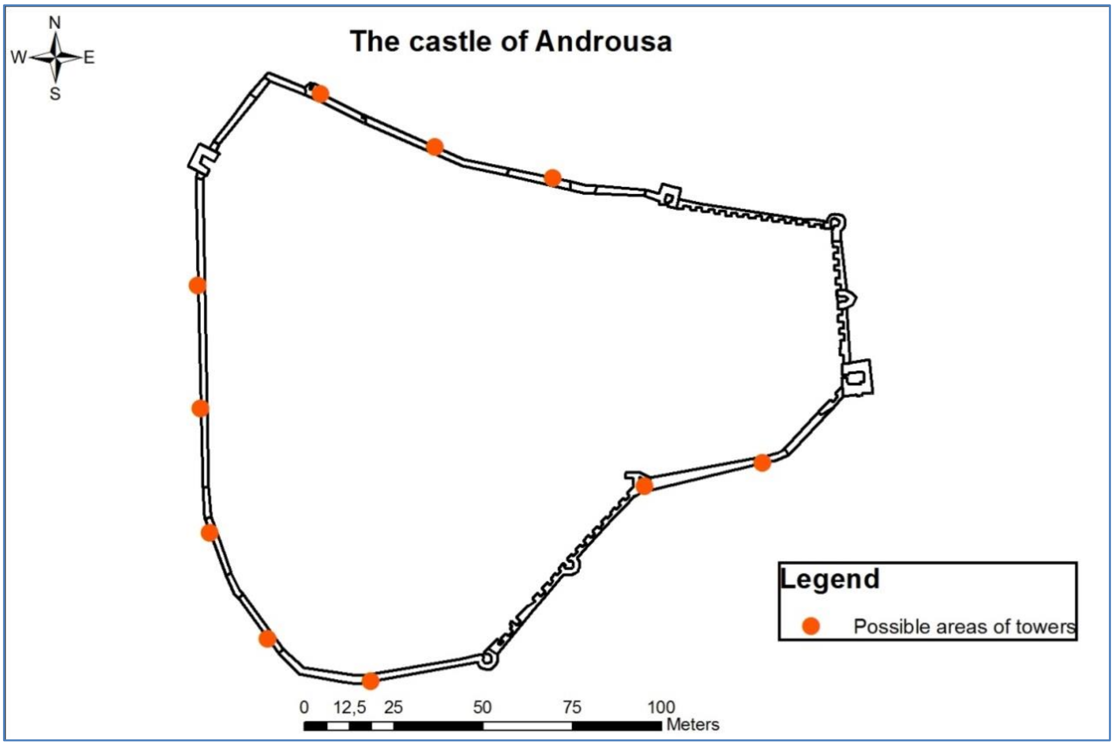


Figure 17: Potential locations of towers in the castle of Androusa

3.2. The analysis of mortars

3.2.1. Purpose of mortar analysis

The purpose of the analysis of the mortars of the castle of Androusa is to determine their composition and the technology used for their preparation. Also, based on the analytical results, a comparative examination of mortars from different building phases of the castle will be carried out.

Considering that the castle was constructed at different historical stages, the raw materials and technology used in the mortars during one stage do not necessary have the same provenance or the same technology with other stages. Technology, raw materials and raw sources can change through time. On this basis, if it assumed that the same components in mortars and the same technology were used in a same historical period, it might be then possible to establish some chronological relationships between the different areas of the fortification of the castle.

Such analytical approaches have been widely used for the characterization of cultural heritage artifacts in studies regarding manufacturing technology and dating, particularly by investigating the chemical elements and examining the specific characteristics of technological evolution with good results (Sanjurjo-Sanchez et al., 2010; Pachta et al., 2014; Franzini et al., 2000; Silva et al., 2011; Gulzar et al., 2013; Silva et al., 2006; Moropoulou et al., 2000).

This study can give a better insight to the technologies employed for the construction of the mortars of the castle and to extract some interesting conclusions in relation to its building phases. The characterization of the mortars will be based on microscopic, chemical and granulometric analytical methods with the use of new technologies.

3.2.2. Sampling

In order to study the historic mortars it is necessary to collect small samples[84]. The final conclusions of the study are heavily depending on the quality of the relevance of the samples taken (Bakolas et al., 1995; Hughes & Valek, 2003; Hughes & Callebaut, 2002). For this reason, some important criteria had to be applied before the sampling process in order to ensure that correct and sufficient materials are sampled:

Sample chronology: Samples should be representative of their time period. This can be addressed with the help of historical sources and the proper study of the stratigraphy of the structure (Hughes & Callebaut, 2002).

Sample condition: Samples should be in good conservation state to avoid false results caused by deterioration or erosion. If possible, the sample should be extracted from inner layers of the masonry that are less exposed to external factors (Μπακόλας-Καραγιάννης, 2002). Generally, it is suggested that the samples should be taken from whole chunks or cores to be representative of the material. The collection of broken fragments or pieces should be avoided (Goins, 2004).

Sample number: The sampling method is a destructive and usually irreversible process and often even prohibited. In order to minimize the intervention damage, the number of samples must be limited, but in the same time representative (Hughes & Callebaut, 2002).

Sample size: The size of the sample should be adequate to assure the identifying of its characteristics and of producing representative results. Usually, a sample of 40gr is a good quantity (Veiga et al., 2001). After the processing, the minimum sample size should ideally be five times the maximum aggregate size or at least three times (Goins, 2004).

[84] Sampling of historic mortars usually aims at assisting a conservation or restoration project of a structure, or an academic study into/on the characteristics of the materials used (Hughes & Valek, 2003).

Methodology of Sampling

In the case of the castle of Androusa, there was no significant historical information about its basic building phases. The separation of the building phases was based on information provided by the Ephorate of Antiquities of Messenia (26th Ephorate of Byzantine Antiquities, 2013). The following table shows the known information related with the construction periods of the fortification of the castle:

Constructional periods of the fortification of the castle of Androusa		
Building phases	**Time Periods**	**Construction – Restoration Works**
1st	13th century (?) Frankish Period	Construction of the Southeastern Tower
2nd	15th century (?) Byzantine Period	Construction of the Eastern Wall, Eastern Tower, Southern Wall, Southern Tower
3rd	Late 15th century – 16th century (?) Ottoman Period	Construction of the northern part of Eastern Wall, Northeastern Tower, Northern Wall, Northern Tower, Northwestern Tower
4th	1969	Restoration of the foundations of the Northeastern Tower
5th	2012-2015	Restoration of the eastern section of the castle of Androusa (Southern Wall, Southern Tower, Southeastern Tower, Eastern Wall, Eastern Tower, Northeastern Tower, Northern Wall, Northern Tower)

Table 6: Constructional periods of the fortification of the castle of Androusa

Since the research takes into account the building phases of the castle, samples from recent restoration works were avoided. The aim was to take samples from the three main building phases of the castle (Frankish Period, Byzantine Period, Ottoman Period) covering the most important areas of the fortification.

The collection of samples is preferable to be done and performed by experienced people (Adriano et al., 2008; Hughes & Valek, 2003). For this reason, the sampling process was carried out by a conservator of the Ephorate of Antiquities of Messenia and an accredited stone conservator of the University of the Peloponnese.

The whole procedure was also attended by a student of the TEI[85] department of Conservation of Cultural Heritage of Ionian Islands.

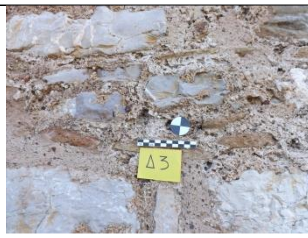
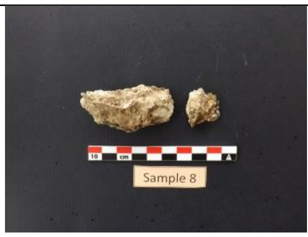
A hammer and small chisels were used for the extraction of the samples from the masonries of the castle. Wherever possible, preference was given in the selection of structural mortar samples without damaging the outer layers (coatings) of the fortification[86]. However, due to the recent restoration works in the castle, finding original structural mortal samples in good preservation state was really difficult, especially in areas that had received extensive restoration works. Despite the difficulties, 11 mortar samples were collected from the castle (2 rendering mortar samples and 9 structural mortar samples). All mortar samples were carefully selected in order to be authentic and not subsequent repair works. The samples weighted approximately 15-400 grams. The whole sampling process was photographically documented with the use of Fujifilm FinePix S4500 camera under natural light and the collected samples were put in plastic zip-bags. The exact positions of the samples were recorded in the GIS map[87] (Figure 18), photographed, numbered and coded. In the table below the data of the collected samples is presented:

List of mortar samples				
Number	**Location**	**Mortar Type**	**Sample Photo**	**Sampling Area Photo**
S1	Northern Tower	Rendering		
S2	Northern Tower	Structural		

[85] TEI: Technological Educational Institute.

[86] Mortars of the external surfaces of the masonries were often renewed over the years. Therefore, their composition may differ from the original one.

[87] A GIS database can be used like a typical database management system (Tennant, 2007).

S3	Northern Tower	Rendering		
S4	Northeastern Tower	Structural		
S5	Northeastern Tower	Structural		
S6	Eastern Wall	Structural		
S7	Southeastern Tower	Structural		
S8	Northern Wall	Structural		
S9	Southern Wall	Structural		

S10	Southern Tower	Structural		
S11	Northwestern Tower	Structural		

Table 7: List of mortar samples collected from the castle of Androusa

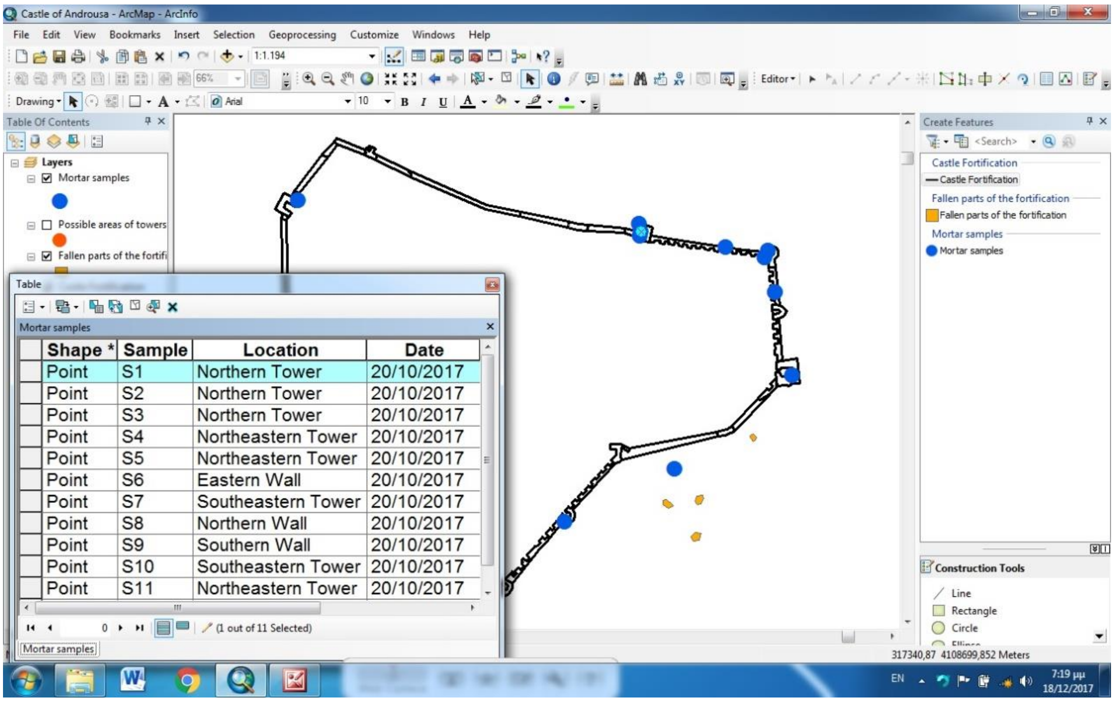


Figure 18: Recorded positions of the sampling areas in GIS

3.2.3. Techniques of analysis

All the analyses of the mortar samples of the castle of Androusa took place in the laboratory of the University of the Peloponnese, Kalamata. Five analytical methods were chosen, based on the available equipment offered by the institution. The table below presents all the analytical techniques and the purpose of their use:

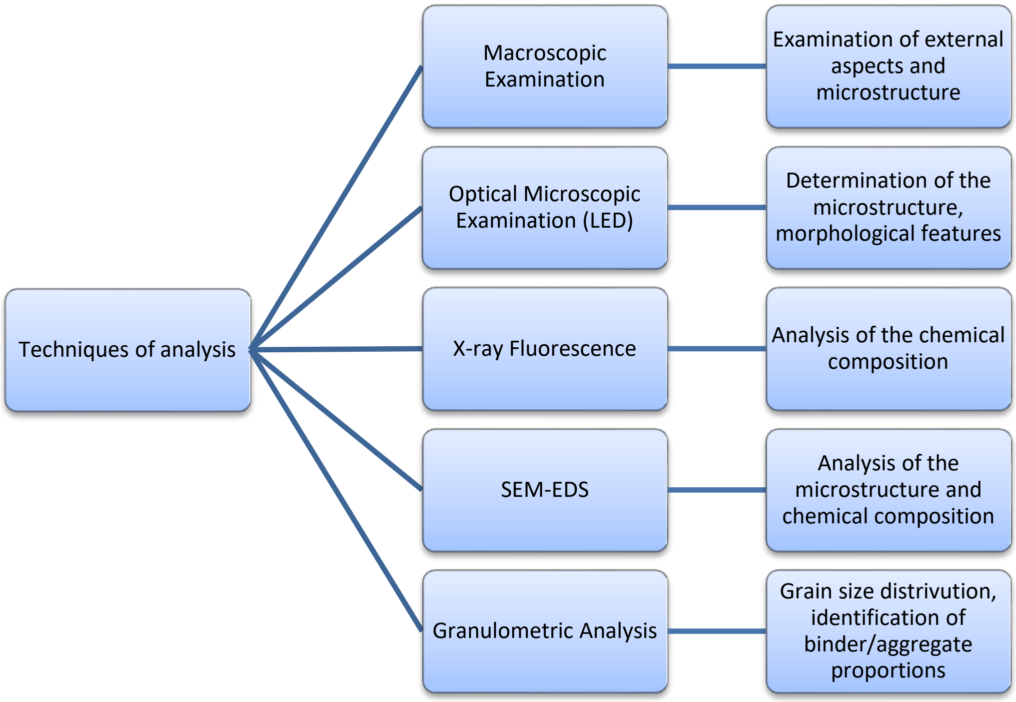


Figure 19: Flowchart illustrating the analytical techniques used for the characterization of mortar samples

3.2.4. Macroscopic Observation

Macroscopic observation constitutes the initial stage for the study of historical mortars. It is basically the visual examination by naked eye (or with the aid of a magnifying lens). Examining the external aspects of the material provides the first information about it and helps determine the analytical techniques to be used thereafter (Bakolas et al., 1995; Martinet & Quenee, 1999).

Methodology of Macroscopic Observation

The macroscopic observation of the samples was conducted firstly in situ during the sampling process and secondly in the laboratory environment under natural light.

3.2.5. Optical Microscopic Examination (LED)

The digital microscope is a variant of the traditional optical microscope that contains a tiny digital camera (CMOS) and is connected to a computer[88]. It differs from the optical microscope (stereo microscope) since it has no provision to observe the sample through an eyepiece. The optical image is projected directly on the monitor of a computer enabling the possibility of having higher quality recorded images than those offered by an optical microscope. The projected images can also be saved on the hard drive as images (in various formats) or videos. Since the digital microscope has the image projected directly on the screen of the computer, it can provide higher quality recorded images in comparison with the optical microscope. In addition, the lens of the digital microscope is usually equipped with a LED source (or sources) providing high power illumination (Scribd Inc., 2017). The digital microscopes are also ideal for in situ observations since they are portable (Μπακόλας-Καραγιάννης, 2002).

Methodology of Optical Microscopic Examination (LED)

The morphological features of the samples were examined by LED Optical Microscopy[89]. The equipment used was a portable Moritex I-Scope USB2.0 microscope by Moritex, with a 1.3 mega CMOS sensor and X10 and X50 lenses, white LED light and USB connection for simultaneous observation on a computer.

3.2.6. X-ray Fluorescence (XRF)

X-ray Fluorescence (XRF) is an analytical technique which is based on the spectroscopy of the fluorescence (“characteristic”) X-ray radiation emitted from a material/sample when it is analyzed by X-rays. In XRF, a source produces X-rays that irradiate the sample[90]. This results to the emission of fluorescent X-ray radiation from the elements presented in the sample with discrete energies that are characteristic of these elements. By measuring the energies emitted from the sample, it can lead to the

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[88] One of the first digital microscopes was made in Tokyo in 1986 by a lens company, now known as Hirox Co Ltd (Scribd Inc., 2017).

[89] The Optical Microscopy examination of the mortars was performed before their cleaning or any prior treatment.

[90] The source can be an X-ray tube or a synchrotron or radioactive material (Brouwer, 2010).

determination of the elements present. This is called qualitative analysis. In addition, by measuring the intensities of the emitted energies it can help to the determination of the quantity of each element present in the sample. This is called quantitative analysis (Brouwer, 2010).

The use of X-ray Fluorescence is an established method of analysis both in laboratorial and industrial environments. Its usefulness on archaeology science is based on practical and economic advantages. It is a non-destructive technique, requires minimum preparation of the samples, is fast, easy to work, and cost effective. XRF technology can detect amounts of major, minor, and trace chemical elements. The major elements are reported as oxide wt%, while minor and trace elements are reported in ppm (Hunt & Speakman, 2014; Liritzis & Zacharias, 2011)[91].

Today, recent advantages in the field of technology have allowed the development of portable X-ray Fluorescence devices (pXRF) that are widely used. These devices are compact, low weight, consume low power and operate at varying voltages (40 to 60 kV) and variable currents (μA: microamps), obtaining fast and accurate real time results. They can accurately and precisely quantify the chemical composition in various materials, thus helping in their in-depth study.

Methodology of X-ray Fluorescence

For the examination of the 11 mortar samples from the castle of Androusa, a pXRF device Bruker Tracer III SD was used. The diameter beam was 3mm and the collecting time for each sample was set to 120 sec. For the better evaluation of the qualitative data two different settings were applied. The first setting was for the determination of major and minor elements ($11 \geq Z \geq 26$) at low energy excitation mode (accelerating voltage at 15kV and current of 25μA) with the additional use of vacuum. The second setting was for minor and trace elements ($Z>26$) and the setting used was an Al/Ti filtered high energy excitation mode (accelerating voltage set 40KV and current of 12μA). The quantification was conducted using S1 p-XRF software and the building calibration curves for soil. Each sample was examined at least from two different sides in order to get more representative results.

[91] wt% signifies weight percentage, while ppm is an abbreviation of parts per million (it is a value that represents the part of a whole number in units of 1/1000000).

3.2.7. Scanning Electron Microscopy (SEM-EDS)

The application of Scanning Electron Microscopy (SEM) coupled with Energy Dispersive X-ray Spectrometry (EDS) is widely used for the study of mortars composition, physical-chemical, mineralogical and microstructural characterization (Adriano et al., 2008). It is very popular among the techniques because it is really easy to be used, requires small samples with minimum preparation and offers attractive images. Despite that, only experienced analysts can measure the analytical results as they tend to be very complex (Hughes & Valek, 2003; Middendorf et al., 2005). The SEM-EDS combines two analytical techniques:

Scanning Electron Microscopy (SEM) is a type of electron microscope that provides high resolution images of very small structures (down to 10's or 100's of nanometers[92]). The electron microscope operates in high-vacuum and very dry environments in order to produce a high-energy electron beam, which is necessary for the imaging. The basis of the imaging system is the electrical conductivity of the sample. The image is formatted by the collection of the different signals reflected as a consequence of the interaction of the high energy beam with the sample. The electrons interact with the sample atoms and produce signals that contain information about the surface topography of the sample, its composition, and other properties (such as its electrical conductivity). The image is formed by the backscattered electrons and the secondary electrons. The relative amount of backscattered electrons increases with an increase in the atomic number (Z) of the electrons, while the relative amount of secondary electrons remains the same. As a result, light elements with low atomic number are depicted with dark to dark gray in photomicrographs, while heavy elements with high atomic number appear very light gray. The grayscale picture produced is used for the interpretation of the morphology of different elements. The application of SEM to mortar studies provides mainly qualitative and quantitative characterization of the components of the mortar and their textures (Adriano et al., 2008; Hughes & Valek, 2003; Κυροπούλου, 2016; Middendorf et al., 2005)[93].

[92] 1 nanometer equals 1 millionth of a millimeter (1nm=1x10^{-9}m).

[93] In order to avoid interferes with image formation during SEM analysis, the samples should be small and covered with a conductive carbonate layer of gold or carbon that helps the removal of the electrical charge created on them (Middendorf et al., 2005).

Electron Dispersive X-ray Spectrometry (EDS)[94] is a technique used for the collection and determination of the energy and the number of X-rays emitted from the atoms of a material. The process is based on the X-rays that are produced by the excitation of a sample by some energy source, transitions of the electrons in the sample between different energy states, and the emission of excess energy from the sample in form of X-rays. In this case, a beam of electrons created in a chamber hits the sample material provoking the emission of X-rays. The energy and the wavelength of the emitted X-rays are characteristic of the elements from which they originated, so it is possible to identify the elements in a sample and their absolute concentration. The process of this technique is known as X-ray fluorescence analysis. This technique is usually available on SEM and the X-ray spectrum is generated from the entire scan area of the SEM. In historic mortar studies, the method of EDS analysis is used to confirm the identification of mineral species (Rakovan, 2004; Hughes & Valek, 2003; Adriano et al., 2008).

Methodology of SEM-EDS

The study of the surface characteristics of the mortar samples was performed under Scanning Electron Microscope (SEM) by JEOL (JSM-6510LV) coupled with Energy Dispersive Spectrometer for quantitative analysis (EDS, Oxford Instruments). The analytical data was obtained by the INCA software. The mortar samples used in the analysis were small so they could be placed correctly in the sample chamber. In addition, the samples didn't receive any treatment prior to the analysis. The measurements were performed on the clean (cut) sides[95] of the samples at 20kV voltage for 120 seconds count time under magnification of X30 and X150 and at a working distance of 15±2mm.

The SEM-EDS provided bulk analysis of the oxide concentration (wt%) of the 11 samples. This analysis was very important for the chemical characterization of the samples and for the correlation process. Moreover, the images taken were used for the qualitative and quantitative characterization of the components of the mortars and their textures. The analysis was made with secondary electron emission in order to examine the microstructure and the texture of the mortar samples and the binder.

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[94] EDS is also known as EDX (Hughes & Valek, 2003).

[95] This was done in order to get better measurements and avoid any products that might have been created on their exposed surfaces either due to corrosion or other external factors.

The bundle was focused on clear areas of the matrix of the samples, avoiding measurements in coarse aggregates that could give false results. The selection of the areas was based on the SEM images. Historic mortars were produced manually hence they are inhomogeneous (Crisci et al., 2004). As a result, the measurements taken in each sample presented significant differences in the oxide concentrations (wt%). For this reason, it was decided to take at least five measurements from each sample from different spots and then calculate the average of the analyses. The measurements of a sample showing significant differences from the rest were considered as outliers and were not included.

3.2.8. Granulometric Analysis

The granulometric analysis helps to determine the grain size and the distribution of aggregates of a mortar and also to make conclusions about their origins. In addition, it is particularly useful for the studying of the technological characteristics of the mortar since it gives important information about the binder/aggregate ratio of the mortar. The proportion of binder/aggregate can depend on the historical period but also on the mortar type or function (Sanjurjo-Sanchez et al., 2010)[96].

The separation of a mortar into its main components is a basic prerequisite for carrying out the granulometric analysis (Μπακόλας-Καραγιάννης, 2002). The main techniques used for the separation process are the following:

1. *Microscopic techniques and schematic analysis for the determination of the particle size and the ratio of binder/aggregates*: this technique does not require the separation of the mortar. The sample is prepared in thin sections in order to be observed in a microscope. Despite its use, this technique can give very doubtful results about the size of the grains and their distribution (Μπακόλας-Καραγιάννης, 2002).
2. *Separation of mortar by frost cycles*: this technique is based on the physical properties of the water. By cooling the mortar in very low temperatures (-20°C) the water in its pores freezes and increases in volume. As a result, the frost water stretches the structure of the mortar causing the separation of the

[96] The proportion of binder/aggregate in mortars is commonly studied in the field of building conservation (Sanjurjo-Sanchez et al., 2010).

mortar into its components. Despite its use, this technique unfortunately destroys porous aggregates and it is also time consuming (Μπακόλας-Καραγιάννης, 2002).

3. *Separation of the mortar with thermal shock*: Based on this technique, the mortar is first submerged in water and then in liquid nitrogen. In this way, the sample is subjected to intense thermal strain which leads to the separation of its components. This technique needs at least 7 repeated cycles in order to separate all the components (Μπακόλας-Καραγιάννης, 2002).
4. *Dry manual separation*: This technique is based on the manual separation of the mortar. The sample is first dried and then it is rubbed with special tools to separate into its components. The partially separated mortar is then weighed and inserted into a series of sieves with holes of different sizes to separate the aggregates in various grain sizes. Finally, the aggregates are cleaned with a hard brush on each sieve[97]. This technique is usually affected by the person doing the separation. Thus, the whole process should be done by the same person so that the results could be more comparable and representative (Μπακόλας-Καραγιάννης, 2002).

Methodology of Granulometric Analysis

The granulometric analysis of the mortars of the castle of Androusa was accomplished with the use of the dry manual separation technique, as it is a method that requires low cost equipment, is user friendly and can be done fast (López, 2017).

The following procedure was repeated for each sample separately. First, a small part of the sample was extracted and weighted. Special attention was paid in this step, since in order to have a representative sieve analysis it is really important that the partial sample is representative of all bulk material that is about to be analyzed. This means that the extracted sample must have the same properties as the whole bulk material. In other case, the results of the sieve analysis will represent only the particular part of the sample (Retsch, 2017). Unfortunately, the extracted samples used for the analysis were lightweight (approximately 10gr), as the main samples were small enough and there was also a need to keep a quantity for future research. Despite that, the analysis was carried out in order to obtain the needed information.

[97] Ultrasonic can also be used for better cleaning of the aggregates (Μπακόλας-Καραγιάννης, 2002).

The sieve analysis was made in accordance with the principles of dry sieving of British Standard EN1015-1:1998 (BSI, 1998). The samples were spread in trays and were dried in a Heraeus UT6 (#50042297) Forced-Air Oven at a temperature of 105^{o}C to remove any organic constituents and moisture. When the samples were ready, they were pressed with the use of a porcelain pestle in order to be separated into their components. For more detailed separation, a lancet was used to remove the binder material from the surface of the aggregates. After this stage of separation, the process continued with the sieve analysis[98]. The materials were put on a series of PVC sieves and were parted into fractions. The PVC sieves had stainless steel grid with holes of different diameters: 1.940mm, 0.466mm, 0.263mm, 0.122mm and 0.062mm. The coarser aggregates of 1.940mm were further parted into fractions of 8mm and 4mm[99]. Finally, the contents of each sieve were weighted separately and the weights were used to calculate the binder/aggregates ratio[100]. Everything with size less than 0.062mm is considered as the binder of the mortars, although it can also contain very small amounts of very fine aggregates (Μπακόλας-Καραγιάννης, 2002; Moropoulou & Bakolas, 1998; Crisci et al., 2004).

[98] Sieves analysis is the oldest and best-known method used for particle size determination (Retsch, 2017). According to this analysis the sediment pass through a series of stacked sieve meshes with defined opening sizes. Each sieve holds the size fraction that is larger than its mesh size. Through the successive sieves the sample breaks up into decreasing size fractions. The sediment fraction in each sieve is then weighed in order to obtain its percentage relative to the whole sample. This technique can either be used in dry or wet conditions (López, 2017).

[99] According to the British Standard EN1015-1:1998 the sieve aperture sizes should be 8,00mm,4,00mm, 2,00mm, 1,00mm, 0,500mm, 0,250mm, 0,125mm, 0,063mm. Unfortunately, the laboratory had only sieves of diameters 1.940mm, 0.466mm, 0.263mm, 0.122mm and 0.062mm. The separation of grades 8mm and 4mm was done by hand using a millimeter paper.

[100] The weighted was done using a KERN 440-21A (60X0.001g) laboratory scale.

4. Results – Discussion

4.1. Macroscopic Observation

In general, most of the mortar samples show color differences between the cut and the exposed areas probably due to corrosion and weathering factors. However, it can be stated that all the samples consist of light colored binders, mainly pale brown. They also seem to have a good consistency between the binder and the aggregates, with the exception of the samples S1, S2, S3 which are very friable. The best consistency is observed at the samples S7, S9, S10 and S11. The consistency of the samples was found empirically after a fragmentation attempt.

Macroscopic observation of the mortar samples			
Sample	**Munsell Color Code[101]**	**Color Description**	**Preservation State**
S1	7.5YR – 8/2	Pinkish white	Bad, friable, low consistency between aggregates-binder
S2	7.5YR – 8/2	Pinkish white	Medium, friable, low consistency between aggregates-binder
S3	10YR – 8/3	Very pale brown	Medium, friable, low consistency between aggregates-binder
S4	10YR – 8/2	Very pale brown	Good, medium consistency between aggregates-binder
S5	7.5YR – 7/2	Pinkish gray	Good, medium consistency between aggregates-binder
S6	10YR – 8/1 (cut area)	White	Good, good consistency between aggregates-binder
	10YR – 5/3 (exposed area)	Brown	
S7	10YR – 7/3	Very pale brown	Good, good consistency between aggregates-binder
S8	10YR – 8/2 (cut area)	Very pale brown	Very good, very good consistency between binder-aggregate
	10YR – 6/3 (exposed area)	Pale brown	
S9	10YR – 8/2	Very pale brown	Very good, very good consistency

[101] The correlation with the Munsell colors was performed under technical light (fluorescence lamps) at the laboratory of the University of the Peloponnese. The Munsell book used was the revised washable edition of 2000 (Munsell Color, 2000).

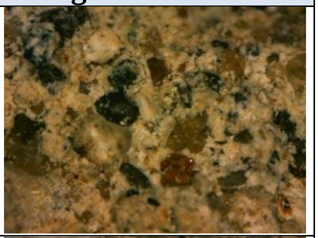
			between binder-aggregate
S10	10YR – 8/2	Very pale brown	Very good, very good consistency, between binder-aggregate
S11	10YR – 8/2	Very pale brown	Good, good consistency between binder-aggregate

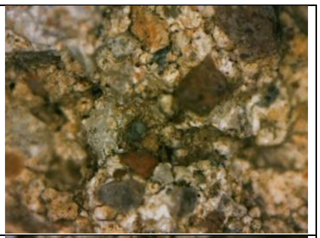
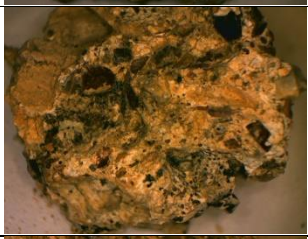
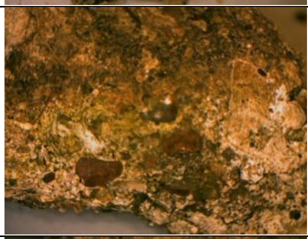
Table 8: Macroscopic observation of the color and preservation state of mortar samples

4.2. Optical Microscopic Examination (LED)

All the samples contain aggregates of similar colors, mostly beige, gray, brownish red, brown and black. The aggregates have different sizes, mainly medium and small but also there were some large ones. The shape of the majority of the aggregates is angular and sub-angular with just a few of them seeming to have a round outline. Calcite lamps are found in all the samples, with the biggest ones being in samples S1, S2 and S3, probably due to the bad mixing of the mortar ingredients. Furthermore, deposits of biological origin, rootlets, dirt and salts are observed on the surfaces of all the mortars.

Table 9: Microscopic examination of mortar samples with LED Optical Microscope

Optical Microscopic examination of mortar samples				
Sample	**Weight**	**Description**	**Magnification X10**	**Magnification X50**
S1	36,069 gr	High porosity, big calcite lamps, dirt, deposits of biological origin, salts		
S2	10,320 gr	High porosity, big calcite lamps, dirt, deposits of biological origin, salts		
S3	14,48 gr	High porosity, big calcite lamps, dirt, deposits of biological origin, salts		

S4	3,381 gr	Low porosity, medium calcite lamps, dirt, salts		
S5	24,929 gr	Medium porosity, many small calcite lamps, salts		
S6	25,487 gr	Low porosity, discoloration, salts		
S7	15,410 gr	High porosity (big porous), dirt, salts		
S8	24,929 gr	Low porosity, rootlets, salts		
S9	25,487gr	Low porosity, dirt, rootlets, salts		
S10	97,804 gr	Low porosity, dirt, rootlets, salts		
S11	90,430 gr	High porosity, big calcite lamps, dirt, deposits of biological origin		

4.3. X-ray Fluorescence (XRF)

The use of pXRF device provided a bulk chemical analysis of the major and trace elements of the mortar samples. However, the analyses conducted in each sample showed significant differences in the concentrations of chemical elements. The beam spot size of pXRF measures the portion of a sample directly in front of the analyzing window and all the materials it includes, without offering the possibility to focus on specific areas. Thus, the analyses were highly affected by the presence of coarse aggregates, especially in areas with big concentrations of them. The larger fluctuations in values were in the analysis of the major elements, while the deviation of the trace elements concentrations was smaller. As a result, it was decided to only use the trace elements detected in the analyses of the samples. The following tables present the major element oxides (wt% normalized to 100%) and the trace elements (in ppm) of the mortar samples analyzed with the use of pXRF.

	Major oxides (wt%, normalized to 100%)									
Samples	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**Fe_2O_3**
S1										
Mean	1.65	2.33	1.65	27.91	1.38	3.06	58.42	0.10	0.06	3.45
Std. Deviation	0.01	0.47	0.45	0.00	0.16	0.35	0.96	0.01	0.00	0.18
Max.	1.67	2.80	2.10	27.91	1.54	3.40	59.38	0.11	0.06	3.62
Min.	1.64	1.85	1.20	27.91	1.22	2.71	57.47	0.09	0.06	3.27
S2										
Mean	1.79	1.41	0.81	26.47	1.41	0.87	64.35	0.13	0.08	2.68
Std. Deviation	0.00	0.14	0.50	2.21	0.00	0.02	2.42	0.00	0.00	0.16
Max.	1.79	1.56	1.31	28.67	1.41	0.89	66.77	0.13	0.08	2.84
Min.	1.79	1.27	0.31	24.26	1.41	0.85	61.94	0.13	0.08	2.51
S3										
Mean	1.80	3.59	0.35	24.18	0.45	1.49	64.43	0.08	0.07	3.55
Std. Deviation	0.02	0.81	0.09	1.24	0.02	0.01	2.13	0.02	0.00	0.14
Max.	1.82	4.41	0.44	25.42	0.47	1.50	66.56	0.10	0.07	3.69
Min.	1.78	2.78	0.26	22.94	0.44	1.48	62.30	0.06	0.07	3.41
S4										
Mean	1.26	0.93	3.03	51.65	1.08	0.84	38.20	0.20	0.07	2.74
Std. Deviation	0.18	0.12	0.44	8.23	0.41	0.24	7.47	0.06	0.02	0.80
Max.	1.49	1.03	3.48	59.20	1.58	1.04	46.25	0.24	0.09	3.39
Min.	1.14	0.79	2.60	42.74	0.76	0.57	31.31	0.13	0.05	1.79
S5										
Mean	1.64	2.12	1.36	33.50	5.26	0.87	51.82	0.12	0.06	3.25
Std. Deviation	0.10	1.17	0.43	5.14	8.09	0.08	12.39	0.01	0.01	0.49
Max.	1.71	3.78	1.78	38.32	16.88	0.95	62.58	0.14	0.07	3.70
Min.	1.51	1.43	0.92	28.03	0.71	0.79	37.80	0.11	0.05	2.72
S6										

Mean	1.69	2.28	0.92	34.24	0.48	0.96	56.91	0.12	0.09	2.30
Std. Deviation	0.10	1.45	0.20	4.56	0.19	0.08	5.41	0.01	0.01	0.37
Max.	1.79	3.73	1.13	38.60	0.69	1.05	63.66	0.13	0.10	2.57
Min.	1.59	0.83	0.73	29.47	0.31	0.88	52.83	0.12	0.08	1.83
S7										
Mean	1.66	2.68	2.88	30.54	2.09	0.64	55.47	0.22	0.08	3.73
Std. Deviation	0.15	1.75	1.36	7.94	0.96	0.07	10.20	0.03	0.01	0.55
Max.	1.85	4.38	4.29	40.42	3.27	0.71	63.59	0.25	0.09	4.21
Min.	1.56	0.89	1.57	24.54	1.34	0.57	43.18	0.20	0.07	3.11
S8										
Mean	1.59	6.07	2.94	37.40	1.01	0.98	44.30	0.17	0.35	5.19
Std. Deviation	0.16	0.50	0.05	3.37	0.04	0.24	5.43	0.17	0.18	1.16
Max.	1.74	6.56	3.00	40.78	1.05	1.22	49.72	0.33	0.53	6.35
Min.	1.43	5.57	2.89	34.03	0.97	0.74	38.87	0.00	0.17	4.03
S9										
Mean	1.23	0.86	4.72	52.82	0.86	1.27	34.60	0.27	0.11	3.27
Std. Deviation	0.06	0.04	0.13	1.85	0.24	0.10	1.71	0.01	0.01	0.47
Max.	1.28	0.90	4.85	54.67	1.10	1.37	36.31	0.28	0.12	3.74
Min.	1.17	0.81	4.59	50.97	0.62	1.17	32.88	0.26	0.09	2.81
S10										
Mean	1.66	8.04	0.27	37.28	0.43	0.55	47.39	0.08	0.10	4.19
Std. Deviation	0.23	0.56	0.27	13.90	0.43	0.09	14.17	0.01	0.02	0.70
Max.	1.90	8.60	0.55	51.18	0.87	0.64	61.56	0.09	0.12	4.89
Min.	1.43	7.49	0.00	23.38	0.00	0.45	33.22	0.06	0.08	3.48
S11										
Mean	1.65	3.26	0.68	37.53	0.03	0.43	53.40	0.10	0.08	2.83
Std. Deviation	0.09	1.90	0.28	1.56	0.03	0.06	0.40	0.02	0.01	0.27
Max.	1.74	5.16	0.96	39.09	0.07	0.49	53.80	0.12	0.09	3.10
Min.	1.56	1.36	0.41	35.98	0.00	0.37	53.00	0.09	0.07	2.55

Table 10: Major oxides (wt%, normalized to 100%) detected with pXRF

	Trace elements (ppm)																		
Samples	**V**	**Cr**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**	**Mo**	**Sn**	**Sb**	**Ba**	**Pb**	**Th**	**U**
S1																			
Mean	5	5	5	38	16	12	3	24	238	22	47	6	17	2	4	627	10	4	2
Std. deviation	5	2.5	0.5	11.5	5	3.5	0	3	3	2.5	4.5	0.5	0.5	0	0.5	416	0.5	0	1.5
Max.	10	7	5	49	21	15	3	27	241	24	51	6	17	2	4	1043	10	4	3
Min.	0	2	4	26	11	8	3	21	235	19	42	5	16	2	3	211	9	4	0
S2																			
Mean	49	28	4	24	25	0	3	16	320	18	38	5	18	3	7	0	9	3	5
Std. deviation	2	4	0.5	1	6	0	0.5	1.5	35.5	0.5	8	0.5	7.5	0.5	3	0	0	0	0.5
Max.	51	32	4	25	31	0	3	17	355	18	46	5	25	3	10	0	9	3	5
Min.	47	24	3	23	19	0	2	14	284	17	30	4	10	2	4	0	9	3	4
S3																			
Mean	21	4	3	26	25	3	4	14	398	20	35	5	3	2	6	258	9	4	1
Std. deviation	0.5	4	0	0.5	2	2.5	0.5	2	15	1.5	3.5	0.5	2.5	0	0.5	65.5	0	0.5	1
Max.	21	8	3	26	27	5	4	16	413	21	38	5	5	2	6	323	9	4	2
Min.	20	0	3	25	23	0	3	12	383	18	31	4	0	2	5	192	9	3	0

S4																			
Mean	72	76	3	32	9	16	6	10	112	11	22	2	5	1	0	112	9	3	0
Std. deviation	18	3.5	3	31.5	12	18	8	10	118	11	22	2.5	6	1	0.5	187	9.5	2.5	0
Max.	93	80	6	63	24	36	16	20	236	22	44	5	12	2	1	374	19	5	0
Min.	57	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S5																			
Mean	41	23	3	26	21	3	2	8	211	9	19	2	6	1	3	107	5	2	1
Std. deviation	3.5	7.5	3	33	26.5	3.5	1.5	9	279.5	9	21.5	2	11	1	4.5	214.5	5	2	2
Max.	44	31	6	66	53	7	3	18	559	18	43	4	22	2	9	429	10	4	4
Min.	37	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S6																			
Mean	61	24	2	19	11	3	1	7	104	10	20	2	6	1	4	97	5	2	0
Std. deviation	8	3	2	20	12	5	2	9	104	11	21	3	6	1	5	121	6	2	0
Max.	67	26	4	40	23	9	3	17	208	22	41	5	12	2	9	242	11	4	0
Min.	51	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S7																			
Mean	38	28	3	21	20	33	3	13	100	11	27	3	4	1	5	197	5	2	1
Std. Deviation	7	6.5	3	22	22.5	37	3	15	108.5	13	29.5	2.5	4.5	1	5	394.5	5	2	1
Max.	44	35	6	44	45	74	6	30	217	26	59	5	9	2	10	789	10	4	2
Min.	30	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S8																			
Mean	28	150	6	71	55	18	2	24	146	27	40	2	34	3	10	1661	9	3	0
Std. Deviation	13.5	113	0.5	6.5	11	17.5	2	1	9	6	0.5	2	4	0	2	1660.5	1	0.5	0
Max.	41	263	6	77	66	35	4	25	155	33	40	4	38	3	12	3321	10	3	0
Min.	14	37	5	64	44	0	0	23	137	21	39	0	30	3	8	0	8	2	0
S9																			
Mean	60	60	7	64	41	20	4	22	248	23	54	5	8	2	4	643	10	4	0
Std. Deviation	13.5	4.5	0.5	8.5	5.5	4.5	0.5	1.5	19.5	0	2.5	0	1.5	0	1.5	98.5	0.5	0	0
Max.	73	64	7	72	46	24	4	23	267	23	56	5	9	2	5	741	10	4	0
Min.	46	55	6	55	35	15	3	20	228	23	51	5	6	2	2	544	9	4	0
S10																			
Mean	34	17	4	28	23	0	3	14	160	20	38	5	24	2	8	1044	10	4	0
Std. Deviation	26.5	16.5	0	0.5	4	0	0.5	0.5	13.5	0.5	1	0.5	7.5	0	2.5	116.5	0	0.5	0
Max.	60	33	4	28	27	0	3	14	173	20	39	5	31	2	10	1160	10	4	0
Min.	7	0	4	27	19	0	2	13	146	19	37	4	16	2	5	927	10	3	0
S11																			
Mean	18	13	6	64	35	5	4	25	431	18	40	5	17	2	4	143	9	4	4
Std. Deviation	14.5	13	0.5	19.5	7.5	5	0	4	30.5	1	4.5	0.5	7	0	1.5	143	0	0.5	3
Max.	32	26	6	83	42	10	4	29	461	19	44	5	24	2	5	286	9	4	7
Min.	3	0	5	44	27	0	4	21	400	17	35	4	10	2	2	0	9	3	1

Table 11: Trace elements (ppm) detected with pXRF

4.4. Scanning Electron Microscopy (SEM-EDS)

The SEM-EDS offered nice detailed images of the surface microtopography of the samples (see Appendix D). However, the main purpose of its use was to get a more precise analysis of the concentration of the major elements in samples.

SEM-EDS analysis of major elements									
Samples	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl**	**K_20**	**CaO**	**Fe_2O_3**
S1	3.09	0.85	1.92	10.50	3.34	3.10	4.10	73.26	1.46
S2	n.d.	0.70	1.96	7.89	1.07	0.48	0.69	86.61	1.13
S3	0.96	0.73	1.55	13.11	0.42	0.78	0.82	81.44	0.72
S4	0.50	0.86	1.96	9.14	1.34	0.31	0.47	85.52	0.72
S5	1.69	0.88	2.33	20.39	15.49	1.94	1.49	54.12	1.67
S6	0.71	1.00	2.98	26.02	5.62	0.31	1.40	60.66	1.54
S7	0.57	0.80	2.49	11.95	0.90	n.d.	0.58	82.00	1.44
S8	0.44	1.12	4.68	54.81	0.81	n.d.	1.20	34.42	3.07
S9	n.d.	0.96	3.51	59.06	0.91	0.09	1.30	31.62	2.54
S10	n.d.	1.27	2.57	69.88	0.66	0.06	0.79	23.82	1.17
S11	0.91	0.90	2.05	8.58	0.80	3.20	1.04	82.38	1.02

Table 12: Chemical composition of the major oxides of mortar samples through SEM-EDS (wt%)

As it can be observed from the table above, the main element oxides found in high concentrations in samples are SiO_2 and CaO. The mortars use lime as their main binder with low magnesium concentration (less than 5%). This means that the limestone used for the production of lime was high-calcium lime and not dolomitic lime (magnesium above 20%). The use of high-calcium lime in all samples can be associated with a common raw source during all historical periods or it can be characteristic of the geological rocks of the area of Androusa[102].

The results of SEM-EDS were used for the classification of the samples into groups with similar chemical composition. Scatter plots were made on the basis of the two predominant elements of the samples, SiO_2 and CaO. As it can be seen in the following diagram, three distinctive groups can be observed.

[102] In the Middle Ages it was common to use certain impure limestones from specific quarries in order to produce lime (Moropoulou et al., 2005).

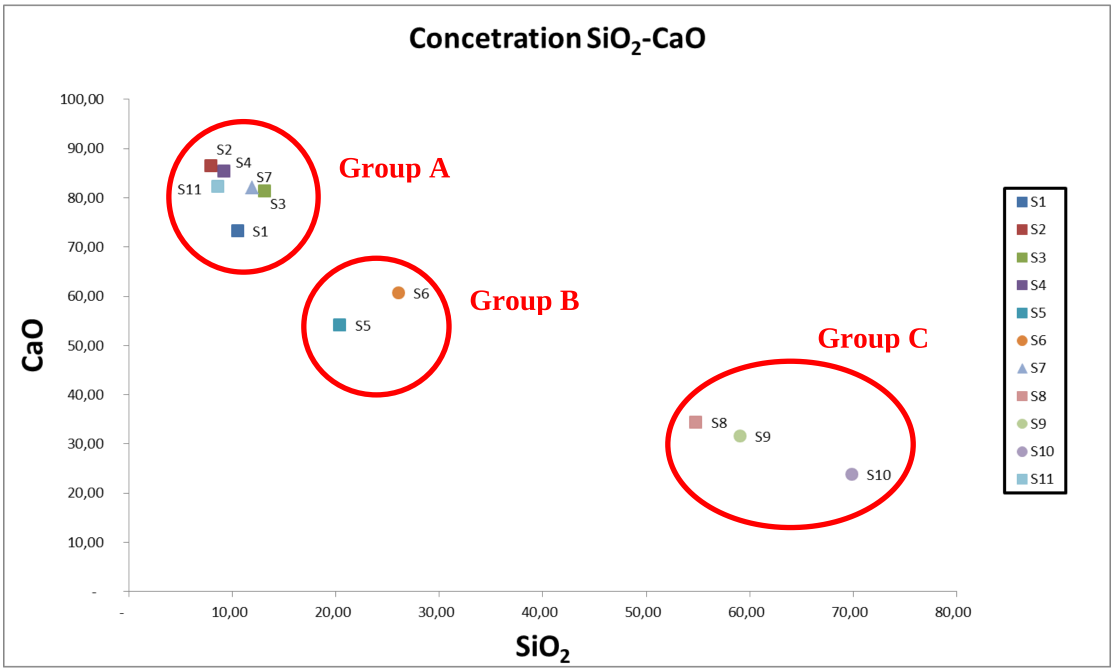


Figure 20: Concentration of SiO_2/CaO of mortar samples (wt%). Samples from the 1st building phase are depicted with a triangle, samples from the 2nd building phase with a circle and samples from the 3rd building phase with a square

The first group (Group A) includes samples S1, S2, S3, S4, S7, and S11 which present higher concentrations of CaO in comparison to SiO_2. The samples S1, S2 and S3 come from the Northern Tower, the S4 from the Northeastern Tower, the S7 from the Southeastern Tower, and the S11 from the Northwestern Tower. As it seems, this group mainly includes samples collected from the northern fortification. The Northern Tower, the Northwestern Tower and the Northeastern Tower are all included in the same building phase (3rd building phase – Ottoman Period). The only exception in this group is the sample from the Southeastern Tower which, although it seems to be in good chemical relation with the rest samples, according to archaeological evidence it belongs to a different building phase (1st building phase – Frankish Period), so its presence in this group should be considered random. Moreover, it can be said that all the three samples from the Northern Tower had the same chemical composition, regardless of their type (rendering or structural mortars).

The second group (Group B) includes samples S5 (Northeastern Tower) and S6 (Eastern Wall). These two samples present relative lower concentrations of CaO and higher concentrations of SiO_2 in comparison to Group A. In addition, high concentrations of sulfur (S) were detected in both samples as it can be seen in the table results. Sulfur is an element usually associated with gypsum. Although the Eastern Wall and the Northeastern Tower were made in different building phases, the samples seem to be in good accordance based on their chemical composition.

Moreover, the sample S5 doesn't have the same chemical composition with S4, despite the fact that they both come from the Northeastern Tower. Unfortunately, the reason of the aforementioned differences cannot be clearly explained. One possible explanation could be that S5 and S6 samples were collected from openings of the fortification. The S5 was collected from a cannon embrasure of the Northeastern Tower and the S6 from an opening (maybe embrasure) of the Eastern Wall. Probably these areas received restoration works during the past or a rendering of gypsum for unknown reasons.

The final group (Group C) includes samples S8, S9 and S10. These samples present very high concentrations of SiO_2 and very low contractions of CaO[103]. The sample S8 was collected from the foundations of the Northern Wall, the sample S9 from a fallen part of the fortification of the Southern Wall and the sample S10 from the masonry of the Southern Tower. Both samples S9 and S10 belong in the southern fortification made during the same building phase (Byzantine Period). As it seems, the southern fortification presents a differentiation in the chemical composition from the rest of the castle. However, the presence of S8 in the same group is really questionable, since it belongs to a different building phase (Ottoman Period). In addition S8 doesn't have the same chemical composition with the rest of the samples of the northern fortification. The higher proportion of SiO_2 in the sample could be due to its use. Silica-rich mortars include higher proportions of sand which is generally hygroscopic material. High silica content results to mortars of higher strength and higher resistance to moisture (Sagin et al., 2012). Such properties could be considered ideal for mortars used in foundations, which are exposed in environments of high moisture.

A Principal component analysis (PCA)[104] was conducted based on the pXRF calculation of trace elements and the SEM-EDS calculation of major elements (Figures 21-22). The following major and trace elements were used for the analysis: V, Cr, Co, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, Nb, Mo, Sn, Sb, Pb, Th, U, Na_2O, MgO, Al_2O_3, SiO_2, SO_3, Cl, K_2O, CaO, FeO.

[103] The high silica concentrations detected in this group may be referred to the size of quartz grains or to a predominantly silicate nature of the binder (Conte et al., 2017).

[104] Principal component analysis (PCA) is a technique used for the compression and classification of data. It offers a reduced dimensionality of a data set (sample) by finding a new set of variables, smaller than the original set of variables, retaining however most of the information of the sample (Jolliffe, 2002).

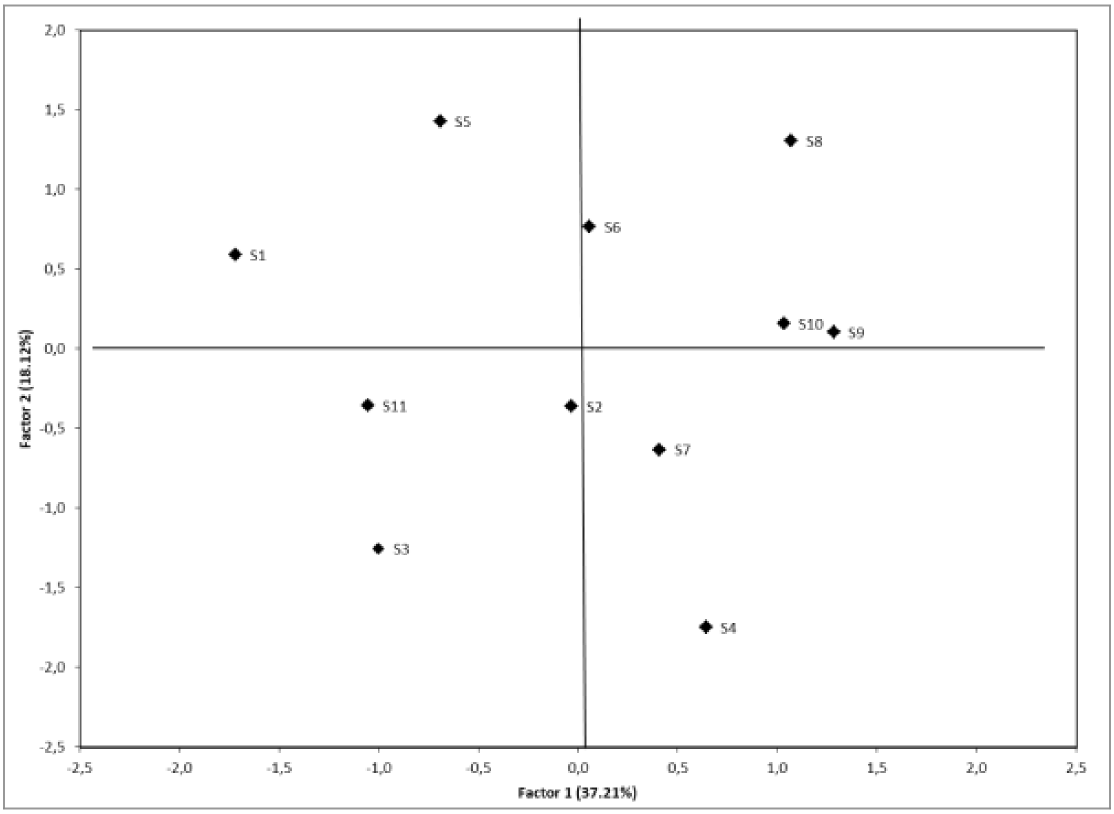


Figure 21: PCA of mortar samples based on SEM-EDS data (major element oxides) and pXRF data (trace elements)

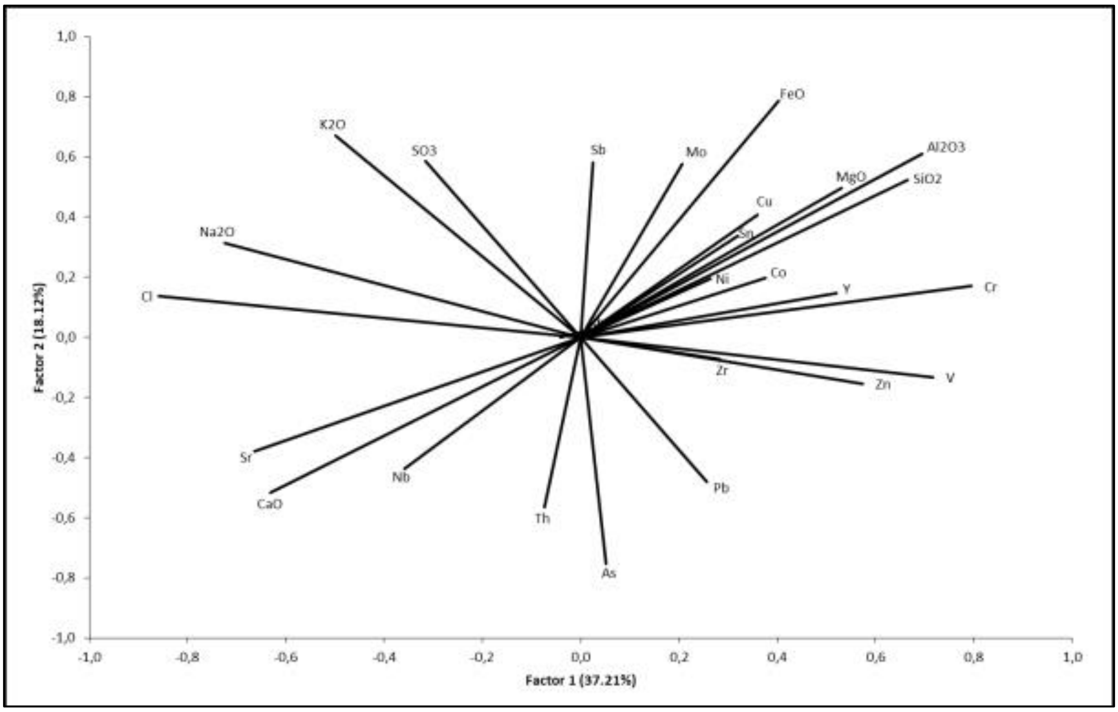


Figure 22: Related vector plot of the PCA data of mortar samples

According to the diagrams, the samples could be divided into groups based on their degree of similarity. The arrange of samples S1, S2, S3, S4, S7, S11 seem to be affected mainly by the presence of the elements As, Sr, Nb, Pb, Th, Na_2O, Cl, CaO, while the arrange of samples S5, S6, S8, S9, S10 is affected by V, Cr, Co, Ni, Cu, Zn, Y, Zr, Mo, Sn, Sb, MgO, Al_2O_3, SiO_2, SO_3, K_2O, FeO. The results of PCA analysis appear to have similarities to the groups resulted from SiO_2-CaO concentration analysis, corroborating the previous division. The first arrangement seems to be affected mainly by the presence of CaO indicating a calcareous nature, while the second arrangement by the presence of SiO_2, Al_2O_3 and MgO indicating probably a siliceous nature. It should be mentioned though, that these results could be either due to the nature of the binder or to the nature of the aggregates[105].

4.5. Granulometric Analysis

The diagram bellow shows the results of the granulometric analysis of all the mortar samples. The results are presented in percentages, based on their grain size distribution of all the different diameters.

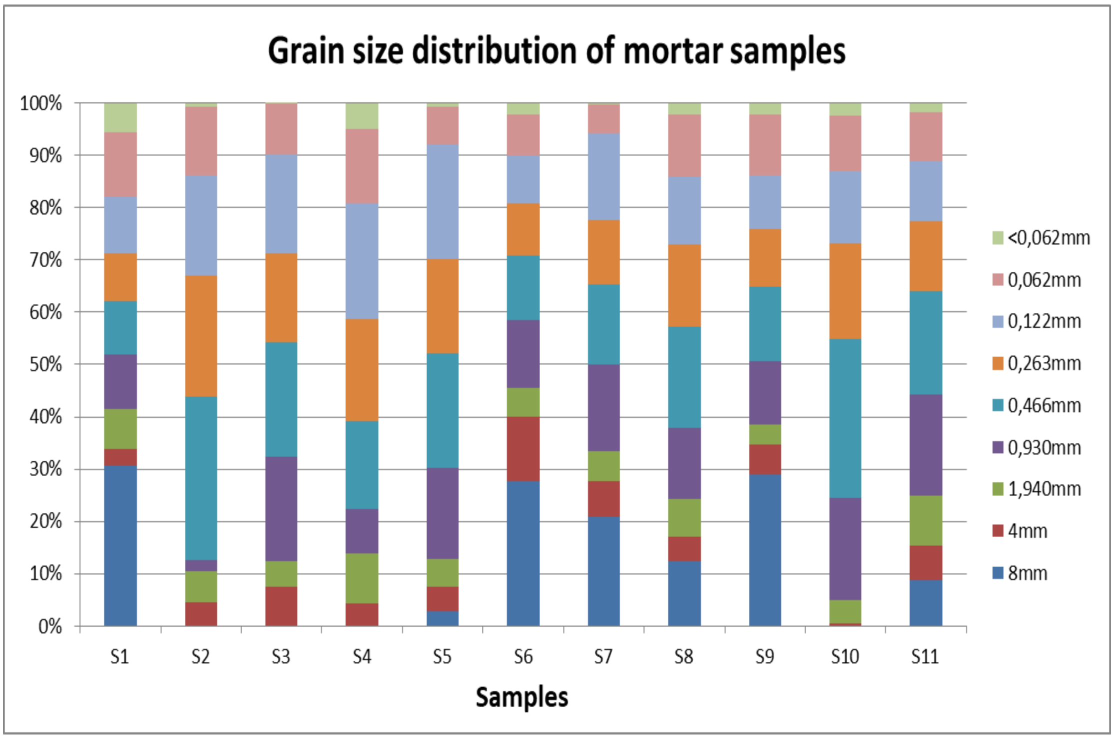


Figure 23: Grain size distribution of mortar samples (wt%) of the different diameters

105 An XRD analysis could help determine the mineralogical composition of the samples.

It can be observed, that there is no clear separation of the mortar samples based on grain size distribution. The coarsest grain mortar sample seems to be the S6, however without significant difference compared to S1, S7 and S9.

Based on the granulometric analysis, a calculation of the binder/aggregate ratio was also made. The following diagram presents the concentration of aggregate versus binder in each sample.

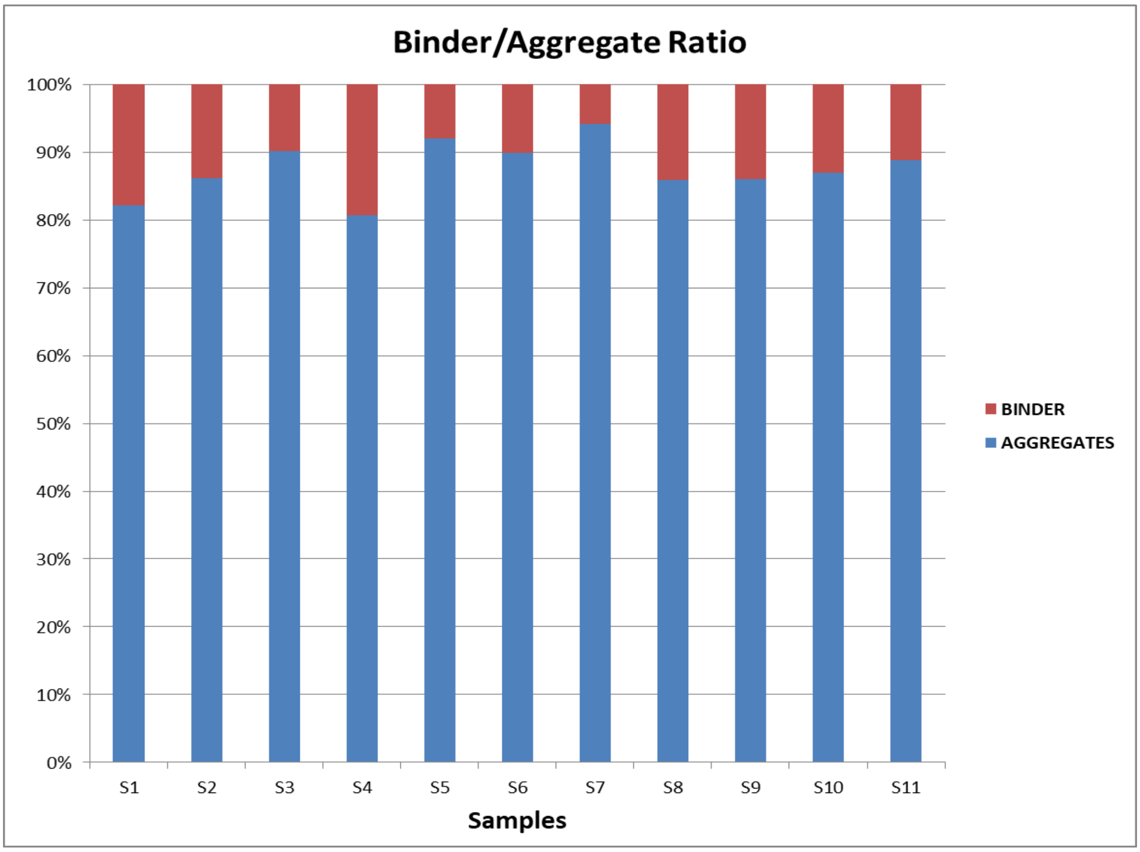


Figure 24: Binder/Aggregate ratio of mortar samples (wt%)

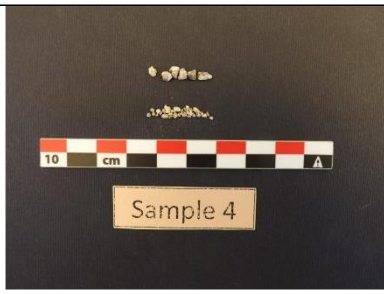
As shown in the above diagram, the highest binder percentage is 20% (S4) and the lowest is approximately 5% (S7). Generally, it can be noted that the samples of the northern fortification (S1, S2, S3, S4, S5, S8, S11) present significant fluctuations of binder/aggregate ratio, even in cases of samples collected from the same area (e.g. S1, S2, S3 all come from the Northern Tower). This may be associated with a less elaborate mortar preparation during the Ottoman period. On the contrary, the southern fortification (S9, S10) seem to have similar ratios of binder/aggregates, indicating that during the Byzantine period there was a more diligent production of mortars. The sample S7 has the smallest proportion of binder. It differentiates from the other samples and it is the only one that comes from the 1st building phase of the castle.

Probably during the construction of the Southeastern Tower (Frankish period) the preparation of mortars was different, including less proportion of binder materials and more of aggregates.

The visual observation of the coarse fractions of aggregates in relation to the shape and color was very useful for the better understanding of their origin. Almost all the coarse aggregates have an angular or sub-angular shape and there is also a big variety of colors among them. The angular shape of the aggregates suggests that they were produced from the fragmentation of stones. It is highly possible that they came from the same quarries as the stones for the building of the castle and were products of human intervention. However, this does not justify the variety of colors found in the aggregates of mortar samples. The norm is that a quarry can give stones of a same color shade. In case of Androusa, the castle has been made mainly from gray, beige and off-white stones. As a result, what seems to be most possible is that the aggregates were naturally produced and collected from rivers of mild nature[106]. In such places due to rainfalls, there is usually an accumulation of stone materials from different sources. This assumption can also be justified from the presence of seasonal rivers (torrents) in proximity to the castle of Androusa (see Figure 15).

Sample	Coarse Aggregates Description (Shape/Color)	Photographs
S1	Shape: angular and sub-angular Color: brown, beige, black, gray, reddish brown	
S2	Shape: angular and sub-angular Color: brown, beige, off-white, gray, reddish brown	

[106] A powerful streaming river results to round and elongate aggregates, due to the continuous transport and friction of the materials. In case of Androusa, the angular and sub-angular aggregates probably came from seasonal rivers.

S3	Shape: angular and sub-angular Color: brown, beige, reddish brown, gray	
S4	Shape: angular and sub-angular Color: brown, beige, reddish brown	
S5	Shape: angular and sub-angular Color: brown, beige, black, reddish brown	
S6	Shape: angular and sub-angular Color: brown, beige, black, reddish brown	
S7	Shape: angular and sub-angular Color: brown, beige, black, reddish brown	
S8	Shape: angular and sub-angular Color: brown, beige, black, reddish brown	

S9	Shape: angular and sub-angular Color: brown, beige, black, reddish brown, green	
S10	Shape: angular and sub-angular Color: beige, black, reddish brown, gray	
S11	Shape: angular and sub-angular Color: beige, black, reddish brown, gray	

Table 13: Description of coarse aggregates (>0,930mm) based on their shape and color

5. Conclusions

5.1. The technological study of the mortars of the castle of Androusa

The technological study of the mortars of the castle of Androusa, although carried out in a limited time and with the use of only a few small mortar samples (11 samples), it managed to lead to some interesting conclusions. Specifically:

About the composition of mortars

All the samples consist of light colored binder materials, with only exception the sample collected from the Eastern Wall (S6), which seems to have a darker color shade. Also, the majority of the samples show good consistency between the binder and the aggregates, except from the mortars of the Northern Tower (S1, S2, S3) that were very friable.

The aggregates found in mortars are common in all building phases of the castle. They are mainly angular and sub-angular and have various colors. Probably, they originate from natural sources, such as streams or low-flow rivers, where accumulation of aggregate materials is usually attested. In the area of Androusa there are several torrents, something that is also stated by the theory that links the name of the city to the Greek word ἄνδηρον, meaning ditch. An analytical comparison of the aggregates found in the nearby streams and those used in mortars could confirm their origin.

All the samples appear to differ greatly from one another according to their grain size distribution, even in the case of samples collected from the same area or belonging to the same building phase. Consequently, these variations could be considered random, supporting the assumption that the aggregates were not deliberately produced by human intervention but rather came from natural sources.

The mortars used for the construction of the castle were lime mortars like in the majority of historical buildings. The main binder of all mortars is lime with low magnesium concentration (less than 5%), indicating that it was produced from limestones of high-calcium lime and not of dolomitic lime. Probably, this can be associated either with the use of common raw lime sources during all building phase periods, or it is due to the geology of the area of Androusa. A study on the geological rocks of the region could provide a better answer to this question.

Most of the mortar samples presented high concentrations of CaO and relative low concentrations of SiO_2. The only exception was the sample collected from the foundations of the Northern Wall (S8) and the two samples of the southern fortification (S9, S10), all of which had high concentrations of SiO_2 and low concentrations of CaO. In the case of Northern Wall, the use of silica-rich mortars could be deliberate as such mortars are more durable and more moisture resistant, suitable for the foundations. The examination of more mortar samples from the foundations of different areas of the castle could help to confirm or not this hypothesis.

About the building phases of the castle

The samples collected from areas built in the same building phase appear to have the same chemical composition. Almost all the samples of the northern fortification (S1, S2, S3, S4, S5, S11 - 3rd building phase) are very similar in chemical composition, reinforcing the theory that this section was built in a single building phase. Also, the two samples collected from the southern fortification (S9, S10 - 2nd building phase) have many similarities in their chemical composition, indicating that the southern fortification was built in a single building phase.

The southern fortification (2nd building phase) shows significant differences from the northern fortification (3rd building phase) based on the chemical composition of its mortars, suggesting that it could probably belong to a different building phase. This is also a theory supported by archaeological research as well. The use of silica-rich mortars could be related with the application of different technology. However, this technology is not attested in the Eastern Wall, although it belongs to the same building phase with the southern fortification. A possible explanation could be that these two sections of the castle were made by separate groups of builders who applied different methods of mortar preparation. Moreover, it is possible that the mortar sample analyzed from the Eastern Wall could had been collected from a part of the wall that had been reconstructed during the past (e.g. after a siege), so it may not be representative.

The analysis of the binder/aggregate ratio showed that the sample collected from the Southeastern Tower (S7 - 1st building phase) had the smallest proportion of binder among the mortars of the castle. This could be considered as an indication that the Southeastern Tower belongs to a separate building phase, as states the archaeological research. This building phase probably involved less use of binder materials in the preparation of mortars.

The mortar samples from the southern fortification (2nd building phase) have the same proportions of binder-aggregates, indicating that they were probably prepared with special attention. On the contrary, the samples of the northern fortification (3rd building phase) show significant fluctuations in their proportions, suggesting that their preparation was less careful. The last assumption is also suggested by the presence of many big calcite lamps in the samples of northern fortification due to pour mixing of the ingredients.

Other considerations

In two of the samples (S5 and S6) high concentrations of SO_3 were detected. The first sample was from a cannon embrasure of the Northeastern Tower and the second from an opening (maybe embrasure) of the Eastern Wall. The presence of sulfur is usually associated with gypsum. It is possible that these areas had been repaired in the past or they had a gypsum rendering that nowadays is not preserved. It must also be stated that gypsum offers acoustic insulation, heat insulation and fire resistance (Karni & Karni, 1995), so it is possible that the gypsum had been used in cannon embrasures deliberately.

Final remarks about the study of mortars

The analysis of the mortar samples and their correlation with the building phases of the castle cannot lead to absolute conclusions, but rather to assumptions based mainly on the study of the materials used and the technology applied.

Mortars are usually inhomogeneous because they were produced manually. Their characteristics and properties depend on raw materials and technological know-how. Human factor plays a very important role in the preparation of mortars, thus there is no specific formula that repeats in the same way throughout the building work. As a result, mortars used in a same building period may show significant differences between them. In addition, superficial architectural modifications and restorations made in historic building at different time periods can make really difficult the distinguishing of the various building phases. Moreover, the use of similar materials (binders, aggregates) can create obstacles in the identification of the original mortars leading to erroneous conclusions.

In order to limit the chances of erroneous conclusions and to extract more secure results it is important that many individual analytical methods and combinations of methods are applied to a sufficient number of samples. In the future, this study could be greatly enhanced with the examination of extra mortar samples from the castle and the use of more analytical techniques (e.g. XRD analysis, Thermal analysis, Luminescence dating etc.) providing further knowledge about the mortars and the castle of Androusa for conservation, restoration or academic purposes.

5.2. The application of GIS in the castle of Androusa

The use of GIS contributed greatly in this study proving to be an excellent tool for processing, synthesizing, analyzing and interpreting archaeological information. Although the final result offers only spatial information about the castle of Androusa, the created database can still be used for further analysis and research in the field of GIS application in archaeology and cultural heritage in general.

Through its use, GIS helped to understand better the fortification of the castle and its relation with its landscape. A representation of the fortification ground plan of the castle and the greater region of Androusa were made. The resulted data were used to extract some important information by utilizing and combining the archaeological knowledge with spatial information and the visualization techniques offered by GIS.

In addition, GIS was also implemented in the management of the information collected from the practical part of the study. The positions of the mortar samples were documented in GIS and were linked with their respective datasets. As a result, a database was created where all the information acquired from this study can be stored and processed in a dynamic and interactive way. This database can offer easy access and update of the archiving data, while maintaining the historical and archaeological data in the same time. In the future it can be enriched with even more information about the castle (e.g. addition of photos, creation of different datasets). Also, a platform which can be renewed and to be open to the wider public through the WEB can be created. The flexibility of the GIS applications is what makes them such a valuable tool for research and knowledge in the field of archaeology.

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7. Appendix

APPENDIX A

The *Donjon* Tower

Most of the crusader castles underwent a series of modifications through ages by the Byzantines, Ottomans and the Venetians so it is usually difficult to distinguish them. Nevertheless, one of the main elements of castles that can be attributed with a good certainty to the crusaders is the keep in form of stone tower, also known as *donjon* (Molin, 2001).

The classic donjon seems to appear in Montbazon in 1017 and soon became the characteristic fortification of the twelfth century (Kennedy, 1994). These square or rectangular towers represented the earliest and most common structures built by the first Latin settlers in the areas of their authority. They are connected with the Westerners much more than certain types of masonry or particular stretches of curtain walls (Molin, 2001).

Usually, the donjon was in the center of the castle or on its highest part. In some cases, it was adjoined in the curtain wall as well. The size of the donjon was not specific, but varied from castle to castle, so it is difficult to create a reproductive model based on its dimensions. However, the donjon towers were larger compared to the other towers of the castle. Their walls were also better reinforced and thicker than the curtain walls. On their top they were covered with a tiled roof or a floor with ramparts. The norm was to have the entrance a few meters above the ground level for safety reasons and an underground cistern[107] in case of siege (Hetherington, 1991; Breuillot, 2005; Curcic, 2010)[108].

In West, donjon tower was also an important element of a castle, but without dominating the other castle buildings. It could be better considered as part of a compact courtyard plan (Kennedy, 1994).

The advantage of these structures was the fact that they were built fast, cheaply and easily, providing the necessary protection to the settlers (Breuillot, 2005). They were either built to stand alone in isolation or were added to older Byzantine or

[107] The role of cistern was vital for the defenders of the donjon. The cisterns had to be cleaned from time to time and the water inside them to be refreshed regularly (Breuillot, 2005).
[108] This arrangement can be attested in a number of cases like in Thurion and Dadi (Molin, 2001).

ancient defenses. There are many cases that older sites were remodeled by the Franks with the addition of donjon towers. Moreover, these towers could be garrisoned only by a few men thanks to their small size. So, even if outer older defenses were left in ruins or they had to be abandoned in the face of a numerically superior army, the tower could still be defended properly (Molin, 2001). The donjon tower was the last line of defense of a castle during a siege. In addition, it could also be used for residential purposes (Curcic, 2010).

Unfortunately, the donjon towers don't have any distinguish feature to help in dating them. Despite that, is believed that most of the towers that exist today in central Greece were built during the 13th-14th century by the crusaders (Hetherington, 1991)[109].

[109] In comparison to the Frankish towers, there are only a few Byzantine towers left (Hetherington, 1991).

APPENDIX B

Photos from the castle of Androusa

Photo 1: Outside view of the castle of Androusa (Ephorate of Antiquities of Messenia, 2016)

Photo 2: Decorative brickwork ornaments in the inner face of the eastern wall (personal archive)

Photo 3: Relieving arch of the eastern wall with decorative brickwork (personal archive)

Photo 4: Inside view of the Eastern Wall (personal archive)

Photo 5: Inside view of the Northern Wall (personal archive)

Photo 6: Part of the Southern Wall of the castle (personal archive)

Photo 7: Outside view of the Northeastern Tower (donjon) (personal archive)

Photo 8: Outside view of the Eastern Tower (personal archive)

Photo 9: Outside view of the Northeastern Tower (personal archive)

Photo 10: Outside view of the Northern Tower (personal archive)

Photo 11: View of the Northwestern Tower (personal archive)

Photo 12: The ruins of the Southern Tower of the castle (archive of the Ephorate of Antiquities of Messenia)

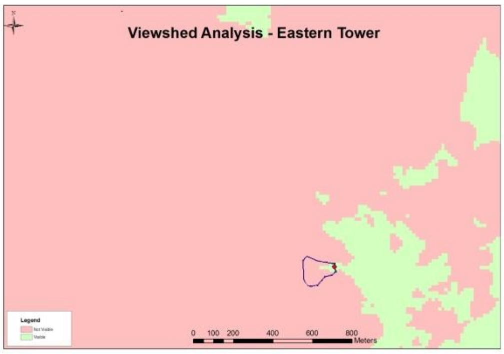
Photo 13: Restoration works at the castle during 2013-2015 (archive of the Ephorate of Antiquities of Messenia)

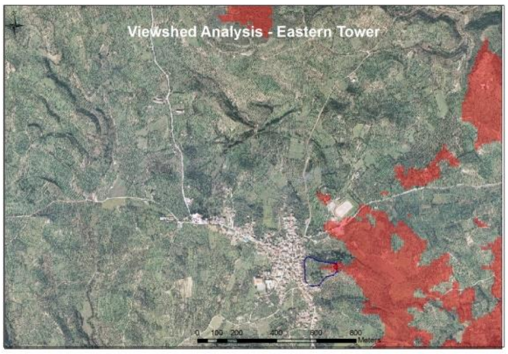
Photo 14: Restoration works at the castle during 2013-2015 (archive of the Ephorate of Antiquities of Messenia)

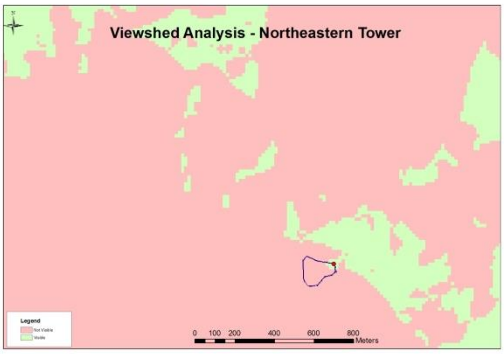
APPENDIX C

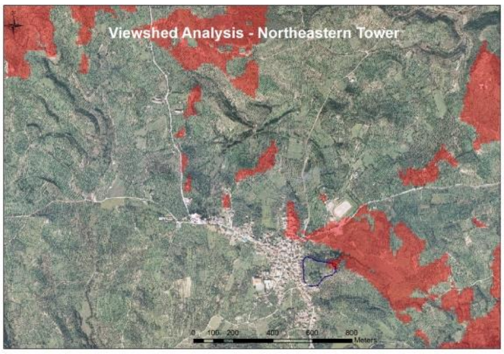
Viewshed Analysis for all the towers of the castle of Androusa with the use of GIS

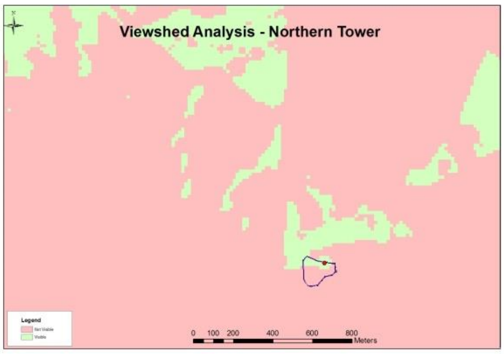
Viewshed Analysis of each tower of the castle of Androusa

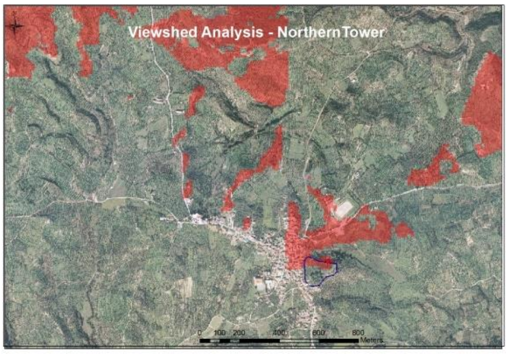


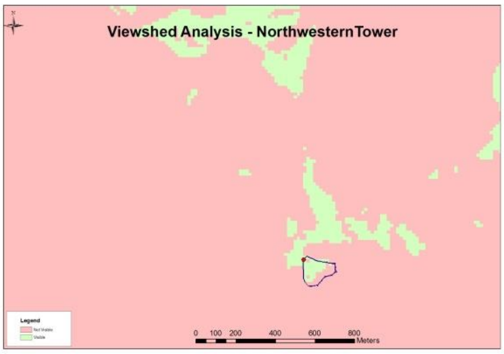


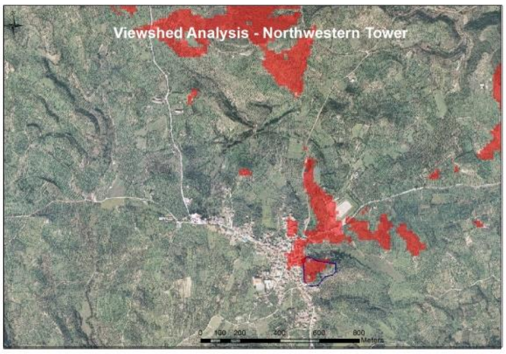


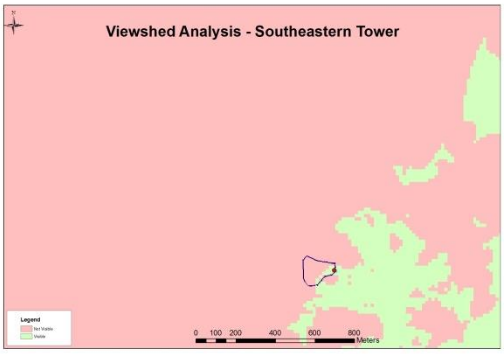


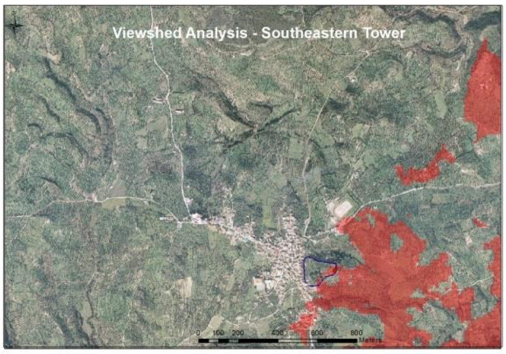









Viewshed Analysis - Southeastern Tower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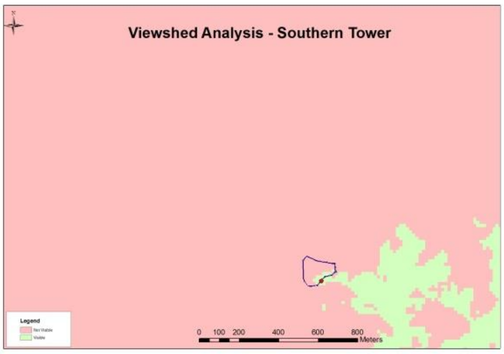
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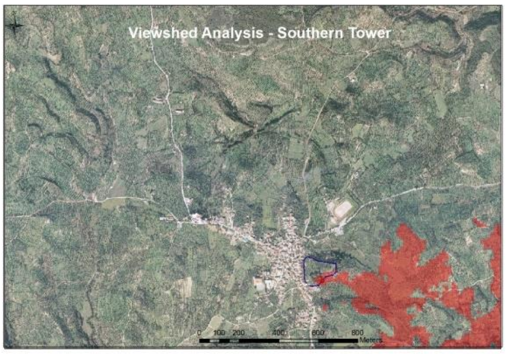
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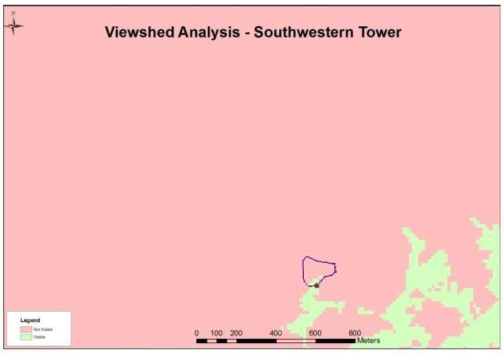
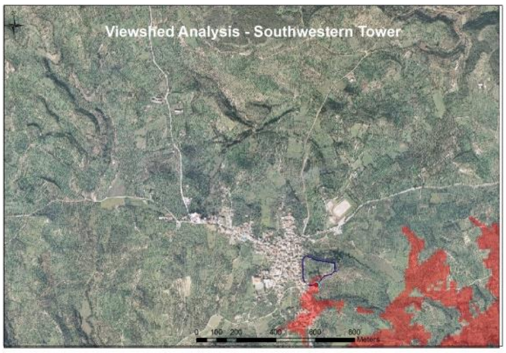

Viewshed Analysis - Southwestern Tower


Viewshed Analysis - Southwestern Tower

APPENDIX D

Images of mortar samples under SEM-EDS microscopy

At the following images, the light-colored zones correspond to nearly pure carbonate, the darker zones correspond to higher silica areas, and the black zones correspond to the porosity.

Mortar samples under SEM microscopy		
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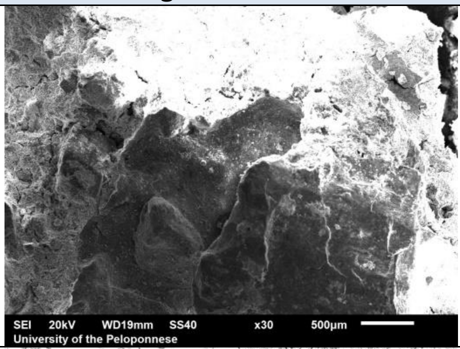
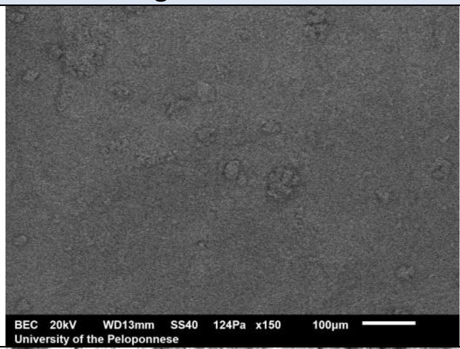
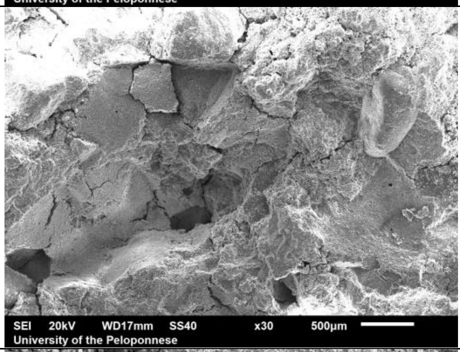
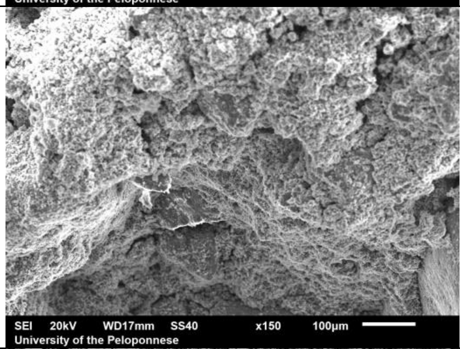
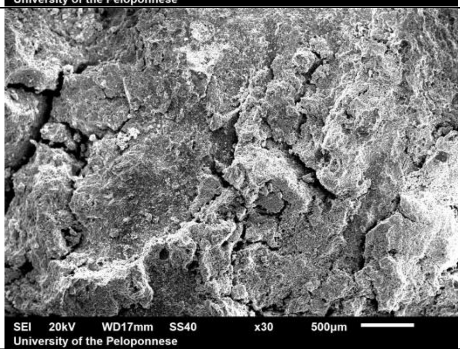
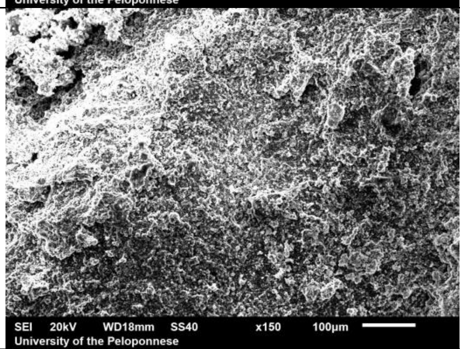
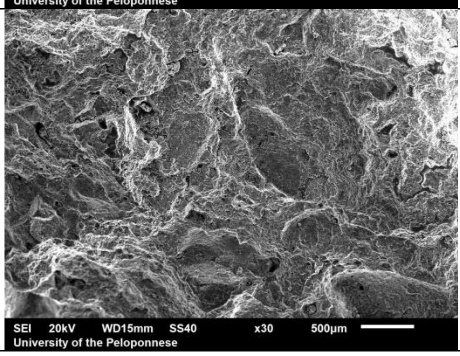
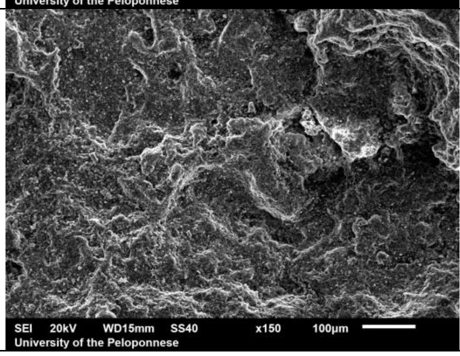
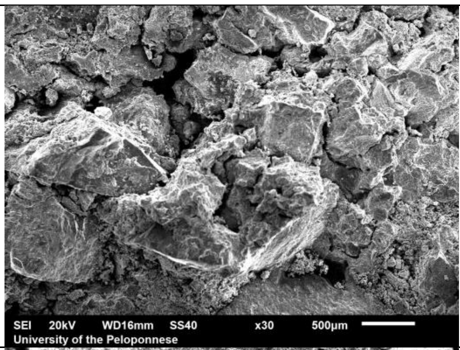
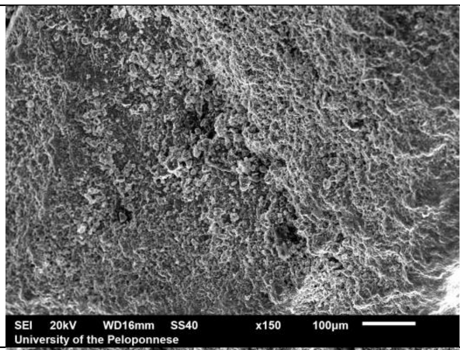
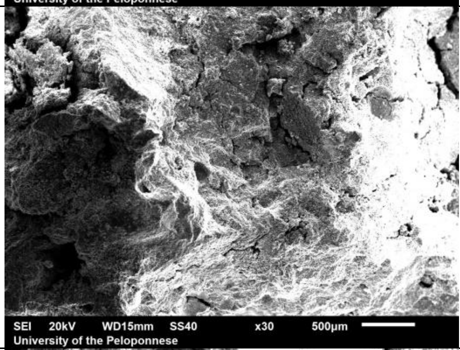
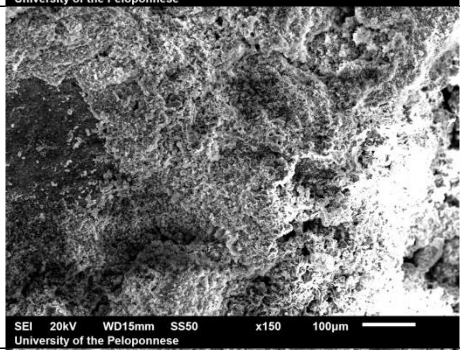
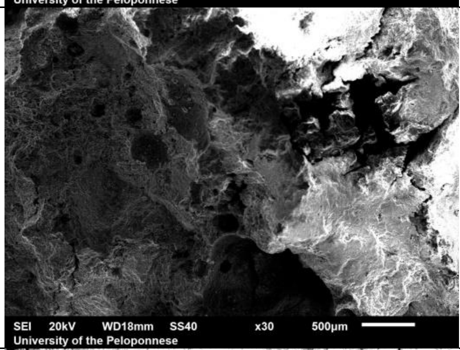
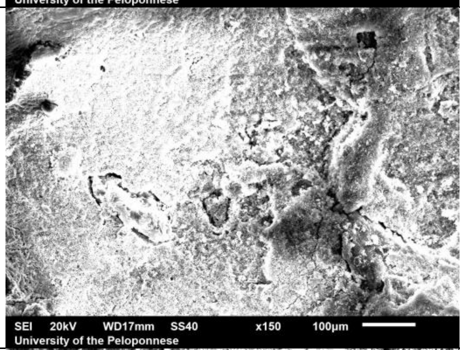
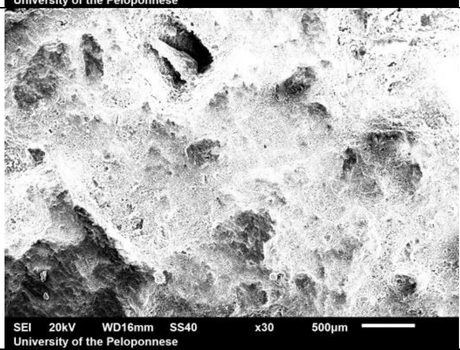
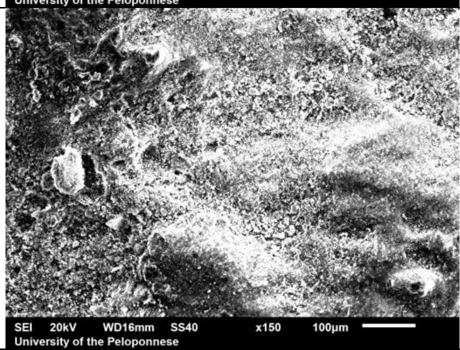
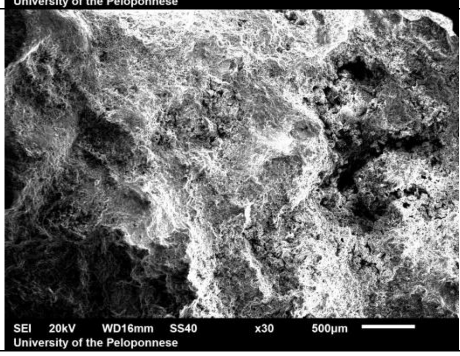
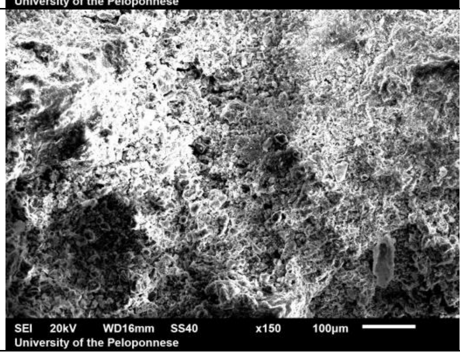
S1		
S2		
S3		
S4		

S5	 SEI 20kV WD16mm SS40 x30 500µm University of the Peloponnese	 SEI 20kV WD16mm SS40 x150 100µm University of the Peloponnese
S6	 SEI 20kV WD15mm SS40 x30 500µm University of the Peloponnese	 SEI 20kV WD15mm SS50 x150 100µm University of the Peloponnese
S7	 SEI 20kV WD18mm SS40 x30 500µm University of the Peloponnese	 SEI 20kV WD17mm SS40 x150 100µm University of the Peloponnese
S8	 SEI 20kV WD16mm SS40 x30 500µm University of the Peloponnese	 SEI 20kV WD16mm SS40 x150 100µm University of the Peloponnese
S9	 SEI 20kV WD16mm SS40 x30 500µm University of the Peloponnese	 SEI 20kV WD16mm SS40 x150 100µm University of the Peloponnese

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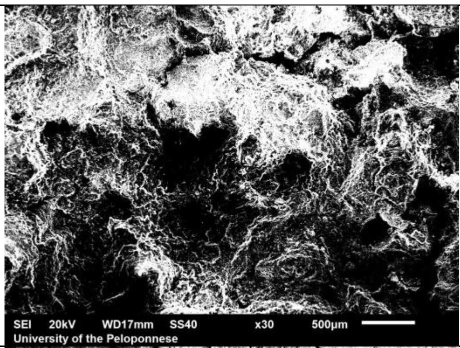
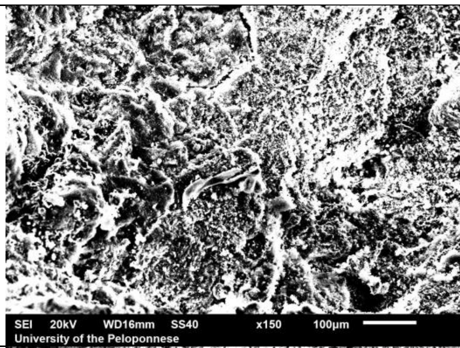
<tr><td>S10</td><td>
</td><td>
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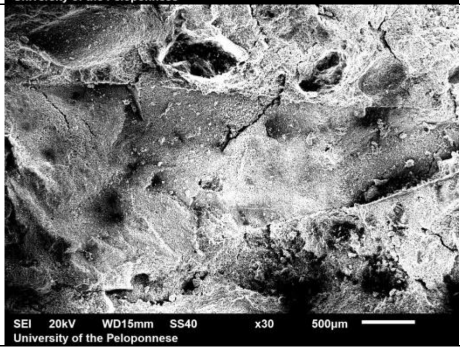
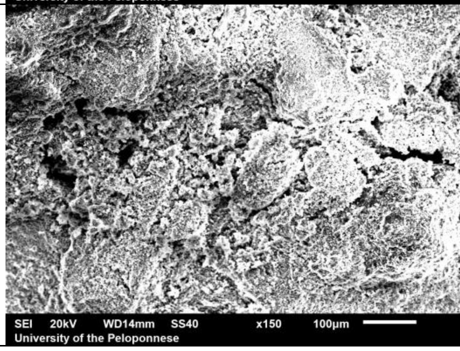
<tr><td>S11</td><td>
</td><td>
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