POLITECNICO DI MILANO

Faculty of Architecture and Society

Laurea Magistrale (Masters) in Architecture

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The Role of Structural Homogeneity in Seismically Active Historical Centers of Abruzzo

Castel del Monte, Castelvecchio di Calvisio, Santo Stefano di Sessanio, Villa Santa Lucia degli Abruzzi

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Academic Year: 2011/2012

Dedication:

I would like to dedicate this thesis to the memory of those
lost on April 6th, 2009 in the L'Aquila earthquake. You will not be forgotten.

Thanks:

First and foremost, I would like to thank the two primary figures in the development of my thesis.


Giuliana Cardani and Cat


Sandra Tonna

Without the dedication and commitment of my thesis advisor, Giuliana Cardani,
this thesis would never have reached the maturity and depth that it did.
I could not have asked for a better advisor. A million thanks!

In the development of this thesis, many hours were spent on-site, in all possible weather conditions.
There is no person I would have rather spent that time with than the Doctorate
student, Sandra Tonna, who made my time in the Baronia collective a real pleasure.
Ti voglio un sacco di bene mia pseudo-nonna!

Professionally, I would also like to thank the University of Padova,
as well as the four villages of Baronia for the research and work that they provided.

Last but not least, I would like to thank my friends and family.
Your love and support is what made this thesis possible.
I love all of you beyond what words can express. Thank you for everything!
A special thanks to mom and dad too!

Summary

On April 6th, 2009 an earthquake struck L'Aquila, Italy, at approximately 3:32 in the morning. The 5.8 magnitude earthquake on the Richter scale and 6.3 on the moment magnitude scale led to the deaths of 308 individuals and created mass destruction to the surrounded architecture. The devastating earthquake has revealed the vulnerability the region of Abruzzo is to large scale earthquakes, regarding the structural stability of the majority of the existing masonry architecture. While L'Aquila was the closest city to the epicenter of the earthquake, the initial shock and aftershocks were felt throughout the entire region of Abruzzo. Closer to the largest mountain in the area, the Gran Sasso, are four communities whose masonry typology and construction history are typical of the entire Abruzzo region.

The communities of Castel del Monte, Santo Stefano di Sessanio, Castelvecchio di Calvisio and Villa Santa Lucia degli Abruzzi are four of the villages of the Baronia Cerepelle, who have created a political collective that will begin the restoration of their respective regions. All four of these villages have fortunately had either few or no serious collapses or damages due to the 2009 earthquake. This leaves the opportunity to preserve the existing structures and protect the local patrimony through restorative efforts. This thesis therefore aims to analyze the construction history, masonry typologies, building typologies and overall structural homogeneity of these four particular communities to better understand their vulnerability to future earthquakes and identify the key changes necessary for an efficient restorative effort. This analysis has been based on on-site observations, on-site analysis and information graciously provided by each community as well as the University of Padova.

Sommario (in Italiano)

La notte del 6 Aprile 2009 una forte scossa di terremoto colpì la città de L'Aquila, Italia, intorno alle 3:32. Il terremoto di 5.8 sulla scala Richter e 6.3 sulla scala di momento magnitudo uccise 308 persone e creò un danno enorme a tutto il patrimonio architettonico dell'area. Tale grave terremoto ha rilevato la vulnerabilità dell'intera regione Abruzzo ai grandi eventi sismici, in particolare delle strutture storiche in muratura. Mentre L'Aquila si è ritrovata la città più vicina all'epicentro del terremoto, lo shock iniziale e le scosse furono sentite in tutti i borghi della regione d'Abruzzo. Tra questi vi sono quattro borghi, localizzati vicino alla montagna più grande dell'area, il Gran Sasso, che presentano una tipologia muraria e storia costruttiva simile e tipica della regione.

I borghi di Castel del Monte, Santo Stefano di Sessanio, Castelvecchio di Calvisio e Villa Santa Lucia degli Abruzzi (AQ) sono quattro dei borghi appartenenti alla storica Baronia di Carapelle e, dopo il sisma, hanno creato in accordo una convenzione politica con l'Università per realizzare ciascuno il piano di ricostruzione e ripianificazione del territorio comunale, definendo le linee di indirizzo strategico per assicurarne la ripresa socio-economica, la riqualificazione dell'abitato e garantendo un'armonica ricostruzione del tessuto edilizio urbano abitativo e produttivo.

Tutti i quattro borghi hanno fortunatamente subito pochi o quasi nulli danni seri a causa del terremoto nel 2009. Esiste quindi ancora l'opportunità di preservare le strutture storiche esistenti e proteggere il patrimonio locale attraverso un opportuno restauro conservativo. La tesi parte dall'analisi della storia costruttiva, delle tipologie murarie riscontrate, delle tipologie edilizie e dell'omogeneità strutturale degli edifici storici in muratura appartenenti a questi quattro borghi, con la finalità di comprendere in modo speditivo la loro vulnerabilità sismica e per identificare i possibili interventi necessari per un restauro efficace. Quest'analisi si è basata sulle osservazioni svolte in sito e sulle informazione gentilmente fornita dai comuni e dall'Università di Padova, con la quale il Politecnico di Milano ha collaborato nella convenzione.

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Italian/English Dictionary

While this thesis is written in English, much of the primary research and on-site work was completed in the Italian language. In order to provide clarity, this is a concentrated dictionary, included in order to define terms used throughout this entire thesis. Much of the Italian vocabulary comes from the local Abruzzo dialect and therefore has no formal translation in English. These terms will be defined here in English and will be henceforth referred to in the following ways:

Original Italian:	**English Translation:**	**Notes:**
Contrafforte	Buttress	
Capochiave	Anchor Rod	
Catene	Tie Rod	
Sporto	Arched Overpass	From local dialect
Curve di Livello	Elevation Curves	
Muratura	Masonry	
Pietra	Stone	
Laterizio	Brick	
Cantonale	Building Corner	
Tipologia Edilizia	Building Typology	
Tipologia Muraria	Masonry Typology	
Rudere	Ruin	
Casa Muro	Historical Boundary Wall House	
Casa Blocco	Block House	
Profferlo	Frontally placed exterior masonry stair	
Basamento	Base	
Scarpe	Spur Buttress	

Aggregato	Aggregate	
Castel del Monte	CdM	Short name used in figures
Santo Stefano di Sessanio	SSS	Short name used in figures
Castelvecchio di Calvisio	CvC	Short name used in figures
Villa Santa Lucia degli Abruzzi	VSL	Short name used in figures

Introduction:

The Seismic event of April 6th, 2009 in the Abruzzo region of Italy led to over 300 deaths and destroyed a large amount of the surrounding architecture and infrastructure. The earthquake also emphasized the vast vulnerability of masonry structures in the Abruzzo region to seismic events. Outside of L'Aquila, the epicenter of the earthquake, are four hill side villages that are architecturally representative of the typology of historical centers in Abruzzo. The four villages that make up the Baronia community include Castel del Monte, Castelvecchio di Calvisio, Santo Stefano di Sessanio, Villa Santa Lucia degli Abruzzi and several others. While there were several minor damages following the earthquake, there was only one notable structural collapse within the Baronia communities; the central Medicea tower in Santo Stefano di Sessanio. Due to the low amount of seismically induced damages and small populations in all four of the villages, they are a prime location for analyzing the structural vulnerabilities of typical historical centers in the Abruzzo region.

In general, the key aspects of a structure that leave it vulnerable to collapse in the case of a seismic event can be described as a lack of structural homogeneity. This homogeneity can be seen on both a micro and macro scale. The micro scale includes individual sections of a structure or the building as a whole, while the macro scale includes aggregates of buildings that are adjacent or connected to one another. The central principle of anti-seismic design is to eliminate architectural irregularity and therefore allow structures or aggregates of structures to act as a single unit. The key is to maintain regularity in plan and elevation, of both stiffness and mass distribution. This will then help to minimize or avoid the concentration of stresses within a single structure or aggregate of buildings. Failing to create situations of structural homogeneity can lead to several types of structural failure, including soft story failure, poor connection failure and failure created by the pounding of two connected structures.

The analysis of the structural homogeneity of the communities of Baronia has been achieved by observing and noting several characteristics of all the buildings located within the historical centers of all four of the villages. These characteristics include the building typologies, masonry typologies, building heights, location of both permanent and temporary interventions, openings, orientation to the elevation curves and the location of arched overpasses (known as "sporti" in the local Abruzzo dialect). All of these elements play a role in the possible vulnerability a structure or aggregate is to a seismic event. Therefore all of these elements are analyzed individually and then combined together to create a concrete conclusion of which specific structures are the most vulnerable and therefore deserve the most attention regarding restoration efforts. The habitation, building uses (public or private) and post-seismic damage levels have also been noted and strongly taken into consideration when concluding which structures deserve the most attention. It is through these conclusions, based on all possible factors that influence structural homogeneity, that the communities of Baronia will hopefully be able to move their restorative efforts forward. These conclusions are not meant to be taken alone, but instead used as an addition to the already existing restorative analysis being conducted by the University of Padova, with the support of the four municipalities within the Baronia collective.

This thesis will begin by first introducing the region of interest as well as the four communities within the Baronia collective to be analyzed. This section will also heavily focus on the seismic history of this region as well as the collective knowledge of anti-seismic design seen in both recent and historical structures. The introduction will then continue by defining all of the structural factors to be analyzed as well as the potential collapsed mechanisms related to these factors. This thesis will then diverge into the four separate villages, analyzing all possible structural factors that influence the villages' structural stability and then will finally make a vulnerability conclusion to determine the aggregates and individual buildings in all four villages that are the most deserving of restorative efforts. This conclusion will be based on the combination of both major and minor structural factors, as well as building inhabitation and previous restorative efforts.

Each village will be discussed in an individual section. This section begins with an introduction presenting the location, history and other background information on the village. Then the four main structural elements, all of which were observed and analyzed on site, will be discussed based on their prevalence and characteristics in each commune. These four factors include building typology, orientation to the elevation curves, building heights and masonry typology. These factors are considered the most prominent indicators of structural vulnerability in the case of a seismic event. These factors, as well as others to be discusses later in each village's section, are combined in each aggregate to then determine a collective homogeneity analysis.

The analysis for each village will then continue into collective homogeneity analysis that combines the homogeneity of each of the four previously mentioned factors in order to determine the collective structural homogeneity of the individual aggregates. Using this information, both negative and positive examples have been chosen to better determine the aggregates and individual structures with a greater need of restorative efforts. Due to the lack of available public funds, these priorities are also based on several other factors, such as building uses, building habitations and previous restoration elements. In addition, several other less important structural factors are considered due to their possible influence on the potential collapse mechanisms of a structure. Ruins are also analyzed in order to determine the possible cause of collapse to minimize this effect on the currently standing structures.

The minor structural factors considered for each of the four villages include openings, permanent structural interventions and temporary structural interventions. Each of these can influence the overall structure if placed improperly. Typically on their own they cannot produce major structural collapses, but in combination with structurally instable major factors, they can produce extremely vulnerable structures in the case of a seismic event.

To conclude each village, information provided by the University of Padova as well as each of the four villages is analyzed. This information includes the post seismic damage assessments as well as the subsequent post seismic restoration priorities. All of this information then culminates in an overall vulnerability conclusion which strives to define a hierarchy of the need for substantial structural restorations within the four aggregates. This information will follow the graphical guidelines provided by the post seismic restoration priorities of the villages in order to compare the two to possibly propose a compromise.

Once all four villages have been concluded, this thesis will then compare all four of the individual villages to one another regarding the amount of restoration required in order to defend both the cultural patrimony and population present in the villages of Baronia. Comparisons will also be made to the United States of America, where the defense of cultural patrimony is extremely high due to its lack of availability. This comparison will then lead into the structural interventions necessary to achieve the desired restoration results. There is no question that these villages will continue to experience seismic activity for the foreseeable future. Therefore it is essential and economically responsible to protect these villages now before future seismic damages make that impossible. Although there are limited public funds available, restoration is always the least expensive choice. However this restoration must be completed in a responsible manner that respects the existing structural dynamics and construction typologies present within these historical centers. As was seen in the case of the Medicea tower of Santo Stefano di Sessanio, which will be discussed in further detail later in this thesis, a lack of respect and continuity with the existing structures can not only hinder their performance but even lead to partial or total collapses in buildings that were considered to be designed properly for seismic events before the restorative effort.

1 BACKGROUND INFORMATION

1.1 Localization

Four villages that are a part the Baronia collective are located in the Central Eastern section of the Italian peninsula. Castel del Monte, Castelvecchio di Calvisio, Villa Santa Lucia degli Abruzzi and Santo Stefano di Sessanio are situated in the L'Aquila province within the Abruzzo region. The four communities are approximately 160 kilometers North-East of the Italian capitol of Rome, 60 kilometers South-West of Pescara and 30 kilometers East of L'Aquila, the capitol of the Abruzzo region and the closest city to the epicenter of the April 2009 seismic event. The region has been

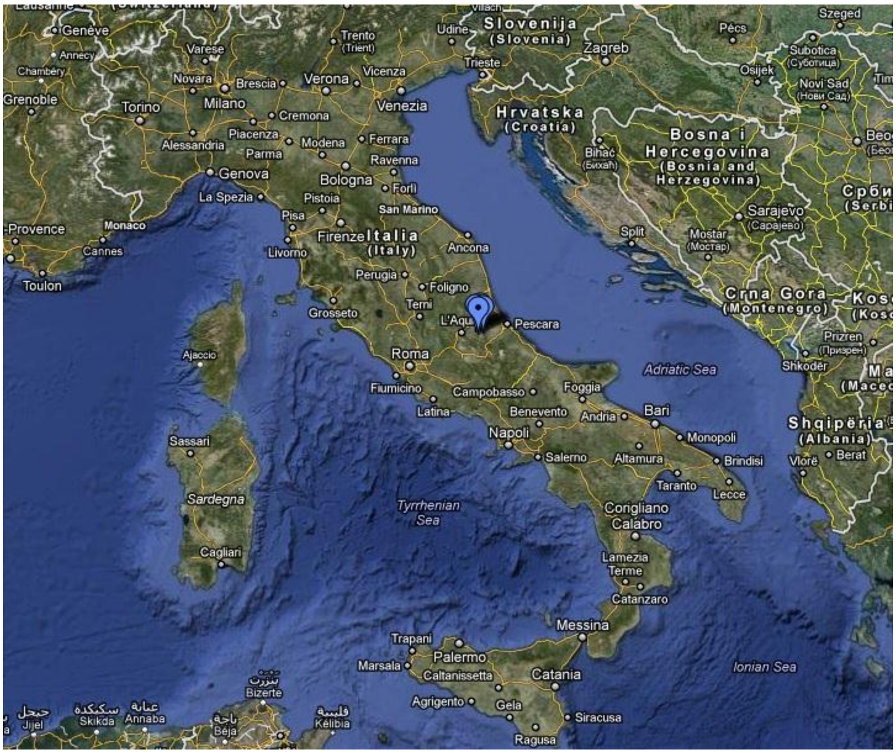


Figure 1.1 Localization of Baronia Communities in the Italian Peninsula (maps.google.com)

characterized by extensional tectonics for the last 5 million years, since the Pliocene epoch. In general, the faults in the region are active and trend from North-West to South-East. Due to this quality, one of the most prominent features of the region is the Gran Sasso Mountain. In addition there is a high plain, known as the Campo Imperatore. Both the mountain and the plain are located within the Gran Sasso and Monti della Laga National Park, along with all of the villages in the Baronia collective.

The communities of Baronia, along with 13 other villages, are also a part of the combined collective of mountain communities known as the Campo Imperatore – Piana di Navelli collective.

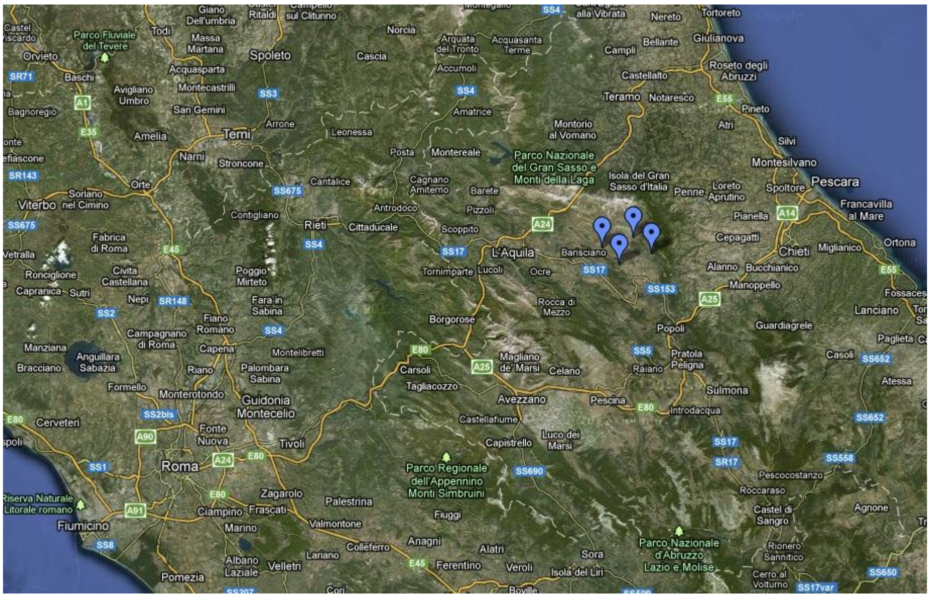


Figure 1.2   Localization of the Baronia Communities in Central Italy (maps.google.com)

They are all located directly South of the largest mountain in the area, the Gran Sasso mountain. They are also located between the larger cities in the area; L'Aquila and Chieti. Regarding their orientation to one another, they are grouped in sets of two. On the Eastern side of the Campo

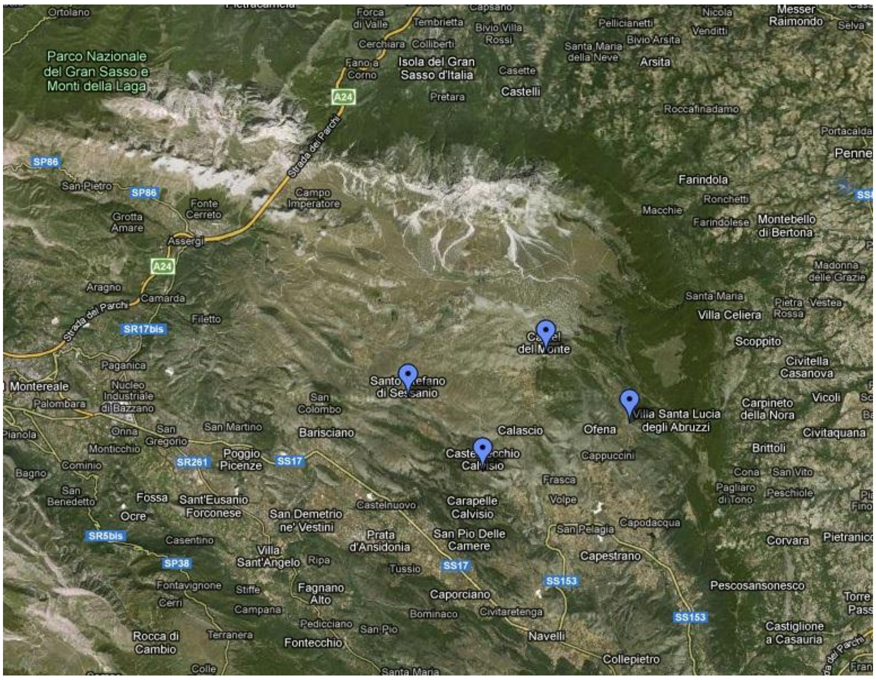


Figure 1.3   Localization of the Baronia Communities to one another (maps.google.com)

Imperatore plain lies Castel del Monte and Villa Santa Lucia degli Abruzzi. On the Western side of the plain are Santo Stefano di Sessanio and Castelvecchio di Calvisio. The elevations of the four villages vary greatly. Castel del Monte is the highest at 1,346 meters above sea level, followed by

Santo Stefano di Sessanio (1,251 meters), Castelvecchio di Calvisio (1,045 meters) and finally Villa Santa Lucia degli Abruzzi (850 meters). They also strongly differ in overall size. Castel del Monte is the largest at 57.83 square kilometers, then Santo Stefano di Sessanio (33.14 square kilometers), Villa Santa Lucia degli Abruzzi (27.84 square kilometers) and finally the smallest is Castelvecchio di Calvisio (15.04 square kilometers).

1.2 Population

Similar to many of the villages in the surrounding area, the communities of Baronia have extremely small populations. Besides Castel del Monte, all of the villages reached a population high at the time of the 1901 Italian census. Castel del Monte would not experience its own population high until the 1921 census. According to the Italian National Institute for Statistics, as of December 31, 2010 the populations of the Baronia communities are as follows; Castel del Monte has 508 inhabitants, Castelvecchio di Calvisio has 187, Villa Santa Lucia degli Abruzzi has 174 and Santo Stefano di Sessanio has 120. As seen in the diagrams below, the two most populated villages in the commune progressed in a similar matter. Both slowly grew until 1921, when the population began to

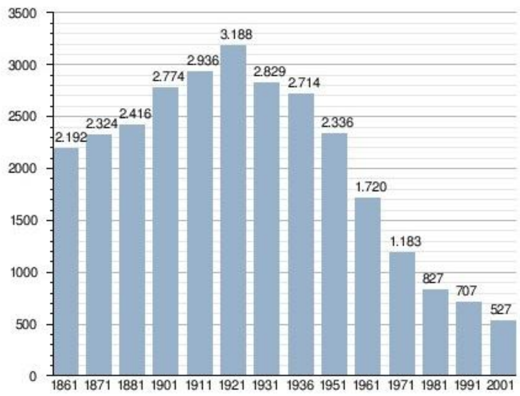


Figure 1.4 Castel del Monte (istat.it)

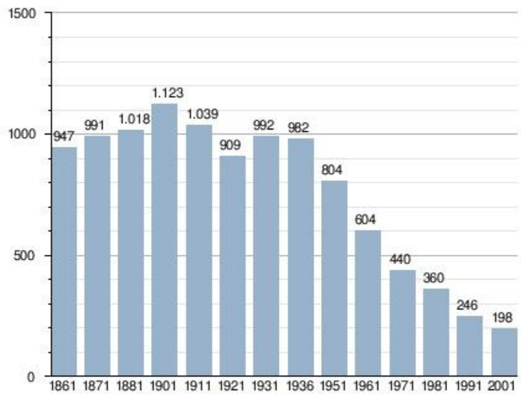


Figure 1.5 Castelvecchio di Calvisio (istat.it)

fall following the First World War. Once again, after the Second World War, there was another significant decrease in population size. Much of the population immigrated, due to a lack of work, to other parts of Italy or abroad to countries such as Canada and the United States of America. However, in the case of Villa Santa Lucia degli Abruzzi, there was a large population spike in 1901 which immediately trailed off. The most irregular of the group, Santo Stefano di Sessanio,

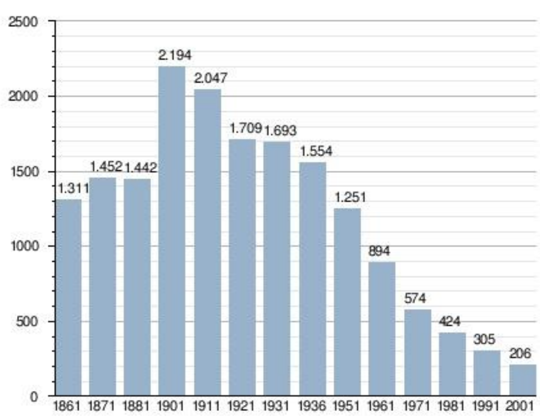


Figure 1.6   Villa Santa Lucia degli Abruzzi (istat.it)

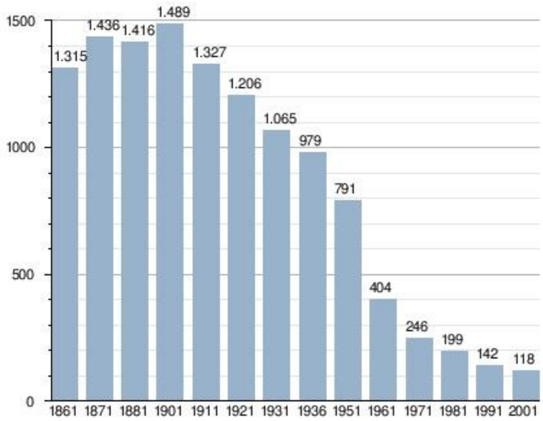


Figure 1.7   Santo Stefano di Sessanio (istat.it)

maintained a similar population until a dramatic drop off after 1951, immediately following the Second World War. The population statistics for all four of the Baronia villages are extremely noteworthy considering the amount of structural interventions or restorations completed in these areas. The villages that maintained higher populations, such as Castel del Monte and Villa Santa Lucia degli Abruzzi have experienced significant structural changes since the villages' original construction. These changes include enlargements, transformations, added floors, replaced floors and roofs. However, in the cases of Castelvecchio di Calvisio and Santo Stefano di Sessanio, their strong downfalls in population size have contributed to the maintenance of much of the original construction.

1.3 Geological Qualities

Beyond the population, the architecture of the region has been strongly influenced by the geographical and geological qualities of the area. The region is geologically defined by the Apennine Mountain range that extends 1,200 km along the length of the Italian peninsula. The entire mountain range is split into three separate smaller chains. Of these, only the Central Apennine chain is present in the region of Abruzzo. While the Italian peninsula lies in a tectonically complex region, the Central Apennines are characterized by extensional tectonics. In general, most of the active faults within the region are normal in type and run from Northwest to Southeast. All seismic events in the region are caused by an extension, which is due to the back-arc basin in the Tyrrhenian Sea, which is opening faster than the African Plate is colliding with the Eurasian Plate. The mountainous landscape and

Figure 1.8 Relief map of the Apennines (Wiki)

seismic risks have led to an architectural typology consisting of several medieval and Renaissance hill towns, built primarily in masonry. All four of the Baronia communities discussed in this thesis fall under this category. In addition, many of the villages within the region are characterized by massive defensive walls. The seismic behavior of the region has also led to the addition of several permanent structural interventions, such as buttresses, scarp walls, tie rods and partial reconstruction of collapsed portions. In most cases, these interventions function well, but in others the vulnerability has remained.

1.4 Seismic Fault Lines

The region has experienced seismic events long before the Baronia communities were built, approximately in the thirteenth century. The region is considered to be the best seismatonically known area in Italy. The Baronia communities are mostly affected by earthquakes caused by the Paganica and Bazzano faults. The four Baronia villages lie to the East of these two existing active faults. The Paganica fault, responsible for the 2009 L'Aquila earthquake, is characterized by normal kinematics, a Northwest-Southeast strike and a length ranging between eleven and

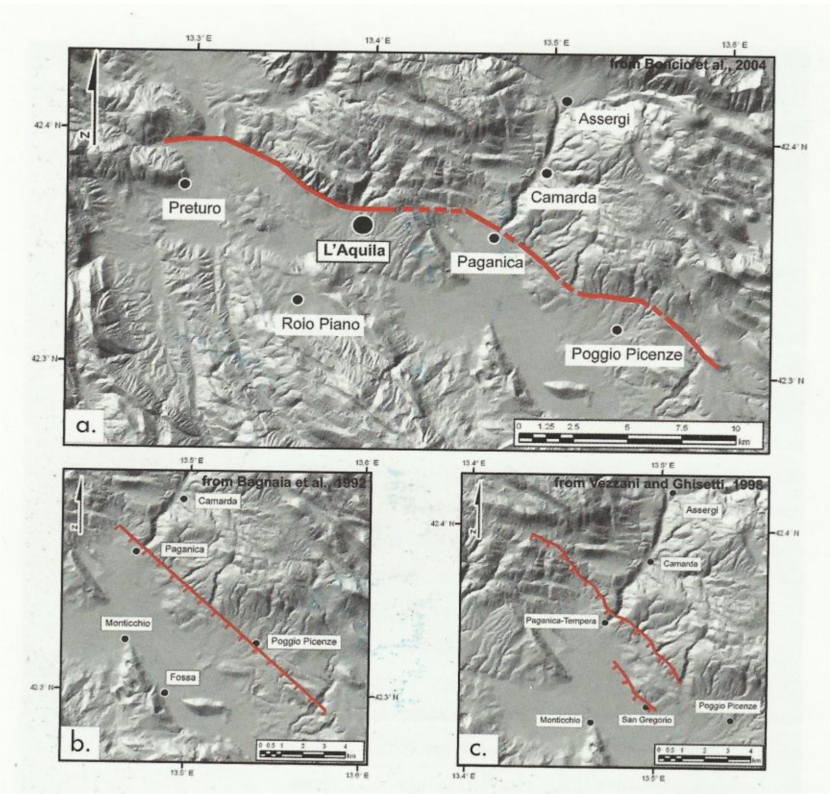


Figure 1.9 Paganica Fault (a. Boncio,04, b. Bagnaia,92, c. Ghisetti,98)

eighteen kilometers. The uncertainty of the length is related to the association to the same structure of small sections to the North. Similar to other faults in the Central Apennine Mountains, the Paganica fault bounds to the East a sedimentary basin filled with course alluvial and slope deposits close to the mountain front. The Paganica fault is generally agreed to be the cause of the 1461 earthquake, today considered to be a twin of the 2009 L'Aquila seismic event.

1.5 Seismic Zone Classifications

It is the many faults along the Central Apennine Mountains, such as the Paganica fault, that have led to the area being considered one of the most seismically dangerous areas in Italy. L'Aquila however was not legally assessed as seismic by the building region code until after the 1915 Fucino earthquake. In 1927 the seismic codes were finally introduced and the L'Aquila region, as well as all four villages within the Baronia collective, was assigned to zone 2. As seen in the figure below, there

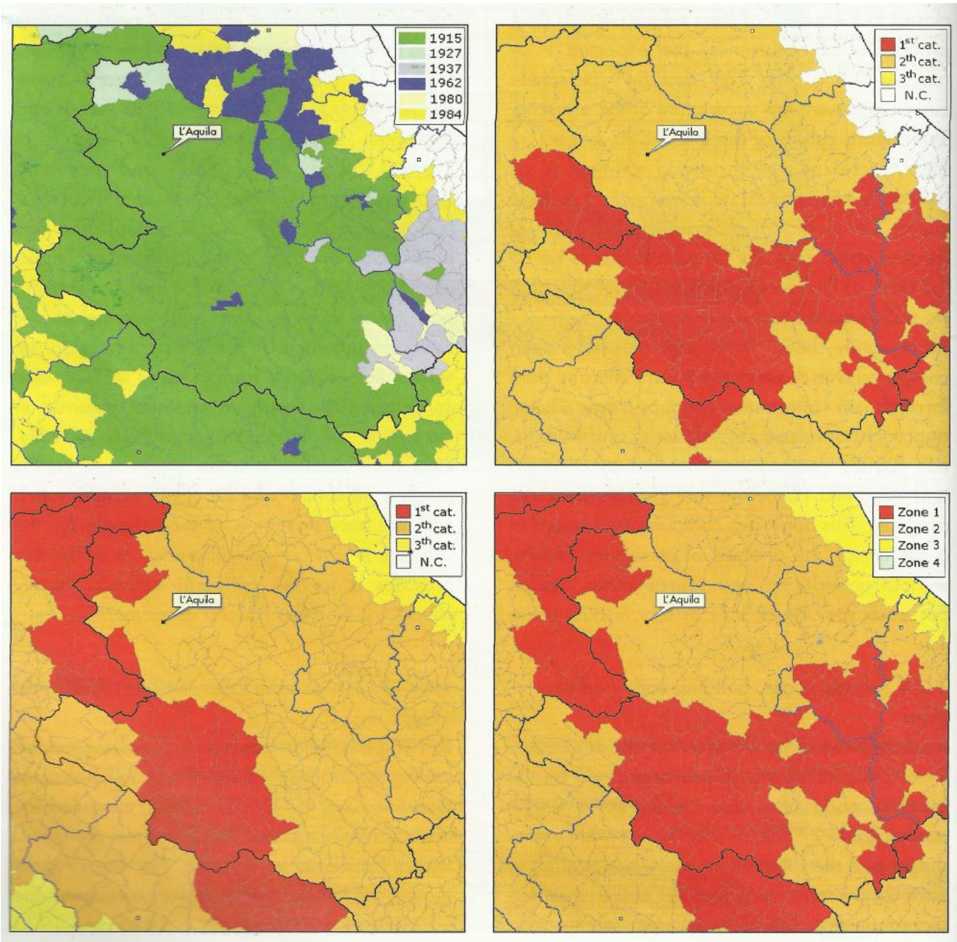
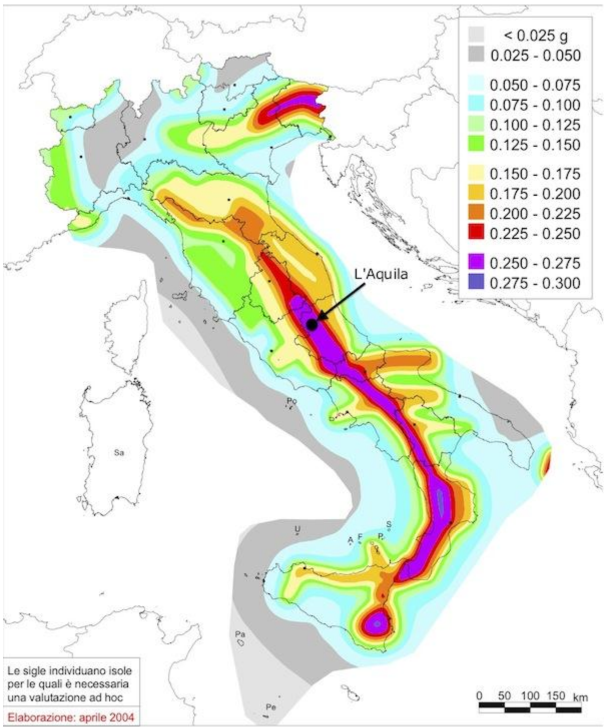


Figure 1.10 a: First Assignment b: 1984 Seismic Zoning c: 1999 Proposed Zoning d: 2003 Seismic Zoning (ingv.it)

were several seismic zoning changes within the region. Three official changes occurred in 1984, 1999 and again in 2003. However in all three zoning changes, L'Aquila and the communities of the Baronia collective remained in zone 2. As of the most recent building code, the areas defined as zone



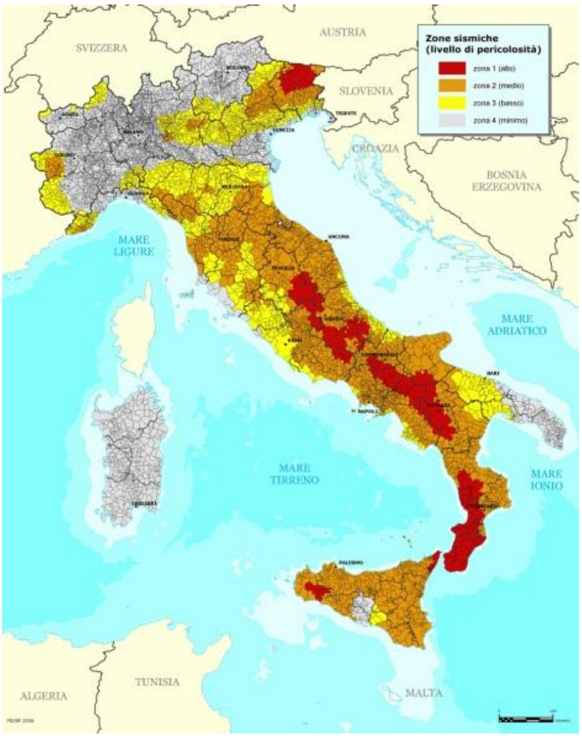


Figure 1.11 Seismic Zone Map (protezione.civile.gov.it) *Figure 1.12 Maximum Seismic Acceleration Map (ingv.it)*

one are beginning to surround L'Aquila to the South. This has led many to argue that L'Aquila should be redefined as a zone one area. However despite the legal status a zone one region maintains, there is little to no difference regarding the actual building requirements. Despite lying in a zone two area, the region is still extremely at risk regarding seismic events, as seen during the 2009 earthquake. In comparison to the rest of the Italian peninsula, the region is one of the four most seismically active regions within Italy. The two figures above are the most recent seismic maps for the Italian peninsula. The first has been provided by the Italian Civil Protection agency and it refers to the legal categorizations throughout Italy. As noted, L'Aquila is defined as zone 2, however it is clearly in the vicinity of one of the four major zone 1 regions of the country. The second figure however represents the maximum ground acceleration caused by seismic activity. The map has been provided by the Italian national institute of Geophysics and Volcanology. It specifically expresses the maximum ground acceleration that has a 10% probability of being exceeding in the next fifty years.

Again, L'Aquila and its surrounding communities find themselves in an extremely vulnerable region, considering the possibility of seismic events.

1.6 Seismic History

The city of L'Aquila, as well as the villages within the Baronia collective has a remarkable seismic history which implies a strong familiarity with seismic damage, as seen through the existing architecture. The first recorded earthquake in the L'Aquila region occurred on December 3rd, 1315. Other significant earthquakes have also struck in 1349, 1452, 1461, 1501, 1646, 1706, 1786, 1958 and the most recent in 2009. Of these, the most severe was that of 1703, while the deadliest was that

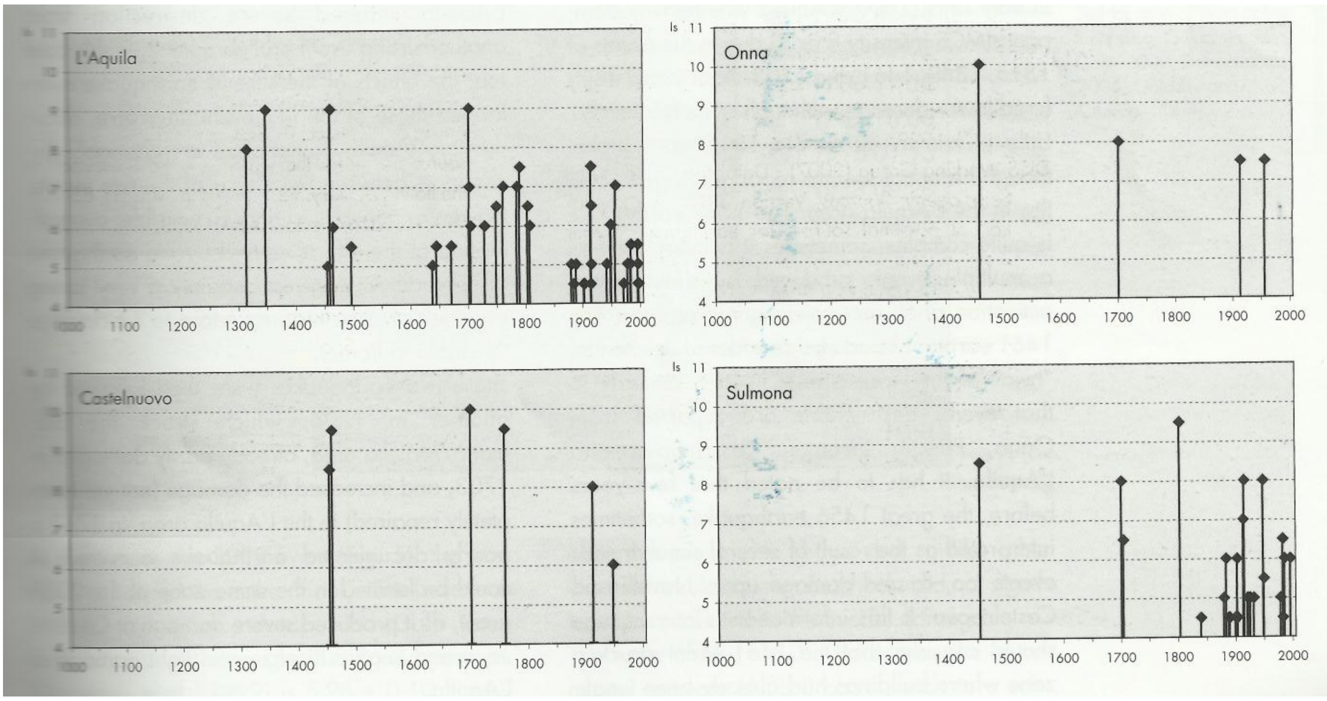


Figure 1.13 Historical earthquakes in L'Aquila, Onna, Castelnuovo and Sulmona (ingv.it)

of 1786. Today, the earthquake that struck L'Aquila in 1461 is considered to be a potential twin for the 2009 seismic event. Both events reported similar damages from the surrounding cities of Onna, Poggio, Picenze, Castelnuovo and L'Aquila. The existing architecture of the region shows substantial record of post-seismic repairs and seismic reinforcements. These can be seen throughout all four of the Baronia communities with the use of scarp walls, buttresses and tie rods. In many cases, a clear knowledge of anti-seismic design is present in construction techniques that considered the vulnerability of masonry structures to seismic events. These techniques often brought about seismic improvements within the limits of the techniques available, eliminating weaknesses and introducing protective measures. Unfortunately, more recent transformations appear to be linked to damages after the 2009 earthquake. This is the case for the collapse of the Medicea central tower in Santo Stefano di Sessanio, which will be described in further detail later in this thesis.In general these negative interventions were substitutions of original roof coverings for new ones, typically made from reinforced concrete with hollow or infill panels, or with metal beams, instead of matching the original wooden structure. Such interventions are one of the primary causes of many of the structural collapses following the 2009 L'Aquila earthquake.

1.7 2009 Seismic Event in L'Aquila

The 2009 seismic event is the third strongest seismic event producing strong motion records in Italy, following only the 1980 Irpinia and 1976 Friuli earthquakes. The largest shock struck South of the L'Aquila area at 3:32:39, the morning of April 6th, 2009. The epicenter was located at approximately 42.334 northern latitude and 13.334 eastern longitude. The main shock was officially rated 5.8 on the Richter scale and 6.3 on the moment magnitude scale. Preceding the main shock were several hundred foreshocks, beginning in December 2008. Of these, 30 had a Richter magnitude greater than 3.5. The aftershocks of the seismic event would not conclude until September 24th, 2009. The largest aftershocks occurred quickly following the main event, on April 7th and April 9th, rated 5.3 and 5.1 respectively on the Richter scale. The area struck belongs to the seismic zone 923 and is characterized by expected peak ground acceleration values with 10% probability of exceedence in 50 years slightly higher than .25g. The seismic zone 923 is described as having average depth (8-12 km), prevailing faulting mechanism of the main earthquakes (normal type), expected maximum of 7 on the Richter scale and a b-value of the G-R relation equal to 1.05. The data from the April 2009 seismic event matched what is to be expected in the 923 seismic zone, specifically the estimated hypo central depth (9.5km) and the faulting mechanism (normal). While this particular seismic event created mass destruction and shocked the region, the characteristics of this earthquake match what is to be expected in this region, both now and in the future. In fact, several geophysical and volcanology scholars had suggested that this region was one of four within the Italian peninsula that should expect a devastating seismic event within the near future.

1.8 Building Typologies

In many cases, the damages sustained during the 2009 L'Aquila seismic event were directly related to the building typologies present in the area. While the building typologies present in the four villages within this thesis vary, within the overall Baronia collective, there are six building typologies. These typologies include historical boundary wall houses, tower houses, buildings oriented parallel to the elevation curves, buildings oriented perpendicular to the elevation curves, block houses and churches/religious structures. Both Castel del Monte and Santo Stefano di Sessanio contain all six of these building typologies. Villa Santa Lucia degli Abruzzi and Castelvecchio di Calvisio both share a lack of the tower house typology. Separately Villa Santa Lucia degli Abruzzi lacks the historical boundary wall house typology while Castelvecchio di Calvisio has no block houses present within the historical center. Each of these building typologies is unique with regards to their individual potential collapse mechanisms. For this reason, each of these six building typologies will be analyzed regarding their individual vulnerabilities, which will play a large role in selecting the final vulnerable aggregates within each of the four villages present within this thesis.

1.8.1 Historical Boundary Wall Houses

All of the villages discussed in this thesis, except Villa Santa Lucia degli Abruzzi, are defined by their massive defensive wall, surrounding their original historical centers. In general, these structures are of higher quality regarding masonry strength and they are also some of the oldest structures within the historical center. In addition, due to their importance within their respective villages, many of them have been restored on numerous occasions or have had permanent structural interventions added to the original structure, such as tie rods or buttresses. Similar to typical row houses, there are many potential collapse mechanisms related to historical boundary wall houses. Primarily, the reaction between the individual houses can create damages, specifically during seismic events. As seen in diagram 1.14 , the most common collapse mechanism is that of the last building of the row house. The laterally directed weight of the other buildings within the row can exceed the

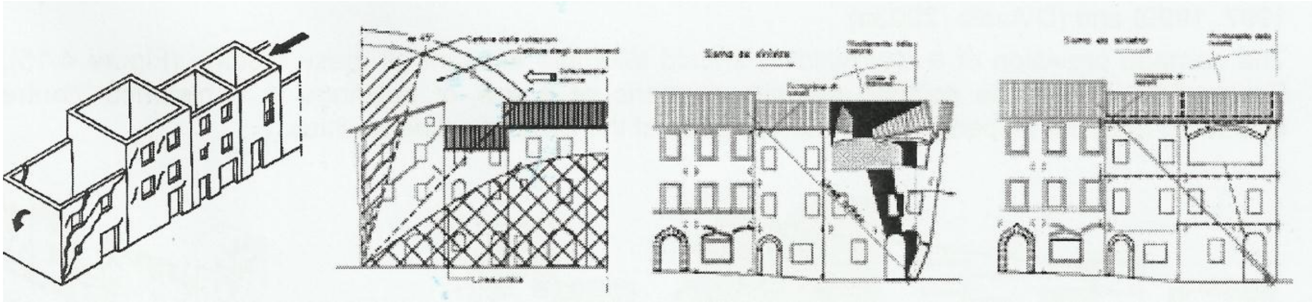


Figure 1.14 Potential Collapse Mechanisms of Row Houses (Gurrieri, 1999 and Avovio, 2002)

maximum lateral bracing capacity of the end building. Another common collapse mechanism for both historical boundary wall houses and row houses, is caused by irregularity in plan. As seen in diagram 1.15, when particular houses within the aggregate project outward from the row houses, this can accumulate stress at several points in the projected structure and the buildings directly attached to it. Damages due to the lack of alignment in a row of houses are generally located primarily along the corners of the projected structure or directly attached structures.

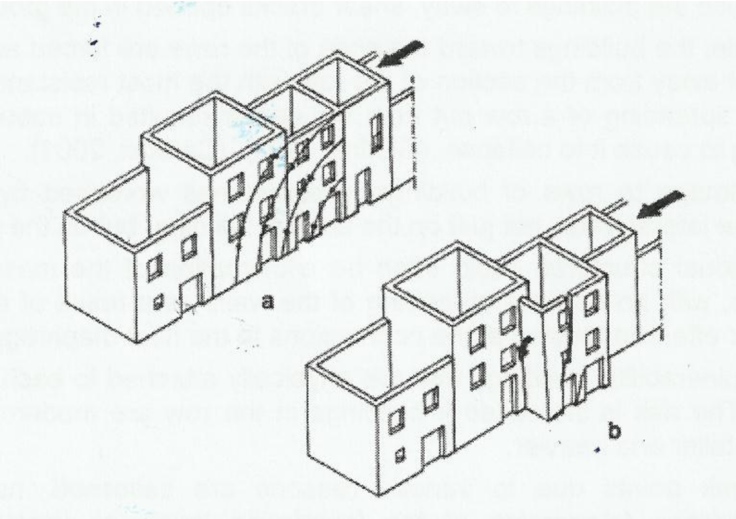


Figure 1.15 Damages due to lack of alignment (Gurrieri, 1999)

1.8.2 Tower Houses

Another prominent building typology present in the villages of the Baronia collective is the tower typology. As will be seen in further detail in the "Building Heights" section, towers can create several potentially dangerous structural mechanisms due to the height difference between a tower and the surrounding structures. This is specifically important when the tower is attached directly to other structures. There are four general types of localizations of towers within an aggregate. These include, but are not limited to, isolated, corner, included and projecting connection conditions. While an isolated location is the preferred location of a tower, within an aggregate the preferred is included, due to the better bracing of the structure on two opposite sides. The corner condition can create potential collapse mechanisms due to the uneven attachment on two adjacent sides of the tower.

The most potentially dangerous points regarding a tower as a part of an aggregate, are the points where the tower touches the roof structures of the attached buildings. When a lateral motion

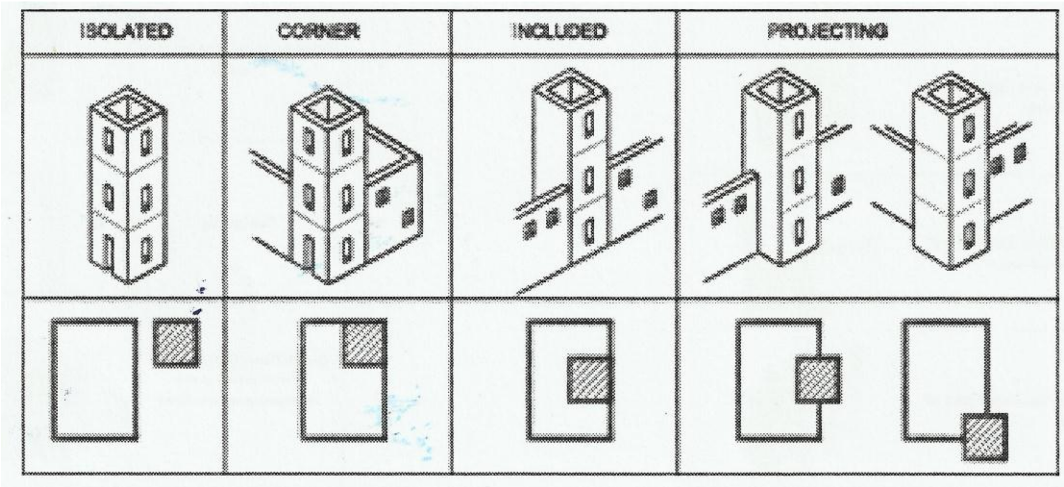


Figure 1.16 Position of the tower in the urban context (Sepe, 2008)

is added, in the case of a seismic event, these points can function as fulcrum points, where the tower structure can potentially collapse onto one of the surrounding structures. These will not only create damage to the tower itself but also potentially cause damage to the surrounding structures both attached to the building and in the area. Towers out of the urban context or isolated are the best position possible, as is the case with block houses as well. This was seen directly in the case of the Santo Stefano Medicea tower, that when collapsed, did not create mass damage to the surrounding architecture as would have been the case if the three towers of Castel del Monte had collapsed during the most recent seismic event.

1.8.3 Buildings Oriented Parallel/Perpendicular to the Elevation Curves

One of the most important characteristics of line houses is their orientation to the elevation curves, which will be discussed in further detail in the "Orientation to Elevation Curves" section of each village. Besides a few exceptions, the row house building typology can be split into separate categories, either oriented parallel or perpendicular to the elevation curves. This orientation, while not definitely implicative of structural stability, tends to play a role in the potential collapse mechanisms of an overall structure. While orientation to the elevation curves may not create damage, it can potentially worsen existing conditions of wall overturning. In the villages of Baronia, there was a substantial connection made between collapsed structures or ruins and a perpendicular orientation to the elevation curves. Buildings are stronger if oriented directly parallel to the elevation curves and worst if oriented at a non 0 or 90 degree angle. These orientations to the elevation curves can increase the amount of torsion present in a structure and thus increase existing potential collapse or damage mechanisms.

1.8.4 Block Houses

All of the villages discussed in this thesis, with the exception Castelvecchio di Calvisio, have block houses present within their historical centers. This particular building typology is rare within the historical centers of Abruzzo, due to the fact that most historical centers are composed of aggregates of structures. Block houses instead are isolated structures with no structural connections to adjacent buildings. This therefore minimizes the structural factors that play a role in these structures' reactions during a seismic event. Block houses are not structurally dependent on surrounding structures and therefore collective homogeneity analysis is unnecessary. This means that the masonry typology as well as orientation to the elevation curves (at an angle or not) become essential in analyzing a block structure's potential vulnerability to seismic activity. In addition, the homogeneity of the structure regarding additions and renovations also becomes increasingly important. These additions to block houses can have a major influence on the structural systems present regarding potential collapse mechanisms. It is also important to note the heights of these structures because in the case of a collapse, they can damage adjacent buildings within their vicinity. However of all the building typologies present in the Baronia collective, they are one of the least complex regarding structural vulnerabilities in seismic events.

1.8.5 Churches or Religious Structures

In general, churches are the most structurally sound regarding masonry typology, due to the high quality of masonry and construction techniques utilized. However due to their high use, irregular plans and towers, they can be highly dangerous in the case of a seismic event. As seen in L'Aquila, the city closest to the 2009 earthquake, many of the collapsed buildings were in fact churches that suffered failures due to their heights, façade irregularities and several other potential collapse mechanisms. Churches and religious structures are also used by a majority of the population thus increasing the potential casualties in the case of a seismic event while the church is in use. Therefore in this thesis, both churches and religious structures will be given a strong emphasis when considering the aggregates and structures most vulnerable and deserving of restorative efforts.

1.9 Orientation to Elevation Curves

As previously discussed, the orientation to the elevation curves, specifically within a single aggregate, is extremely important. This is due to the fact that the orientation of a building to the

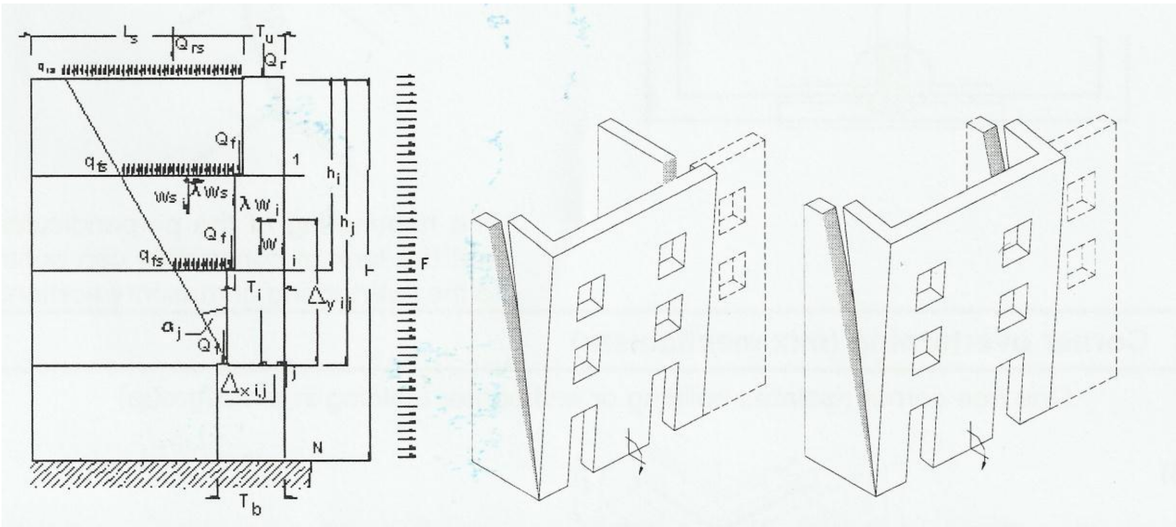


Figure 1.17 Overturning of one or two side wings (NIKER)

existing elevation curves is most closely related to the collapse mechanism known as wall overturning. The overturning of a wall can be caused by many reasons, but in general it is created by

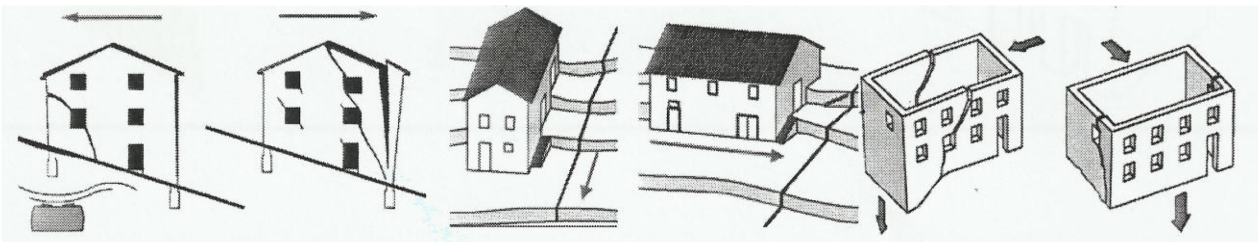


Figure 1.18 Diagram of how slope can worsen wall overturning (Borri, 2004 and Carocci, 2001)

the lack of connection between the façade and the interior or other exterior elements. One of the most common retrofitting anti-overturning interventions is the placement of tie rods. Tie rods are placed between two opposite facades, literally holding the two surfaces together. Without the addition of tie rods or buttresses, meant to brace the exterior wall in place, the building can be vulnerable to the collapse mechanism of wall overturning. These mechanisms can be enhanced by a structure’s orientation to the elevation curves, thus increasing the likeliness of collapse. It is also important to note that the orientation of a building to the orientation curves that is between 0 and 90 degrees can also be extremely dangerous due to the increase of torsion forces within the structure. As seen in figure 1.18, this irregular orientation, neither parallel or perpendicular, can worsen the collapse mechanism of wall overturning.

1.10 Building Heights

Differences in building heights can be extremely important, specifically within a single aggregate. As seen in the diagram below, the change in stiffness due to the differing heights of the two structures can lead to several forms of damage, including rotational damage, wall overturning and pounding. Pounding is extremely common in cases where structures of different heights are connected.

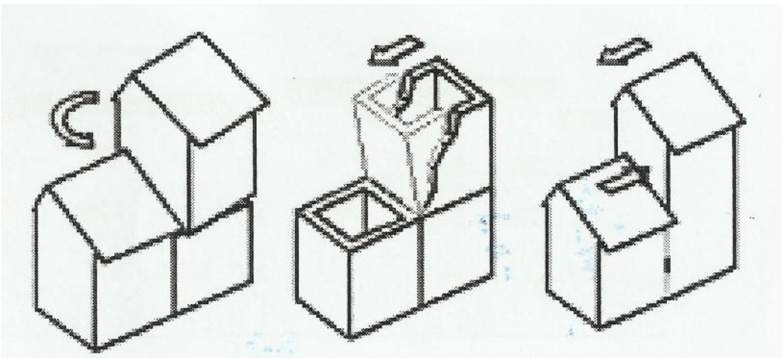


Figure 1.19 Damages due to stiffness and height changes (Binda, 2006)

Structures with different heights experience different periods of movement. Thus the two adjacent buildings are pulled apart, so any connections between the two such as arches or sporti can be destroyed as well. In addition, when the buildings naturally return to their initial positions, they bring with them increased inertia which leads to structural pounding between the elements. Pounding is the condition in which the buildings hit one another, leading to extreme damages or even the collapse of both structures. Due to the vicinity of structures in an aggregate, especially ones with extreme irregularity in

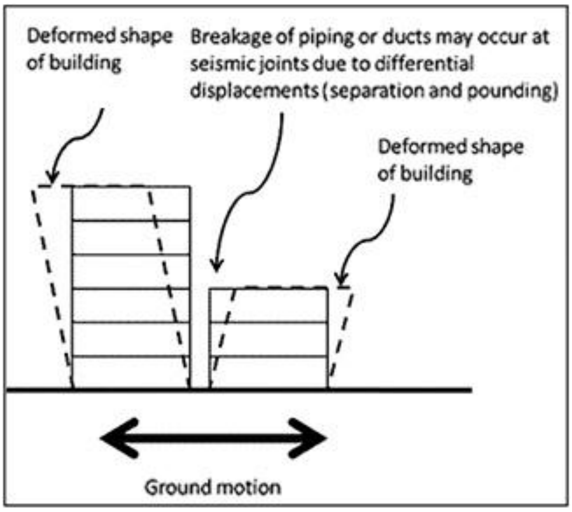


Figure 1.20 Seismically induced pounding (fema.gov)

building heights, pounding is very likely. Even in the case of no major structural collapses, portions of the taller building can create damage by falling onto the other structure thus compromising the roof structure. This partial collapse of the taller structure can, in extreme cases, lead to the collapse of the adjacent structure as well.

In all cases of height changes, as seen in the diagram below, the weakest point is the connection point between the adjacent structures. This point can act as a fulcrum point, which the taller structure can collapse around. Any structural connections, such as beams, or mechanical

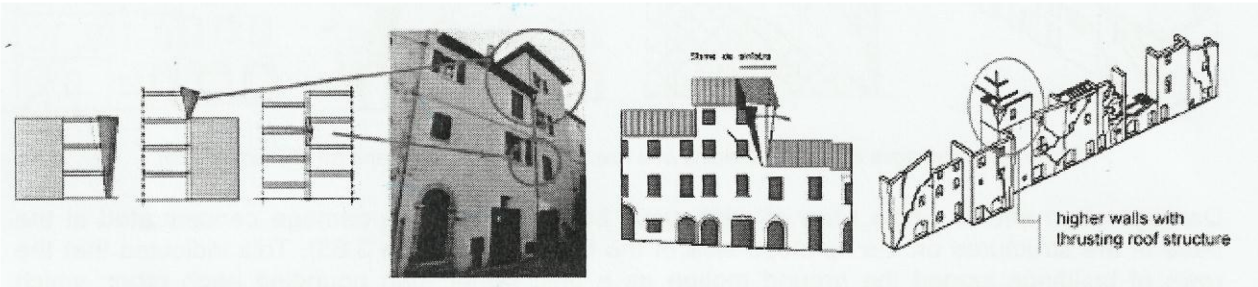


Figure 1.21 Damages due to height changes in a row and of the floor alignment (Gurrieri, 1999)

connections such as piping or ducts, are vulnerable to collapse in the case of a separation between the two adjacent structures.

As seen in the figure below, these elements serve anti-seismic functions, such as physically separating two adjacent buildings and thus decreasing the chance of pounding. In the case of a seismic event, the different periods of movement of the two involved structures are controlled by the arch. However it is important to note that, as seen in the diagram on the left, these connection elements can cause damages to the adjacent buildings if large enough, such as cracks, either vertical or diagonal in nature. However these cracks are rare and are unlikely to cause complete collapse on their own.

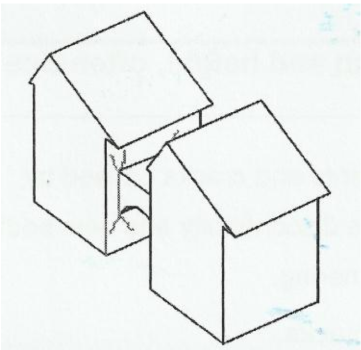


Figure 1.22 Arch Damage (NIKER)

. The final most important collapse mechanisms related to building heights is that of adjacent volumes that differ in height. There are several examples of these volumes in the Baronia collective. In general these volumes can be meant for storage or as an addition added to the original structure. The additional weight of these volumes can lead to the mechanism of wall overturning or, as seen in

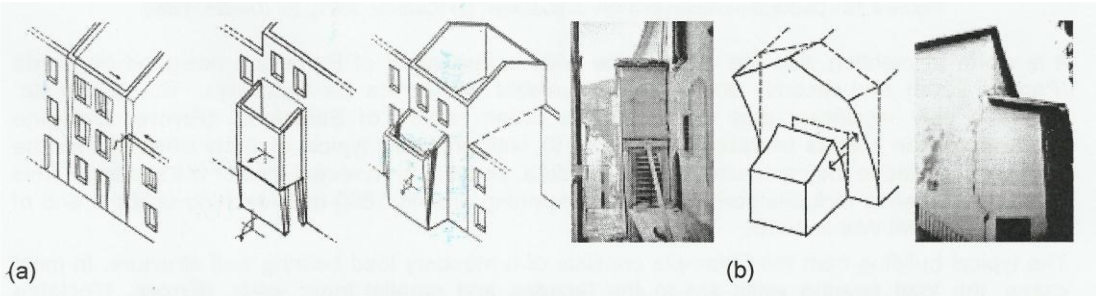


Figure 1.23 Interaction between adjacent volumes (Doglioni, 1999)

cases of non-structural connection elements, can cause cracks in the structural masonry as seen in the diagram above. Building heights therefore play an essential role in the overall vulnerability of buildings within an aggregate due to a strong correlation to collapse mechanisms produced in the case of a seismic event.

1.11 Masonry Typology

All four of the communities within the Baronia collective have a wide variety of masonry typologies. However these typologies can be divided into four categories corresponding to the normative NTC 2008 and the modifications proposed by the RELUIS project. These are classifications relevant only to masonry typologies. The original normative was a part of the ordinance 3274/2005 in the table 11.D.1 and table C8B.1 of the NTC 14.01.08 normative. These masonry typologies are highly representative of a structure’s potential vulnerability in the case of a seismic event. As will be seen in the section “Collective Homogeneity”, the combination of several masonry typologies within a single structure, due to restorative efforts or structural additions, can increase the likelihood of partial or complete collapse. The first three masonry typologies seen in the table above are present throughout the Baronia collective. These range from low to medium to high quality, in the order as seen in the NTC 2008 and RELUIS table. Each

Tipologia di muratura	f_m (N/cm²)	τ_0 (N/cm²)	E (N/mm²)	G (N/mm²)	w (kN/m³)
	Min-max	min-max	min-max	min-max	
Muratura in pietrame disordinata (ciottoli, pietre erratiche e irregolari)	100 180	2,0 3,2	690 1050	230 350	19
Muratura a conci sbozzati, con paramento di limitato spessore e nucleo interno	200 300	3,5 5,1	1020 1440	340 480	20
Muratura in pietre a spacco con buona tessitura	260 380	5,6 7,4	1500 1980	500 660	21
Muratura a conci di pietra tenera (tufo, calcarenite, ecc.)	140 240	2,8 4,2	900 1260	300 420	16
Muratura a blocchi lapidei squadrati	600 800	9,0 12,0	2400 3200	780 940	22
Muratura in mattoni pieni e malta di calce	240 400	6,0 9,2	1200 1800	400 600	18
Muratura in mattoni semipieni con malta cementizia (es.: doppio UNI foratura ≤ 40%)	500 800	24 32	3500 5600	875 1400	15
Muratura in blocchi laterizi semipieni (perc. foratura < 45%)	400 600	30,0 40,0	3600 5400	1080 1620	12
Muratura in blocchi laterizi semipieni, con giunti verticali a secco (perc. foratura < 45%)	300 400	10,0 13,0	2700 3600	810 1080	11
Muratura in blocchi di calcestruzzo o argilla espansa (perc. foratura tra 45% e 65%)	150 200	9,5 12,5	1200 1600	300 400	12
Muratura in blocchi di calcestruzzo semipieni (foratura < 45%)	300 440	18,0 24,0	2400 3520	600 880	14

Figure 1.24 RELUIS Masonry Typology Strengths (NTC)

masonry typology differs in their potential collapse mechanisms. In general, the highest quality,

Definizione contenuta nell'ordinanza 3274/2005, nella tabella 11.D.1 e in tabella C8B.1 della NTC 14.01.08).	Proposta di modifica della definizione di tipologia (RELUIS)	Esempi di tessiture murarie
Muratura in pietrame disordinata (ciottoli, pietre erratiche e irregolari)	Muratura in pietrame (ciottoli, pietre erratiche, ecc.), disordinata per forma, dimensione e tipo di materiale degli elementi. Muratura a lisca pesce	
Muratura a conci sbozzati, con paramento di limitato spessore e nucleo interno	Muratura a conci sbozzati, di dimensioni variabili e con prevalenza di filari orizzontali	
Muratura in pietre a spacco con buona tessitura	Muratura in pietre a spacco (anche di forma irregolare) con buona tessitura (pietre ben ammorsate)	
Muratura a conci di pietra tenera (tufo, calcarenite, ecc.)	Muratura a blocchi squadrati di pietra tenera (tufo, calcarenite, ecc.)	
Muratura a blocchi lapidei squadrati	Muratura a blocchi squadrati di pietra non tenera	
Muratura in mattoni pieni e malta di calce	Nessuna modifica	

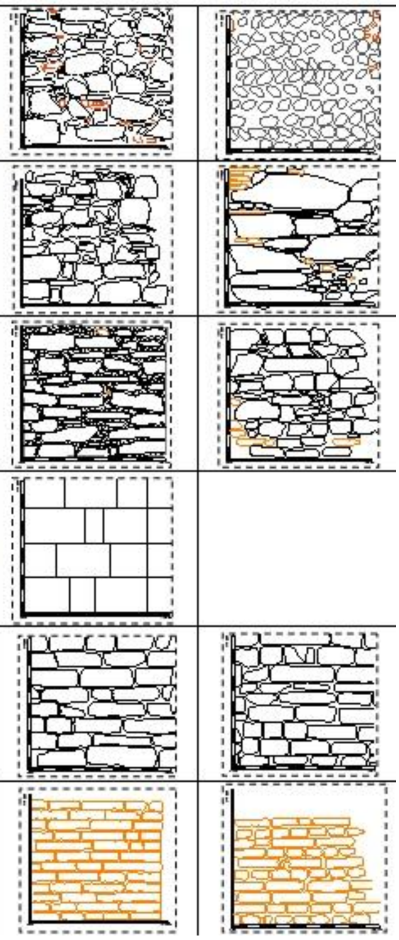
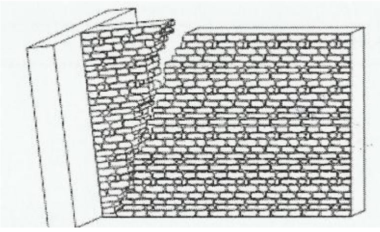


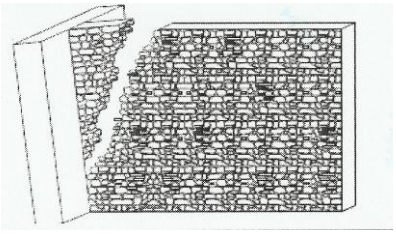
Figure 1.25 NTC 2008 and RELUIS Modifications of Masonry Classifications (NTC)

henceforth referred to as masonry typology three, will experience shear failure, with cracks positioned in a 45 degree angle. The medium quality masonry, masonry typology two, will however suffer shear failure, with cracks positioned at 30 degrees from the vertical axis. Finally the lowest quality masonry, masonry typology one, will show cracks at less than 30 degrees with harsher edges than seen in the two aforementioned typologies.

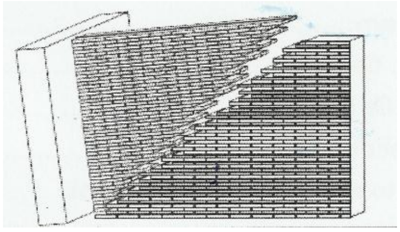
All three typologies are common in their use of a two leaf system, regarding the sectional makeup of the structure. However in many cases of ruins within the Baronia collective, many were masonry sections poorly constructed, thus not allowing the masonry element to respond to forces as a single unit. This will be further discussed in the "Ruins" section. All three of these masonry typologies are seen throughout the Baronia collective, however masonry typology three has a



1.26 Masonry Typology Three

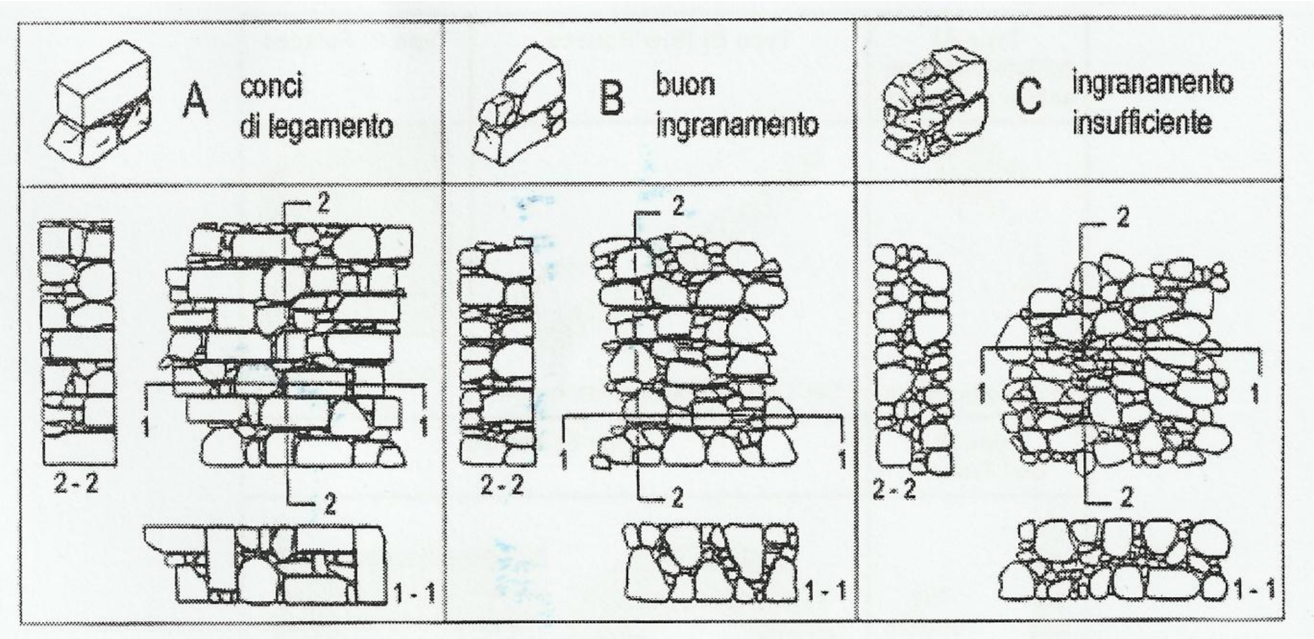


1.27 Masonry Typology Two



1.28 Masonry Typology One

tendency of being used for buildings of higher social importance, such as churches, religious structures or governmental facilities. The diagram below represents the section, elevation and plan composition of all three masonry typologies present in the Baronia collective. While both typologies



1.29 Stone Masonry Survey representing very good, good and low quality masonry connections (Giuffre,1993)

three and two have the presence of horizontal rows, differing only in stone quality, masonry typology one is characterized by its lack of regularity, but still maintains a strong two leaf sectional system in most cases. These characteristics are extremely important when considering the vulnerability of an aggregate, specifically when considering the masonry composition of the buildings involved.

1.12 Existing Ruins

Ruins, unlike churches, are scarce in the Baronia collective. Ruins are important to note, not because of their influence on the vulnerability of aggregates but due to their potentially revealing features. In this thesis, ruins from all four of the studied villages will be including in order to better understand their collapse mechanisms which may reveal possible vulnerabilities in adjacent structures or other aggregates within the villages. Many ruins unfortunately were studied on an observational basis from afar due to the lack of accessibility to the site. However several were accessible and contained revealed sections which allowed for further detail. These sections then revealed the masonry typology as well as possible collapse mechanisms that led to the ruined condition. These possible revelations from the ruins therefore make them extremely useful in the analysis of each individual village.

1.13 Collective Homogeneity Analysis and Negative/Positive Examples

The collective homogeneity analysis is primarily based on four specific factors, all of which have been determined through on-site analysis. These include the topics of the previous four sections, including building typology, orientation to elevation curves, building height and masonry typology. As seen in the attached map of Castel del Monte for "Collective Homogeneity", the four previously mentioned factors' maps have been overlaid to locate the aggregates with a uniform structure, regarding all four elements. The aggregates that present the most and least uniformity regarding these four elements will be discussed in sections of each village, entitled "Positive Homogeneous Examples" and "Negative Homogeneous Examples".

1.14 Openings

While openings within a structure may appear to be of little structural importance, their placement can increase collapse mechanisms to the point of structural failure, especially in the presence of other structurally vulnerable factors. Openings are preferably located as far away from major structural elements as possible, this includes corners and other openings. Several openings near to one another can increase the risk of failure of both openings. The optimal placement within a façade is in a line, evenly spaced from one another. This minimizes the influence of the openings on the façade surface and thus minimizing the possibility of their role in structural collapse. This is seen best in diagram 1.32, which emphasizes the possible role of openings in the overturning of the vertical strip of the façade. The area in gray is the affected area, which is best when situated in the center of the façade instead of to the sides, close to the corners. The most likely damage due to the poor placement of openings is the overturning of the wall in question.

The locations of openings to one another is also extremely important. The subdivision of vertical openings within a wall is tied to the collapse mechanism of wall overturning. As seen in the diagrams on the left, both single buildings as well as those inter-closed in an aggregate are vulnerable to wall overturning, caused by the placement of openings. In addition, as seen in the diagram at the bottom of the page, the relationship between openings and the structural walls can determine the location of possible collapse mechanisms, specifically overturning of the exterior wall. The closer openings are located to one

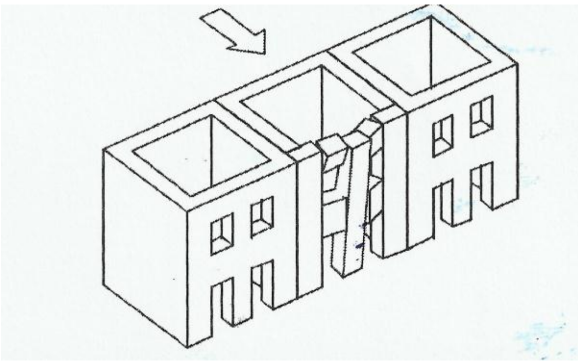


Figure 1.30 Partial Overturning of the Wall with Vertical Strips Subdivision – Inter closed Cell (NIKER)

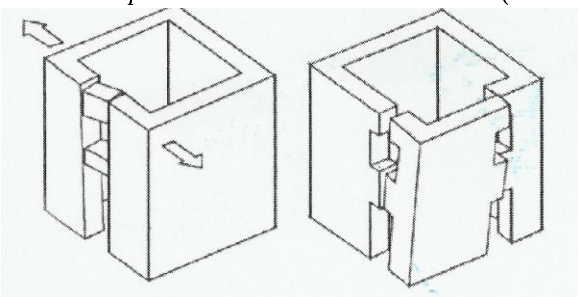
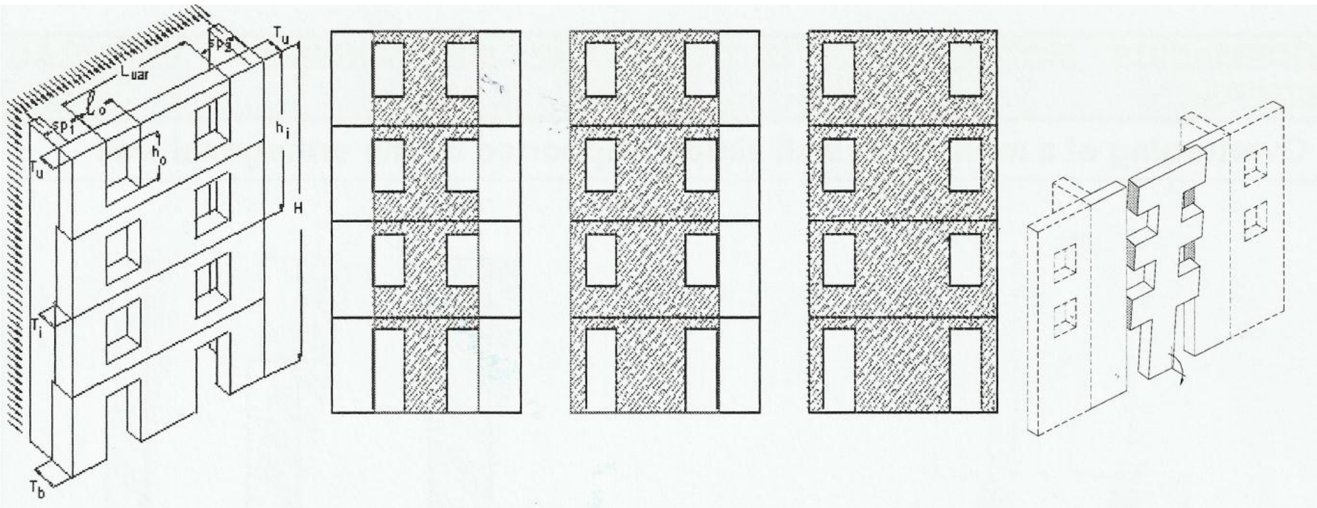


Figure 1.31 Overturning of Wall, Building (NIKER)



1.32 Overturning of Vertical Strip – Depending on the Openings Layout (NIKER)

another, the more likely they influence overturning of the exterior wall. Openings are therefore extremely important when analyzing each village in terms of their structural vulnerability.

1.15 Permanent Structural Interventions

Within the Baronia collective, there is a strong presence of permanent structural interventions, added after the original construction. These interventions include scarp buttresses, typical buttresses and tie rods, and showcase the knowledge of anti-seismic design within the region of Abruzzo. There are four main points when considering the criteria for interventions. The first is

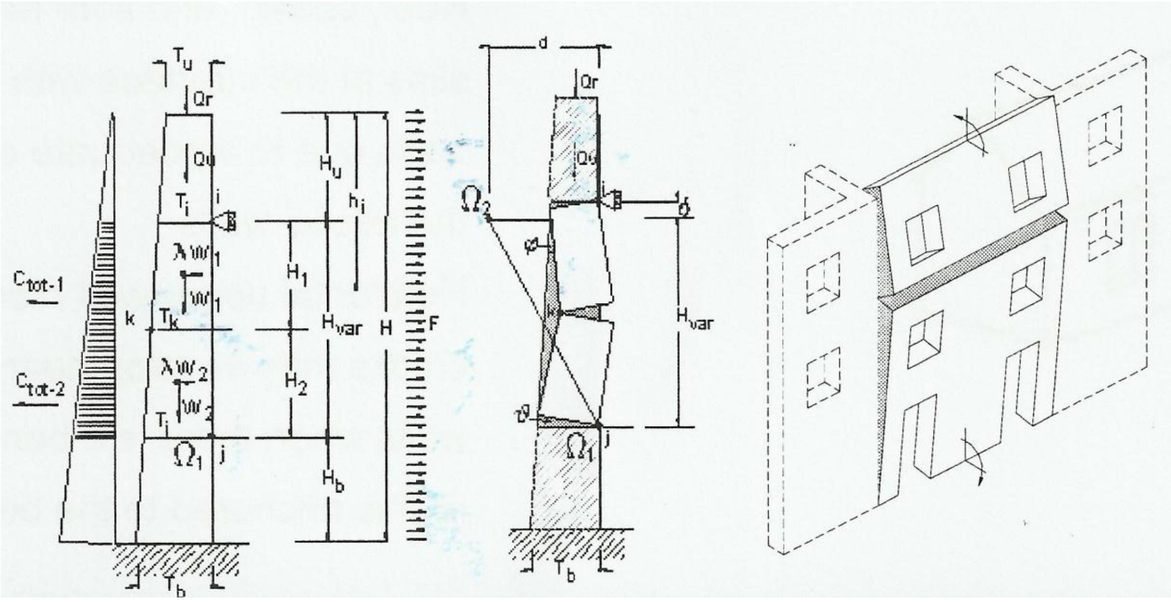


Figure 1.33   Vertical arch mechanism due to presence of tie or ring beams at the top of the wall (NIKER)

that interventions are meant to reduce accidental loads and live loads that caused previous damages. The second is rehabilitation of the load capacity. The third is to remove the causes of material degradation. The fourth and final criteria for interventions is modification of the static scheme. The improvement of the bearing capacity can be made by regenerating the structural element, increasing the section resistance of the floor supporting structure and replacing degraded elements with other similar elements.

The most common of the permanent structural interventions in the Baronia collective is the tie rod. Tie rods are slender structural elements used as a tie between structures, capable of carrying tensile loads only. Tie rods are exclusively made out of metal that join and reinforce two separate structural elements such as opposite facades. While structurally important, tie rods must be placed strategically to avoid increasing the collapse mechanisms in place. As seen in the diagram to the left, tie rods can create damage if not placed evenly along the face of the façade. Being placed unevenly can increase the probability of wall overturning. Tie rods are exceptionally important in seismically active zones, considering the high probability of wall overturning, the most likely type of collapse mechanism. Buttresses as well reduce the chance of wall overturning as seen in the example on the following page. The figure describes the effects of the constraints imposed by both tie rods and

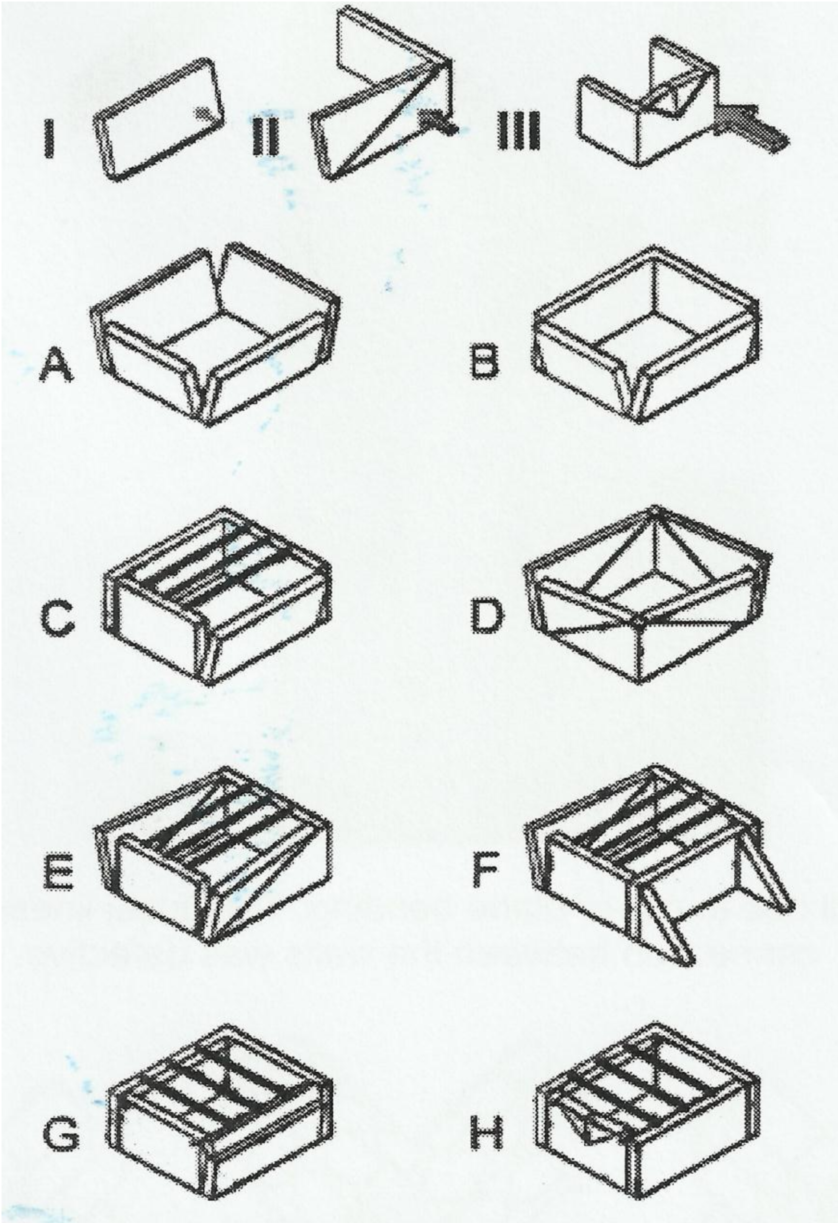


Figure 1.34 Effects of the constraints imposed by tie rods and buttresses on the box behavior (Corocci, 2004)

buttresses on the box behavior of a structure. These influences have a substantial effect on the potential collapse mechanisms of a structural, specifically in the case of a seismic event.

1.16 Temporary Structural Intervention

Both before and after the 2009 seismic event in L'Aquila, temporary structural interventions have been put into place to minimize the collapse mechanisms in several structures that have shown signs of structural instability. There are several types of temporary interventions present in the four villages of the Baronia collective. These include surface rendering, wooden grid and tie, traditional prop, arch/opening support and shoring system interventions. The most common, seen throughout L'Aquila after the 2009 earthquake, is the traditional prop intervention, which props the façade with the goal of avoiding the collapse mechanism of wall overturning. These however can be inconvenient for many practical reasons, including road occupation that prevents the passage of traffic. In addition, a substantial amount of time is required to both set up and take down these large temporary structures. In the case of wooden grid and tie systems as well as surface rendering interventions, the ground in front of a structure is not occupied and their application and subsequent removal is much faster. The use of ties and bands are also extremely useful because they transfer action from the out of plane loaded walls to the perpendicular wall, which act in their plan of higher stiffness. Traditional props, while achieving the same objective, can create more damages, such as hammering of the façade from the poles causing local damage in the case of high intensity aftershocks. Regarding the fourth type of structural intervention, arch/opening support system, they are extremely common in the Baronia collective. This is due to the fact that in villages, such as Castel del Monte, the streets are extremely narrow and traditional prop systems are impossible and highly avoided. In addition, sporti and arches are commonplace in Castel del Monte and the rest of the Baronia collective. In all of these cases, it is important that interventions do not increase the natural stress distribution of the damaged structure. The load and force placed on the structure by the temporary intervention should be evenly distributed to avoid further collapse.

Of the four temporary intervention typologies previously introduced, the most common in the Baronia collective is the arch/opening support intervention. This intervention is extremely important

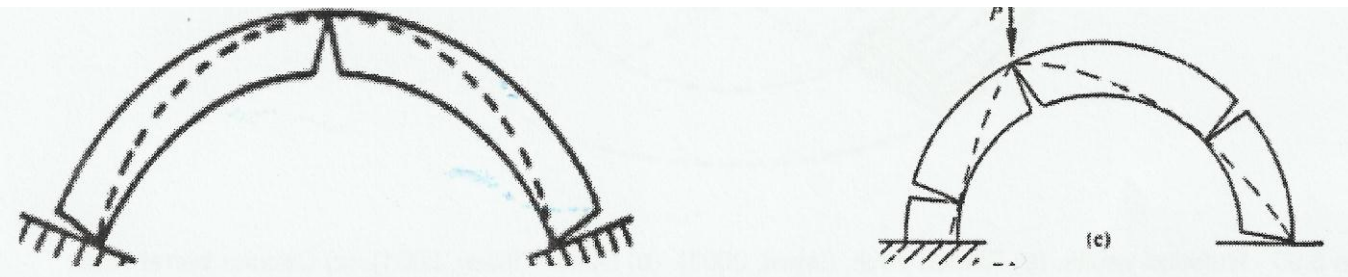
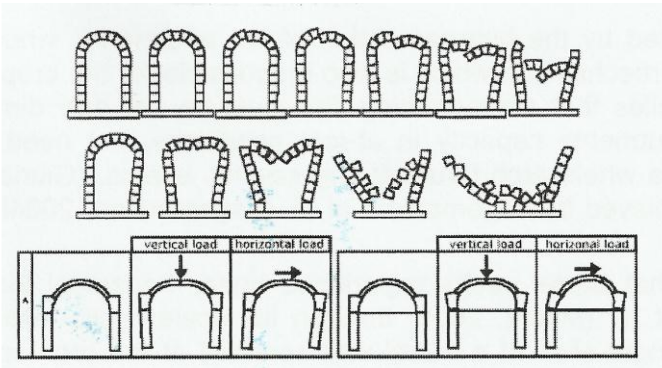


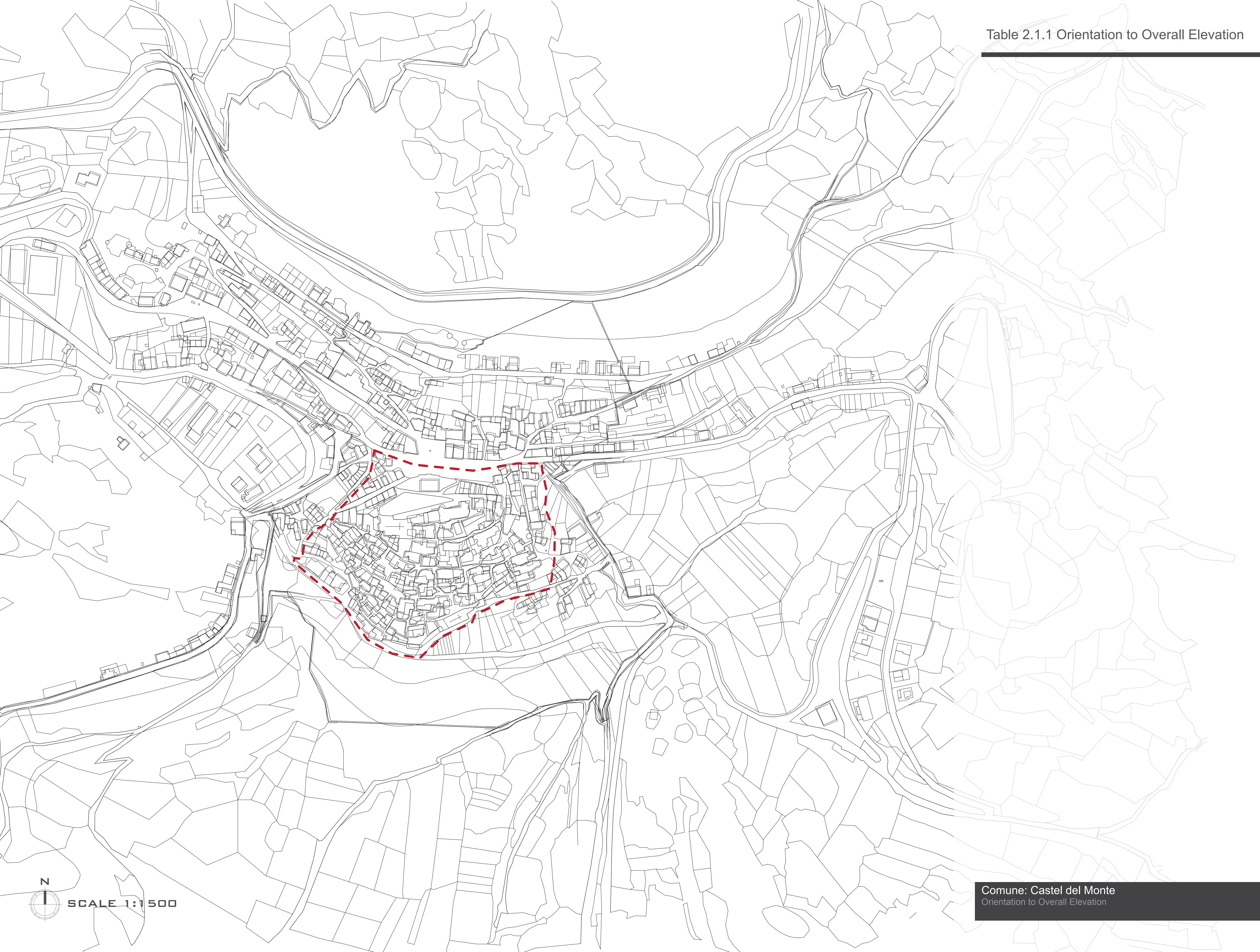
Figure 1.35 Voussoir Arch: Stable state of cracked arch (left) and Collapse under point load (right) (Heyman, 1995)

due to the natural load distribution of arches. As seen in the first diagram above, in a Voussoir arch, a stable arch will crack in the center, but when point loads are not added uniformly, collapse is possible. This is also the case when point loads are added from below in the case of temporary structural interventions. This can also be seen in the figure 1.36 for both unreinforced and tied arches. When an arch or opening support intervention is added, it is important that all point loads are as evenly distributed as possible to avoid interrupting the natural structural mechanisms of the arch in question. It is important to note that the possible effects of these temporary interventions should not be overlooked due to their possible negative consequences.



1.36 Damage mechanism for arches (Avovio, 2002)

Table 2.1.1 Orientation to Overall Elevation



Comune: Castel del Monte
Orientation to Overall Elevation

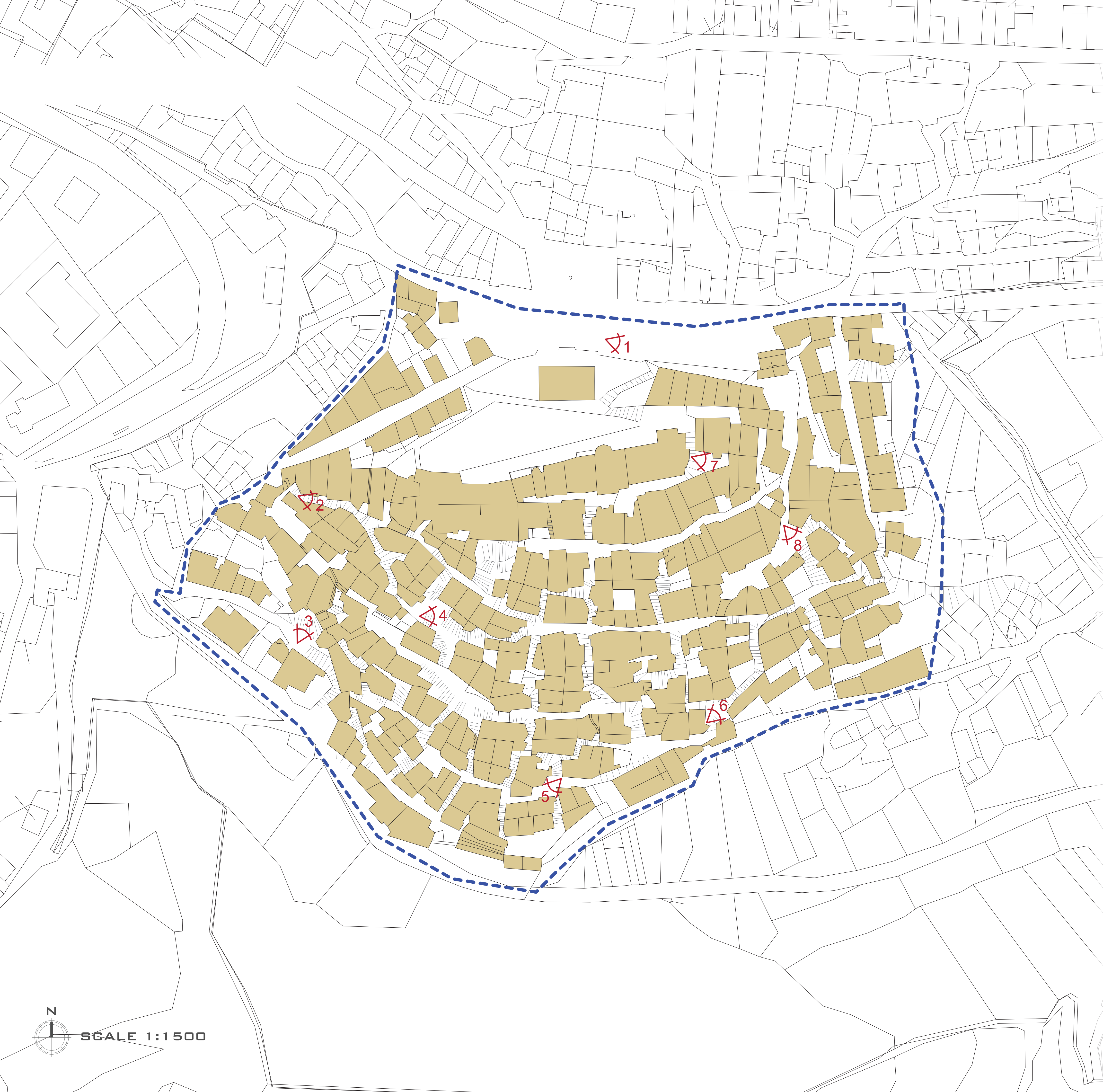
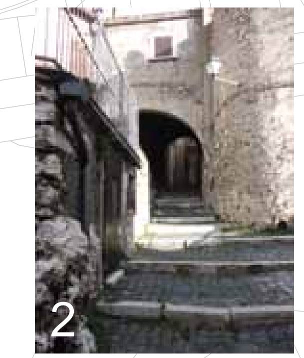


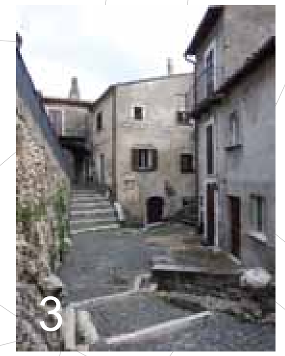
Table 2.1.2 Photographic Introduction

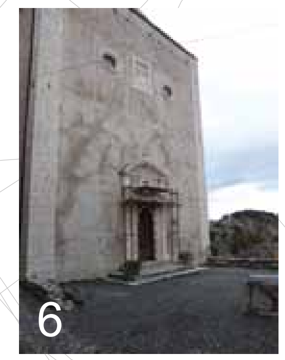
KEY:

Location of Photograph

Site Boundary







Comune: Castel del Monte

Photo Introduction

Table 2.1.3 Aggregate Locations

KEY:

Buildings

Aggregate Boundaries

DEFINITION:

An aggregate is made of one or more houses that are separate houses that are joined together to make a whole, single unit.

PHOTO EXAMPLES:

Aggregate CdM 031

Aggregate CdM 101

FACTS:

Total Number of Aggregates:	58
Total Number of Churches:	2
Total Number of Municipalities:	1
Total Number of Towers	1

Comune: Castel del Monte

Aggregate Locations

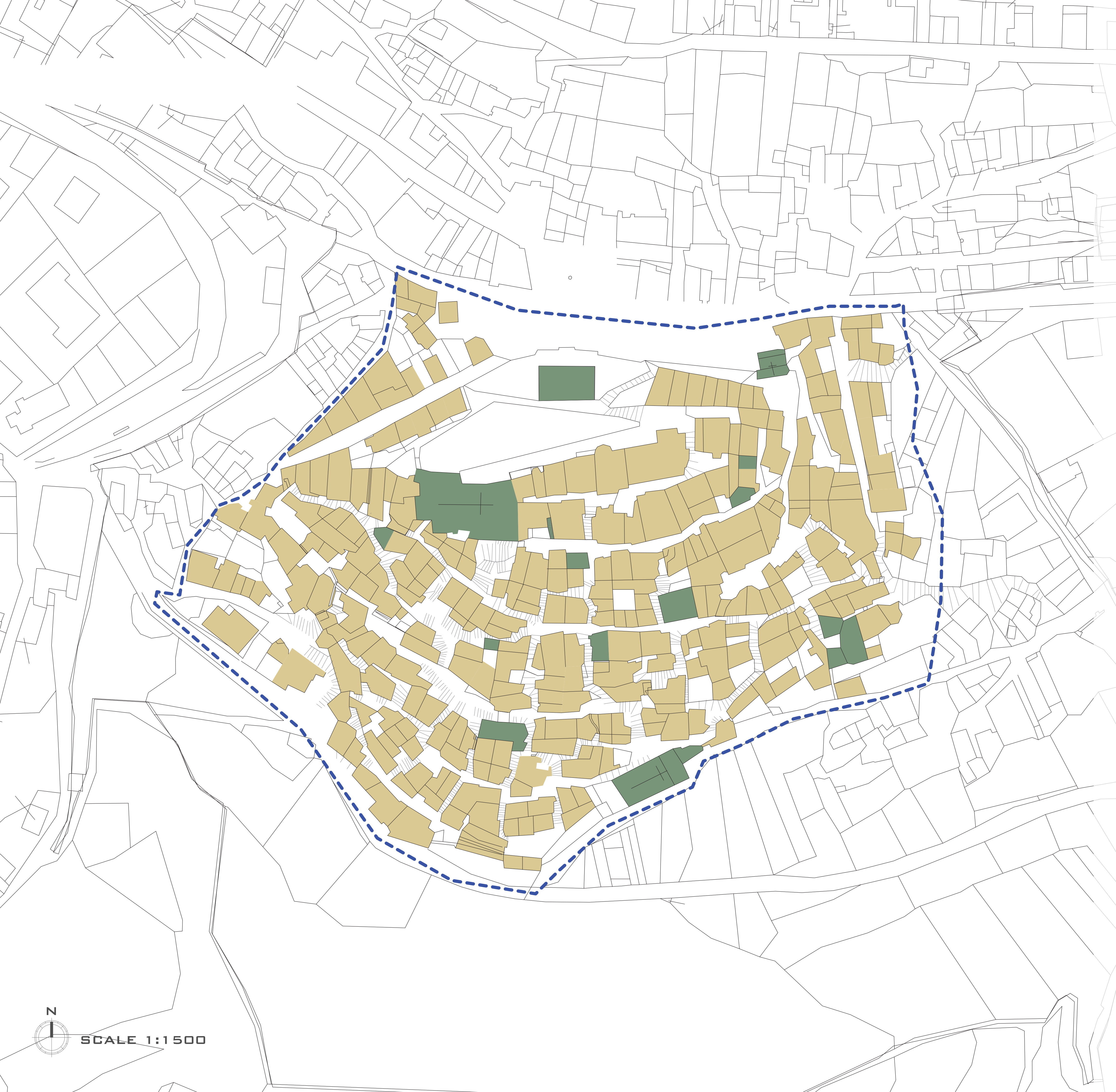
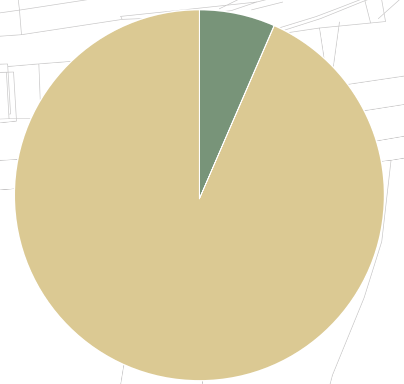


Table 2.1.4 Pre 2009 Seismic Building Uses

KEY:

- Private Property Buildings
- Public Property Buildings



EXAMPLES:

Public Use Building Types
-Monastery (Above Left)
-Church (Above Right)
-Municipality

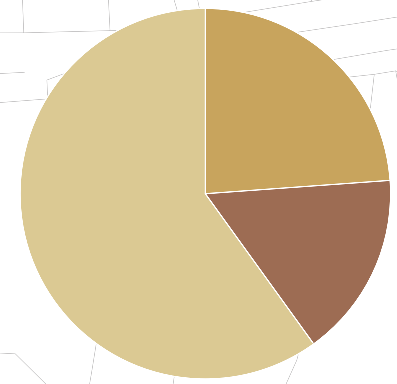
Private Use Building Types
-Uninhabited Residence (Above left)
-Inhabited Residence (Above Right)
-Uninhabitable Residence

Comune: Castel del Monte
Pre 2009 Seismic Building Uses

Table 2.1.5 Building Inhabitation

KEY:

- Uninhabited Building
- Inhabited Building
- Uninhabitable/Ruined Building



DEFINITIONS:

Uninhabited Building

Building that may or may not be in use, but is currently uninhabited. These may imply a public use building or one that is not lived in full-time.

Inhabited Building

Building that is currently being lived in and is therefore a priority regarding the restorative efforts, along with public use buildings.

Uninhabitable Building

Building that is in ruins, crumbling or structurally instable and therefore uninhabitable. These building are crucual to the restoratvie effort if their structural instability can damage adjacent buildings or create significant damages in the case of a future seismic event.

EXAMPLES:

Inhabited Building Example

This is an example of one of the inhabited buildings, which is inhabitable due to its structural stability. It was most recently inhabited by the restorative architects working in the area.

Uninhabited Building Example

This is one of the three churches in Castel del Monte and while it is not uninhabitable, it is considered an uinhabited building due to its public use.

Comune: Castel del Monte

Building Inhabitation

2 CASTEL DEL MONTE

2.1 Introduction

The village of Castel del Monte, with a population of 508 people, lies in the heart of the Central Apennine mountain range, below the Gran Sasso Mountain. The name Castel del Monte originally derived from the Latin *Castellum Montis*, meaning “Castel of the Mountain”. The city maintains a rich history, beginning during the height of the Roman Empire in the fourth century BC.

Figure 2.1 View of Castel del Monte (provided by the University of Padova)

The village was later abandoned after the fall of the Western Roman Empire. It would then be replaced by the fortified villages of Ricetto, which is now the historic center of Castel del Monte. Control of the village shifted several times in the course of its history. Pope Honorius the Third gained control in 1223, the Counts of Aquaviva in 1298, Alessandro Sforza in 1474 and later the Piccolominis. Finally in 1579, the Medici family would begin their governance of the village, which would last more than a century. Their contributions include the Churches of both San Marco and San Rocco. Also during the Medici rule, the town’s defensive walls and great gate were completed. In 1743, control of the village would be passed on to the King of Naples and Sicily until the village became a part of the unified Italy in 1861.

The village of Castel del Monte is a Renaissance hill town set into a steep hillside, above the Navelli plain. The village's vicinity to the nearby plain has led to a strong tie to sheep farming, which has played a large role in their economic wellbeing. Between the 12th and the 16th centuries, the area was one of the most prolific wool producers across Europe. In the 1850s however, the annual sheep drive south to Apulia, that passed through Castel del Monte, known as Transhumance, would cease to exist. The village's population would never return to its pre-1850 size, despite a population peak in the 1920s. After the Second World War, much of Castel del Monte's population migrated to other countries due to a lack of work. These countries include, but are not limited to, France, Switzerland, the United Kingdom and the United States. Currently, the economic wellbeing of the village relies primarily on wool production, pecorino (sheep) cheese, lamb and limited tourism. The lack of economic developments during the 20th and 21st centuries, have directly affected the village's architecture. Over the past one hundred years, there has been very little new construction. As a result, most structures within Castel del Monte, especially the historical center, are several centuries old and many have changed very little from their original construction in the Middle Ages or the Renaissance. In 1993, the area surrounding Castel del Monte, was placed within the National Park of the Gran Sasso Mountain. This change required that all land surrounding the village be maintained in a wild state, thus preventing the village from ever growing beyond its current borders.

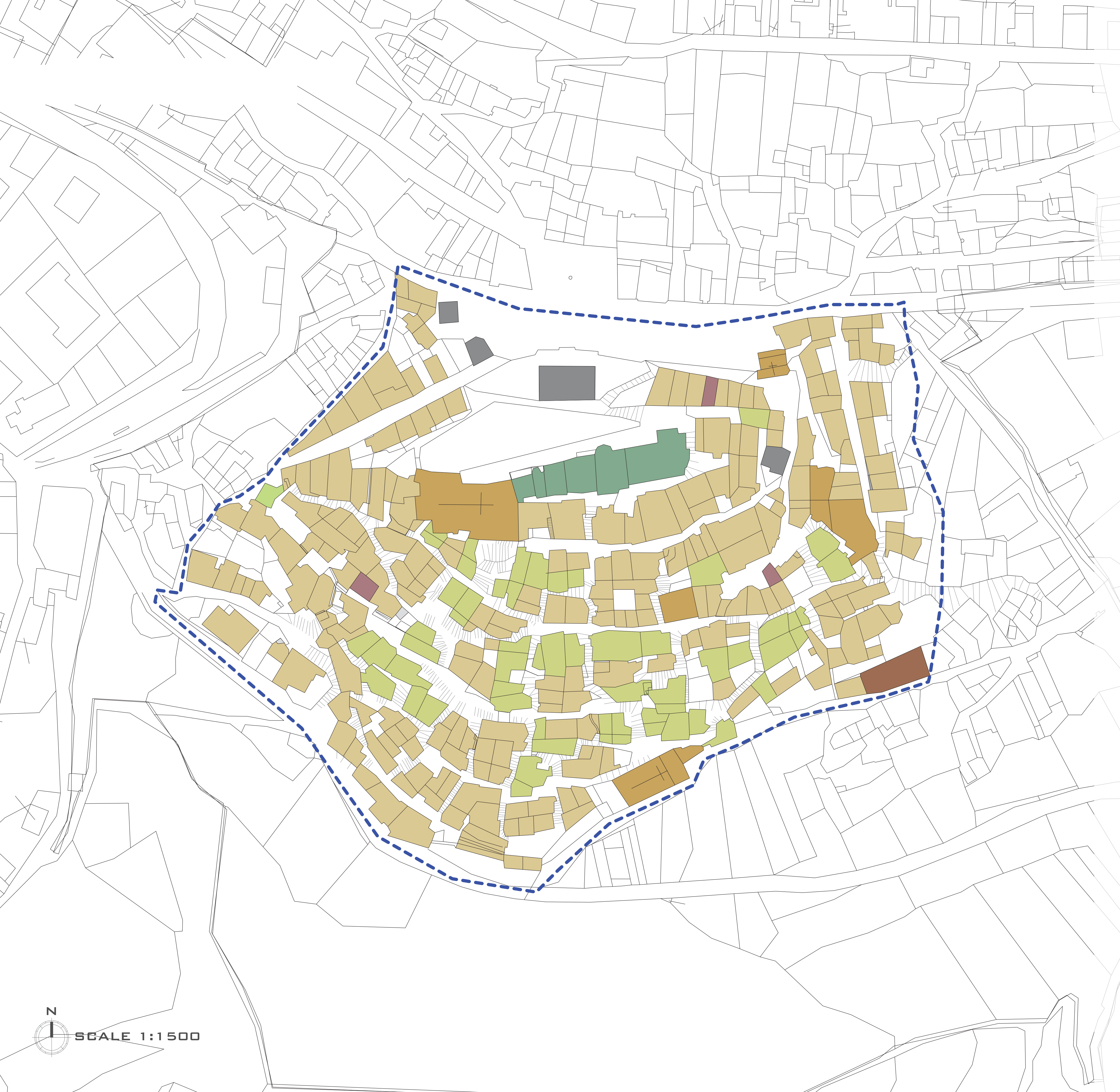
The village of Castel del Monte, similar to the entire Abruzzo region, has a rich history of seismic activity. The village, along with the entire Baronia collective, lies just North-East of a series of fault lines, such as the Paganica fault that led to the 2009 L'Aquila earthquake. The village however has received little to no major damage due to seismic events. The most recent seismic event, that of April 2009, however has showcased many structural vulnerabilities within the historical center of Castel del Monte. The most severe damage was that of the tower belonging to the San Marco church. While the tower remained standing, it was structurally compromised due to the earthquake and required temporary structural intervention, as seen in the photo below. In addition,


Figure 2.2 Tower of San Marco Church

several interventions were required to better support the many arches and “sporti” present in Castel del Monte. The village currently maintains very few ruins, which collapsed due to lack of use and maintenance, not from seismic events. However the construction typology, specifically in the historic center, reveals a strong relation and public knowledge of anti-seismic design. The use of buttresses, scarp buttresses, tie rods and other forms of permanent structural interventions are present throughout the historical center.

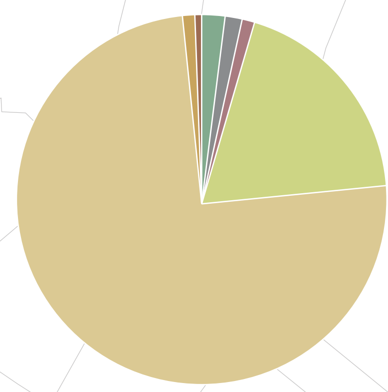
Due to the high risk of seismic events in the region of Abruzzo, Castel del Monte along with all of the Baronia village communities has begun restorative analysis, along with the University of Padova. The goal of this analysis is to prioritize the structural vulnerabilities within the historical center in order to afford the best possible use of the limited public resources available for seismic retrofitting. This retrofitting will be aimed at respecting the existing structural typology in order to avoid compromising the structural stability even further. However due to the lack of available funds, strong consideration is being given to areas of the historical center that are inhabited or commonly used by the existing population of Castel del Monte. Seismic events have occurred in this area repeatedly since its initial settlement and will continue to do so in the foreseeable future. Thus now is the time to protect both the cultural patrimony and lives present in the village of Castel del Monte before future seismic events make that impossible.

Table 2.2 Building Typology



KEY:

- Historical Boundary Wall House
- Block House
- Tower House
- Buidling Oriented Perpendicular to the Elevation Curve
- Building Oriented Parallel to the Elevation Curve
- Religious Building
- Ruins



Wall House:
6 Total (2%)

Block House:
4 Total (1.5%)

Tower House:
3 Total (1%)

Perpendicular:
60 Total (19%)

Parallel:
230 Total (75%)

Religious:
7 Total (2%)

Ruins:
1 Total (.5%)

Total Buildings: 311

Historical Boundary Wall House
Row of houses, oriented in a line

Block House
Single builings, unattached to other buildings

Tower House
Building significantly taller than all buildings it touches

Buidling Oriented Perpendicular to the Elevation Curve
Building Unit set in a row, perpendicular to the elevation curve (partially underground with a rock foundation)

Building Oriented Parallel to the Elevation Curve
Building Unit set in a row, parallel to the elevation curve (partially underground with a rock foundation)

Religious Building
Any religious based building such as a church or convent

Ruins
Any building with significant damage to the point of being uninhabitable

Comune: Castel del Monte
Building Typology

2.2 Building Typology

2.2.1 Historical Boundary Wall Houses

The community of Castel del Monte, similar to many medieval and Renaissance hill towns, is defined by its massive defensive wall, surrounding the historical center. On the Northern portion of this defensive wall, six row houses are placed within the historical wall structure. In general, these

Figure 2.3 Example of Historical Boundary Wall Houses in Castel Del Monte

structures are of higher quality regarding masonry strength, however they are some of the oldest

Figure 2.4 Location of Aggregate

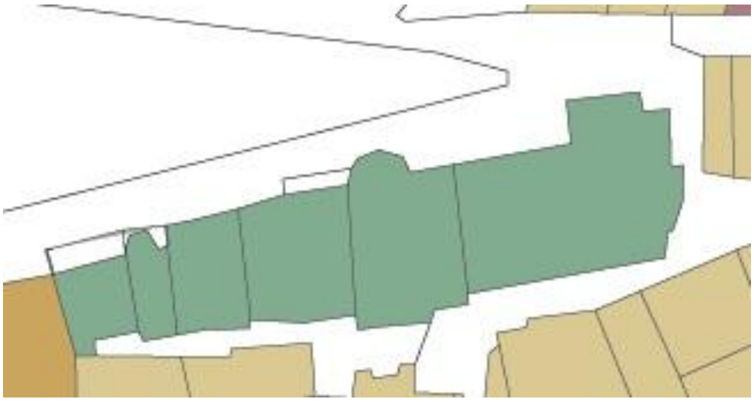


Figure 2.5 Historical Boundary Wall Houses

structures within the historical center. In addition, due to their importance within the village of Castel del Monte, many of them have been restored on numerous occasions or have had permanent structural interventions added to the original structure, such as tie rods or buttresses. Similar to typical row houses, as seen through out Castel del Monte, there are many potential collapse mechanisms of historical boundary houses. Primarily, the reaction between the individual houses can create damages, specifically during seismic events. As seen in the diagram above, the most common collapse mechanism is that of the last building of the row house. The laterally directed weight of the other buildings within the row can exceed the maximum lateral bracing capacity of the end building. In Castel del Monte, this potential collapse mechanism occurs once in the case of the historical boundary wall houses, as seen above. The farthest East building of the aggregate is open at the end of the aggregate and thus vulnerable to collapse, in the case of a seismic event or extreme lateral movement from the attached structures. However on the other end of the structure, the aggregate is braced by the presence of the San Marco church. This connection point between the aggregate and the church can also lead to potential collapse mechanisms as well. It is the combined weight of the aggregate as a whole that leads to its damaging potential.

Another common collapse mechanism for both historical boundary wall houses and row houses is caused by irregularity in plan. When particular houses within an aggregate project outward from the row houses, this can accumulate stress at several points in the projected structure and the buildings directly attached to it. Damages due to the lack of alignment in a row of houses are generally located primarily along the corners of the projected structure or directly attached structures.

One of the most important characteristics of line houses is their orientation to the elevation curves, which will be discussed in further detail in the "Orientation to Elevation Curves" section. Besides a few exceptions, the row house building typology can be split into separate categories, as seen in the attached Table 2.2. In this table, the traditional row houses have been divided based on their orientation to the elevation curves, either parallel or perpendicular. This orientation, while not definitely implicative of structural stability, tends to play a role in the potential collapse mechanisms of an overall structure. As seen in the figure below, while orientation to the elevation curves may not create damage, it can potentially worsen existing conditions of wall overturning. In Castel del Monte and the other three villages of Baronia, there was a substantial connection made between collapsed structures or ruins and a perpendicular orientation to the elevation curves. Building are stronger if oriented directly parallel to the elevation curves and worst if oriented at a non 0 or 90 degree angle. These orientations to the elevation curves can increase the amount of torsion present in a structure and thus increase existing potential collapse or damage mechanisms.

2.2.2 Tower Houses

Another prominent building typology present in Castel del Monte and all of the Baronia communities is the tower typology. As seen in the Table 2.2, there are only three towers present in Castel del Monte, excluding that of the San Marco church. As will be seen in further detail in the "Building Heights" section, towers can create several potentially dangerous structural mechanisms due to the height difference between a tower and the surrounding structures. This is specifically important when the tower is attached directly to other structures. There are four general types of localizations of towers within an aggregate. These include, but are not limited to, isolated, corner, included and projecting connection conditions. In the case of Castel del Monte, the three towers are of two different typologies. The most prominent tower, that is at the Northern portion of the historic center, in aggregate CdM 008, and the tower that is a part of aggregate CdM 110, are both included towers, lining up with the existing row condition. However the tower included in aggregate CdM 020 is located in a corner condition. While an isolated location is the preferred location of a tower, of the two typologies present in Castel del Monte, the preferred is included, due to the better bracing of the structure on two opposite sides. The corner condition, as seen once in Castel del Monte, can create potential collapse mechanisms due to the uneven attachment on two adjacent sides of the tower.

2.6 Tower of Castel del Monte

The most potentially dangerous points regarding a tower as a part of an aggregate, is the points where the tower touches the roof structures of the attached buildings. When a lateral motion is added, in the case of a seismic event, these points can function as fulcrum points, where the tower structure can potentially collapse onto one of the surrounding structures. These will not only create damage to the tower itself but also potentially cause damage to the surrounding structures both attached to the building and in the area. Towers out of the urban context or isolated are the best position possible, as is the case with block houses as well. This was seen directly in the case of the Santo Stefano Medicea tower, that when collapsed, did not create damage to the surrounding architecture as would have been the case if the three towers of Castel del Monte had collapsed during the most recent seismic event.

2.2.3 Buildings Oriented Parallel to the Elevation Curves

Within Castel del Monte, the majority of the existing structures are typical aggregate houses oriented parallel to the elevation curves. This particular building typology makes up over 75 percent of the structures within the village, specifically 230 of the 311 buildings present in the analyzed section of the historical center. These types of buildings are located evenly through the entire area, with no specific concentration. It is important to note that this is the case for all four of the villages discussed in this thesis. This is also the most common building typology in all four villages. These structures are generally considered to be of high structural quality, regarding orientation, and very few are oriented at an angle to the elevation curves, which can increase the force of torsion in a structure and therefore increasing the possibility of collapse.

2.7 Example of Building Oriented Parallel to the Elevation Curves

2.2.4 Buildings Oriented Perpendicular to the Elevation Curves

The second most common building typology in Castel del Monte is that of buildings oriented perpendicular to the elevation curves. This building typology makes up 19 percent of the building of the village, specifically 60 of the 311 structures present. Castel del Monte has one of the higher percentages of buildings oriented perpendicular to the elevation curves of the four villages discussed. While there is no specific concentration of these structures, they tend to be located in the heart of the village. While there is no directly proven relation between structural stability and the orientation of a building to the elevation curves, in all four of the villages discussed a connection has been noted between ruins and a perpendicular orientation to the elevation curves. However it is important to note that the orientation of a structure is only considered dangerous when mixed with differing orientations in a single aggregate. This is the case for many of the aggregates located in Castel del Monte and will therefore be strongly considered when determining the vulnerability of the entire village.

2.8 Example of Building Oriented Perpendicular to Elevation Curves

2.2.5 Churches or Religious Structures

The remaining typology present in Castel del Monte is churches or religious structures. There are five churches or religious structures in Castel del Monte. In general, churches are the most structurally sound regarding masonry typology, due to the high quality of masonry and construction techniques utilized. However due to their high use, irregular plans and towers, they can be highly dangerous in the case of a seismic event. As seen in L'Aquila, the city closest to the 2009 earthquake, many of the collapsed buildings were in fact churches that suffered failures due to their heights, façade irregularities and several other potential collapse mechanisms. They are therefore given emphasis when considering the village's overall vulnerability.

Figure 2.9 Example of Church

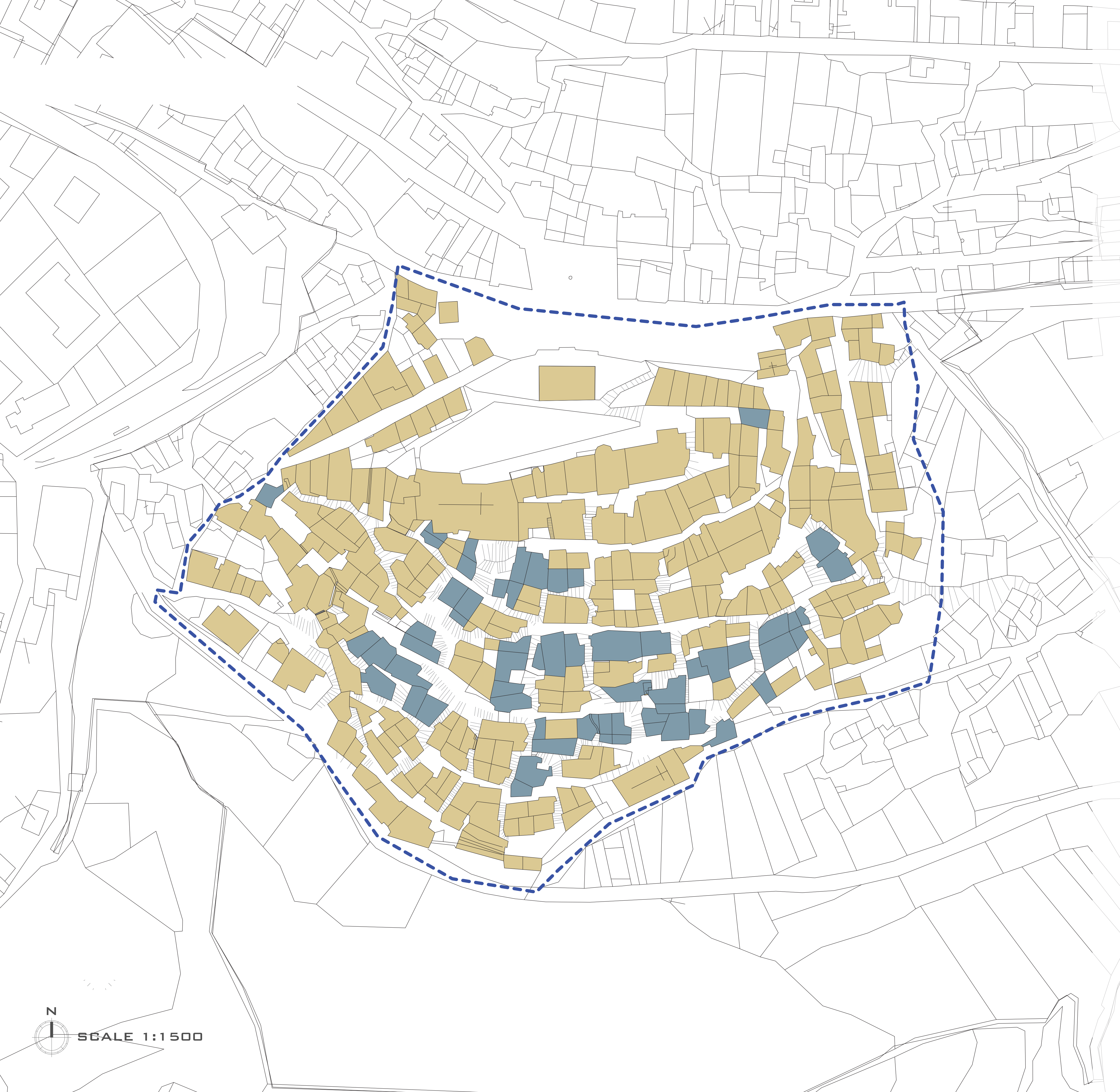
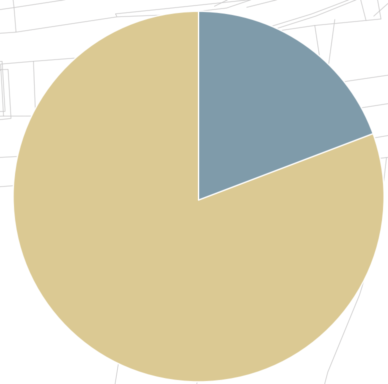


Table 2.3 Building Orientation to Elevation

KEY:

- Building unit positioned parallel to the elevation curves
- Building unit positioned perpendicular to the elevation curves



EXAMPLES:

PARALLEL
These building units are positioned parallel to the elevation curves

PERPENDICULAR
These building units are positioned perpendicular to the elevation curves

2.3 Orientation to Elevation Curves

As can be expected in this particular region of the Central Apennine mountains, close to the Gran Sasso mountain, Castel del Monte is located on one of the many hills in the region. This makes the orientation of the structures within Castel del Monte to the elevation curves extremely important, regarding their structural stability. Similar to the other villages within the Baronia collective, the majority of the structures within Castel del Monte (75 percent) are oriented parallel to the elevation curves, while the remainders are oriented perpendicular to the elevation curves. These classifications have been determined on-site and therefore can be considered accurate. As described in the previous section “Building Typologies”, the orientation of a building to the orientation curves can be considered very important in determining the vulnerability of a structure to a future seismic event.

In general, buildings oriented perpendicular to the elevation curves are considered more instable than those oriented parallel. In many cases, not in Castel del Monte but other villages within

Figure 2.10 Parallel Example

Figure 2.11 Perpendicular Example

the Baronia collective, ruins showed a tendency to being built perpendicular to the elevation curves although this was not always the case. Seen above are the two orientations to the elevation curves present in Castel del Monte. In addition, there are several structures that while categorized in one of the two aforementioned categories, they are in fact oriented between 0 and 90 degrees to the elevation curves. These are the least favorable of the orientations. In these cases, the propensity for collapse is the most extreme, due to increased torsion movement of a structure in this condition.

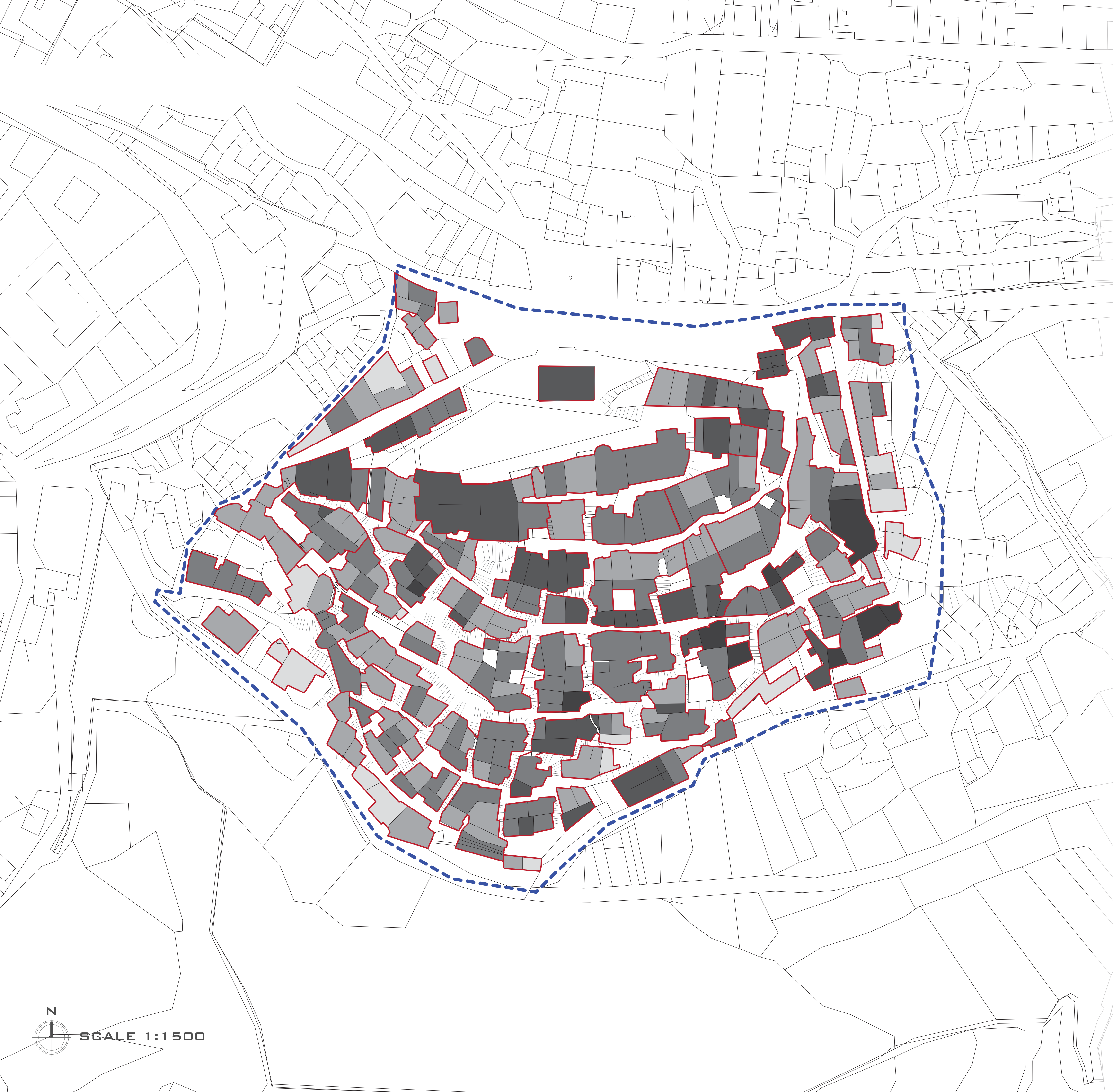


Table 2.4 Building Heights by Aggregate

KEY:

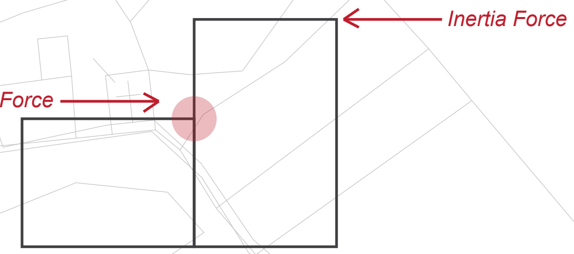
- 5 Floors Equivalent (or above)
- 4 Floors Equivalent
- 3 Floors Equivalent
- 2 Floors Equivalent
- 1 Floor Equivalent
- Aggregate Border

DESCRIPTION:

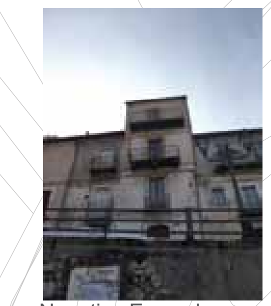
All building heights indicated on this map are distinguished by aggregate, which is why all heights are "equivalent" and not to be compared between aggregates. These heights are meant to distinguish which aggregates are the most and least homogeneous, regarding building height. Aggregates that are less homogeneous in height are more likely to suffer seismic damage due to pounding, which is described below.

TALLER ADJACENT BUILDING POUNDING:

Pounding is created between two buildings of differing heights due to different moments created in each structure, when they shake due to a seismic force. This creates different dynamic responses in each structure. The point where they meet, the fulcrum point, is the point of the most vulnerability. It is here where most damages can happen. This damage is due to irregularity in elevation, but can also happen between buildings of equal height.



POSITIVE/NEGATIVE EXAMPLES:


Negative Example


Positive Example

2.4 Building Heights

Castel del Monte, of all of the villages of Baronia, has some of the more extreme examples of height differences in individual aggregates. As seen in the attached table, in many cases the building heights shift within the aggregate, corresponding to the changing elevation curves. In addition there are several cases of towers within an aggregate that are much taller than their surrounding structures. This is the case for the tower in aggregate CdM 008. While this tower is not severe in nature, the

Figure 2.12 Example of a tower in aggregate CdM 008

lack of homogeneity regarding the building heights within the individual aggregate creates an increased propensity for collapse in the case of a seismic event. As seen throughout Castel del Monte, in many cases structures that are not physically adjacent to one another or even in the same aggregate, are connected through non-structural elements such as arches or "sporti". These elements can create minor cracks, but in general they are considered to be successful anti-seismic elements that help to separate structures of differing heights. This therefore minimizes the chance of partial or complete damage due to the pounding of two structures with different heights, either within a single aggregate or not.

2.13 Example of arch in CdM

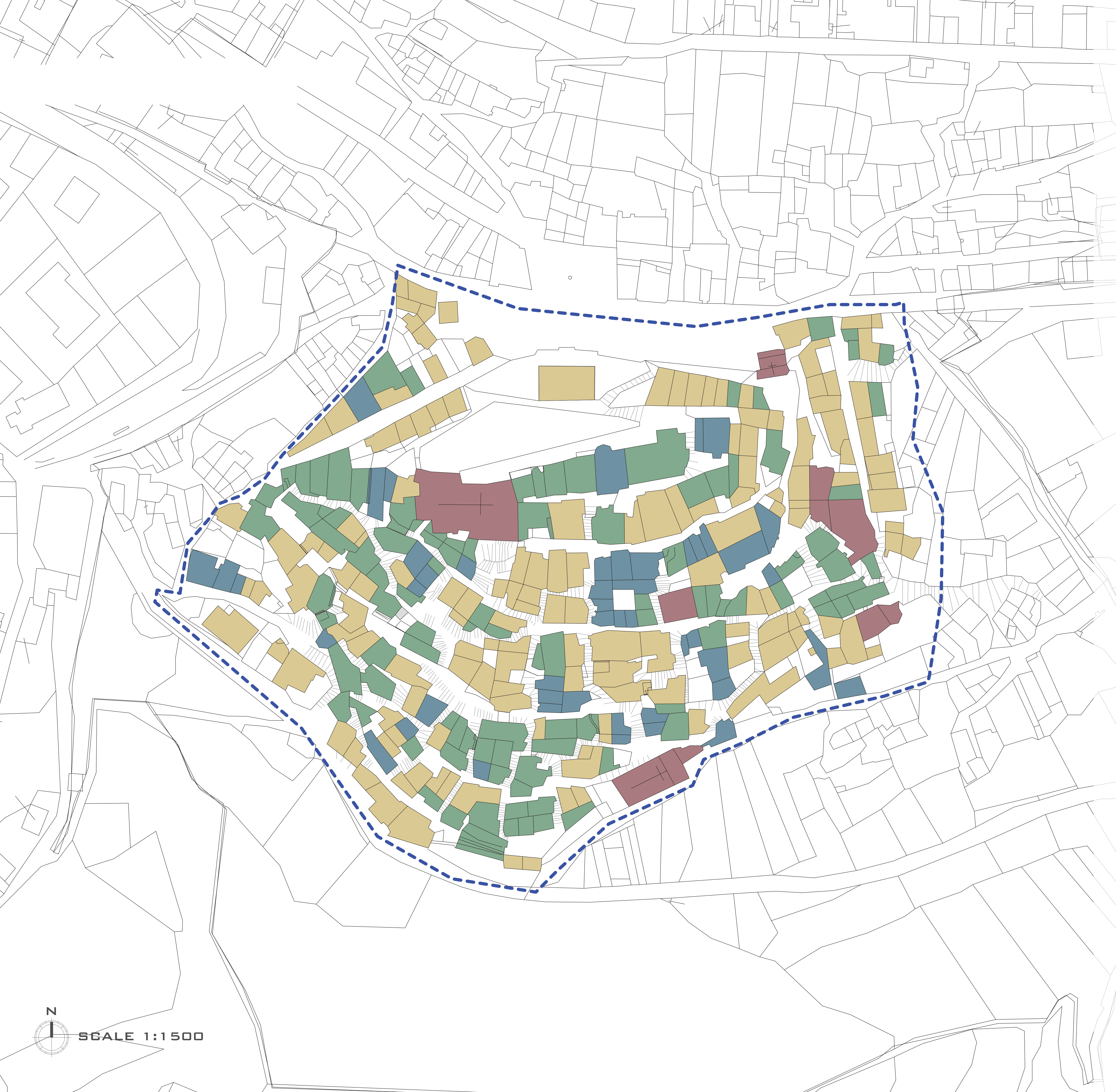
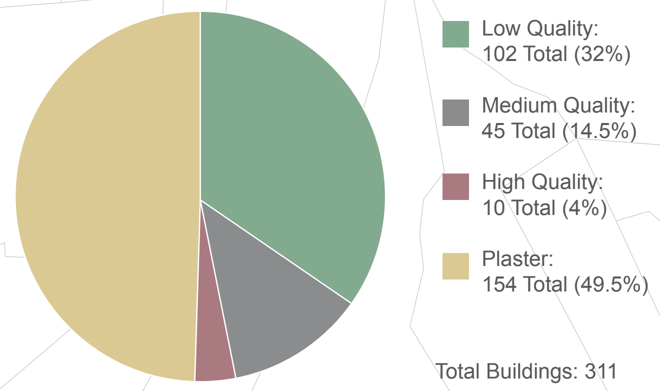


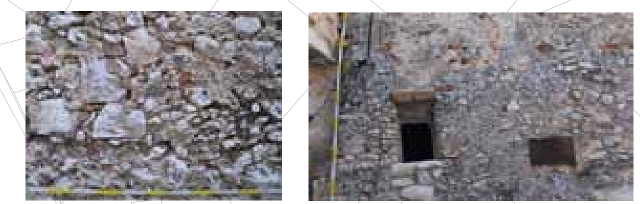
Table 2.5 Masonry Typology

KEY:

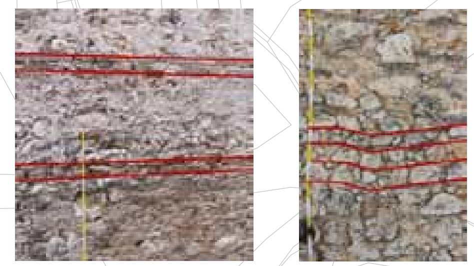
- Irregularly formed masonry (regarding shape, dimensions and materials) stone
- Subhorizontal masonry with roughly cut stones (of varying dimensions)
- Horizontal masonry courses with roughly cut stones (well interlocked)
- Plaster Covered



EXAMPLES:



Low Quality



Medium Quality

High Quality

Comune: Castel del Monte
Masonry Typology

2.5 Masonry Typology

2.5.1 Masonry Typology One

The lowest quality is the first in the NTC table, translated in English to irregularly formed masonry stones, regarding shape, dimensions and materials. From this point on, this typology will be

Figure 2.14 Masonry Elevation – Typology 1

Figure 2.15 Masonry Elevation – Typology 2 – Elevation

referred to as masonry typology number one. This is the lowest quality of masonry present in Castel del Monte. After plaster covered buildings, masonry typology one is the most common, making up 32 percent of the existing buildings within the historic center. As seen in the photos above, in Castel del Monte, this particular masonry typology is defined by its lack of regularity, both in the formation of horizontal rows as well as individual stone sizes. This quality of masonry is common in hillside communities across the Abruzzo region. Due to the access of irregular stones in the region as well available cheap construction labor, this particular typology was extremely cost efficient.

Masonry typology one is present in several building typologies within Castel del Monte,

Figure 2.16 Historical Boundary House – Masonry 1

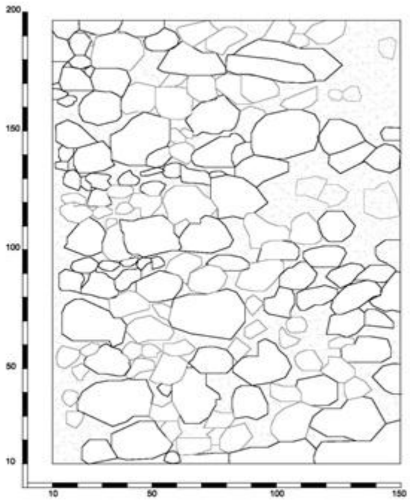


Figure 2.17 Historical Boundary House – Masonry

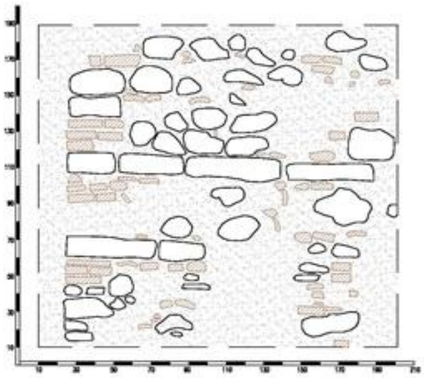
including historical boundary wall houses, towers, houses oriented parallel to the elevation curves, houses oriented perpendicular to the elevation curves and ruins. In the case of the historical boundary houses, which are seen exclusively in aggregate CdM 031, masonry typology one is the primary masonry present in this building typology, with the exception of one building, constructed of masonry typology two, which is the second masonry typology, seen in the NTC 2008 classifications and RELUIS modifications table. Of these, one building has been chosen to represent the classification of a historical boundary wall house consisting of masonry typology one. The photographic and diagrammatic elevations are shown above of the representative structure. This structure is similar to many buildings within Castel del Monte. The use is private residential, currently uninhabited and including a “sporto” arched overpass, common to the villages of Baronia.

2.18 Front-South Façade (Aggregate CdM 031)

2.19 Front-North Façade (Aggregate CdM 031)

2.20 Front-North Façade (Aggregate CdM 031)

Being the most widespread of the visible masonry typologies present in Castel del Monte, its use is spread across several building typologies as previously mentioned. The next example comes from another private residential building within the historical center, however the structure is characterized as a tower, again composed of masonry typology one. While the masonry composition



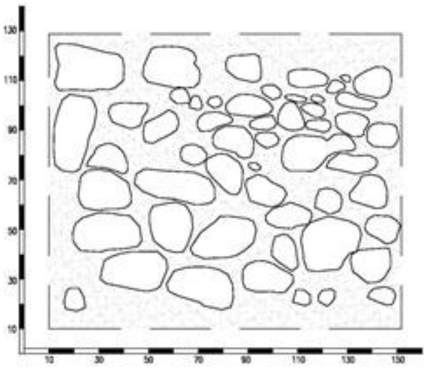
2.21 Tower House – Masonry 1 – Photo *2.22 Tower House – Masonry 1 - Diagram*

was similar to the previous historical boundary house example, this particular example still maintains a large percentage of its original plaster covering, as seen in the photos, both above and below. This covering is essential to the protection of the masonry from human and environmental factors.

Figure 2.23 Front North Façade

Figure 2.24 Front North Façade

The next building typology with the presence of masonry typology one is that of the structures oriented parallel to the elevation curves. This particular example is extremely irregular in

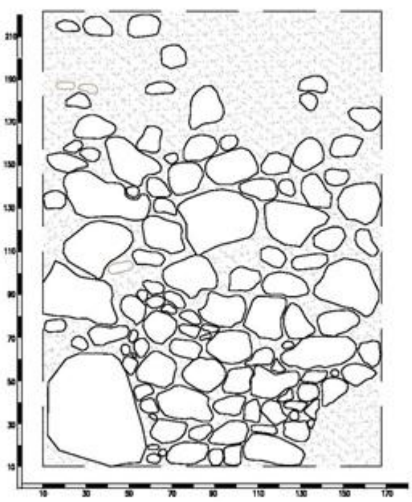


2.25 Parallel Orientation – Masonry 1 – Photo *2.26 Parallel Orientation – Masonry 1 - Diagram* its elevation masonry composition. It is important to note the varying stone sizes in the elevation diagram and photo on the last page. This characteristic can create irregular unit movements in the case of a seismic event and thus accelerate the collapse mechanisms of the masonry. This is why the individual analysis of an aggregate as a whole is extremely important when considering structural vulnerability in the case of a seismic event. While all of the aforementioned examples are considered to be masonry typology one, their individual makeup can vary drastically. This will be seen in the "Collective Homogeneity" section, when considering the collective vulnerability of an aggregate or individual structure.

Figure 2.27 Front North Façade (Aggregate CdM 022-B)

The final prominent building typology with the presence of masonry typology one is that of structures oriented parallel to the elevation curve. The best representative of masonry typology one in this particular building typology is located in aggregate CdM 017. This is yet another example of higher quality composition within the category of masonry typology one. This particular building is

2.28 Perpendicular – Masonry 1 – Photo



2.29 Perpendicular – Masonry 1 - Diagram


2.30 West Side Façade (Aggregate CdM 001)

typical of the building typology of structures oriented perpendicular to the elevation curves. As previously noted, there has been a tendency in the Baronia collective of ruins to be oriented parallel to the orientation curves, however this example is a reminder that it is not the case in all buildings with a perpendicular orientation. In fact, in many cases they have higher quality masonry than their parallel counterparts.

The last major building typology, churches, has no building composed of masonry typology one. This is due to the use of higher quality materials and construction in the case of religious structures. However, as previously mentioned, this particular masonry typology is very prominent through Castel del Monte and the other communities within the Baronia collective. While masonry typology one is the lowest within Castel del Monte, it is still a structurally stable masonry. The masonry is characterized by a sub-horizontal structure with horizontal elements, approximately every 35 centimeters. In addition, the masonry has staggered vertical joints, partially regulated by the addition of wedges and pieces of limestone. In general, walls made from masonry typology one are composed of blocks of stone, most likely limestone excavated from the local area. These stones are typically roughly sketched and vary in size (between 15 and 25 centimeters). They vary in color, but are typically white or gray, which comes from an excellent state of preservation, considering the age of the masonry. The mortar is generally a mix of lime and sand, thus maintaining a light gray color. The classification of these structures into masonry typology one was determined by on-site inspections, based solely on the appearance of the exterior, as more invasive analysis was impossible.

2.5.2 Masonry Typology Two

The second strongest masonry typology present in the Baronia collective, known as masonry typology two and located second in the NTC 2008 and RELUIS table, is also the second most common of the masonry typologies present in Castel del Monte. Masonry typology two makes up 14.5 percent of the 311 structures within the historical center of the village. As seen in the elevation

2.31 Masonry Elevation – Typology 2 – Zoom

2.32 Masonry Elevation – Typology 2 - Zoom

examples above, masonry typology two is defined by sub-horizontal rows every 50 centimeters, however are still irregular in composition. The masonry does not have regular staggering vertical elements but the use of wedges made of lime stone and brick is clear. Similar to masonry typology one, the masonry is composed of limestones excavated from the local area, ranging in length from 15 to 25 centimeters with alternating edges added for structure stability. It is important to note the mortar which has a firm texture and is light gray or brown in color. In most cases, this mortar has a very low state of preservation. It is made of lime and sand, similar to the mortar present in masonry typology one. It is again the case that this typology was distinguished through on-site investigations, but no invasive inspections were possible and therefore there is little information on their sectional makeup. This particular masonry is seen primarily in the building typologies of towers, houses oriented parallel and houses oriented perpendicular. There is only one example of this typology in historic boundary wall houses (which will not be discussed) and none in the category of churches.

The first example comes from the tower building typology, specifically from aggregate CdM Tower. Due to its importance as the gate of the historical center, the masonry quality was given more importance than typical residential structures. As seen in the elevation photo and diagram below, the individual stones are still irregular but there is a stronger presence of horizontal rows than is seen in

Figure 2.33 Tower- Masonry 2 - Photo

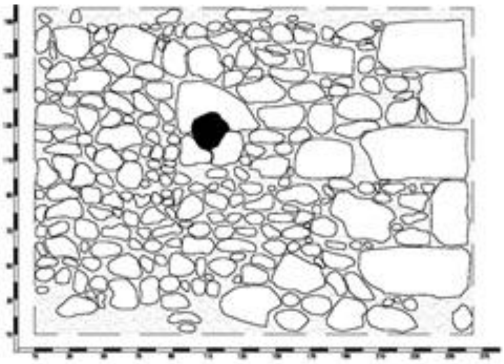


Figure 2.34 Tower – Masonry 2 – Diagram

the case of masonry typology one. In addition, corner stones within the structure tend to be more prominent in size and of higher quality. As seen in the two examples below, the buildings of this

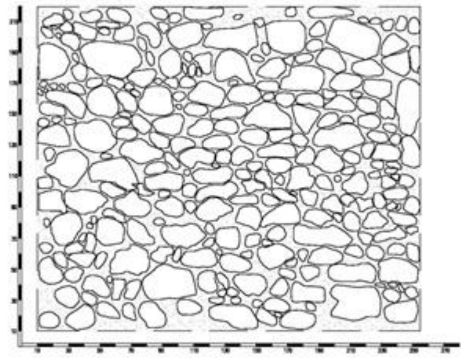
2.35 Front West Façade (Aggregate CdM Tower)

2.36 Front West Façade (Aggregate CdM 010)

2.37 Front North-West Façade (Aggregate CdM Tower)

particular masonry typology are of higher quality in general. All of the towers within Castel del Monte are made of masonry typology two.

There are also several examples of masonry typology two throughout the typical row houses of Castel del Monte, seen in both those oriented parallel and perpendicular to the elevation curves. In the example below, seen in aggregate CdM 010, the masonry does not have perfectly horizontal rows but unlike masonry typology one, there is a strong horizontality. However there are no present vertical systems as will be seen in the case of masonry typology three. As seen in the photo on the next page, masonry typology two is generally present in taller buildings, presumably of higher social



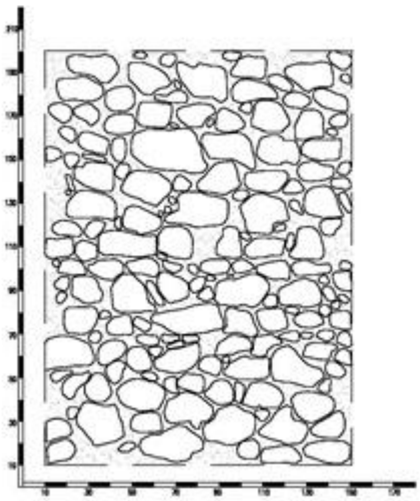
2.38 Parallel Orientation – Masonry 2 – Photo *2.39 Parallel Orientation – Masonry 2 - Diagram*

importance. This will also be seen in the case of structures oriented perpendicular to the elevation

Figure 2.40 South Façade (Aggregate CdM 020)

curves. While the stones present in this masonry are more regular in size, they still strongly differ, which is an important factor to consider in the case of a seismic event that would affect the structure.

The final building typology in which masonry typology two is present is in row houses oriented perpendicular to the elevation curves. As is seen below, in aggregate CdM 014, the quality of masonry is high regarding the individual



2.41 Perpendicular - Masonry 2 – Photo *2.42 Perpendicular – Masonry 2 – Diagram*

stones. Again, as is a characteristic of masonry typology two, there is a presence of horizontality within the masonry structure. In this example, more than in the previous two, there is more regularity

2.43 Front West Façade (Aggregate CdM 014)

regarding stone size as well as a higher quality stone as well. However the lack of mortar leaves the masonry vulnerable to human and environment related factors that can damage the structure. There is again no presence of vertical alignments but the masonry is still one of a higher quality than many within the category of masonry typology two.

2.5.3 Masonry Typology Three

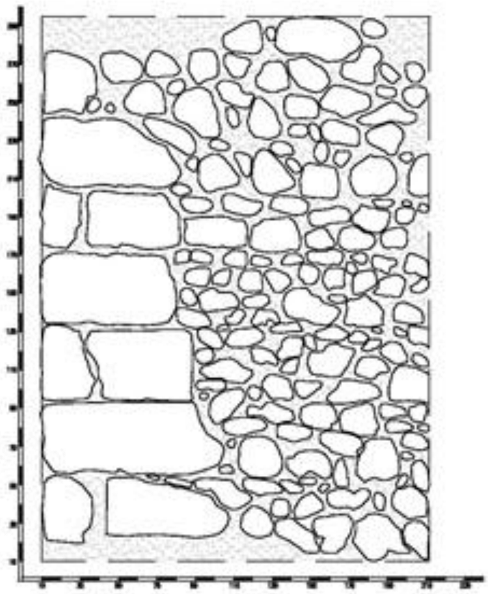
Similar to masonry typology one, masonry typology two is not present in church structures. Instead churches and other religious facilities are reserved to masonry typology three, which is of the highest quality. This is due to the importance given to religious facilities in the Abruzzo region as well as financial support provided by the Catholic Church in the past. The masonry is characterized by horizontal courses with elements every 30 centimeters. There is very little presence of wedges due to the quality of the masonry but when there are, they are of high quality typically made of lime stone. The stones within the masonry are blocks of lime stone, excavated from the local region with smooth treated edges. The size of the stones differs very little with an average length of 20 to 25 centimeters. The mortar is of high quality. It is defined by its tough texture and white or gray color.

2.44 Masonry Elevation – Typology 3 – Façade

2.45 Masonry Elevation – Typology 3 - Zoom

It is in a good state of preservation, most likely due to the importance of the structure to the local society. Similar to the two aforementioned masonry typologies, the typology is located throughout Castel del Monte, present only in the building typology of churches. As seen in the example, in the aggregate CdM Church 2, masonry typology three is present in the Madonna del Suffragio church in

2.46 Church – Masonry 3 – Photo



2.47 Church – Masonry 3 – Diagram

the South of the historical center. There is a strong horizontal presence, forming coherent horizontal rows, more clearly defined than in masonry typology one and two. While there is no concrete vertical structure as seen in present day masonry structures, there is a subtle vertical structure which aids in the proper structural reaction of the masonry to both structural loads and seismic events. As seen in the elevation photo and diagram above, there is also a strong presence of stone corner elements. The stones are very regular in shape and size, implying a high quality. This is seen in all of the churches and religious buildings present in Castel del Monte., as well as the other three villages discussed in this thesis.

Figure 2.48 North Façade (Aggregate CdM Church 2)

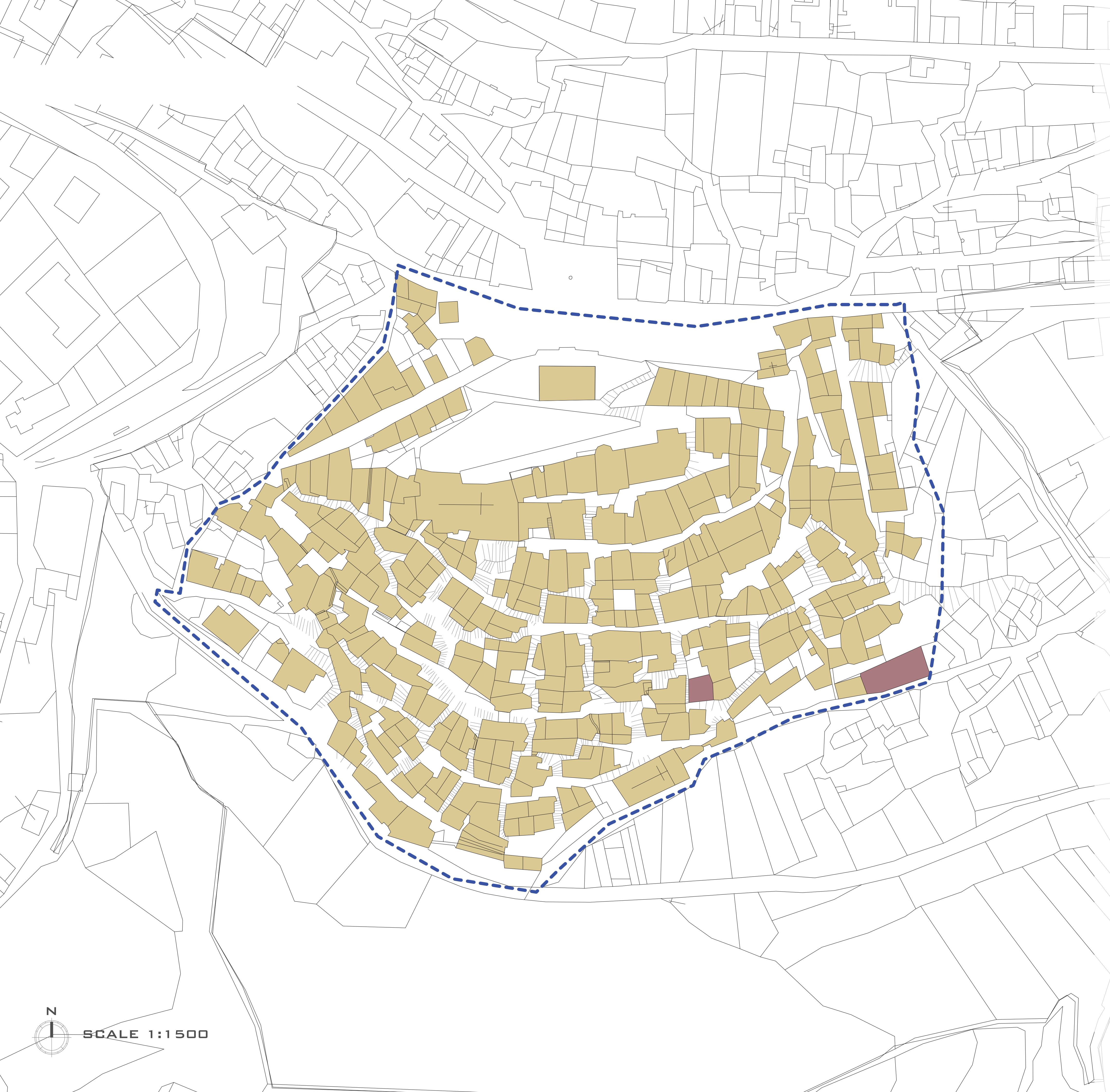
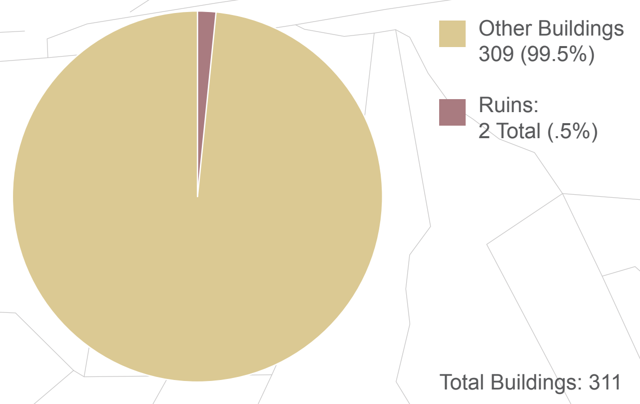


Table 2.6 Location of Ruins

KEY:

- Usable Building
- Building in Ruins

Total Number of Ruins: 2
Total Buildings: 311



DEFINITION:

“Ruins” are considered any building that is beyond uninhabitable, but instead is to the point of having lost all structural stability. The building will in general have collapsed entirely or at least partially. It is important to note these structures because they can hint at a particular vulnerability of an aggregate or area of buildings. They also, if not properly controlled, create damage to surrounding buildings or structures.

EXAMPLES:

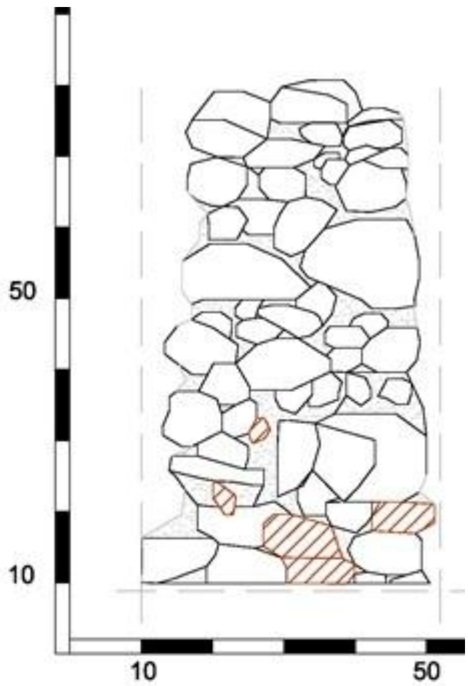
Comune: Castel del Monte
Location of Ruins

2.6 Existing Ruins

Of the villages within the Baronia collective, Castel del Monte has the least amount of ruins. Within the historical center there are only two examples of ruins. However in this section, only one of these ruins will be discussed due to a lack of masonry in the other ruin to be analyzed. Another ruin will be introduced that is located just outside of the historical center, but is similar to the building typologies present in the historical center and therefore useful in this study.

This first ruin to be discussed is that outside of the historical center. The following analysis will be based on the assumption that the wall section analyzed is representative of the overall masonry of the structure. Upon initial observation, it is clear that the masonry has been assembled with a certain effectiveness. This fact is in line with other information gained from observed analysis. Despite the small size of the section under examination, it can be deduced that the masonry is comprised of two leaves with a thickness of 40 centimeters. Both leaves are made up stones of either medium or large size with the presence of some larger stones that provide clamping between the adjacent elements. There is also the important presence of limestone wedges that provide a more

2.49 Section Photo (Aggregate: Not Applicable)



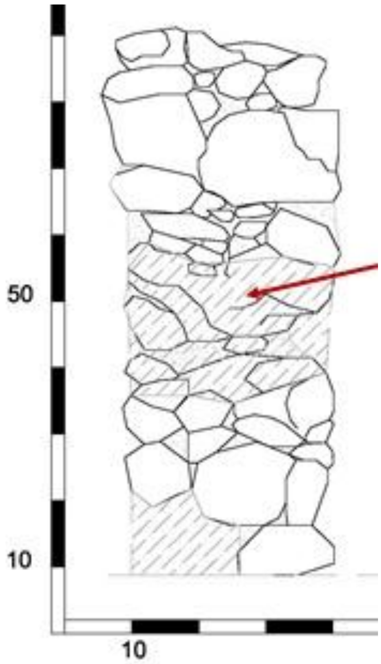
2.50 Section Diagram (Aggregate: Not Applicable)

cohesive structural connection. Within the section, the mortar is still in good condition with a firm consistency. The aggregates within the section are larger than the visible mortar on the surface, composed instead of very fine gravel of angular shape and light gray color. Within the section there were no voids that could have possibly compromised the structural stability of the wall. Following the NTC 2008 table, the masonry can be likened to masonry typology one, as described in the previous "Masonry Typology" section. As described by the NTC categorization and RELUIS modifications, the section is composed of irregularly formed masonry stones (regarding dimensions and materials). In this particular example, it can be deduced that the masonry had little to no influence on the collapse of the structure. However it is important to note that this conclusion is based on the limited evidence available and can be considered simply an assumption without further information or details.

Figure 2.51 Overall Ruins - Photo

Figure 2.52 Overall Ruins - Photo

The second ruins present in Castel del Monte to be analyzed are located within the historical center, unlike the previous example. While the structure of the present day ruins collapsed before the official naming of the aggregates, the ruins are located directly East of aggregate CdM 115, lying adjacent to the still standing single structure of that aggregate. Based on the close proximity of the ruins to the aggregate, it can be presumed that the ruins were once a part of the CdM 115 aggregate. Similar to the previously discussed ruins, the analysis of these ruins will be based on the assumption that the wall section under observation is a proper representative of the overall masonry of the collapsed structure. Initial observation indicates that the masonry has been assembled with a certain effectiveness, which is in line with what was observed in the ruins overall. Although the sample section is of small proportions, it can be deduced that the masonry is composed of a single leaf with a thickness of 35 centimeters. It consists of stones of both medium and large size with the presence of



2.53 Section Photo (Aggregate CdM 115) *2.54 Section Diagram (Aggregate CdM 115)*

larger connecting stones, indicated by the red arrow in the diagram above, on the right. Also it is important to note the presence of limestone wedges that connect that increase the structural stability of the section. The mortar within the section if in good condition and is of firm consistency. The aggregates are larger than the visible mortar on the surface, which are instead of very fine gravel and light gray color. There were no visible voids within the section that could have risked the structural stability. Following the definitions given be the NTC 2008 categorization and RELUIS modifications, the examined masonry can be likened to masonry typology two, of medium quality. This type of masonry is, defied by RELUIS, a sub-horizontal masonry with roughly cut stones (well interlocked).

2.55 Overall Ruins - Photo

2.56 Ruins Elevation - Photo

Due to a lack of information available, it is impossible to conclude the cause of collapse based solely on analyzing the masonry section of the ruins, however the quality of the masonry can be noted. In the case of both analyzed section, the quality of masonry was low or medium (regarding the three masonry typologies present in Castel del Monte), but was assembled with a certain effectiveness and knowledge of construction and anti-seismic design. The lack of evidence of masonry failure suggests that the quality of masonry in Castel del Monte, even the quality of the lowest masonry typology one, is still structurally reliable regarding its vulnerability to seismic events. This then puts all other elements involved as a possible factor in the collapse of these two previously discussed structures or the possible future collapse risk of the still standing structures within the historic center. It is also important to note that both structures are oriented parallel to the elevation curves.

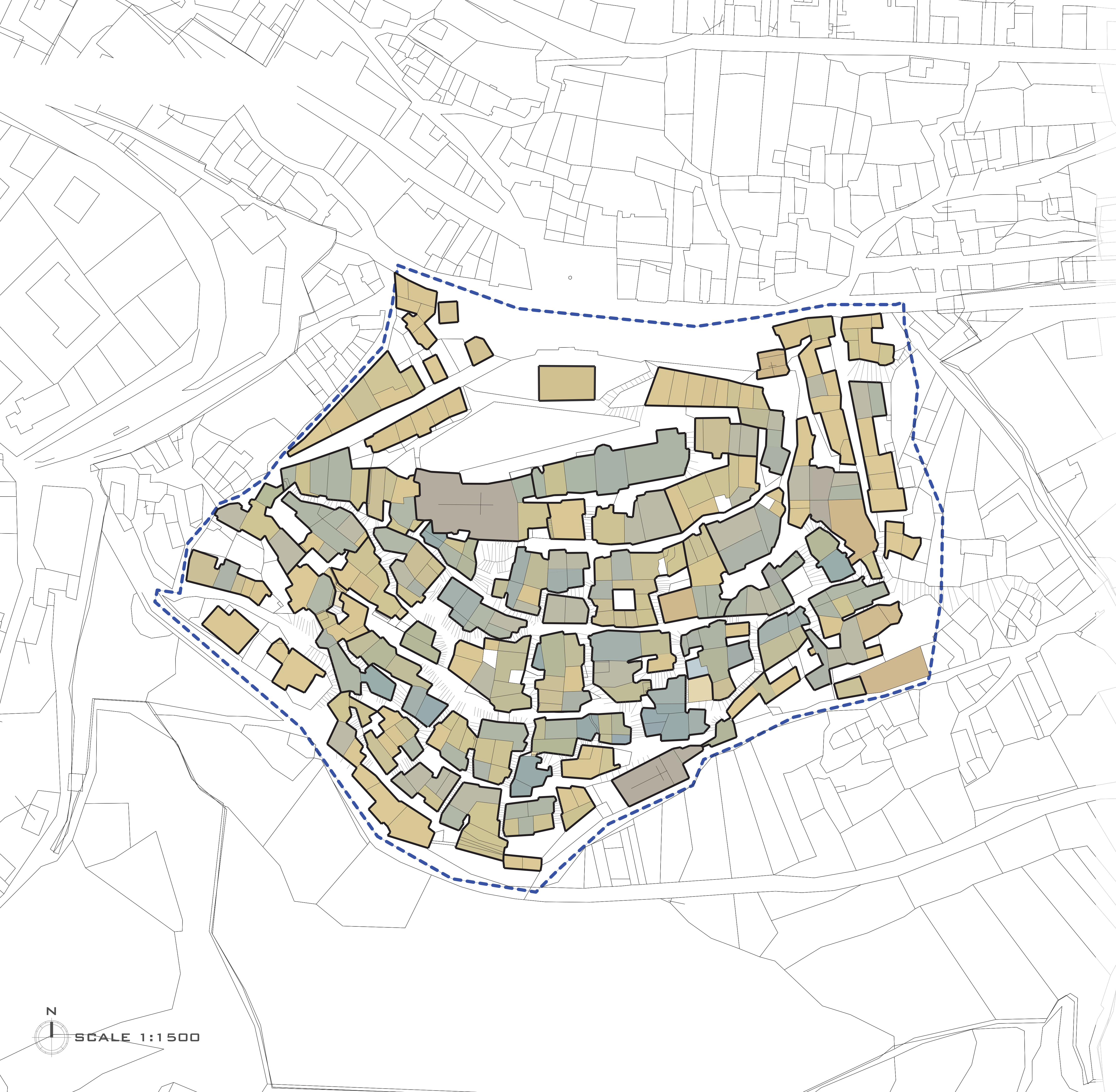


Table 2.7 Collective Homogeneity Analysis

DESCRIPTION:

This collective homogeneity map includes all major structural characteristics that influence the homogeneity of an aggregate. This includes building height, building typology, masonry typology and orientation to the elevation curves. All of the previously mentioned maps have been overlaid over each other to emphasize the aggregates that are the best positive and negative examples of structural homogeneity. This was underlined in the following maps and then analyzed within the text of the thesis to better understand the vulnerability or lack of vulnerability of certain aggregates.

GENERAL KEY:

- Buildings
- Aggregate Boundaries

BUILDING HEIGHTS:

- 5 Floors Equivalent (or above)
- 4 Floors Equivalent
- 3 Floors Equivalent
- 2 Floors Equivalent
- 1 Floor Equivalent

BUILDING TYPOLOGIES:

- Historical Boundary Wall House
- Block House
- Tower House
- Buidling Oriented Perpendicular to the Elevation Curve
- Building Oriented Parallel to the Elevation Curve
- Religious Building
- Ruins

MASONRY TYPOLOGIES:

- Irregularly formed masonry (regarding shape, dimensions and materials) stone
- Subhorizontal masonry with roughly cut stones (of varying dimensions)
- Horizontal masonry courses with roughly cut stones (well interlocked)
- Plaster Covered

ORIENTATION TO ELEVATION CURVES:

- Building unit positioned parallel to the elevation curves
- Building unit positioned perpendicular to the elevation curves

Comune: Castel del Monte

Collective Homogeneity Analysis

2.7 Collective Homogeneity

The collective homogeneity analysis is primarily based on four specific factors, all of which have been determined through on-site analysis. These include the topics of the previous four sections, including building typology, orientation to elevation curves, building height and masonry typology. As seen in the attached map of Castel del Monte for “Collective Homogeneity”, the four previously mentioned factors’ maps have been overlaid to locate the aggregates with a uniform structure, regarding all four elements. The aggregates that present the most and least uniformity regarding these four elements will be discussed in the following two sections, entitled “Positive Homogeneous Examples” and “Negative Homogeneous Examples”.

Overall, Castel del Monte is one of the least collectively homogeneous, considering these structural factors, of the villages of the Baronia collective. An initial analysis of the attached map reveals that more homogeneous aggregates are located along the periphery of the historical center, while the center of the historical center is more irregular in the overall structural makeup. A lack of structural homogeneity can create several types of damages because the aggregate is more likely to act as separate elements instead of a single unit in the case of a seismic event. This can increase the chances of several collapse mechanisms within the individual aggregates as well as those that are adjacent to one another.

In the case of Castel del Monte, there are several aggregates that are vulnerable to seismic events due to their lack of structural homogeneity and will therefore be strongly considered as structures to be restored with the limited public funds available. These structures will be discussed in the “Negative Homogeneous Examples” section, while in the “Positive Homogeneous Examples” section, aggregates of homogeneous construction will be used as a guide for possible restoration work for the aggregates considered to not be homogeneous.

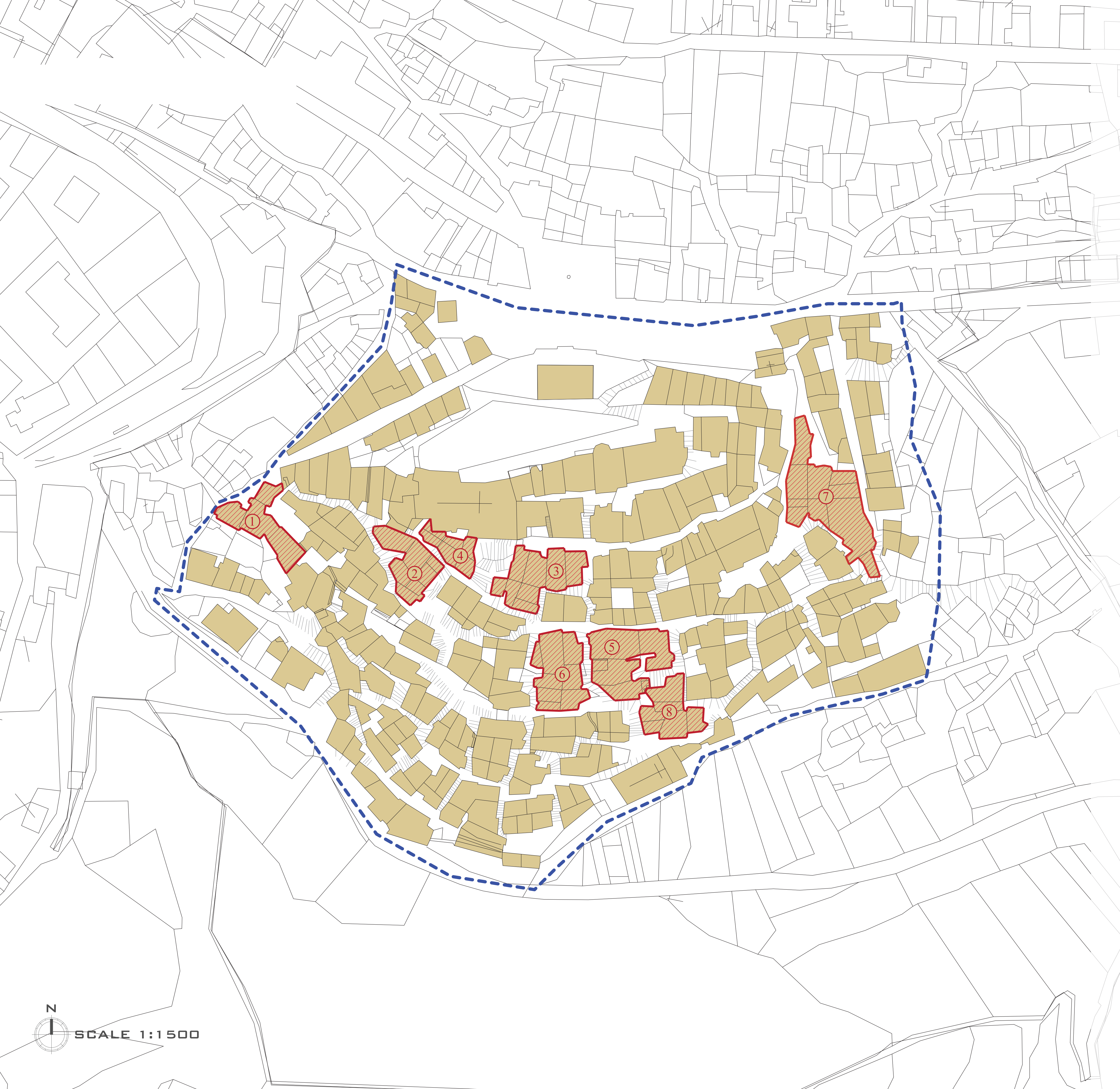


Table 2.8 Location of Negative Examples

KEY:

Typical Building

Aggregate Boundary

Negative Homogenous Example

INFORMATION:

Number of Examples: 7

Example 1: CdM 028

Example 2: CdM 013

Example 3: CdM 002

Example 4: CdM 001

Example 5: CdM 023

Example 6: CdM 036

Example 7: CdM 100

Example 8: CdM 101

DESCRIPTION:

These negative examples showing a lack of homogeneity were chosen based on the “Combined Homogeneity analysis” map for Castel del Monte. The previously mentioned map was created by combining the following maps:

Building Heights

Building Typologies

Masonry Typologies

Orientation to the Elevation Curves

All of these maps were laid on top of one another. Then several examples of aggregates were chosen back on their lack of homogeneity regarding these four principal elements. These examples will be further analyzed within the text of the thesis.

DEFINITION:

A “negative example of homogeneity”, in the context of this thesis, is defined as an aggregate made up of several buildings. These buildings will be of different heights and made from several different types of masonry possibly with restorations made of different masonry from that of the original constructions. In addition, the building typologies of all of the buildings within the aggregate are different and the orientation to the elevation curves will be different. All or several of them will also be oriented perpendicular to the elevation curves. It is all of these qualities, or variations of them, that make a specific aggregate a “negative example of homogeneity”

Comune: Castel del Monte

Location of Negative Examples

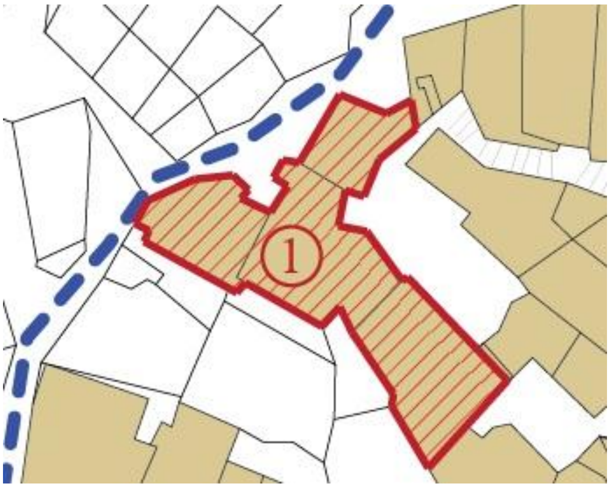
2.8 Negative Homogeneous Examples

As described in the previous "Collective Homogeneity" section, the final negative examples have been chosen considering the structural homogeneity of each aggregate within Castel del Monte. The overall structural homogeneity was determined by the analysis of four key structural factors including the building typology, orientation to elevation curves, building height and masonry typology. In the case of Castel del Monte, eight negative examples of structural homogeneity within a single aggregate have been chosen, considering the collective homogeneity of all 58 aggregates present in the historical center of Castel del Monte.

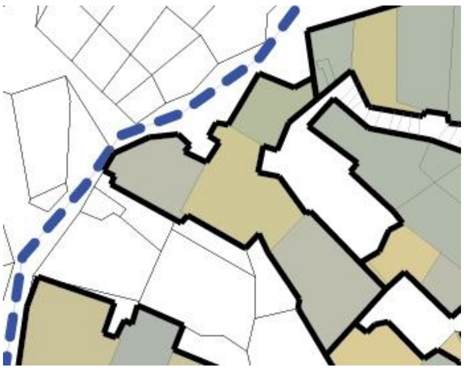
2.8.1 Negative Collective Homogeneity Example One

The first example of negative structural homogeneity comes from aggregate CdM 028. This particular aggregate is found on the North-East section of the historical center of Castel del Monte.

2.57 Location of aggregate within Castel del Monte

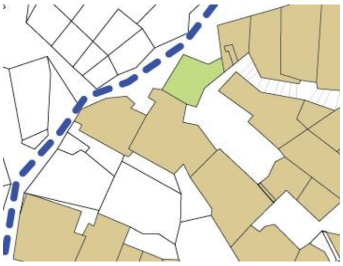


2.57 Location of aggregate CdM 028

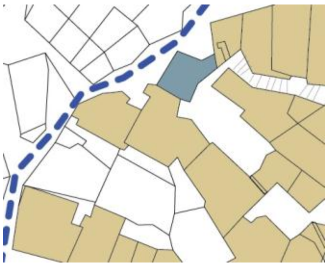


2.58 Collective Homogeneity

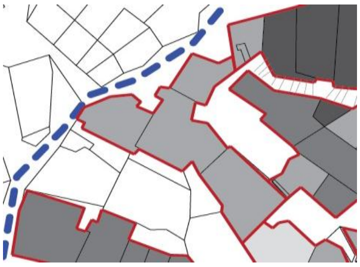
As seen in the collective homogeneity analysis below, overall the aggregate is extremely homogeneous. The aggregate is made of four connected buildings, all of which are structurally diverse with the four factors taken into consideration for the collective homogeneity analysis. In addition, the plan of the aggregate as well as the individual structures is extremely irregular. This adds to the overall vulnerability of the aggregate in the case of a seismic event. As seen in the separate diagrams above, the Northern most structure of the aggregate is the least



2.59 Building Typology



2.60 Orientation to Elevation



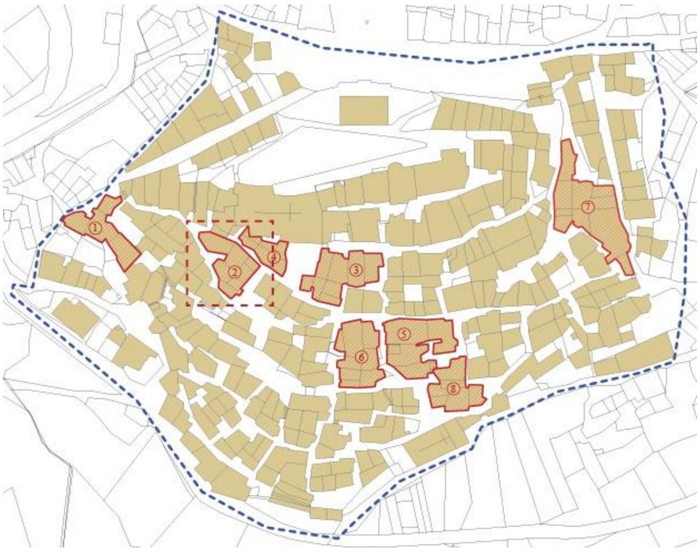
2.61 Building Height

2.62 Masonry Typology

homogenous, regarding the overall aggregate. It is the only structure within the aggregate that is oriented perpendicular to the elevation curves. In addition, it is also composed of a different masonry typology than the other half of the structures within the aggregate. This diversity of a single element suggests this particular building was added to the aggregate after its initial construction. Additions do not necessarily imply vulnerability, but when they are constructed without considering the existing construction typologies in place, as is the case in this particular aggregate, they can risk the structural stability of the entire aggregate in the case of a seismic event. Beyond this particular structure, the aggregate is fairly homogeneous, especially with regards to the building heights that are all equal.

2.8.2 Negative Collective Homogeneity Example Two

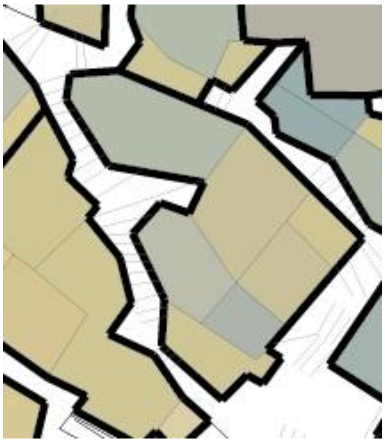
The second aggregate considered to be a negative example of structural homogeneity is aggregate CdM 013. This aggregate is located closer to the middle of the historical center.



2.63 Location of aggregate within Castel del Monte

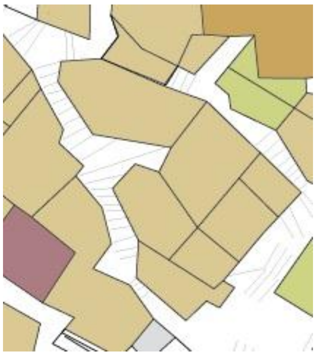
2.64 Location of aggregate CdM 013

Similar to the previous example, the aggregate is extremely irregular in plan, specifically regarding the structure within the aggregate, to the North-West. This location and separation from the rest of the aggregate could imply it was an addition to the original construction, however this is simply

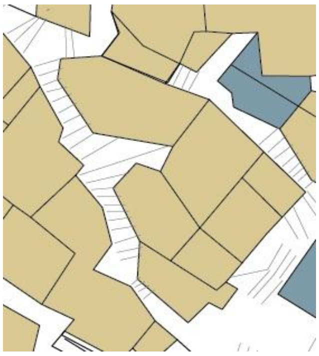


2.65 Collective Homogeneity

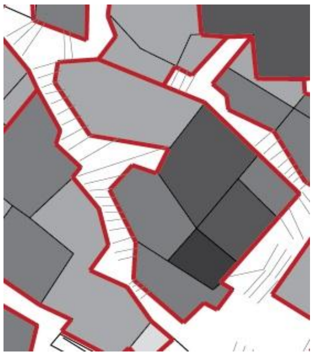
conjecture. The entire aggregate is oriented parallel to the elevation curves. However the aggregate lacks in homogeneity in both masonry typology and building heights. There are seven total structures within the aggregate. In the case of the building heights, almost all of the buildings are touching at least one other structure within the aggregate with a height difference of two stories. In addition, one of the structures on the South-East of the aggregate has tower like characteristics, which could lead to potential collapse mechanisms. Regarding the



2.66 Building Typology



2.67 Orientation to Elevation



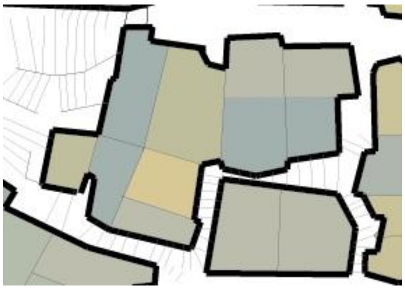
2.68 Building Height

2.69 Masonry Typology

masonry typology, three different typologies are present and located throughout the aggregate. In the case of a seismic, this could lead to the separate structures within the aggregate reacting in different manners, which is only amplified by the extreme differences in height within the aggregate. Overall this aggregate can be considered extremely vulnerable in the case of a seismic event, especially with its proximity to San Marco church.

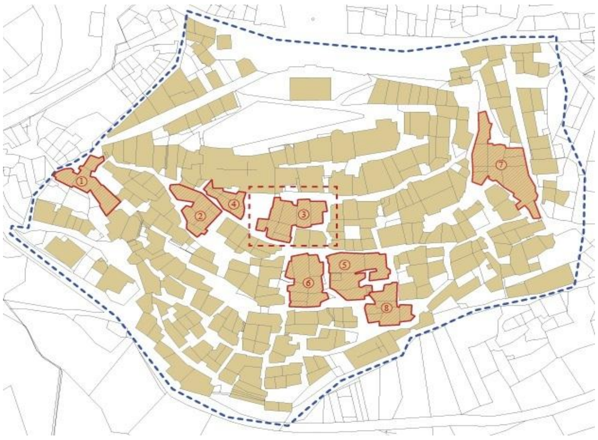
2.8.3 Negative Collective Homogeneity Example Three

The third negative example comes again from the Central-North portion of the historical center, in the form of aggregate CdM 002. The aggregate is formed by eight separate structures. This negative example is unique due to the fact that the masonry throughout the aggregate is entirely uniform, which suggests a recent restoration. However regarding the remaining three factors considered for the collective homogeneity analysis, the aggregate functions as two separate units. Half of the aggregate is oriented perpendicular to the elevation curves, while the other half is



2.70 Collective Homogeneity

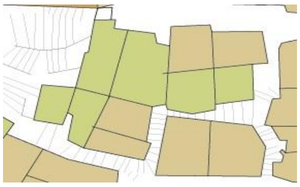
oriented parallel. In addition, the structures in the aggregate are taller on the half of the aggregate that is uphill, while the other half that is downhill is shorter. This is a common construction characteristic within both Castel del Monte and other hillside villages. This type of structural scheme requires addition buttresses and tie rods to avoid the common collapse mechanism of out of plane wall overturning. This



2.71 Location of aggregate within Castel del Monte

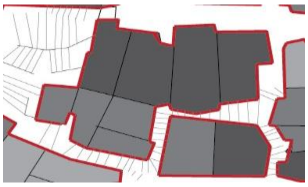
2.72 Location of aggregate CdM 002

aggregate is extremely vulnerable to this particular collapse. Therefore this example is very important when considering the overall vulnerability of the village, specifically discussed later in this thesis.

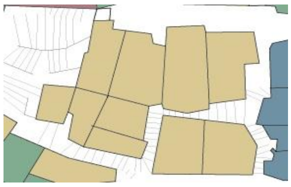


2.73 Building Typology

2.74 Orientation to Elevation



2.75 Building Height



2.76 Masonry Typology

2.8.4 Negative Collective Homogeneity Example Four

The fourth aggregate is located in the Northern section of the historical center and is connected to

2.77 Photo of aggregate CdM 001

2.78 Photo of CdM 001

the San Marco church, aggregate Church. This negative example of structural homogeneity is found in aggregate CdM 001. Similar to the previous example of structural homogeneity, the aggregate is irregular in both plan and elevation. In addition, considering the collective homogeneity analysis, the aggregate, made of six separate structures, is lacking in structural homogeneity regarding all four of the considered factors. The center of the structure is oriented parallel to the elevation curves while

2.79 Location of aggregate within Castel del Monte

2.80 Location of aggregate CdM 001

the two end sections are oriented perpendicular. This could reveal that both the end sections were additions after the initial construction phase and therefore vulnerable to collapse, away from the center portion of the aggregate. The aggregate is fairly homogeneous regarding the masonry

2.81 Collective Homogeneity

typology. Almost the entire aggregate is masonry typology one, except for a single building on the South-East corner of the aggregate. The aggregate is also homogeneous regarding the buildings heights within the aggregate. There is no more than a one story difference between two connected buildings. What makes this negative example unique is that it has been structurally separated into three sections. The differing

2.82 Building Typology

2.83 Orientation to Elevation

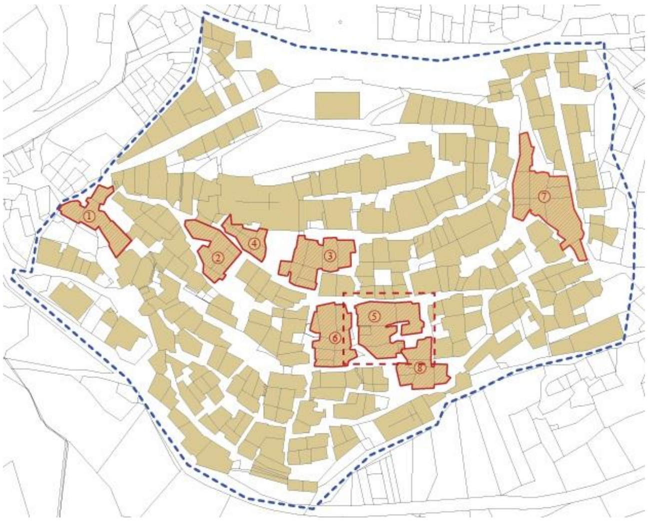
2.84 Building Height

2.85 Masonry Typology

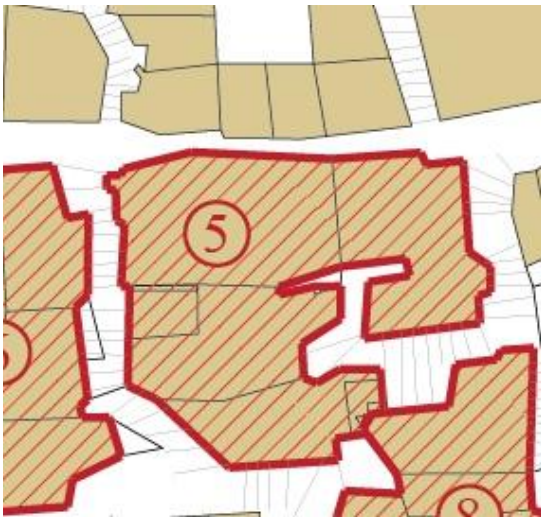
orientations to the elevation curves can lead to the separation of the three sections from one another as well as the possible out of plan wall turning of the downhill facades. In order to diminish the vulnerabilities to collapse present in the aggregate, several structural renovations are essential, including the addition of buttresses on the Southern facades as well as stronger connections between the three separate portions of the aggregate. These interventions will prevent substantial damages both to the aggregate as well as the adjacent church in the event of future seismic activity.

2.8.5 Negative Collective Homogeneity Example Five

The fifth negative example is seen in the aggregate CdM 023. This particular aggregate is made up of four buildings and features a traditional "sporto". Sporti or arched interior overpasses are a common structural element within the Baronia collective and specifically Castel del Monte. This aggregate is irregular in plan but fairly regular in elevation, specifically regarding the building heights within the aggregate. As seen in the previous example, this aggregate is separated into three separate sections structurally. The center portion of the aggregate is oriented parallel to the elevation curves,



2.86 Location of aggregate within Castel del Monte



2.87 Location of aggregate CdM 023

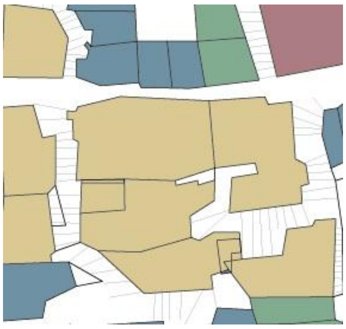
while the two ends to the North and the South are oriented perpendicular. Besides the orientation to the elevation curves, the aggregate is completely homogeneous. The masonry typology and building heights are homogeneous in all four of the buildings within the aggregate. The largest concern is the sectional separations within the aggregate and different orientations to the elevation curves. In both cases, the addition of buttresses and stronger

2.88 Collective Homogeneity


2.89 Building Typology


2.90 Orientation to Elevation


2.91 Building Height


2.92 Masonry Typology

connections between the buildings are integral in avoiding future collapse mechanisms or major damages in the case of a seismic event.

2.8.6 Negative Collective Homogeneity Example Six

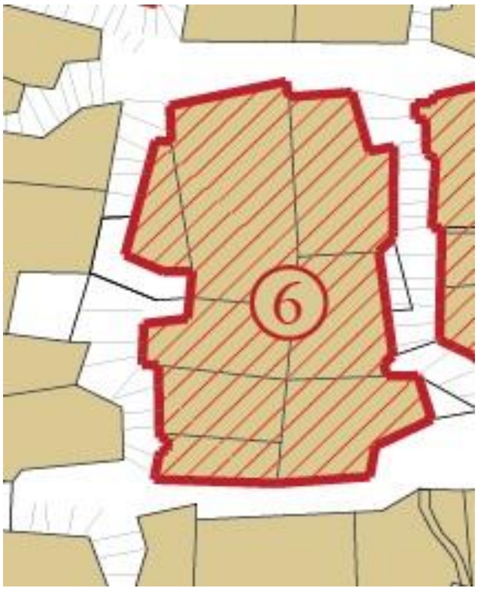
The sixth example is adjacent to the previously discussed aggregate. This particular example of negative structural homogeneity is found in aggregate CdM 036. As seen in the following photos,


2.93 Photo of aggregate CdM 036

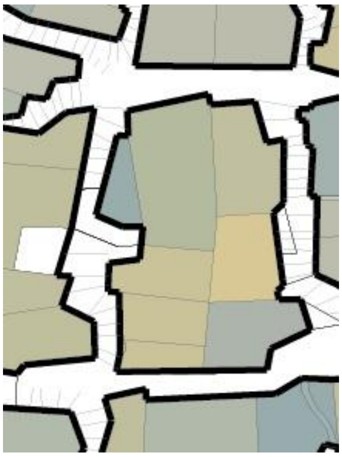

2.94 Photo of aggregate CdM 036

this aggregate has been added to and renovated on multiple occasions since its original construction. The aggregate is formed by eight separate buildings. This aggregate can be considered one of the least homogenous within the historical center of Caste del Monte. However aggregates that have been substantially changed over the course of their lives are common throughout Abruzzo, specifically in the villages of the Baronia collective. Regarding building typology, the Southern half

2.95 *Location of aggregate in Castel del Monte*

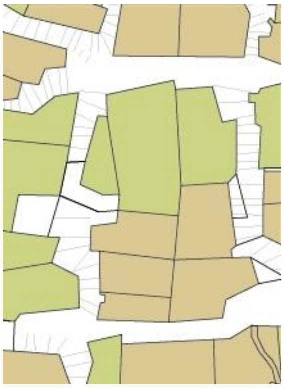


2.96 *Location of aggregate CdM 036*

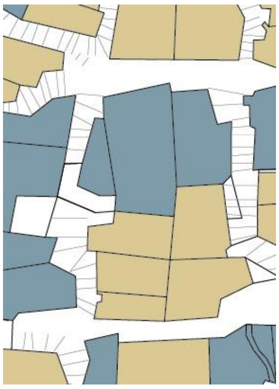


2.97 Collective Homogeneity

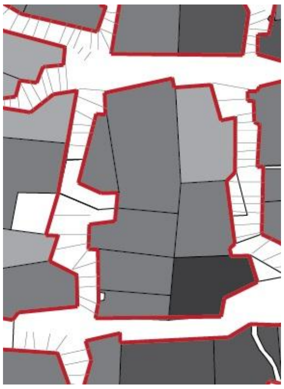
of the aggregate is oriented parallel to the elevation curves while the Northern portion, consisting of three separate buildings, is oriented perpendicular as seen in the diagrams below. The heights of the aggregate vary significantly, with a tower like structure at the South-East corner of the aggregate. In addition, the masonry typology consists of three separate types. The North-East corner of the aggregate is covered in plaster, which implies a recent restoration of the structural masonry. The North-West corner however is composed of masonry typology one, while the entire Southern portion is made up of masonry typology two. This also implies the addition of an piece to the Southern portion of the aggregate. Overall the aggregate, regarding renovations, needs the



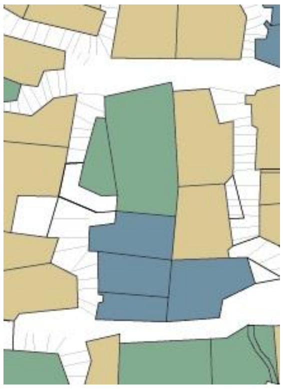
2.98 Building Typology



2.99 Orientation to Elevation



2.100 Building Height



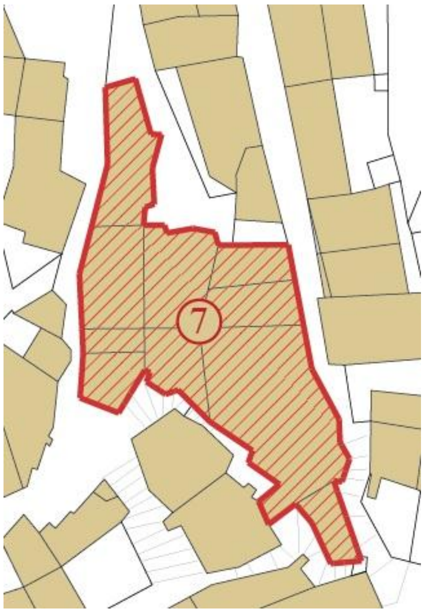
2.101 Masonry Typology

addition of both plaster covering for the exposed masonry as well as tie rods in order to better the connections between the individual units of the aggregate. These interventions will not only help to minimize the effects of decay on the structural masonry, but also deter the out of plane actions of the Southern wall, in the case of a seismic event.

2.8.7 Negative Collective Homogeneity Example Seven

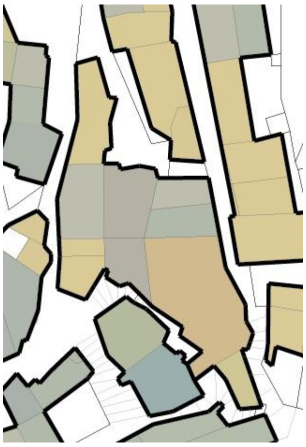
The second to last example of negative homogeneity in the historical center of Castel del Monte, is seen in aggregate CdM 100. This is the largest of all of the aggregates in Castel del Monte. There are ten separate buildings within the aggregate. The aggregate is especially important in the village due to the placement of a seminary within the aggregate. Currently three of the buildings within the aggregate are inhabited. The aggregate is notable due to it being extremely irregular

2.102 Location of aggregate within Castel del Monte



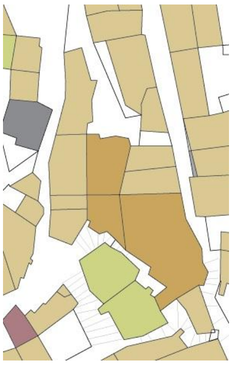
2.103 Location of aggregate CdM 100

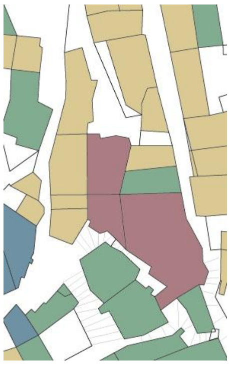
in both plan and elevation. This regularity as well as its location on the edge of the historical center



2.104 Homogeneity

of the village implies much of the building is additions or restorations, added after the initial construction. This is also justified by the location of plaster covered units on the extremities of the aggregate. However even the center of the aggregate, including six buildings, lack an overall structural homogeneity. The core of the aggregate is exclusively programed as religious spaces, being used a seminary for the village. The rest of the building however is classified as structures oriented parallel to the elevation curves. The overall building heights are varied, with the most extreme being the building on the



2.105 Building Typology *2.106 Orientation to Elevation* *2.107 Building Height* *2.108 Masonry Typology*

South-East corner, which is more than two stories taller than the adjacent structures. This structure is one of the renovated buildings and is the center of the religious buildings. The masonry of the three religious buildings is of the highest quality, masonry typology three. The remainder of the aggregate are either masonry typology one or covered in plaster. Despite the lack of collective homogeneity, the aggregate is only slightly vulnerable to seismic events due to the fact that the buildings within the aggregate that are irregular are of higher quality than the rest of the aggregate. Regarding restoration, attention should be paid to the tower-like structure within the group of religious buildings. The remainder of the aggregate needs very little restorative work, especially considering the lack of habitation within the rest of the buildings of the aggregate.

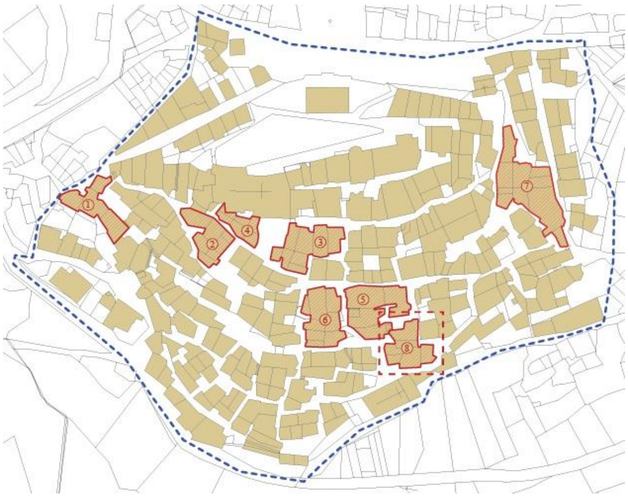
2.8.8 Negative Collective Homogeneity Example Eight

The eighth and final negative example of structural homogeneity within Castel del Monte

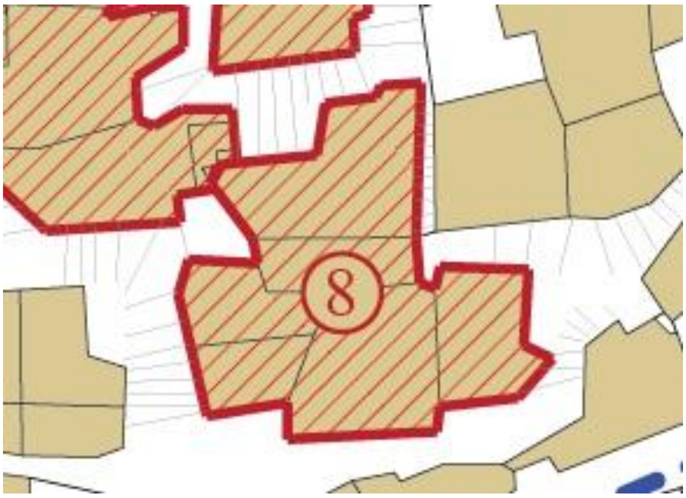
2.109 South-East Elevation of Aggregate

2.110 North-East Elevation of Aggregate

comes from aggregate CdM 101. While the aggregate appears to be homogeneous following the collective homogeneity analysis, further observation implies several stages of renovations and additions that failed to respect the existing masonry and construction typology. Similar to many of the previous negative examples of structural homogeneity, the aggregate is extremely irregular in plan. The entire aggregate is oriented perpendicular to the elevation curves. While being oriented

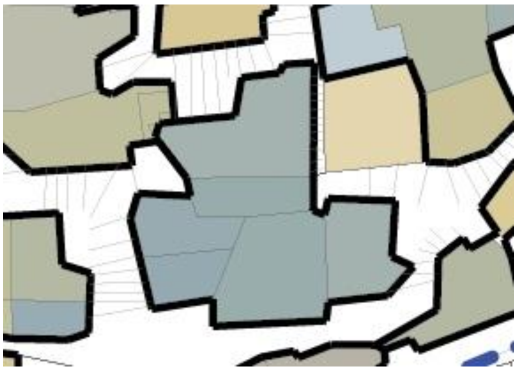


2.111 *Location of aggregate within Castel del Monte*



2.112 *Location of aggregate CdM 101*

perpendicular has been related to ruins in the Baronia collective, it can pose a structural risk. However due to the fact that the entire aggregate is homogeneous regarding the orientation to the elevation, it is highly unlikely this orientation will cause structural damage. The building heights within the aggregate are fairly regular, with the exception of the tower-like structure within the



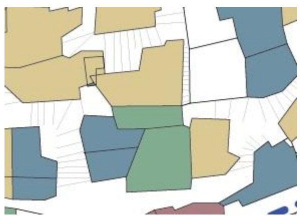
2.113 *Collective Homogeneity*

aggregate. The largest risk, regarding structural vulnerabilities in seismic events, is the masonry typology of the aggregate. There are three different masonry typologies present in the aggregate and several are present in single units of the aggregate. As seen in the photos introducing aggregate CdM 101, several restorations of

2.114 Building Typology

2.115 Orientation to Elevation

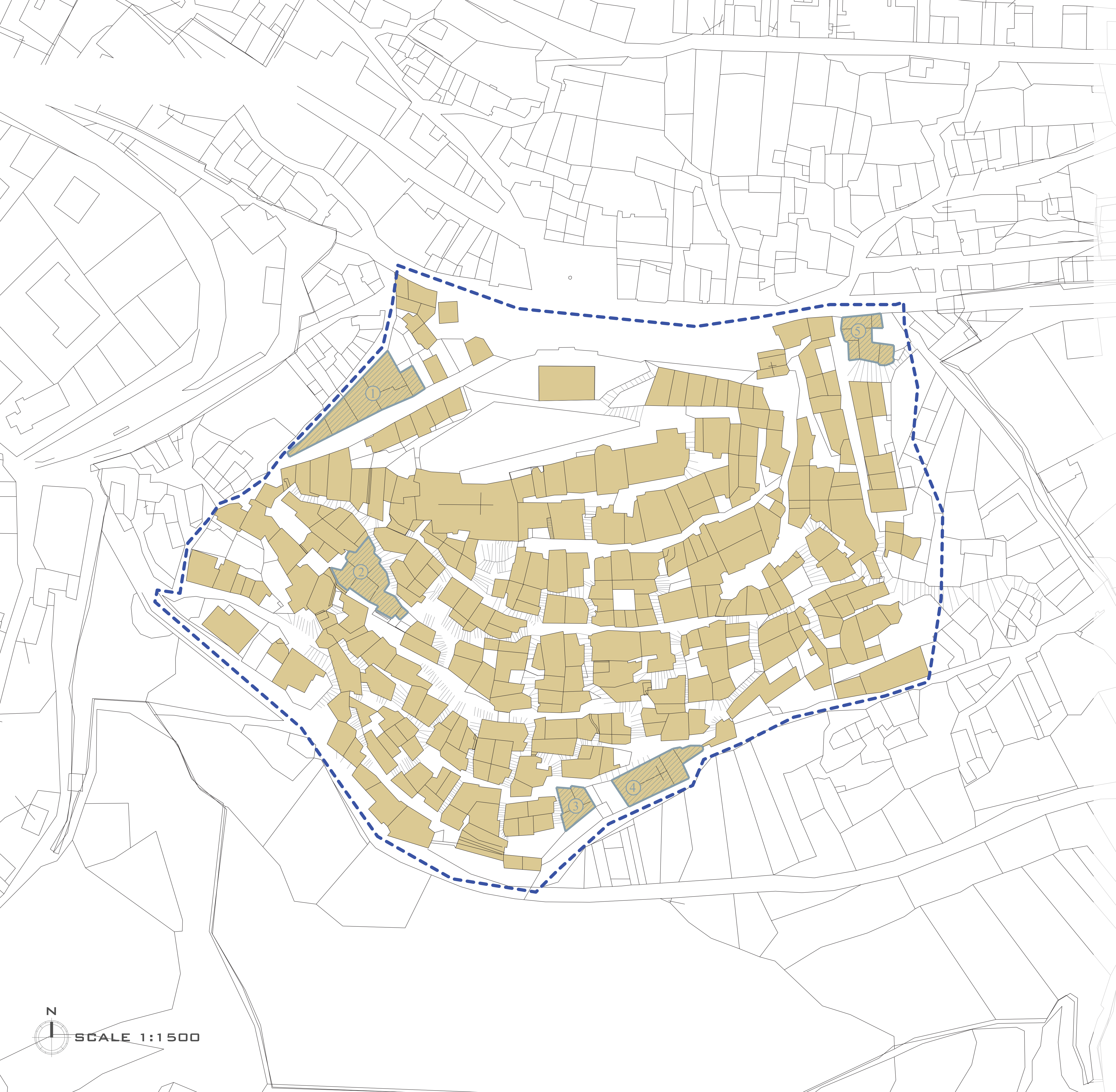
2.116 Building Height



2.117 Masonry Typology

the aggregate have been added over the years, mixing several masonry typologies in single units.

Table 2.9 Location of Positive Examples



KEY:

- Typical Building
- Aggregate Boundary
- Positive Homogenous Example

INFORMATION:

Number of Examples: 6

Example 1: CdM 030

Example 2: CdM 110

Example 3: CdM 006

Example 4: CHURCH 2

Example 5: CdM 005

DESCRIPTION:

These positive examples showing homogeneity were chosen based on the “Combined Homogeneity analysis” map for Castel del Monte. The previously mentioned map was created by combining the following maps:

Building Heights

Building Typologies

Masonry Typologies

Orientation to the Elevation Curves

All of these maps were laid on top of one another. Then several examples of aggregates were chosen back on their homogeneity regarding these four principal elements. These examples will be further analyzed within the text of the thesis.

DEFINITION:

A “positive example of homogeneity”, in the context of this thesis, is defined as an aggregate made up of several buildings. These buildings will be of the same height and made from the exact same type of masonry, without restorations made of different masonry from that of the original constructions. In addition, the building typologies of all of the buildings within the aggregate are the same and the orientation to the elevation curves will be the same. All or several of them will also be oriented parallel to the elevation curves. It is all of these qualities, or variations of them, that make a specific aggregate a “positive example of homogeneity”

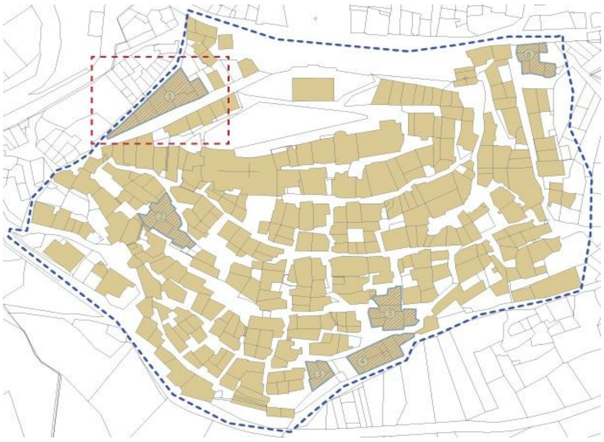
Comune: Castel del Monte
Location of Positive Examples

2.9 Positive Homogeneous Examples

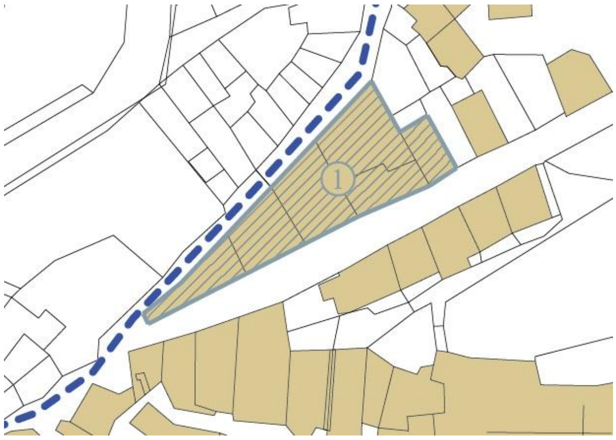
As described in the previous "Collective Homogeneity" section, the final positive examples have been chosen considering the structural homogeneity of each aggregate within Castel del Monte. The overall structural homogeneity was determined by the analysis of four key structural factors including the building typology, orientation to elevation curves, building height and masonry typology. In the case of Castel del Monte, six positive examples of structural homogeneity within single aggregates have been chosen, considering the collective homogeneity of all 58 aggregates present in the historical center of Castel del Monte. However, only one example will be discussed.

2.9.1 Positive Collective Homogeneity Example One

The first example of positive structural homogeneity is in aggregate CdM 030. This particular aggregate is composed of seven buildings that together are defined as a row house, regarding the



2.118 Location of aggregate within Castel del Monte



2.119 Location of Aggregate CdM 030

building typology of the individual elements within the aggregate unit. The aggregate is located within the historic center but just beyond the historic boundary wall to the North-West. This example of positive homogeneity is representative of the general typology of aggregates outside of the historic boundary wall. Several of these buildings and aggregates have been restored and well maintained throughout the years. However it is important to note that many of these structures are not as old as those of the historical center and therefore show less damage than those that were built in the original construction of Castel del Monte. In addition, their location within the historic center, close to the municipality and historical boundary wall and gate, has added social importance to the structure, warranting extra restorative efforts and general maintenance. The aggregate is also currently of private use with only one of the buildings currently inhabited.

The diagram below is a representation of the collective homogeneity of the aggregate, as seen in the previous "Collective Homogeneity" section. The aggregate overall maintains a fairly homogeneous composition, in all four of the considered factors. As seen below the building typology and orientation to elevation curves of the individual structures within the aggregate are all equal. The structures are typical row houses, oriented parallel to the elevation curves. This homogeneous composition allows the overall aggregate to react as a single structure in the case of a seismic event, significantly reducing the number of plausible collapse mechanisms. The overall buildings heights differ, however there is only a single case in which two adjacent buildings within the aggregate differ (regarding height) by more than two stories. The connection between these two structures, located on the South of the aggregate, can be considered a point of concern, especially considering the current occupancy of the shorter building. This could possibly lead to the collapse of the taller structure onto the short structure which is inhabited. Regarding the masonry composition of the aggregate, the structures are fairly homogeneous. Half of the structures are plaster covered while the other half are either of masonry typology one or two, low or medium quality. However structurally this should be of little concern considering the overall homogeneity of the aggregate as well as the similarity between masonry typology one and two. An important fact of the aggregate is that it is also regular in plan.

2.120 Collective Homogeneity

2.121 Building Typology *2.122 Orientation to Elevation* *2.123 Building Heights* *2.124 Masonry Typology*

2.10 Openings

Within Castel del Monte, there are several examples of both positive and negative opening placements. Many of the aggregates included in the "Negative Homogeneous Examples" section are present here in the form of negative examples of openings. In many cases, the openings considered to be negative examples are located too close to structural elements or too close to one another. In

2.125 Negative Opening Example No.1

2.126 Negative Example No.2

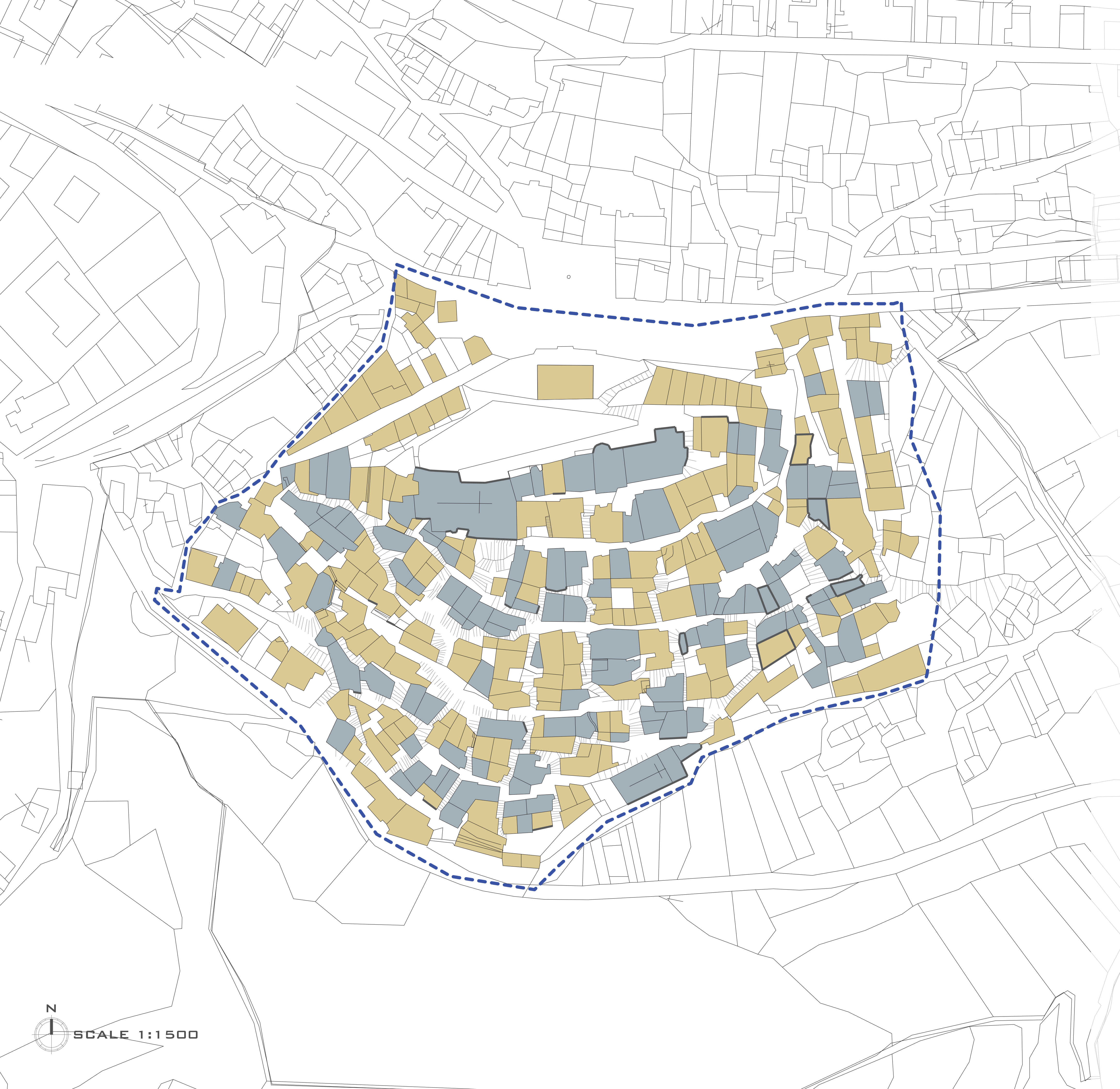
2.127 Negative Example No.3

example number one, there are several structural flaws considering the location of the openings. In general, the openings are extremely close to one another. In addition, there is an opening in the corner which destroys the continuity of the vertical structure, increasing the likeliness of shear failure. Examples two and three are further examples of openings being placed too close to one another, thus compromising the structure of the wall. The positive examples seen to the left utilize openings placed far apart as well *as* being placed somewhat off center in order to lessen the possibility of the wall overturning collapse overturning.

2.128 Positive Example No.1

2.129 Positive Example No.2

Table 2.11.1 Permanent Interventions



KEY:

- Typical Building
- Buttress Location
- Building with Tie Rods in Place

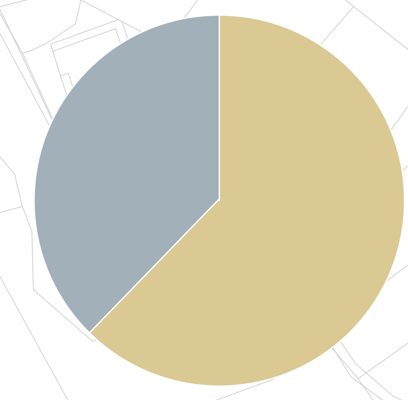
DEFINITION:

Buttress - A mass of masonry or brick work projecting from or built against a wall to give additional strength, usually to counteract the lateral thrust of an arch, roof or vault. There are several different types of buttresses, including angle, clasping, diagonal, flying, lateral, pier and setback buttresses.

Tie Rod - A slender structural unit used as a tie and capable of carrying tensile loads only. Tie Rods are generally used on opposite facades, meant to literally tie the building together in order to prevent facade overturning.

INFORMATION:

Number of Buildings with Tie Rods:	121
Number of Buildings with Buttresses:	26
Total Number of Buildings:	311



EXAMPLES:

Tie Rod

Buttress

Comune: Castel del Monte

Permanent Intervention Locations

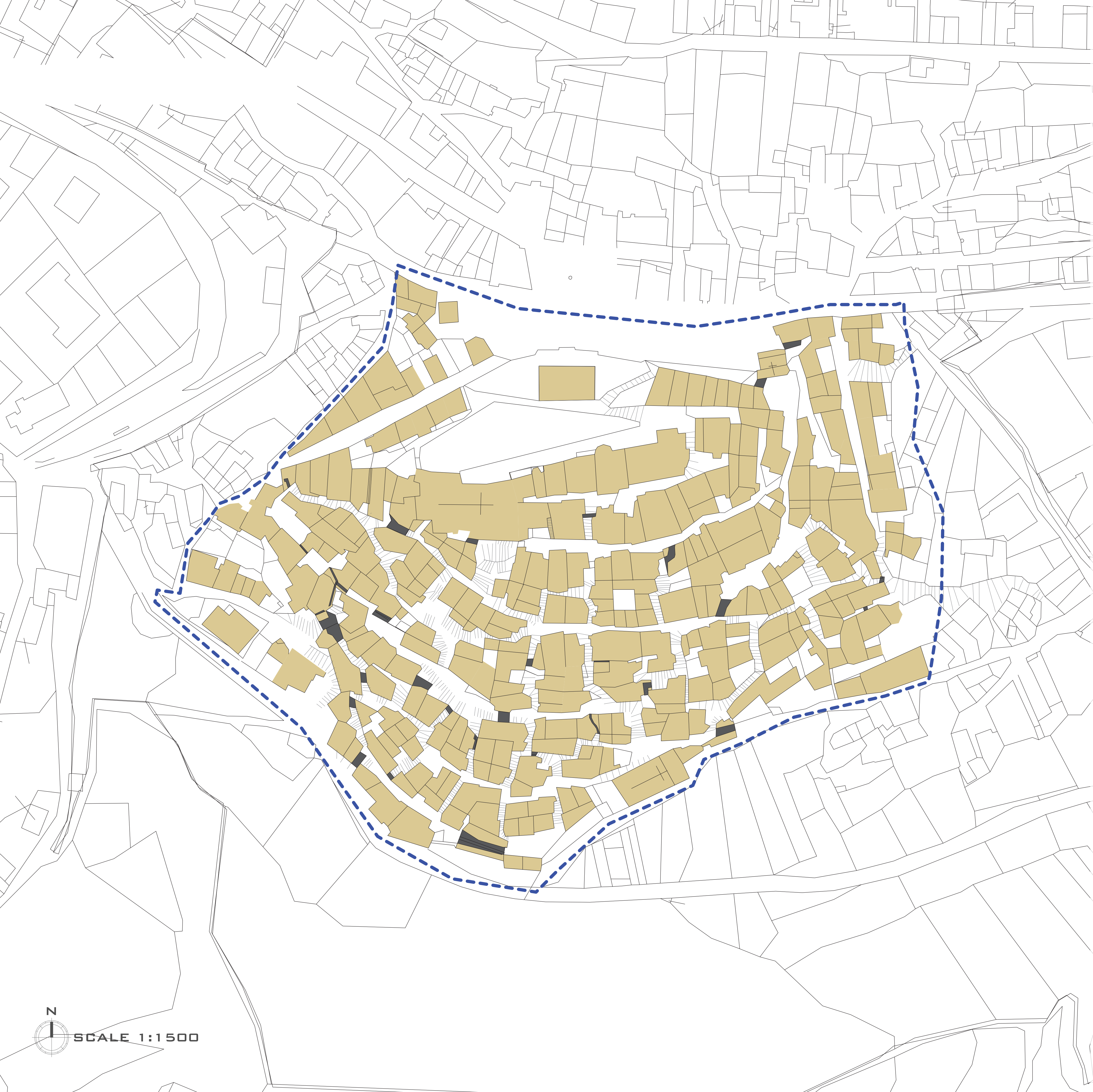


Table 2.11.2 Arched Overpass Locations

KEY:

Typical Building

Arched Overpass

DEFINITION:

Any arched overpass, that is considered to be either a structural or non-structural element. Any arched overpass, referred to as a “sporto” in the Abruzzo-Italian dialect, is an arched overpass with one or more stories of interior space above the arch. However there are also standard arches included here, that hold no structural weight but themselves.

INFORMATION:

Total Number of Arched Overpasses: 30
Total Number of Buildings: 311

NOTE:

Castel del Monte is famous for their large amount of “sporti”, or arched overpasses. However all four regions have at least a few arched overpasses present. Castelvecchio di Calvisio also has a substantial amount of arched overpasses. This characteristic of the four communes is a special construction typology, common in the Abruzzo region’s architecture.

Comune: Castel del Monte
Arched Overpass ("Sporto") Locations

2.11 Permanent Interventions

Castel del Monte, similar to the other three villages within the Baronia collective, has both buttresses and tie rods placed throughout the entire historical center. As seen in the attached "Permanent Interventions" map, the structural interventions in some cases are both present in a single structure. The effects of these interventions either separately or together are described in the introduction. Both are essential in structural interventions in seismic events but only when they are used properly. In the case of Castel del Monte, the types of buttresses and tie rods are typical in nature. Structures with buttresses are generally located on the downhill side of an aggregate, while tie rods are seen throughout the historic center, evenly spread through the village, depending on the structural needs of each building.

2.130 Example of Buttress in CdM

2.131 Example of Tie Rod in CdM

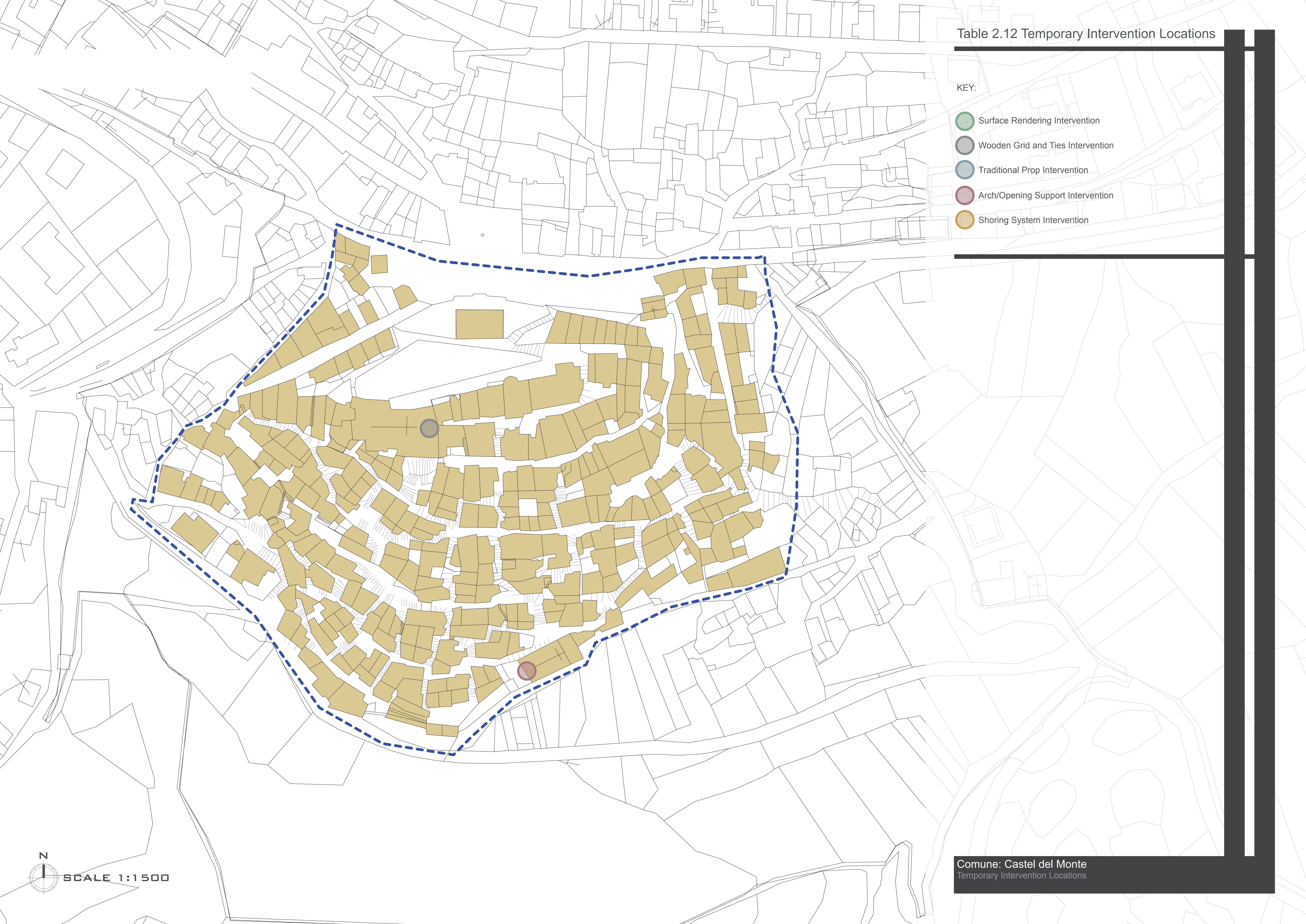


Table 2.12 Temporary Intervention Locations

2.12 Temporary Interventions

Within Castel del Monte, there are very few temporary structural interventions. In general the interventions present are minimal and only to ensure there are no future collapses or damages. This is the case in one of the two examples of temporary structural interventions in Castel del Monte. This is secifcally seen in the photo to the left at the church of Madonna del Suffragio. The support uses angled wooden elements to distribute the forces created by the intervention, to avoid the accumulation of stress on the opening. The second example in Castel del Monte is seen at the San Marco church. The intervention is a typical wooden grid system, applied immediately after the 2009 seismic event to avoid the possible overturning of the church's tower. Both interventions are only precautions and do not imply sever damages after the 2009 earthquake. It is important to note that Castel del Monte has the least temporary interventions of the four villages discussed in this thesis.

2.132 Grid Intervention

2.133 Opening Intervention

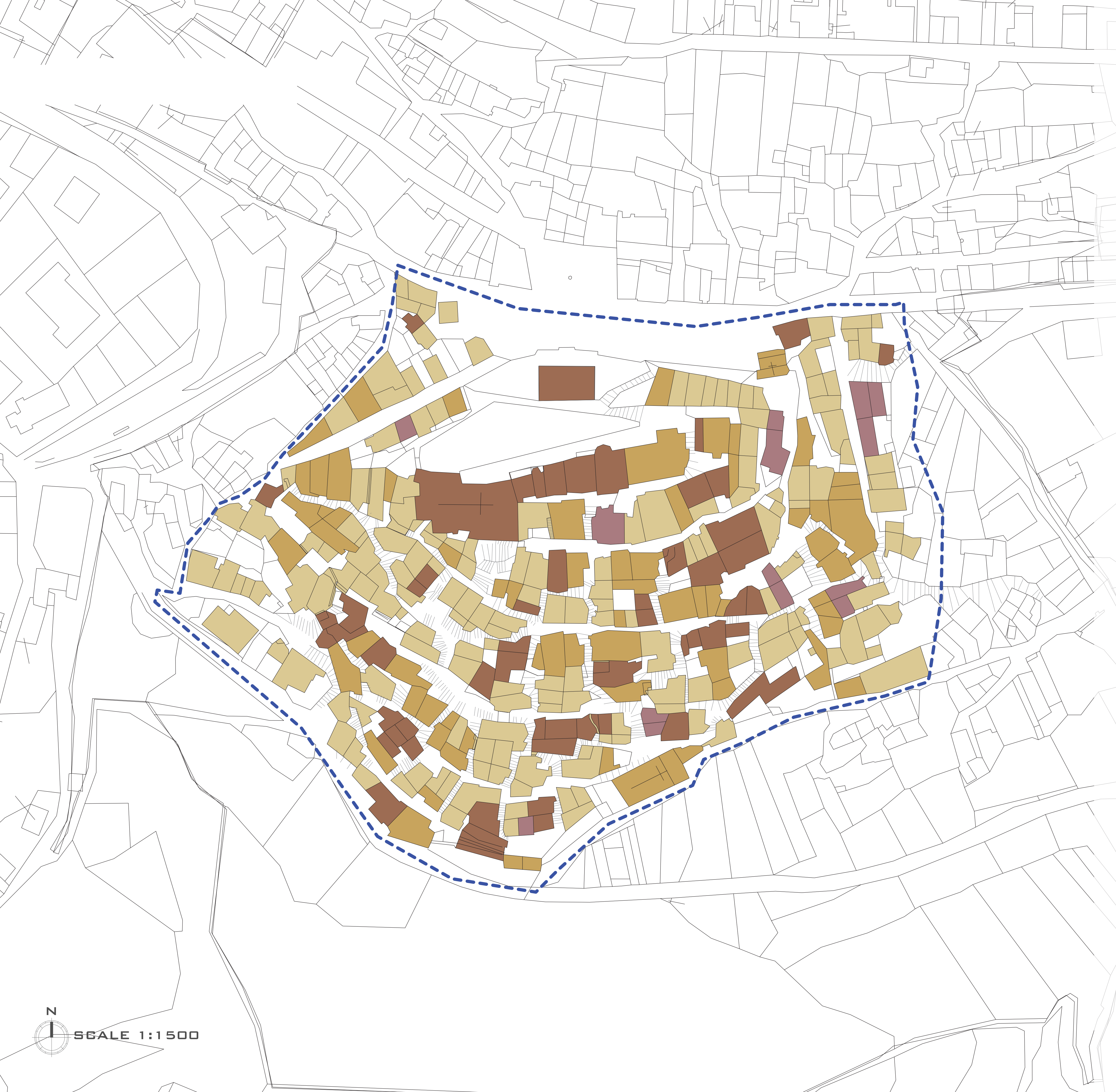
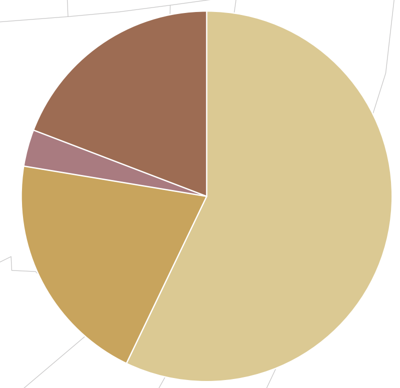
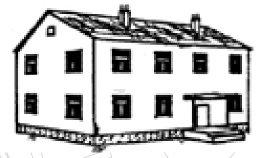


Table 2.13 Immediate Post-Seismic Damages

KEY:

- Damage Level A
- Damage Level B
- Damage Level C
- Damage Level E

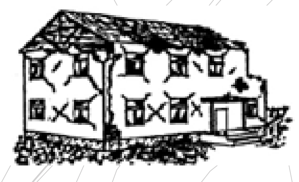




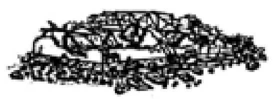
Grade 1 Damage (Level A, B)
Negligible to slight damage, no structural damage slight non-structural damage.

Grade 2 Damage (Level C)
Moderate damage, slight structural damage, moderate non-structural damage

Grade 3 Damage (Level E)
Substantial to heavy damage, moderate structural damage, heavy non-structural damage.



Grade 4 Damage
Very heavy damage, heavy structural damage, very heavy non-structural damage



Grade 5 Damage (Ruins)
Destruction, very heavy structural damage

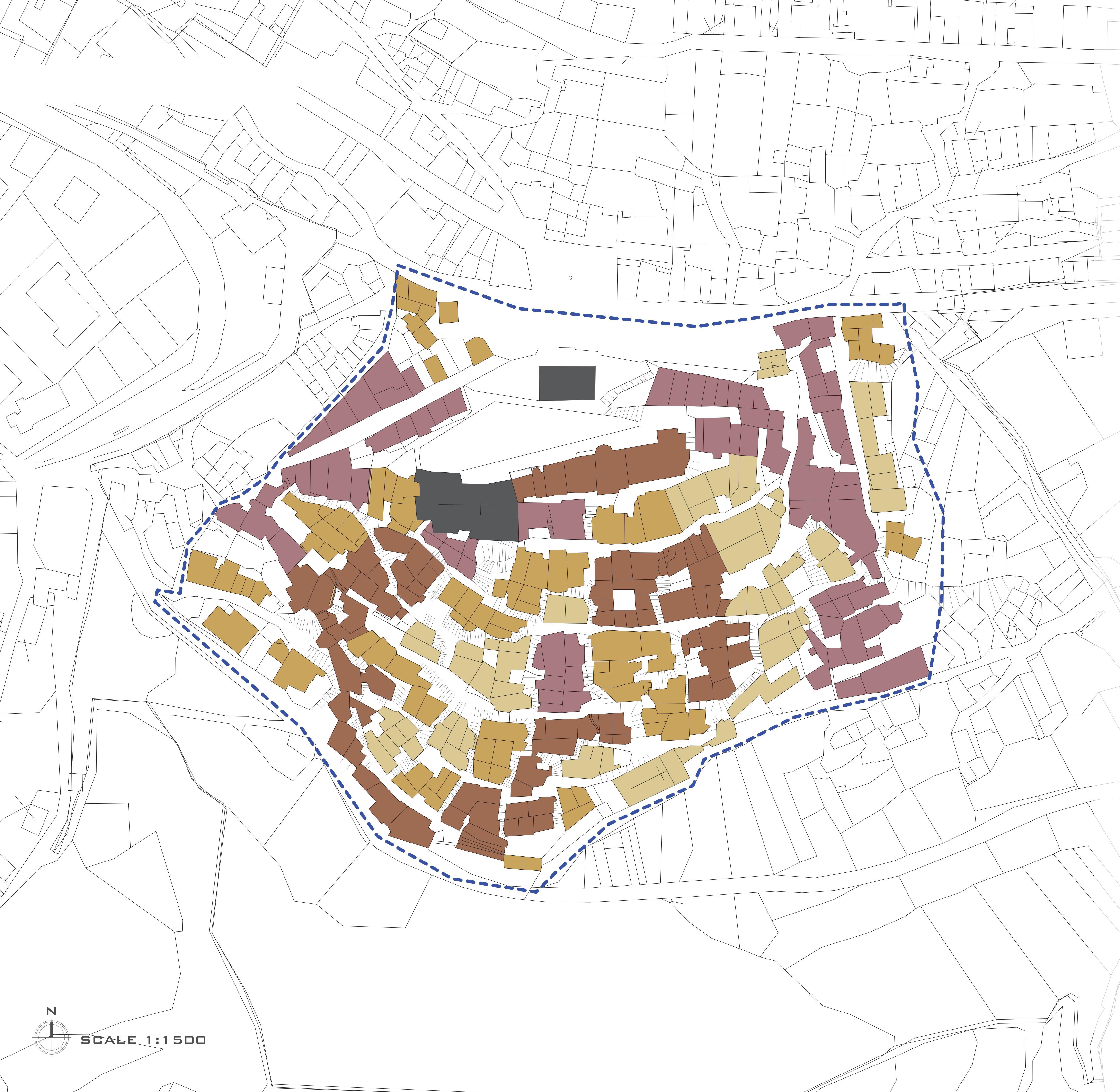
Comune: Castel del Monte
Immediate Post-Seismic Damages

2.13 Post-Seismic Damages

Immediately following the 2009 L'Aquila seismic event, the four communities of Baronia surveyed the structures within the four separate villages to determine the post-seismic damages. These damages have been defined to four different levels, level A, B,C and E. Level A is approximately equivalent to the legal damage level 1, where there is negligible to slight damage. There is no structural damage with limited non-structural damages. Level B and C are approximately equivalent to damage grade 2. This grade includes moderate damage, specifically with slight structural damage and moderate non-structural damage. The final damage category is level E, which is approximately equivalent to damage grade 3. In this case, there is substantial to heavy damage that includes moderate structural damage and heavy non-structural damage. In most cases, these damage assessments are slightly exaggerating. As seen in the attached "Post-Seismic Damages" map, the varying degrees of damage are equally spread throughout the historical center, implying that there is no terrain feature in the area that amplifies the force of a seismic event. The worst area for damages was seen at the San Marco church as well as the attached aggregate that is a part of the historical boundary wall of the city. This area is extremely vulnerable, which has been previously discussed in the "Building Typology" section. The only major structural damage, the tower of the San Marco church, is a part of this region with a majority of the buildings sustaining level E damage. As seen in the photo to the left, the tower suffered moderate structural damage including cracks and small collapsed pieces. The damages sustained are typical of tower structures in seismic areas and the temporary wooden grid intervention is common to prevent the collapse mechanism of wall overturning.

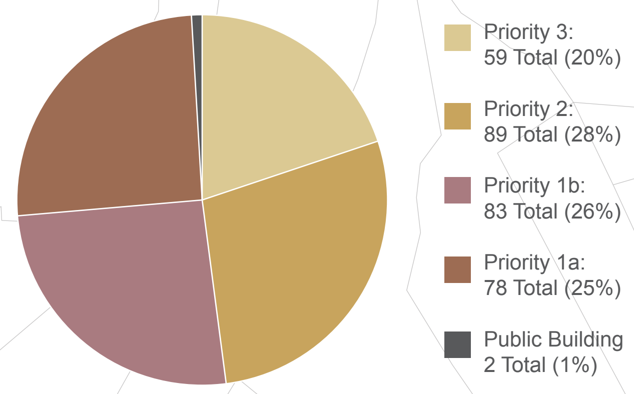
2.134 Damaged in Castel del Monte

Table 2.14 Post-Seismic Intervention Priorities



KEY:

- Priority 3
- Priority 2
- Priority 1b
- Priority 1a
- Public Buildings with Financing



Total Buildings: 311

Priority 3 (Lowest Priority)
Aggregates not added in the following priorities

Priority 2 (Low Priority)
Aggregates with primary reisdences habitable
Isolated Buildings

Priority 1b (High Priority)
Aggregates with primary residences inhabitable
Immediate Post-Seismic Damage Level E

Priority 1a (Highest Priority)
Aggregates with primary residences inhabitable
Immediate Post-Seismic Damage Level B-C

Public Building with Financing

Comune: Castel del Monte
Post-Seismic Intervention Priorities

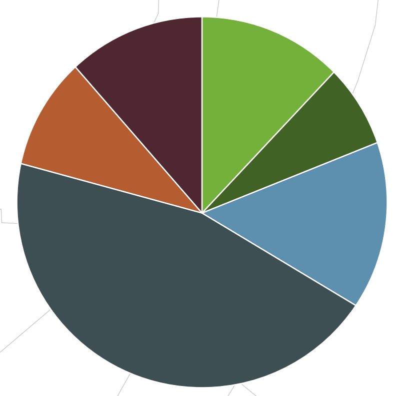
2.14 Post-Seismic Priorities

Immediately following the post-seismic damage assessment, the villages of the Baronia collective defined post-seismic priorities regarding the location of possible interventions. These priorities have been localized by aggregates and not individual buildings. The highest priority is given to public buildings with financing, such as the municipality and the San Marco church. The remainder of the aggregates has been given a priority rating of 1a, 1b, 2 and 3. The priority rating of 1a is the highest priority while rating 3 is the lowest. The priorities relate roughly to the post-seismic damage assessment. The areas with dispersed higher damages have been given the highest priority. This is specifically the case of the aggregate contained within the historical boundary wall. The aggregates have been divided almost equally between the four separate priority levels. It is important to note that these priority levels due not consider the habitation of the structures in question, which will be taken into consideration in the following “Vulnerability Conclusion”.

Table 2.15.1: Vulnerability Conclusion

KEY:

- Priority 6
- Priority 5
- Priority 4
- Priority 3
- Priority 2
- Priority 1



Priority 6: 42 Total (13%)
Priority 5: 19 Total (6%)
Priority 4: 45 Total (14%)
Priority 3: 135 Total (44%)
Priority 2: 29 Total (10%)
Priority 1: 41 Total (13%)

Total Buildings: 311

Priority 6 (Lowest Priority)
NOT CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 5
NOT CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 4
CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 3
CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 2
INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

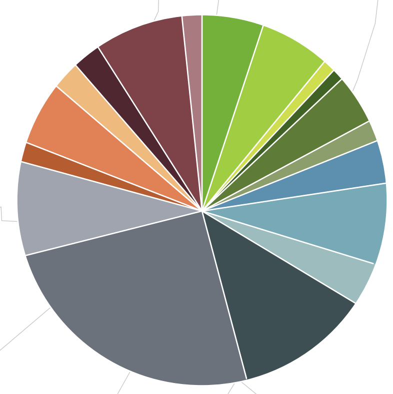
Priority 1 (Highest Priority)
INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Comune: Castel del Monte
Vulnerability Conclusion

Table 2.15. 2: Vulnerability Conclusion

KEY: (TOTAL)

Priority 6a (16)	Priority 6b (23)	Priority 6c (3)
Priority 5a (2)	Priority 5b (11)	Priority 5c (6)
Priority 4a (11)	Priority 4b (21)	Priority 4c (13)
Priority 3a (36)	Priority 3b (74)	Priority 3c (25)
Priority 2a (6)	Priority 2b (17)	Priority 2c (6)
Priority 1a (9)	Priority 1b (27)	Priority 1c (5)



Total Buildings: 311

Priority 6 (Lowest Priority)
NOT CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 5
NOT CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 4
CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 3
CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 2
INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 1 (Highest Priority)
INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Comune: Castel del Monte
Vulnerability Conclusion

2.15 Vulnerability Conclusion

2.15.1 Overall Vulnerability Conclusion

The vulnerability conclusion is a cumulative result of the previous fourteen sections of analysis. However it is important to note that these conclusions have been based strongly on four separate analyzed factors, all of which have been previously discussed in the Castel del Monte analysis. These factors have then been subdivided to include a more complete and thorough conclusion to the vulnerability of all of the structures within this village.

The first and most important factor, when determining the vulnerability and therefore priorities within the aggregate, is the inhabitation of the individual structures and aggregates. When considering anti-seismic design and post-seismic structural interventions, both permanent and temporary, the two goals should be to protect both cultural patrimony and human life. While both are essential when protecting a village, such as Castel del Monte, human life should always be given the highest priority. Therefore when considering the six final priority levels to be introduced in this section, the first two priority levels are reserved solely to inhabited structures and the third and fourth priority levels are reserved for structures within the near vicinity or within the aggregate of an inhabited structure.

The second most important factor considered when determining the vulnerability of the aggregate is the collective structural homogeneity of each aggregate and structure. This analysis, as previously discussed, has been determined through the collective evaluation within an aggregate of the building typologies, orientations to the elevation curves, building heights and masonry typologies present. While the cause of potential collapse mechanisms during a seismic event varies, at the foundation of all of these causes is a lack of homogeneity. This lack of homogeneity can be seen in plan, elevation, masonry composition, distribution of stresses, etc. This lack of homogeneity, either in separate elements or factors, or as a whole can lead to collapse mechanisms such as hammering, out of plane wall overturning, torsion and many more. This information was therefore used as a primary source when considering the vulnerability conclusion of each aggregate.

The third and last important factor considered was the existing vulnerability of the aggregate, based on both the post 2009 seismic damages as well as the presence of permanent structural interventions such as tie rods and buttresses. The existing damages imply an inherent vulnerability as well as a need for immediate interventions. Therefore this factor is considered crucial when determining the level of vulnerability in an aggregate. In addition, buildings with existing permanent structural interventions are better protected than those without and therefore are noted in order to diminish the vulnerability priority of an aggregate with these types of interventions present. It is the presence of post-seismic damages and permanent structural interventions that determine the subcategories within the previously mentioned six priority levels.

Each of the six priority levels are split into three separate subsections, which are described on the attached vulnerability conclusion maps. The first subdivision, for all six priority levels, is of the highest priority because it is reserved for structures with post-seismic damages as well as a lack of permanent structural interventions. The second subdivision is for buildings with either no post-seismic damages but a lack of permanent interventions, or with post-seismic damages but with permanent interventions. The third and final subdivision is only for buildings with no post-seismic damages and that also have permanent interventions in place. These structures, within any of the six major priority levels, is considered to be of little priority and requires only observational on-site analysis to determine the extent of the vulnerability, which is presumably minimal. However all structures within the first two subcategories of the six priority levels require more thorough analysis to determine the amount of restoration interventions needed.

In the following sections, specific examples of these vulnerability levels will be discussed. These examples come from aggregates and structures within the higher priority levels. These examples will be used to better describe the priority categories as well as to showcase what higher priority structures are like. This will aid in determining what type of restorative efforts may be necessary for the higher priority aggregates. It is important to note however that these priority levels do not inherently mean there is a need for restoration, but instead they imply the likeliness that

structural interventions are necessary. Each aggregate and building should be taken on a case by case basis following additional on-site observation (interior as well as exterior) to determine the exact need of every structure within the priority levels.

2.15.2 Specific Vulnerability Example One

The first example of one of the more vulnerable aggregates is found in the heart of the historic center, near the San Marco church, specifically in aggregate CdM 013. This example, as all

Figure 2.135 Aggregate CdM 013

Figure 2.136 Aggregate CdM 013

of the examples chosen for further analysis in the vulnerability conclusion, was also chosen as one of the previously discussed negative examples. This example has been chosen for several reasons. First

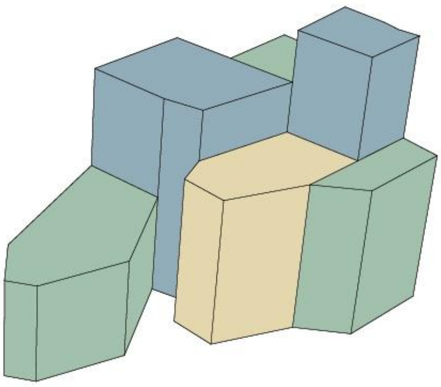


Figure 2.137 Aggregate CdM 013 Model

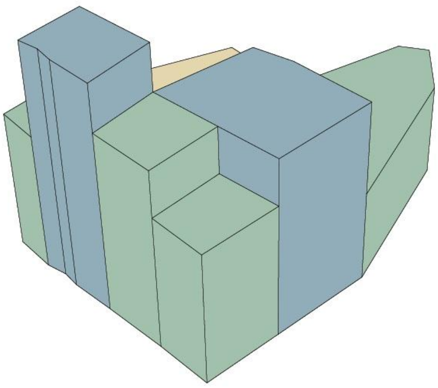


Figure 2.138 Aggregate CdM 013 Model

and foremost this aggregate was chosen due to the fact that two of the six structures are inhabited.

In addition, as previously mentioned, this aggregate has been determined to be negative regarding its collective homogeneity. As seen in the models above, the aggregate is extremely irregular regarding the building heights and masonry typology composition. There were also damages in the aggregate after the 2009 L'Aquila seismic event and not all of the structures within the aggregate have permanent structural interventions in place. As seen in both figures 2.135 and 2.136, there is also irregularity in both additions to the structures as well as openings. Openings have been placed too close to structural elements such as the roof or corners. Also additions, such as bathrooms have been added as cantilevers to the original structure which is extremely vulnerable to collapse in the case of a seismic event due to the uneven mass distribution. It is also important to note the extreme changes of the aggregate over time, with elements of different masonry composition, has contributed to the determination of this particular aggregate as a high priority level. Regarding a future for this aggregate, there are several restoration options available. First and foremost, additional permanent and temporary structural interventions need to be added to better control the reactions between the irregular units within the aggregate. These interventions should specifically be placed in vulnerable areas such as fulcrum points between two attached structures of different heights as well as in locations such as the cantilever addition seen in figure 2.136. In addition, any damages sustained during the most recent seismic event of 2009 need to be thoroughly analyzed and resolved to better protect the inhabitants of the aggregate.

2.15.3 Specific Vulnerability Example Two

The second example of a high priority structure is found in the historical center, specifically in aggregate CdM 101. This example has been previously discussed as one of the negative examples within Castel del Monte. This aggregate has been chosen for several reasons, the first of which is that one of the six structures within the aggregate in currently inhabited. In addition, as previously mentioned, the aggregate has been considered to be negative regarding its overall collective homogeneity. This particular aggregate is extremely irregular in both masonry typology composition and the building heights of the individual units within the aggregate. The aggregate is also irregular in

Figure 2.139   Aggregate CdM 101

Figure 2.140   Aggregate CdM 101

both plan and elevation. There were also damages in the aggregate after the 2009 L'Aquila seismic event and not all of the structures within the aggregate have permanent structural interventions in

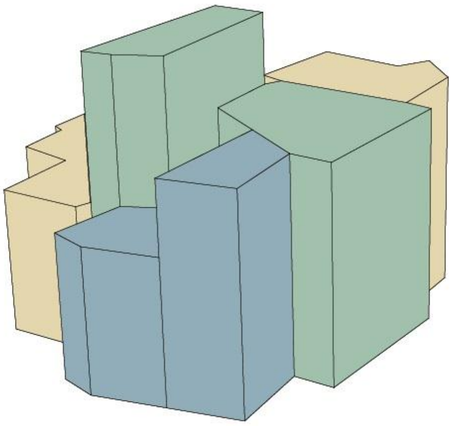


Figure 2.141   Aggregate CdM 101 Model

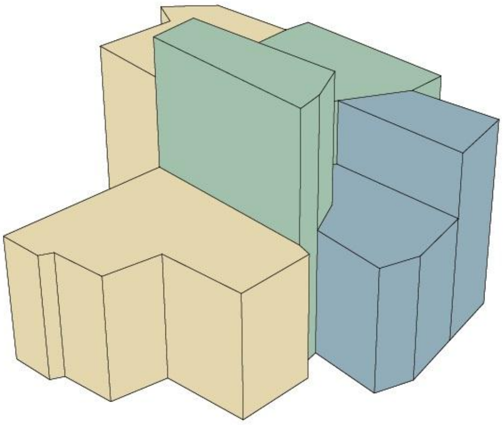


Figure 2.142   Aggregate CdM 101 Model

place. As seen in both figures 2.139 and 2.140 there is also irregularity in both additions to the structures as well as openings. Openings have been placed too close to structural elements such as the roof or corners. Regarding a future for this aggregate, there are several restoration options available. Additional permanent and temporary structural interventions need to be added to better control the reactions between the irregular units within the aggregate. These interventions should specifically be placed in vulnerable areas such as fulcrum points between two attached structures of different heights. In addition, any damages sustained during the most recent seismic event of 2009 need to be thoroughly analyzed and resolved to better protect the inhabitants of the aggregate.

2.16 Conclusion:

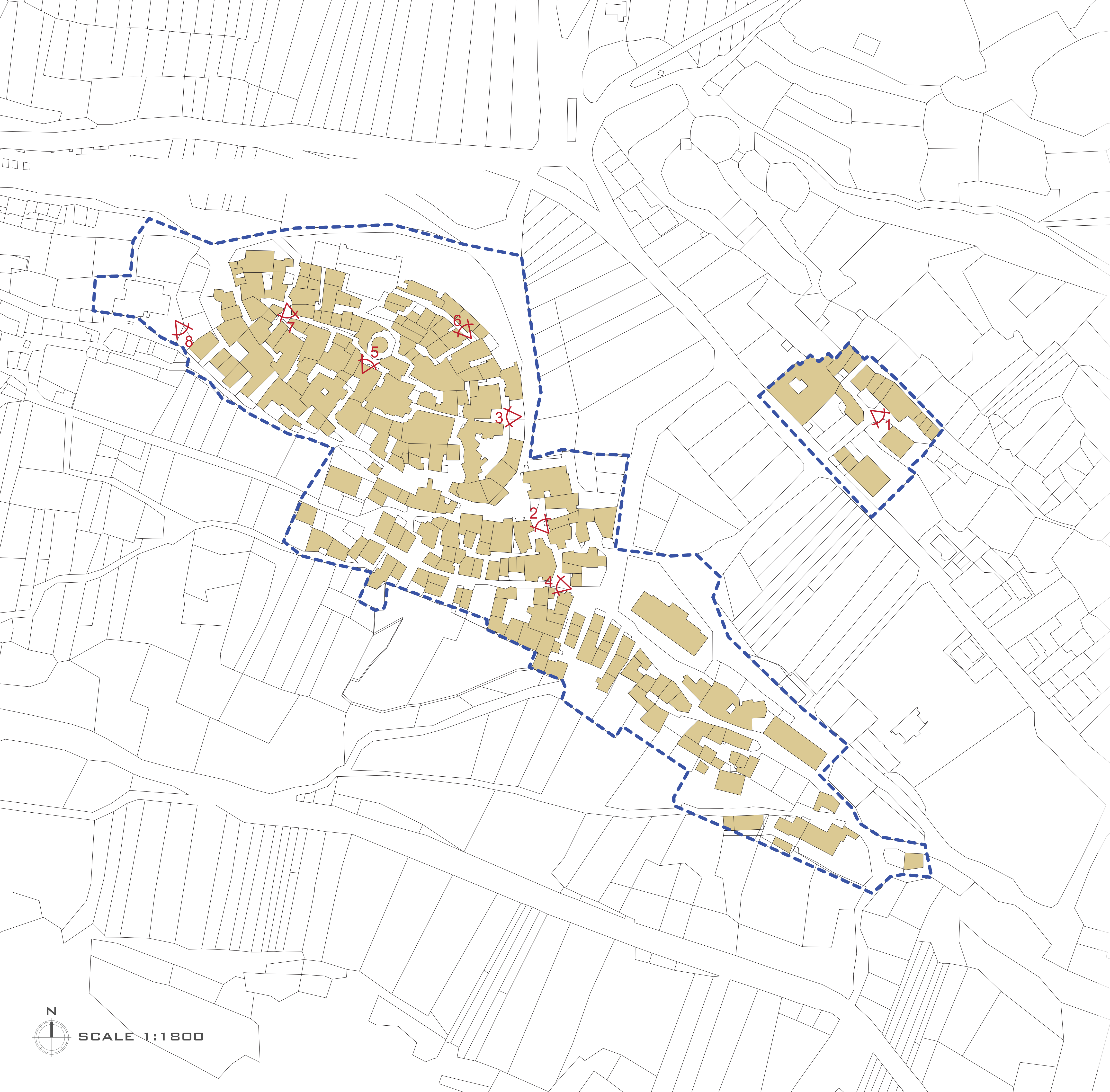
While the earthquake of April 2009 in L'Aquila resulted in little to no major structural damages in Castel del Monte, the seismic event should be utilized as a reminder of the vast vulnerability of masonry structures within the historical center. The village is the most vulnerable of those discussed within this thesis. This is due in part to the higher population size, as well as more structures with existing post 2009 seismic minor damages. Fortunately several of the structures have permanent structural interventions in place. However the village is still in dire need of additional reinforcements as well as seismic retrofitting measures. It is important to note that the higher priority structures within the village are evenly distributed throughout the historical center. This vast distribution requires extensive additional analysis, both interior and exterior, to better determine the aggregates that are the most deserving of the limited public funds available for restoration. An initial visual analysis should be the first step of any restoration process, followed by more invasive analysis to determine the structural vulnerability of the masonry elements. Finally the most vulnerable aggregates should be prepared for restorative efforts as soon as possible, in order to protect the existing population.

While restorations are costly efforts, they are always the most economical choice over the reconstruction of structures damaged or destroyed after a major seismic event. Now is the time to protect both the architectural patrimony and populations of the village of Castel del Monte, as well as the rest of the Baronia collective. More specifically, time between seismic events, such as now following the 2009 earthquake, is the opportune time to analyze the existing architecture, regarding collective homogeneity, structural vulnerability and building inhabitations to be better prepared for the next seismic event to come. Any analysis completed now can be utilized in both immediate earthquake aftermath, regarding finding citizens who may be hurt, as well as in the long term aftermath, regarding which structures are more dangerous and should remain vacant until restoration efforts can ensure the safety of the building's inhabitants during a seismic event.

Table 3.1.1 Orientation to Overall Elevation

Comune: Santo Stefano di Sessanio
Orientation to Overall Elevation

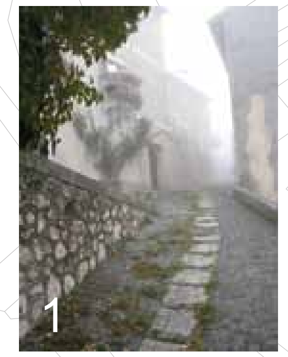
Table 3.1.2 Photographic Introduction

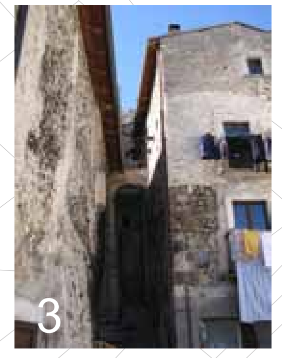


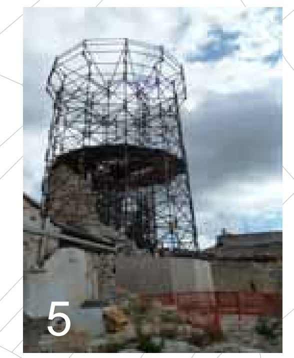
KEY:

Location of Photograph

Site Boundary







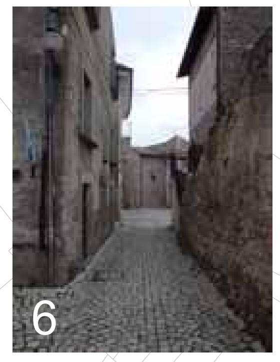


Table 3.1.3 Aggregate Locations

KEY:

Buildings

Aggregate Boundaries

DEFINITION:

An aggregate is made of one or more houses that are separate houses that are joined together to make a whole, single unit.

PHOTO EXAMPLES:

Aggregate SSS 017

Aggregat SSS 005

FACTS:

Total Number of Aggregates:	71
Total Number of Churches:	1
Total Number of Municipalities:	0
Total Number of Towers	2

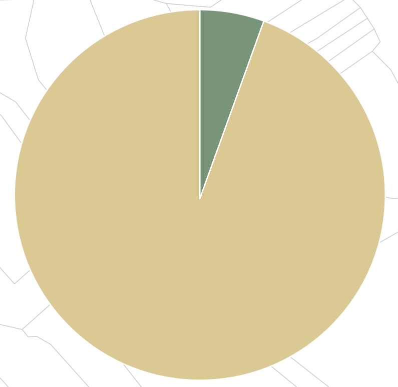
Comune: Santo Stefano di Sessanio

Aggregate Locations

Table 3.1.4 Pre 2009 Seismic Building Uses

KEY:

- Private Property Buildings
- Public Property Buildings



EXAMPLES:

Public Use Building Types
-Tower (Above left)
-Church (Above Right)
-Municipality

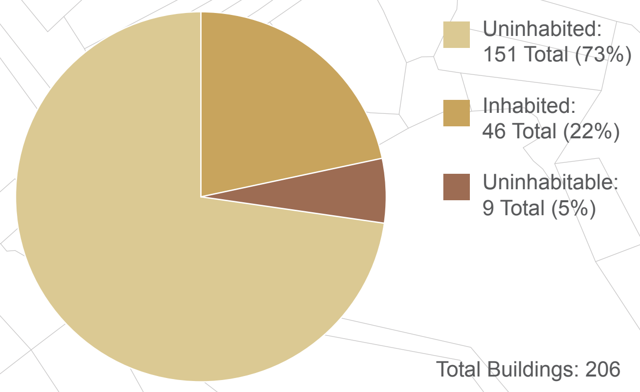
Private Use Building Types
-Uninhabited Residence
-Inhabited Residence (Above right)
-Uninhabitable Residence (Above left)

Comune: Santo Stefano di Sessanio
Pre 2009 Seismic Building Uses

Table 3.1.5 Building Inhabitation

KEY:

- Uninhabited Building
- Inhabited Building
- Uninhabitable/Ruined Building



DEFINITIONS:

Uninhabited Building

Building that may or may not be in use, but is currently uninhabited. These may imply a public use building or one that is not lived in full-time.

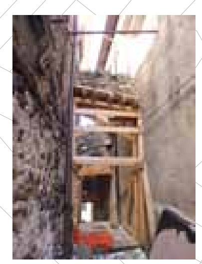
Inhabited Building

Building that is currently being lived in and is therefore a priority regarding the restorative efforts, along with public use buildings.

Uninhabitable Building

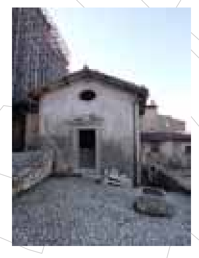
Building that is in ruins, crumbling or structurally instable and therefore uninhabitable. These building are crucual to the restoratvie effort if their structural instability can damage adjacent buildings or create significant damages in the case of a future seismic event.

EXAMPLES:



Uninhabitable Building Example

The building on the left is one of several examples that currently have extensive temporary interventions in place and is therefore seen as structurally instable as well as uninhabitable.



Uninhabited Building Example

This is one of the churches in the Santo Stefano di Sessanio area and is therefore considered an uninhabited building due to its public use.

3 SANTO STEFANO DI SESSANIO

3.1 Introduction:

The village of Santo Stefano di Sessanio, with a population of 120 inhabitants, is a hill town in the province of L'Aquila in the Abruzzo region of Italy. The commune is located in the heart of the Central Apennine mountain range, situated below the Gran Sasso mountain. The village, along with

Figure 3.1 View of Santo Stefano di Sessanio (provided by anticaforuli.it)

three other villages within the Baronia collective, is situated within the Gran Sasso and Monti del Lago National Park. The commune also sits adjacent to the Campo Imperatore plain. The name of the village, "Sextantia" in Latin, is the patron saint of the village, which originates from the Roman Empire. While the first inhabitants of the area are documented as far back as before the Roman Empire, most of the structures within the village date from the eleventh through the fifteenth centuries. During these years, Santo Stefano di Sessanio was a part of the Baronage of Carapelle, which included Castel del Monte, Castelvecchio di Calvisio, and several other villages in the region. A majority of the historical landmarks of the city were created during the reign of the Medici family of this region. These landmarks include the recently collapsed Medicea tower as well as the village portal. Still to this day, the entrance portal is emblazoned with the Medici coat of arms.

While the village has a strong connection to sustainable agriculture, their primary source of income comes from tourism with small boutiques, restaurants and art galleries in the historical center. This reputation of being a capital of tourism has long been the case. Historically, Santo Stefano di Sessanio is the common location of summer homes. The first account of this as well as of the village itself came in 760 when a Roman nobleman, Calvin Calvisio, chose the village as his summer residence. The village's fortification would not be reported until 1308. The commune would play an important role in transportation between L'Aquila and Barisciano, two adjacent cities in the region. While there is strong proof of pastoralism in the area, the village was officially owned by the Medici family since 1579 until 1743. It was at this time that Santo Stefano di Sessanio would reach its economical peak, specifically regarding the production of wool that was sold throughout Europe. This prosperity would continue until the unification of Italy in the nineteenth century. This would also lead to the privatization of land as well at the end of the transhumance sheep drive in Central Italy. Soon after the village began to decline and its overall size was greatly reduced due to emigration. However as of 2004, several foreign investors have contributed funds to the village's historical center in order to increase tourism.

Santo Stefano has also recently come into popularity due to the effects of the 2009 L'Aquila earthquake on the village. One of the village's churches, the 17th Century Church of Madonna del Lago, lost most of its front façade and suffered severe roof damages. In addition, the village lost the symbol of the city, the Medicea tower, which collapsed due to the seismic event. As will be discussed in further detail in the "Permanent Intervention" section, it is believed that the collapse of the prized tower was due to 20th Century renovations. These renovations aimed at replacing the structure of the tower's observation platform. The original structure was a wooden deck but was replaced in the restoration process by a deck made of reinforced concrete. This renovation thus made the tower top heavy and in the case of the 2009 seismic event, made the period of movement of the tower much higher thus leading to its collapse. The cost, determined immediately following the collapse, of the

Figure 3.2 Tower of Medicea – Pre Seismic

Figure 3.3 Post Seismic

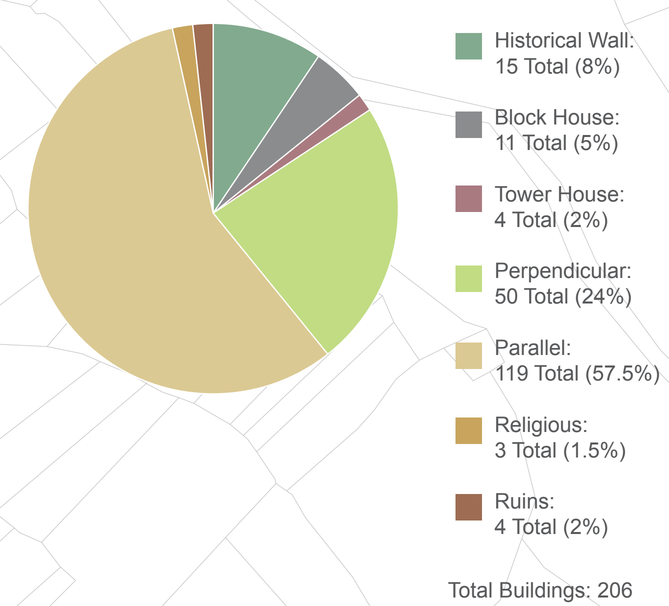
post-seismic restoration of the tower has been estimated to be one million euros, for an intervention process of over two years. This tower has been used in many studies concerning the restoration of the L'Aquila region, following the 2009 earthquake.

Due to the high risk of seismic events in the region of Abruzzo, Santo Stefano di Sessanio, along with all of the Baronia village communities have begun restorative analysis, along with the University of Padova. The goal of this analysis is to prioritize the structural vulnerabilities within the historical center in order to afford the best possible use of the limited public resources available for seismic retrofitting. This retrofitting will be aimed at respecting the existing structural typology in order to avoid compromising the structural stability even further, as seen in the case of the Medicea tower. However due to the lack of available funds, strong consideration is being given to areas of the historical center that are inhabited or commonly used by the existing population of Santo Stefan di Sessanio. Seismic events have occurred in this area repeatedly since its initial settlement and will continue to do so for the foreseeable future. Thus now is the time to protect both the cultural patrimony and lives present in the village of Santo Stefano di Sessanio, before future seismic events make that impossible.

Table 3.2 Building Typology

KEY:

- Historical Boundary Wall House
- Block House
- Tower House
- Buidling Oriented Perpendicular to the Elevation Curve
- Building Oriented Parallel to the Elevation Curve
- Religious Building
- Ruins



Historical Boundary Wall House
Row of houses, oriented in a line

Block House
Single builings, unattached to other buildings

Tower House
Building significantly taller than all buildings it touches

Buidling Oriented Perpendicular to the Elevation Curve
Building Unit set in a row, perpendicular to the elevation curve (partially underground with a rock foundation)

Building Oriented Parallel to the Elevation Curve
Building Unit set in a row, parallel to the elevation curve (partially underground with a rock foundation)

Religious Building
Any religious based building such as a church or convent

Ruins
Any building with significant damage to the point of being uninhabitable

Comune: Santo Stefano di Sessanio
Building Typology

3.2 Building Typology:

3.2.1 Historical Boundary Wall Houses

Santo Stefano di Sessanio, similar to the other villages in the region has a wide range of building typologies present in the historical center. Similar to both Castel del Monte and Castelvecchio di Calvisio, Santo Stefano di Sessanio is defined by the presence of a historical boundary wall, which structurally includes several buildings of social importance. While the area considered for analysis can be considered the historical center, the historical boundary wall only surrounds the buildings within the original area of the village's construction. The remainder of the structures outside of this defensive wall were constructed after this initial construction, once the

Figure 3.4 Aggregate SSS 013 Front North

Figure 3.5 Aggregate SSS 017 Front South

village began to evolve. As seen above, buildings within the historical wall are typically massive in both height and size. In almost all cases, they are composed of higher quality masonry due to their importance in the society. They are also defined by buttresses on the exterior of the original historical center as well as several other typologies of structural interventions. These interventions imply a history of renovations and restorations since the original construction of the village. There are also several tower structures within the historical boundary wall, used for defensive purposes in the earliest years of Santo Stefano di Sessanio's history. In total there are 15 historical boundary wall houses, the most of the four villages previously introduced. Unlike the other building typologies which are spread throughout the entire area of Santo Stefano di Sessanio, all of the historical boundary wall houses are exclusively located in the original historical center of the city. They can be considered to be among the oldest structures within the village. While these walls and buildings contained within them are no longer used for defensive purposes, they are still important to the village of Santo Stefano di Sessanio for several reasons. First and foremost, the historical boundary wall is a defining characteristic of both Santo Stefano di Sessanio, as well as the Baronia collective. The structure also contains several important structures due to programmatic reasons, such as political and religious uses. Beyond the aesthetical appeal and representational value, the historical boundary wall houses are also important due to their possible effects in the case of a seismic event. As previously discussed in the background information section, these heavy structures can easily destroy adjacent buildings if not properly structured. In many cases, as will be discussed in the "Permanent Structural Interventions" section of Santo Stefano di Sessanio, the existing exterior buttresses are small in stature compared to the historical boundary wall. These reinforcements can be increased due to the amount of open space beyond the exterior of the original historical center. These reinforcements, as well as added protection against out of plane collapse mechanisms of the towers within this defensive wall, will aid in minimizing the potential threats that these massive structures pose to the surrounding architecture.

3.2.2 Tower Houses

Similar to the building typology of historical boundary wall houses, tower houses are specifically located in the original historical center. Three of these towers are within the historical boundary wall and can be considered structurally comparable to the previously discussed building typology of boundary wall houses. The fourth of these towers is the Tower of Medicea which unfortunately collapsed in the most recent seismic event of 2009. The collapse of the Medicea is an excellent example of the possible collapse mechanisms that towers are prone to. The towers within Santo Stefano di Sessanio are tall, a characteristic that contributes to their structural vulnerabilities.

Figure 3.6 Aggregate SSS 013 Front North

Figure 3.7 SSS 017 Front North

As explained in the background information section, towers adjacent to shorter structures are vulnerable to both hammering and collapse on top of the surrounding structures. The masonry quality of tower houses in Santo Stefano di Sessanio is high. In addition, the three tower houses within the historical boundary wall of the village center are characterized by several permanent structural interventions. These include both exterior buttresses as well as tie rods. The importance of the historical boundary wall has led to several evident restorations and renovations to these tower houses. Observational analysis implies that these restorations have been of high quality, respecting the existing masonry and construction typologies present in the three tower houses.

The fourth and final tower in Santo Stefano di Sessanio, as previously mentioned, is the tower of Medicea. The tower was built in the initial construction of the village and became a symbol of Santo Stefano di Sessanio before its eventual collapse in 2009. The tower survived several major and minor seismic events over its extensive life time and only suffered collapse after a 20th century structural restoration. This restoration replaced the original wooden viewing deck with a reinforced concrete version. The addition of reinforced concrete failed to respect the existing construction as well as the existing structural mechanics of the tower. The addition of the heavier viewing deck

Figure 3.8 Pre-Seismic Medicea Tower

created a top heavy effect to the tower. When the seismic event struck in 2009, the tower, with a much heavier deck, reacted to the seismic event with more momentum and therefore experienced an exaggerated period of movement. These new structural dynamics would be too much for the masonry structure to take in the case of a seismic event and led to its eventual collapse. This renovation will be further discussed in the "Permanent Interventions" section. However it is important to note the possible collapse mechanisms present in tower houses and the very present vulnerability they pose to the surrounding structures within a historic center, such as Santo Stefano di Sessanio. These towers will therefore be highlighted when concluding which of the structures within Santo Stefano di Sessanio are the most vulnerable in the case of a seismic event and therefore deserve the limited public funds available for restoration efforts.

3.2.3 Buildings Oriented Parallel to the Elevation Curves

The most common of the building typologies present in Santo Stefano di Sessanio are buildings oriented parallel to the elevation curves. This is also the most common of the building

Figure 3.9 SSS 013 South

Figure 3.10 SSS 015 North

Figure 3.11 SSS 013 South

typologies in the four villages of Baronia presented in this thesis. 119 of the 206 building in Santo Stefano di Sessanio are of this typology. This typology is distributed throughout the entire village but is concentrated in the original historic center. On-site analysis has revealed that many ruins within the Baronia collective were originally buildings oriented perpendicular to the elevation curves. While this is solely a tendency, it is important to note. As seen below, these structures vary in masonry typology, building heights and general construction type. However their similar parallel orientation to the elevation is important because when located within a single aggregate, it is important that structures be oriented evenly across the aggregate regarding the elevation curves. Differing orientations can lead to several collapse mechanisms, most commonly out of plane wall overturning. In the case of aggregates lacking in homogeneity regarding the orientation of the individual structure, additional connections between these structures as well as permanent structural interventions are needed in order to counteract these potential collapse mechanisms. Due to the commonness of this building typology, it is difficult to characterized their other structural qualities. For structures and aggregates within this particular typology, it therefore becomes essential, when analyzing collective homogeneity, to emphasize the consideration of the two other major structural qualities, masonry typology and building heights within the aggregate. It is also important to note if a structure is oriented perfectly parallel to the elevation curves or at an angle. When oriented at a large angle, the force of torsion acting on the structure is increased and is likely to increase several collapse mechanisms or induce collapse with this force alone, if strong enough.

3.2.4 Buildings Oriented Perpendicular to the Elevation Curves

While buildings oriented perpendicular to the elevation curves are present in all of the villages within the Baroia collective, they are the most prominent within Santo Stefano di Sessanio. There are a total of 50 buildings categorized as being oriented perpendicular, which makes up 24 percent of the individual buildings within the village. This is a substantial amount and important to note considering the number of ruins or partially ruined buildings present, specifically outside of the original historical center. As noted in the previous section 2.2.3, after thorough on-site analysis in four of the villages of the Baronia collective, a connection between buildings oriented perpendicular to the elevation curves with partially or completely collapsed structures has been observed. While this is just an on-site observation, it is important to note that perpendicularly oriented structures are in the minority within hillside historical centers of Abruzzo, specifically in the villages of the Baronia collective. Despite the connection made between ruins and structures oriented perpendicular to the hillside, these structures are only considered structurally vulnerable when placed within an aggregate with structures oriented parallel to the elevation curves. Buildings under these two conditions react structurally in very different ways during a seismic event. Thus the combination of these two buildings within an aggregate can induce several collapse mechanisms, the most likely of which is hammering. While this is of little concern in the original historical center of Santo Stefano di Sessanio, it is present in several aggregates within the most recent addition of the historical center. These damages along with out of plan wall overturning can be diminished through the strategic use of permanent structural interventions, such as tie rods and exterior buttresses.

Figure 3.12 Unknown Aggregate

Figure 3.13 Unknown Aggregate

Figure 3.14 SSS 016 Front North

3.2.5 Block Houses

The presence of block houses are scattered in the Baronia collective, seen in all four of the communities discussed in this thesis except Castelvecchio di Calvisio. Block houses are typically uncommon in historical centers as is the case in Santo Stefano di Sessanio. Block houses are present only outside of the original historical center. These structures tend to be of either governmental or private residential use. Structurally speaking, block houses are dependent solely upon themselves. Similar to isolated towers, these structures are separate from any aggregate structure and therefore many of their characteristics are negligible. For example, their orientation to the elevation curves can be considered of little structural significance unless the structure is oriented at an angle to the surrounding typography. The height of block houses can be important in the case of a tower-like structure due to the period of movement in the case of a seismic event. The most structurally notable characteristics in all cases of block houses is therefore the masonry typology, specifically the homogeneity of the masonry composition. As seen in the composition of aggregates within the Baronia collective, structural additions and renovations are commonly present in block houses as well. These modifications to the original structure are integral to the stability of the overall structure. These changes should respect the existing structure and most importantly, the existing structural dynamics. As seen in the case of the Medicea tower of Santo Stefano di Sessanio, the chosen materials in a restorative effort or addition must not change the weight distribution within the structure. Improper modifications can lead to soft story failure, out of plane wall turning or increase the effects of forces of torsion and shear failure.

3.2.6 Churches or Religious Structures

There are three churches or religious structures present in Santo Stefano di Sessanio, all of which are located within the original historical center. The first example is found in aggregate SSS 047. This particular church is situated within the historical defensive boundary wall, surrounding the original historical center of Santo Stefano di Sessanio. The church is irregular in plan as well as in mass distribution due to its varying heights. During the most recent seismic event of 2009, the church sustained little to no damages. Similar to many churches with the region of Abruzzo, this church, although constructed with higher quality materials, is extremely vulnerable to seismic activity. Renaissance or Roman churches are characterized by large vaults and high ceilings. In

Figure 3.15 SSS 047 Front East

Figure 3.16 SSS 047 Front East

addition, they are popular in use due to their cultural and social importance within Italy. Despite their higher construction standards, as is the case of this particular church, permanent structural interventions are recommended in order to minimize damage to the cultural patrimony of the village as well as to minimize the casualties in the case of the next seismic event to come. Luckily, this church has a rectangular façade, which can help to minimize the common out of plane wall overturning in church facades.

The second example of a church or religious structure within Santo Stefano di Sessanio comes from aggregate SSS 014. This religious structure is rare within the Baronia collective due to its inclusionwithin an aggregate. As seen in the image to the left, the aggregate to which the church is

Figure 3.17 SSS 014 Front East

connected is currently under restoration due to minor damage after the 2009 earthquake. The church is the smallest of the three present in Santo Stefano di Sessanio. Similar to the other churches in the area, the church is composed of high quality masonry as well as created using higher construction standards. This church is less vulnerable than the other two present in the village due to its extreme regularity, small stature and lack of vaults. However this church is not isolated and is therefore vulnerable to the influences of the aggregate in which it is located. Therefore any recommended structural interventions would be regarding its connection to the buildings within its aggregate.

The third and final church within Santo Stefano di Sessanio, located in aggregate SSS 068, is well known due to the substantial damage its façade sustained during the 2009 seismic event.


Figure 3.18 SSS 068 Front East


Figure 3.19 SSS 068 Front North

While the church is composed of higher quality masonry, the entire structure lacks in homogeneity regarding the heights of each individual section. In addition, the structure is connected to adjacent aggregates, therefore increasing its vulnerability in the case of a seismic event. As seen in the images of the church on the previous page, the damages were almost exclusively maintained on the façade only. Restoration efforts and temporary structural interventions are both already in place. It is important to note in this case the irregularity of the structure regarding mass distribution, despite being extremely regular in plan. The varying height of the church as well as the presence of vaults has left the church vulnerable to seismic movements. Restoration efforts are important for the future structural stability of the church but should be specifically concentrated on the connections of the varied sections of the church as well as the out of plan overturning tendency of the facades.

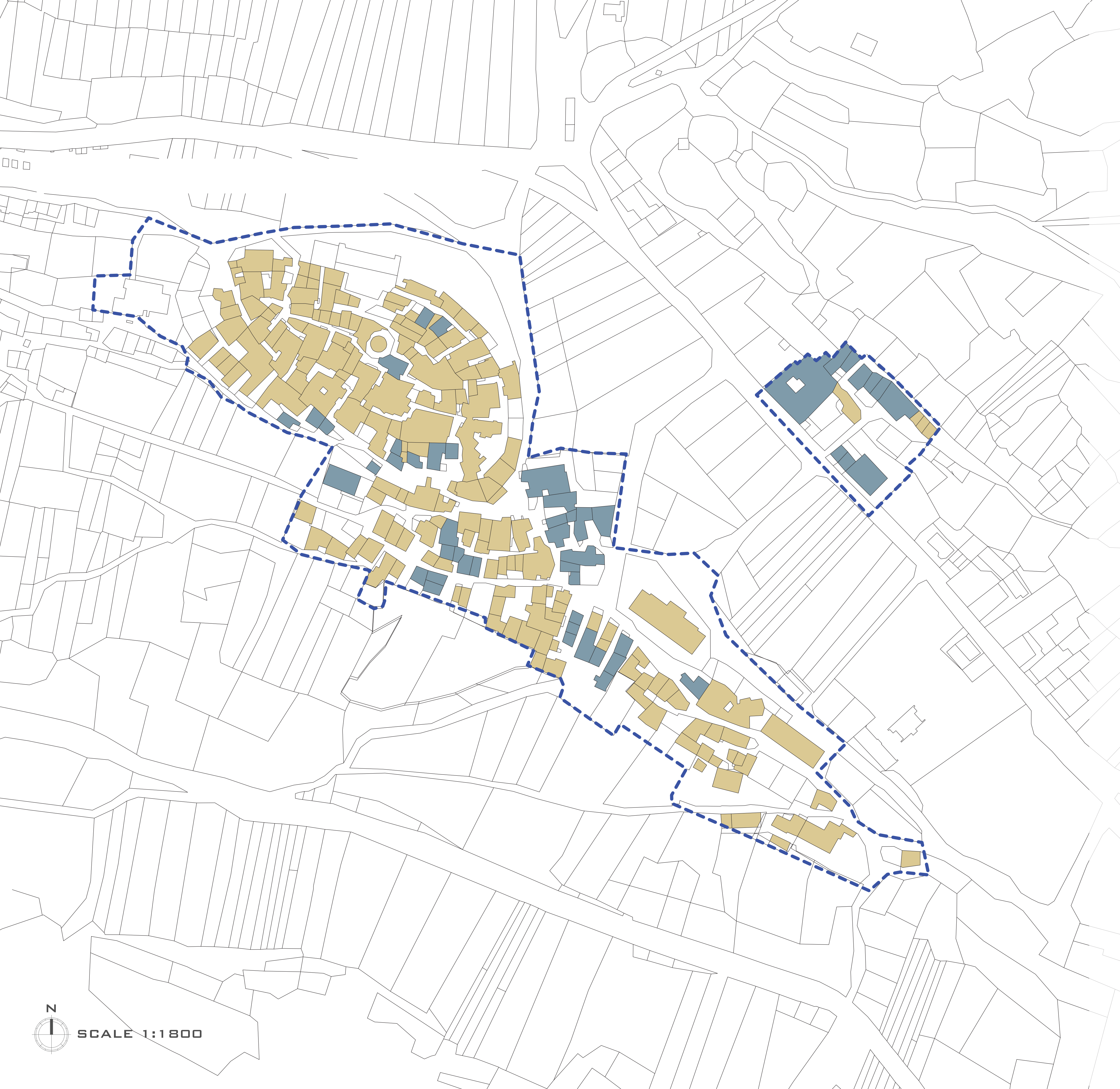
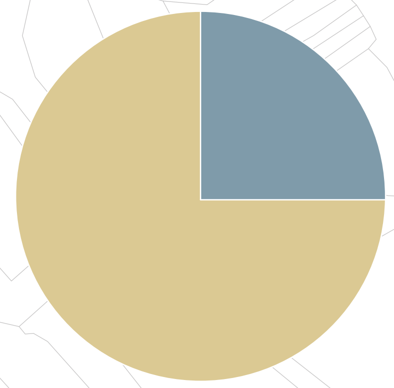


Table 3.3 Building Orientation to Elevation

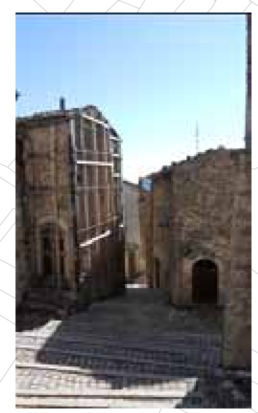
KEY:

- Building unit positioned parallel to the elevation curves
- Building unit positioned perpendicular to the elevation curves



EXAMPLES:

PARALLEL
These building units are positioned parallel to the elevation curves



PERPENDICULAR
These building units are positioned perpendicular to the elevation curves

Comune: Santo Stefano di Sessanio
Building Orientation to Elevation Curves

3.3 Orientation to the Overall Elevation Curves:

As thoroughly discussed in the building typology sections 2.2.3 and 2.2.4, the orientation of a group of connection structure, aggregate, is extremely important to the overall structural stability of each of the individual structures. The orientation of a structure to the overall elevation curves can greatly affect the force of torsion or possible collapse mechanism of out-of-plane wall overturning. Although not seen in Santo Stefano di Sessanio, structures oriented at an angle to the elevation curves are extremely vulnerable to the force of torsion and can experience several structural failures due to this force. All of the structures within Santo Stefano di Sessanio have been divided into two difference categories regarding their orientation to the overall elevation curves; parallel or perpendicular. While both orientations are structurally acceptable, it is their combination within a single aggregate that makes a structure vulnerable to several collapse mechanisms.

3.3.1 Buildings oriented parallel to the elevation curves

Of the 206 buildings present in the area under analysis in Santo Stefano di Sessanio, 156 buildings, approximately 75 percent, are oriented parallel to the elevation curves. In general, this is the most common building orientation within the Baronia collective. While there is no substantial proof to claim that buildings oriented parallel are of higher structural stability, a connection has been noted in the villages of Baronia between ruins and building oriented perpendicular to the elevation curves. In general however, the most important factor, when considering the orientation's impact on structural stability, is the orientation of the adjacent buildings within the same aggregate. The most structurally sound aggregate will be composed of structures solely oriented parallel to the elevation curves. In addition, structures should be oriented either directly parallel or directly perpendicular to the elevation curves. Being oriented at an angle to the elevation can not only increase the force of torsion present in a structure but also increase the likeliness of potential collapse mechanisms already existent within the structure.

3.3.2 Buildings oriented perpendicular to the elevation curves

Of the four villages presented in this thesis, Santo Stefano di Sessanio has the largest percentage of structures oriented perpendicular to the elevation curves. More than 25 percent of the 206 building are oriented perpendicular to the elevation curves. However these structures are typically placed outside of the original historic center. With the exception of one of these 50 buildings, even those within the historical center or located along the historical boundary wall. As mentioned in the previous section 3.3.1, the most important characteristic of orientation to elevation curves is the homogeneity of each aggregate regarding this major structural factor. The majority of structures oriented perpendicular to the elevation curves in Santo Stefano di Sessanio are either isolated structures or located within aggregates consisting of structures only oriented perpendicular to the elevation curves. The remainder is located within aggregates consisting of a mix of both parallel and perpendicular orientations. These are the most instable of the orientations to the elevation curves, regarding overall aggregates. The collapse mechanisms present in buildings oriented parallel or perpendicular are extremely diverse and therefore when acting together, increase the likelihood of collapse in all structures involved, increasing the existing collapse mechanisms. Therefore aggregates consisting of a combination of both orientations to the elevation curves require substantial restoration regarding the connections of the structures and their out-of-plane wall overturning tendencies.

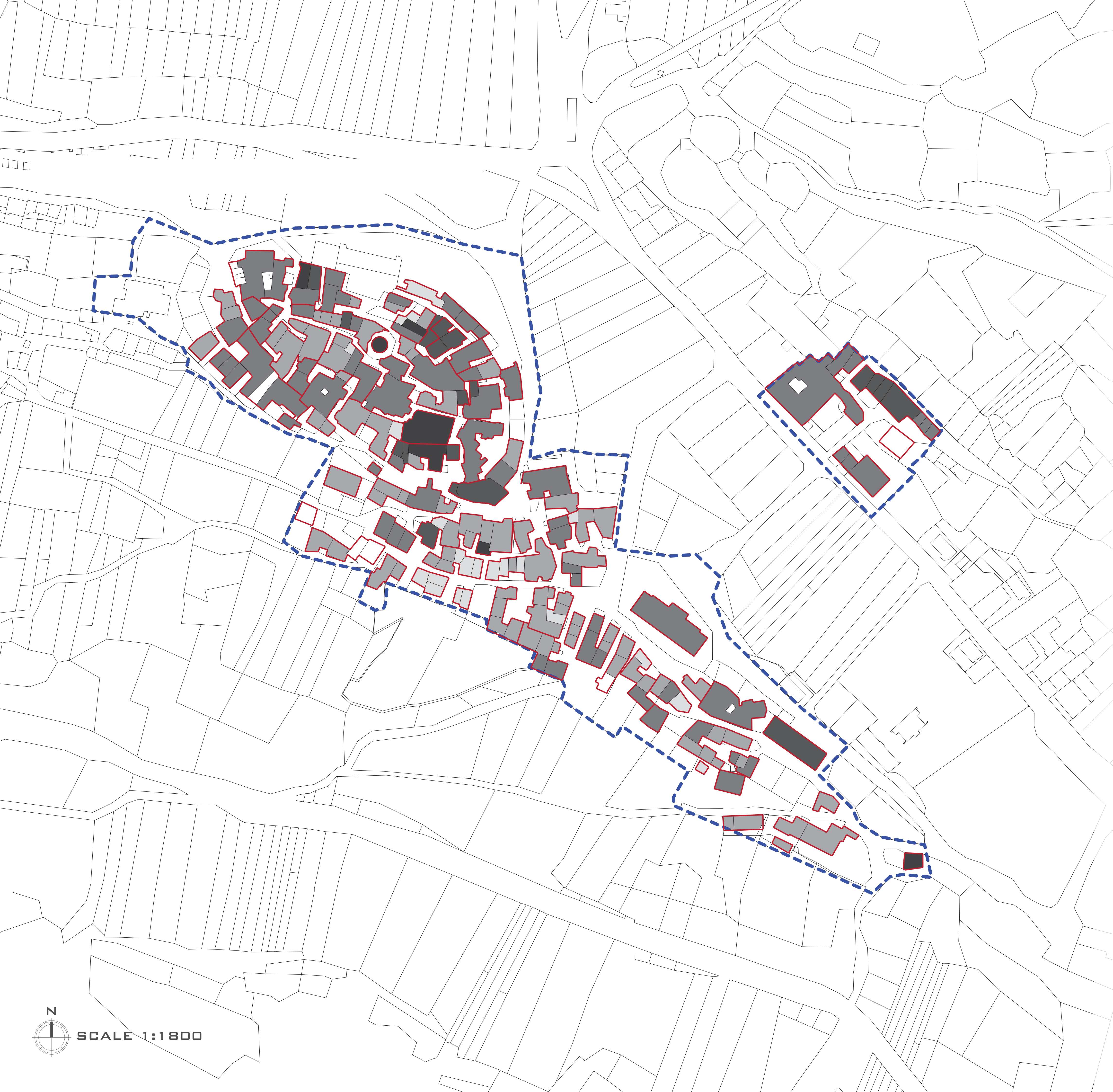


Table 3.4 Building Heights by Aggregate

KEY:

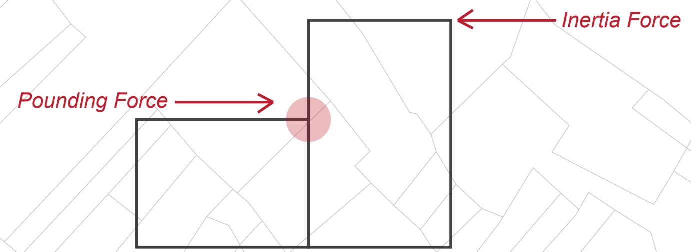
- 5 Floors Equivalent (or above)
- 4 Floors Equivalent
- 3 Floors Equivalent
- 2 Floors Equivalent
- 1 Floor Equivalent
- Aggregate Border

DESCRIPTION:

All building heights indicated on this map are distinguished by aggregate, which is why all heights are "equivalent" and not to be compared between aggregates. These heights are meant to distinguish which aggregates are the most and least homogeneous, regarding building height. Aggregates that are less homogeneous in height are more likely to suffer seismic damage due to pounding, which is described below.

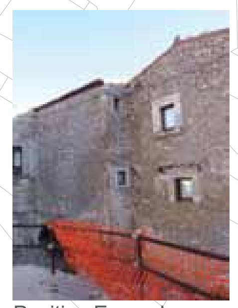
TALLER ADJACENT BUILDING POUNDING:

Pounding is created between two buildings of differing heights due to different moments created in each structure, when they shake due to a seismic force. This creates different dynamic responses in each structure. The point where they meet, the fulcrum point, is the point of the most vulnerability. It is here where most damages can happen. This damage is due to irregularity in elevation, but can also happen between buildings of equal height.



POSITIVE/NEGATIVE EXAMPLES:


Negative Example


Positive Example

Comune: Santo Stefano di Sessanio
Building Heights by Aggregate

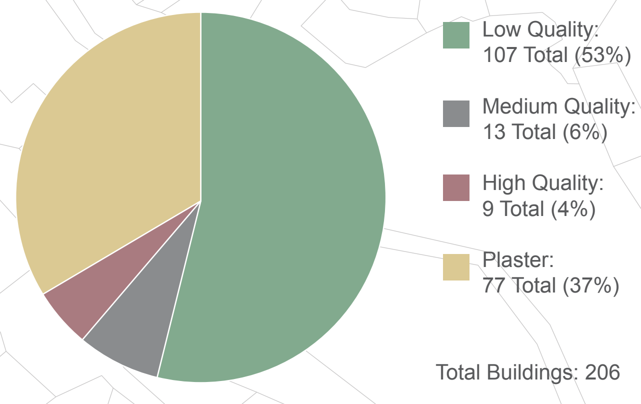
3.4 Building Heights

The building heights within Santo Stefano di Sessanio are fairly even regarding each individual aggregate. There are however a few tower-like structures located both within the historical center as well as outside of it. These structures include both the Medicea tower as well as several of the churches present in Santo Stefano di Sessanio. In most cases, these tower-like structures are isolated from the adjacent aggregates. This is the preferable location of tower-like structures. When placed within an aggregate, towers can suffer out-of-plane wall overturning at the connection point with the shorter connected structures. This can lead to both partial or complete collapse as well as damages to the surrounding structures. In addition, towers within an aggregate can also experience major damage due to hammering in the case of a seismic event. Outside of the historical center, there are very few cases where connected structures differ in height by more than one story. However within the historical center, there are several instances of aggregates with connected structures differing by two or more stories. These height differences increase the likeliness of both hammering and out-of-plane turning, due to the creation of fulcrum points. These are the points where the two structures of different heights touch and become a point at which the taller structure is likely to rotate and structurally fail. This can not only produce out-of-plane wall overturning but also destroy the shorter building in the case of collapse. In order to minimize these effect, substantial structural restoration are required where these structures connect to one another. These renovation efforts can come in the form of either buttresses or tie rods.

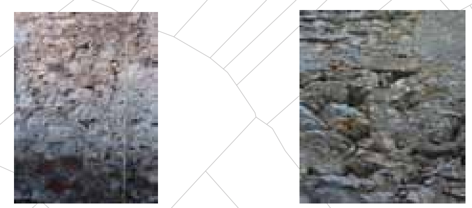
Table 3.5 Masonry Typology

KEY:

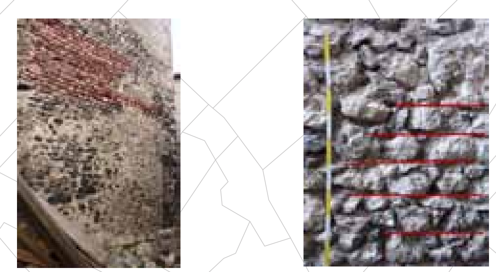
- Irregularly formed masonry (regarding shape, dimensions and materials) stone
- Subhorizontal masonry with roughly cut stones (of varying dimensions)
- Horizontal masonry courses with roughly cut stones (well interlocked)
- Plaster Covered



EXAMPLES:



Low Quality



Medium Quality

High Quality

Comune: Santo Stefano di Sessanio

Masonry Typology

3.5 Masonry Typology

Within the analyzed portion of Santo Stefano di Sessanio, all four of the previously introduced masonry typologies are present. The historical center is composed almost exclusively of the first three masonry types, while outside of the historical center, the majority of the structures are plaster covered, therefore their structural masonry typology could not be determined. As introduced in section 1.11, the three exposed masonry typologies will be defined as masonry typology one, two and three. All of these three typologies are present in Santo Stefano di Sessanio but dispersed unevenly through the six building typologies present in the village.

3.5.1 Masonry Typology One

Masonry typology one, defined as irregularly formed masonry stones, regarding shape, dimensions and materials, is the most common within Santo Stefano di Sessano. This typology considered to be of the lowest quality of those present in the Baronia collective make up 53 percent of the structures within the village. The majority of the historical center is structurally composed of masonry typology one as well as a vast majority of the structures outside of the historical center. The two figures to the left are two examples of masonry typology one within the village of Santo Stefano di Sessanio. As seen, the masonry lacks in continuous horizontal bands and have no visible vertical structural system. This particular majority is also the majority of the masonry typologies used in all four of the villages in discussion. Masonry typology with Santo Stefano di Sessanio is present in four building typologies, including historical boundary wall houses, towers, building oriented parallel to the elevation curves and buildings oriented perpendicular to the elevation curves.

Figure 3.20 Typology 1

Figure 3.21 Typology 1

Masonry typology one is present in several of the structures categorized as in the historical building wall house building typology. The example to be examined comes from aggregate SSS 014. This particular aggregate is located within the historical center. All of the structures within the structure are currently of private use and uninhabited. As seen in the photo below of the overall aggregate, the structure is composed of structures of varying height. In addition, the building within the aggregate have not been used in a substantial amount of time. This is the case with several structures in Santo Stefano di Sessanio. In most cases, structures composed of masonry typology one were originally covered in a plaster covering in order to protect the masonry structure below. As seen in the figures below, the masonry typology one present in this particular aggregate also was once covered in plaster. However the plaster has begun to decay and is revealing the masonry typology below. This slight decay of the plaster

Figure3.22   Aggregate SSS 014

Figure 3.23   Typology 1   Historical Boundary Wall

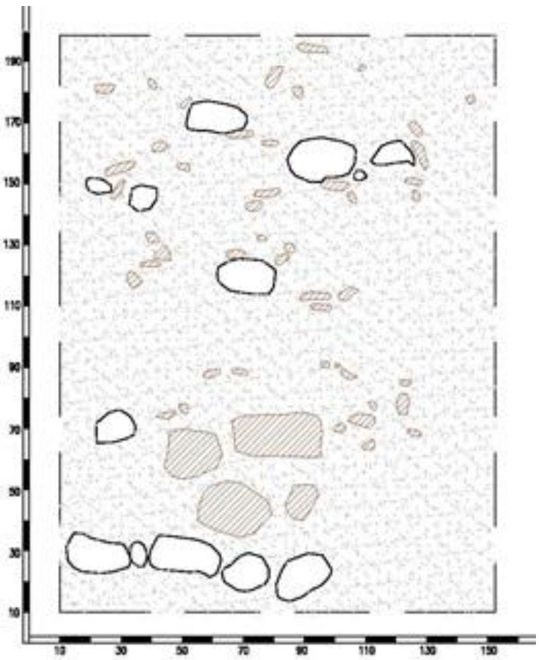


Figure 3.24   Typology 1   Historical Boundary Wall

cover implies a recent restoration or renovation, due to the fact that the original structure was built when the city of Santo Stefano di Sessanio was initially constructed. As visible in the photos and masonry analysis above, there are no distinctive horizontal or vertical structures within the masonry which is what categorizes the masonry as the lowest quality present in Santo Stefano di Sessanio. However it is important to note that this structure has survived hundreds of seismic events and should not be considered structural insufficient regarding the masonry typology.

The next example of masonry typology one within Santo Stefano di Sessanio is seen in the case of a tower. In order to accurately show masonry typology one within the tower building typology, two separate examples will be introduced. The first example is located in aggregate SSS

Figure 3.25 Aggregate SSS 017

Figure 3.26 Typology 1 Tower House

017. This example is located within the historical center, attached to the historical boundary wall. This aggregate is also located adjacent to the tower of Medicea. This particular aggregate is currently of private use, with all of the buildings currently uninhabited. The structure also originally had a plaster covering of the masonry structure but, as seen in the photos above, it has been decayed over time revealing masonry typology one as the primary structure. This particular example of masonry typology one is of a higher quality, with a slight presence of horizontal rows of the bricks. This higher quality of the masonry is due to the social importance of the historical boundary wall of the historical center. This wall overall was created using higher quality stones as well as a higher

construction quality. However the overall formation of the structure can still be considered to be masonry typology one.

The next example of masonry typology one is located within the most common building typology in Santo Stefano di Sessanio; buildings oriented parallel to the elevation curves. The combination of this masonry typology and building typology is the most common structural combination seen in Santo Stefano di Sessanio. The example to be analyzed is located in aggregate SSS 001. This particular aggregate is located within the historical center of the village. In addition, the aggregate is currently of combined public and private use. The single building within the aggregate of private use is the only structure within the aggregate that is currently inhabited. As seen in the photo to the left, the aggregate is composed of structures of similar heights and has several forms of permanent structural interventions. The masonry typology present is highly visible due to a high level of decay of the protective plaster cover. Again the masonry lacks any

Figure 3.27 Aggregate SSS 001

Figure 3.28 Typology 1 Parallel

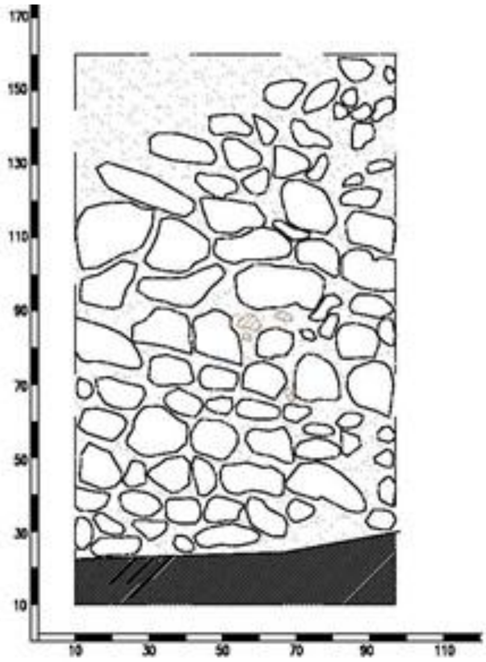


Figure 3.29 Typology 1 Parallel

consistent horizontal or vertical structures. The overall composition of the masonry is structural stability but is still the lowest quality masonry typology within Santo Stefano di Sessanio. The irregularity of the stones, clearly visible in the attached masonry analysis figures is evidence of the fact that the masonry stones come from the surrounding area, which was the most economical choice when the village was originally constructed. This is one of the better examples of masonry typology one within Santo Stefano di Sessanio due to the quantity and consistency of the masonry stones within the structure.

The final example of masonry typology one is found in a building oriented perpendicular to the elevation curves. This particular structure is located within the aggregate SSS 016. The aggregate is located within the historical center but is unattached to the historical boundary wall. The aggregate is proposed of five structures, all of which are both privately owned and currently uninhabited. In addition, as seen in the photo to the left, the aggregate is composed of several buildings of varying heights. The structure in question is composed of masonry typology one with a plaster covering that has experience substantial decay, this revealing the structural masonry typology present. Similar to the previous example of masonry typology one within the parallel orientation to the elevation curves building typology, the masonry sample examined is of high quality. Structurally speaking there is no significant presence of either a horizontal or vertical structural system, however the masonry stones are of high quality, coming from the surrounding area, and the overall masonry system is of structurally sounds. Due to the placement of the aggregate within the historical center, the age of the structure can be estimated to the same period in which Santo Stefano di Sessanio was originally constructed. Due to the presence of small traces of a plaster covering, it can be determined that if any restorative measures were taken during the structure's lifetime, they were not recent interventions. The most important

Figure 3.30 Aggregate SSS 016

Figure 3.31 Typology 1 Perpendicular

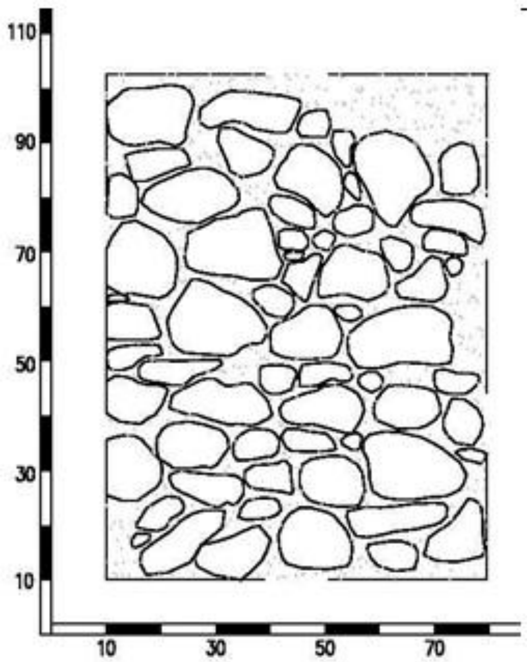


Figure 3.32 Typology 1 Perpendicular

characteristics of this masonry example to note are the varying sizes of stones used in the masonry, as well as the properly spaced distances between each of the stones. In addition, despite the loss of the plaster cover, the masonry still maintains a large amount of mortar, helping to stabilize the masonry in the case of a seismic event. Of all the examples of masonry typology one within Santo Stefano di Sessanio, this is one of the higher qualities examples.

3.5.2 Masonry Typology Two

Masonry typology two is the second most common typology of revealed masonry in Santo Stefano. Out of the 206 buildings present within the village, 13 are composed of masonry typology two. This typology therefore makes up 6 percent of the buildings within the area of analysis.

Figure 3.33 Typology 2

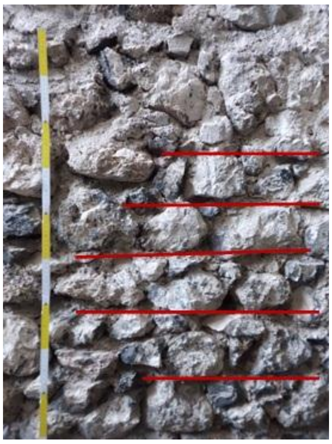


Figure 3.34 Typology 2

Masonry typology two is of higher structural quality than that of masonry typology one. There is a presence of horizontal structural systems, which is not present in masonry typology one. More importantly, the stones are slightly larger and of higher quality. The legal definition of this masonry typology, deriving from the RELUIS definitions, is sub-horizontal masonry with roughly cut stones (of varying dimensions). Despite the limited use of this particular masonry typology in Santo Stefano di Sessanio, This typology is present in three building typologies present in the village, including historical boundary wall houses, towers and buildings parallel to the elevation curves. In all cases, the masonry is of high quality and originally had a plaster covering that in most cases has decayed substantially over time.

The first example of masonry typology two in Santo Stefano di Sessanio comes from a structure within the historical boundary wall. This example is located in aggregate SSS 017, which is entirely within the historical boundary wall. The entire aggregate as well as this building is privately owned and currently uninhabited. Similar to several structures within the historical boundary wall, the masonry is of higher quality due to the social importance of the defensive wall. As seen in the

Figure 3.35   Aggregate SSS 017

Figure 3.36   Typology 2   Historical Boundary Wall

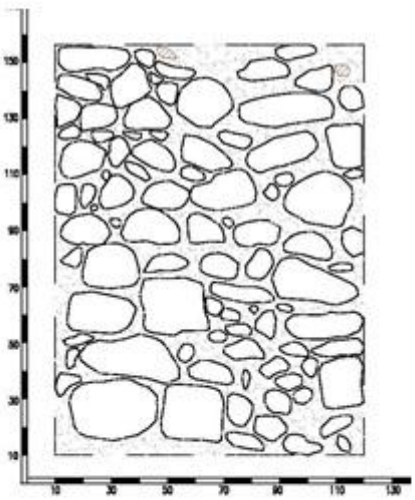


Figure 3.37   Typology 2   Historical Boundary Wall

masonry analysis above, there are very few traces of the once existent plaster covering of the masonry, which has now almost entirely decayed away. The revealed masonry has a subtle presence of horizontal rows of stones. The masonry is also of higher quality due to the proper spacing between stones as well as the varying sizes of the stone which provide a stronger structural stability. Due to the massive heights of the structures within the historical boundary wall, the masonry typology becomes extremely important regarding the structure's vulnerability in the case of a seismic event. The structure is also supported with the addition of buttresses in order to prevent the out-of-plane wall overturning tendencies of taller structures such as those within this particular aggregate. It is however important to note that the masonry typology, while of higher quality, is a single element when considering the overall vulnerability of both a single building was well as an aggregate.

The second example of masonry typology two in Santo Stefano di Sessanio is again within the historical boundary, however in this case, due to the presence of partial collapses of the structure, a masonry section is available for analysis. This example comes from the aggregate SSS 003. This particular example is located within the historical center, specifically within the historical boundary wall. The entire aggregate is currently privately owned as well as being uninhabited. The structure under analysis is partially collapsed and therefore has provided the rare opportunity of observing the masonry typology two in section. The wall is a typical exam of masonry typology two, with the presence of horizontal rows as well as higher quality stones, placed properly apart. As seen in the photo below of the masonry section, the section is composed of two structural leaves. Based on observational analysis alone, there appears to be poor connection between the two leaves of the section. In addition, there appear to be little to no large stones that span the entire width of the section. This is important to note

Figure 3.38 Typology 2 Historical Boundary Wall

Figure 3.39 Typology 2

because a lack of connection between leaves in a masonry section can produce several types of damages as well as potential collapse mechanisms. These characteristics are important to note due to the lack of thorough structural information provided through the observation analysis of exposed masonry on the structure's façade. In order to thoroughly analysis the masonry structure, both structural exams and samples would have be taken from the site. However in this case, the sectional view is a fairly accurate assessment of the structural faults present in this particular example of masonry typology two.The second building typology in which masonry typology two is present is the tower building typology. This particular example is located in aggregate SSS 017. The aggregate is located both within the historical center as well as the within the historical boundary wall. The aggregate is currently both privately owned as well as uninhabited. While no elevation analysis was available, even in the photo to the left, the masonry typology is clear. There is a substantial presence of horizontal rows of the stones as well as a high quality of stones both regarding cut and shape. Masonry typology two is strongly defined by its regularity in form and higher quality construction. Again, structures within the historical boundary were generally given more structural importance due to their social place within the village. While there is a small presence of a plaster covering, most of this protection from the elements for the masonry has decayed. This implies a restoration within the lifetime of the structure, if not recently. This is to be expected given the social standing of the tower within the historical boundary well.

Figure 3.40 Aggregate SSS 017

The final example of masonry typology two within Santo Stefano di Sessanio is found in the building typology of buildings oriented parallel to the elevation curves. This particular example comes from within the historical center, unattached from the historical boundary wall. The building is located within aggregate SSS 013. This aggregate is composed of seven structures, all of which are privately owned and two are currently inhabited. In addition, of the seven building present in this aggregate, three are structurally composed of masonry typology two, one of the most of any single aggregate. This example has almost no evidence of the once existent plaster cover and therefore is extremely accessible regarding observational analysis. As is seen in the attached figures of the masonry analysis, the masonry composition is extreme regular, with a subtly visible presence of horizontal rows. In addition, the masonry typology is composed of stones of varying sizes that are properly placed apart. The quality of the masonry is particular aggregate is also extremely important considering the varying sizes of the separate structures within the aggregate. Another strong consideration in choosing this specific example was the amount of openings within the façade of the structure. This the elevation example analyzed is taken at one of these opening. As is seen in the masonry analysis below, the opening is a fluid

Figure 3.41 Aggregate SSS 013

Figure 3.42 Typology 2 Parallel

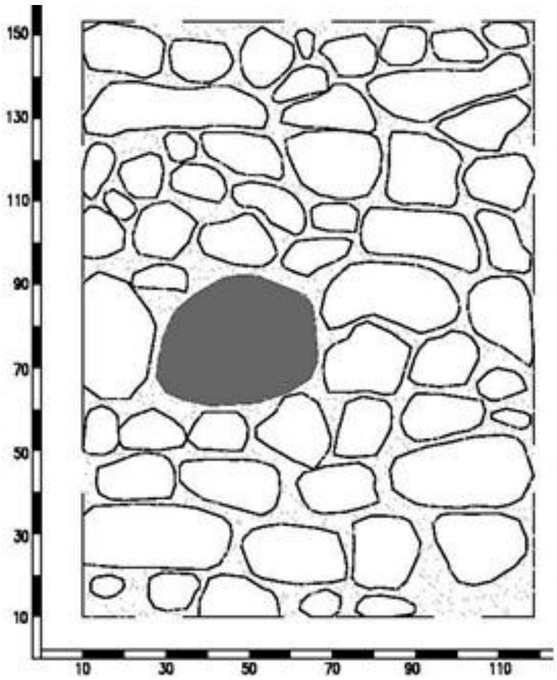


Figure 3.43 Typology 2 Parallel

element within the masonry structure. The opening fails to interrupt the rhythm of the masonry. This is important to note considering the structural importance of openings within a masonry structure. This will be further discussed in the Openings section 3.10. In this particular masonry sample, it is also important to note the size of the stones. These stones are the typical size of stones found in the surrounding region. These stones are of high quality and have been constructed with high quality, which is expected for structures within the historical center of the village. This choice of stone was also considered to be economical due to the lack of transportation costs.

3.5.3 Masonry Typology Three

The final masonry typology, present in both Santo Stefano di Sessanio as well as the remainder of the villages within the Baronia collective, is masonry typology three. This masonry is the highest quality present in all of the four villages discussed in this thesis. Within the Baronia collective, this masonry typology is typically reserved for church or religious structures due to their social and cultural importance in the area. In addition, these structures are typically subsidized by the Catholic church, which allowed for higher quality materials and construction. The masonry is legally defined as horizontal masonry courses with roughly cut stones (well interlocked). In the case of Santo Stefano di Sessanio, masonry typology three is present in only nine structures within the village, most of which are either symbols of the village, such as the tower of Medicea, or for religious or governmental use. This masonry typology makes up only 4 percent of the buildings within Santo Stefano di Sessanio, which is the least of any of the masonry typologies present in the village.

Figure 3.44 Typology 3

Figure 3.45 Typology 3

The first and only example this masonry typology is from the church or religious structure building typology. The example is located in aggregate SS 047. This particular aggregate is located on the edge of the historical center but is unattached from the historical boundary wall. The building under analysis is publically owned while the remainder of the aggregate is privately owned. Currently the entire aggregate is uninhabited, however the church is still in use. The masonry present in this particular church is one of the highest quality masonries present in Santo Stefano. As is seen in the sample elevation of the masonry typology, the stones as well as their arrangement is quite regular.

Figure 3.46 Aggregate SSS 047

There is no plaster cover present to protect the bricks and there is no evidence to suggest that there was a cover at one time. This appears to be an aesthetical choice. In addition, it is important to note the varying sizes of the masonry stones as well as the proper spacing between each stone element. Due to the social importance of both churches and religious structures in both Santo Stefano di Sessanio as well as the rest of the Baronia communities, these structures are of the highest masonry and construction quality. However while these structures are composed of more structurally sound masonry, they are extremely vulnerable.

Figure 3.47 Typology 3 Church

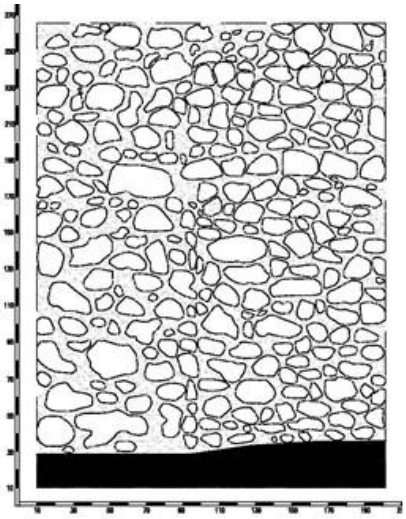


Figure 3.48 Typology 3 Church

Table 3.6 Location of Ruins

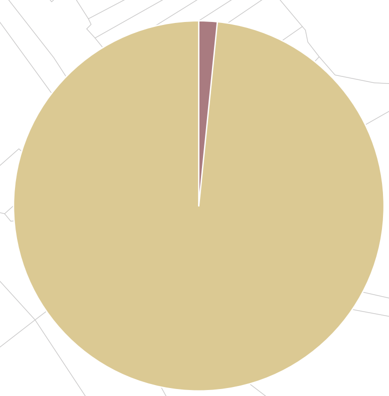
KEY:

Usable Building

Building in Ruins

Total Number of Ruins: 4

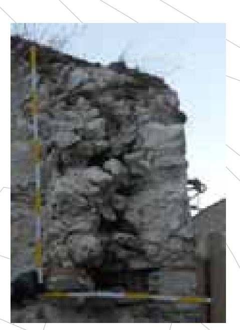
Total Buildings: 311



DEFINITION:

“Ruins” are considered any building that is beyond uninhabitable, but instead is to the point of having lost all structural stability. The building will in general have collapsed entirely or at least partially. It is important to note these structures because they can hint at a particular vulnerability of an aggregate or area of buildings. They also, if not properly controlled, create damage to surrounding buildings or structures.

EXAMPLES:



Comune: Santo Stefano di Sessanio

Location of Ruins

3.6 Existing Ruins:

Within Santo Stefano di Sessanio, there are very few examples of ruins. Within the village there are only four ruins, which make up 2 percent of the buildings within the village. Two of the examples are located within the historical center and two are located outside of the historical center. Three of the four ruins present in the village will be discussed, through the use of sectional and elevation analysis.

The first example of a ruin comes from within the historical center. The ruin is located in aggregate SSS 018. This particular ruin suffered total collapse, with several structures within the

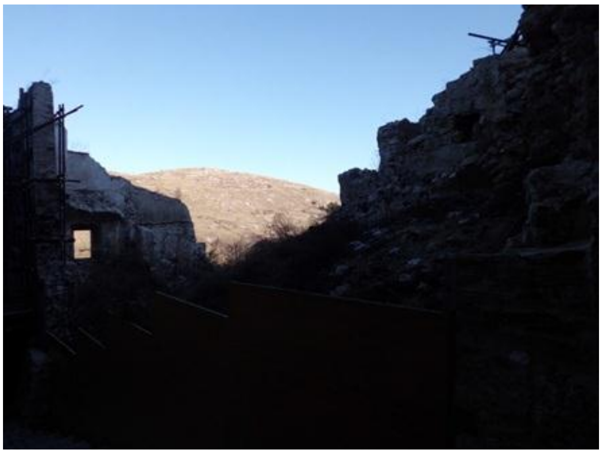


Figure 3.49 Aggregate SSS 018

Figure 3.50 Ruins

Figure 3.51 Ruins

Aggregate suffering at the least partial collapse. Based on observations it is possible to conclude that the original aggregate lacked homogeneity in height. This may have played a role in the eventual collapse of the two structures within the aggregate.

Observation analysis of the sections within the ruins have been used to determine the quality of the primary masonry structures. This analysis will be based on the assumption that the wall sections analyzed are representative of the overall masonry of the structure. Upon initial observation, it is clear that the masonry has been assembled with a little effectiveness. This fact is in line with other information gained from observed analysis. Despite the small size of the sections under examination, the overall masonry composition can be deduced. Section 1 uses a two leaf system, both in the wall and vault sections. The wall section appears to have very few connecting stones to connect the two leaves together. The second section however appears to be composed of either two or three leaves, with the presence of a few larger stones meant to old the two sides of the wall section together. The third and final section is, based on observational analysis, composed of three leaves. In this case, the section is composed almost entirely of smaller stones and lacks any larger stones within the wall structures. It is important to note that these sections are extremely difficult to analysis on an solely observational analysis method, therefore these conclusions should be considered only temporary preliminary analysis

Figure 3.52   Section 1

Figure 3.53   Section 2

Figure 3.54   Section 3

until extensive future analysis can be completed both on-site and off-site in a laboratory. However it is important to note that even in observational analysis, the masonry sections are structurally flawed in several regards, which may have played a role in the eventual collapse of the two structures within the aggregate. In addition, both structures have been notable composed of the lowest masonry quality within Santo Stefano di Sessanio, masonry typology one.

The second example of ruins within Santo Stefano di Sessanio is located extremely close to the first example. This is an important point to note due to their close vicinity, foundation or terrain conditions could have been influential in the two separate aggregates' collapses, however that is solely conjecture without further analysis. This second example is located in aggregate SSS 020. The aggregate is composed of a single structure which, despite the addition of permanent structural interventions such as tie rods, experience total collapse. As seen in the photo to the left, the structure

Figure 3.55 Aggregate SSS 020

lost its entire roof as well as a majority of the interior and exterior walls. As seen in the figure, there is currently a temporary structural intervention in place in order to minimize the collapse mechanisms as well as to avoid damages to the surround structures or street way. This ruin is important to note due to the existence of damages caused by the use of tie rods, this will be further discussed in the temporary interventions section 3.11. As seen in the figure of the section to the left, the wall section appears to be composed of three leaves, the outermost of which is primarily a plaster cover. The inner two leaves are notable due to

Figure 3.56 Ruins Section 1

the use of extremely small stone masonry elements as well as the lack of larger stones connecting the leaves together. These stones that span the entire width of a masonry section are critical in the structural stability of a masonry section. Additional observation of the collapse mechanisms present within the ruins implies that the masonry played a substantial role in the collapse of the structure. This conclusion is only preliminary and based off of observational analysis only. Therefore to verify this conclusion, addition on-site and off-site laboratory analysis would be necessary. This is the case for all masonry sections analyzed in this thesis.

The third and final example of a ruin in Santo Stefano di Sessanio is located outside of the historical center. The ruin is located within aggregate SSS 038. This aggregate consists of two structures both of which are currently ruins. Due to the high amount of vegetation present in both sites, their collapses can be considered not recent events. As seen in the photo analysis to the left, it is extremely difficult to determinboth the masonry quality as well as the cause of the collapse. Due to a lack of access within the site of the ruins, sectional analysis was impossible. However based on

Figure 3.57 Aggregate SSS 038

extremely limited observational analysis, several preliminary conclusions can be made. The first and most important of these conclusions is the collapse mechanisms that appear to be present in the ruins. The structural failure is clearly related to the degradation of the masonry, which appears to have suffered shear failure. The view of the masonry sections from a distance suggests a two leaf system with the presence of larger stones to

Figure 3.58 Ruins

Figure 3.59 Ruins

better connect the sides of the wall section.However due to the lack of a plaster cover and what appears to be the lack of mortar, the connection of the individual elements could have played a role in the collapse. Again, this conclusion is only preliminary and must verified with further thorough analysis of the masonry present to verify the preliminary observational claim.

Table 3.7 Collective Homogeneity Analysis

DESCRIPTION:

This collective homogeneity map includes all major structural characteristics that influence the homogeneity of an aggregate. This includes building height, building typology, masonry typology and orientation to the elevation curves. All of the previously mentioned maps have been overlaid over each other to emphasize the aggregates that are the best positive and negative examples of structural homogeneity. This was underlined in the following maps and then analyzed within the text of the thesis to better understand the vulnerability or lack of vulnerability of certain aggregates.

GENERAL KEY:

- Buildings
- Aggregate Boundaries

BUILDING HEIGHTS:

- 5 Floors Equivalent (or above)
- 4 Floors Equivalent
- 3 Floors Equivalent
- 2 Floors Equivalent
- 1 Floor Equivalent

BUILDING TYPOLOGIES:

- Historical Boundary Wall House
- Block House
- Tower House
- Buidling Oriented Perpendicular to the Elevation Curve
- Building Oriented Parallel to the Elevation Curve
- Religious Building
- Ruins

MASONRY TYPOLOGIES:

- Irregularly formed masonry (regarding shape, dimensions and materials) stone
- Subhorizontal masonry with roughly cut stones (of varying dimensions)
- Horizontal masonry courses with roughly cut stones (well interlocked)
- Plaster Covered

ORIENTATION TO ELEVATION CURVES:

- Building unit positioned parallel to the elevation curves
- Building unit positioned perpendicular to the elevation curves

Comune: Santo Stefano di Sessanio
Collective Homogeneity Analysis

3.7 Collective Homogeneity Analysis:

The collective homogeneity analysis is primarily based on four specific factors, all of which have been determined through on-site analysis. These include the topics of the previous four sections, including building typology, orientation to elevation curves, building height and masonry typology. As seen in the attached map of Santo Stefano di Sessanio for “Collective Homogeneity”, the four previously mentioned factors’ maps have been overlaid to locate the aggregates with an extremely uniform or non-uniform structure, regarding all four elements. The aggregates that present the least and most uniformity regarding these four elements will be discussed in the following two sections, entitled “Negative Homogeneous Examples” and “Positive Homogeneous Examples”.

Overall, Santo Stefano di Sessanio is one of the more collectively homogeneous, considering these structural factors, of the villages of the Baronia collective. An initial analysis of the attached map reveals that more homogeneous aggregates are located withinthe historical center, while the areas outside of the historical center are more irregular in their overall structural makeup. A lack of structural homogeneity can create several types of damages because an aggregate is more likely to act as a separate element instead of a single unit in the case of a seismic event. This can increase the chances of several collapse mechanisms within the individual aggregates as well as those that are adjacent to one another. In the case of Santo Stefano di Sessanio, there are several aggregates that are vulnerable to seismic events due to their lack of structural homogeneity and will therefore be strongly considered as structures to be restored with the limited public funds available. These structures will be discussed in the “Negative Homogeneous Examples” section, while in the following “Positive Homogeneous Examples” section, aggregates of homogeneous construction will be used as a guide for possible restoration work for the aggregates considered to not be homogeneous and therefore possibly structurally instable.

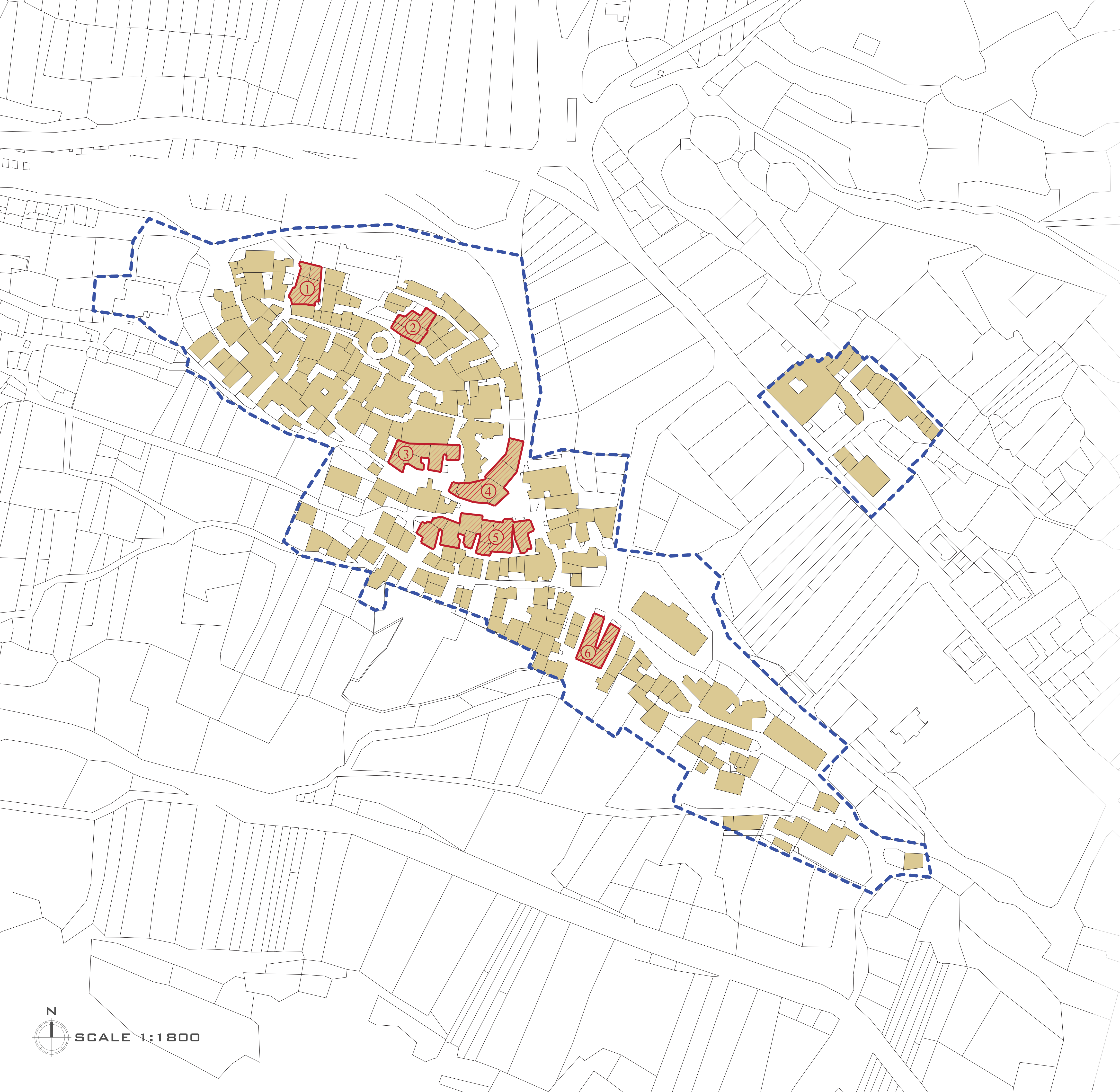


Table 3.8 Location of Negative Examples

KEY:

Typical Building

Aggregate Boundary

Negative Homogenous Example

INFORMATION:

Number of Examples: 6

Example 1: SSS 07

Example 2: SSS 016

Example 3: SSS 067

Example 4: SSS 023

Example 5: SSS 060

Example 6: SSS 045

DESCRIPTION:

These negative examples showing a lack of homogeneity were chosen based on the “Combined Homogeneity analysis” map for Santo Stefano di Sessanio. The previously mentioned map was created by combining the following maps:

Building Heights

Building Typologies

Masonry Typologies

Orientation to the Elevation Curves

All of these maps were laid on top of one another. Then several examples of aggregates were chosen back on their lack of homogeneity regarding these four principal elements. These examples will be further analyzed within the text of the thesis.

DEFINITION:

A “negative example of homogeneity”, in the context of this thesis, is defined as an aggregate made up of several buildings. These buildings will be of different heights and made from several different types of masonry possibly with restorations made of different masonry from that of the original constructions. In addition, the building typologies of all of the buildings within the aggregate are different and the orientation to the elevation curves will be different. All or several of them will also be oriented perpendicular to the elevation curves. It is all of these qualities, or variations of them, that make a specific aggregate a “negative example of homogeneity”

Comune: Santo Stefano di Sessanio

Location of Negative Examples

3.8 Negative Examples of Collective Homogeneity in Aggregates

Overall six examples of negative collective homogeneity have been determined within Santo Stefano di Sessanio. Three of these examples are located within the historical center and three are located outside of the historical center. As described in the previous Collective Homogeneity Analysis section 3.7, these examples are based on the collective homogeneity, a combination of the overall homogeneity of the building typology, orientation to elevation curves, building heights and masonry typology. These examples will be later further analyzed when considering the most vulnerable aggregate within the four villages discussed.

3.8.1 Negative Collective Homogeneity Example One

The first negative examples is found within the historical center of Santo Stefano di Sessanio

Figure 3.60 Aggregate within Santo Stefano

Figure 3.61 Location of Aggregate SSS 007

The example is the entirety of aggregate SSS 007. This aggregate is extremely regular in plan. Howeverthe aggregate is considered to be a negative example of collective homogeneity due to the

Figure 3.62 Collective Homogeneity Analysis

presence of historical boundary within half of the aggregate. This creates an exaggerated height disparity from the Northern portion of the aggregate to the Southern. As is expected, the buildings within the aggregate, within the defensive wall, are much higher than the other structures. This portion of the aggregate is also formed using higher quality masonry as well as differing in building typology. While both of the

3.63 Building Typology

3.64 Building Orientation

3.65 Building Heights

3.66 Masonry Typology

Northern structures within the aggregate are considered to be a part .Of the historical boundary wall, one of them is also considered to be a tower structure regarding building typology. Despite this strong lack of collective homogeneity within the aggregate, the entire aggregate is oriented parallel to the elevation curves. Overall, the aggregate is generally lacking in structural homogeneity, specifically between the Northern and Southern structures. However the aggregate would merit little restorative efforts due to the already existent buttresses and tie rods, specifically present in the portion of the aggregate within the historical boundary wall. Due to their social importance, structures and aggregates within the historical boundary wall are traditional given restorative precedence and therefore will require little to not additional restoration.

3.8.2 Negative Collective Homogeneity Example Two

The second negative example of collective structural homogeneity comes from aggregate

Figure 3.67 Aggregate within Santo Stefano

Figure 3.68 Location of Aggregate SSS 016

SSS 016, located within the historical center of Santo Stefano di Sessanio. This particular example is fairly regular in plan, however is significantly lacking in homogeneity in the four major structural factors considered in the collective homogeneity analysis. Regarding building typology, all of the structures within the aggregate are oriented parallel to the elevation curves, with the exception of

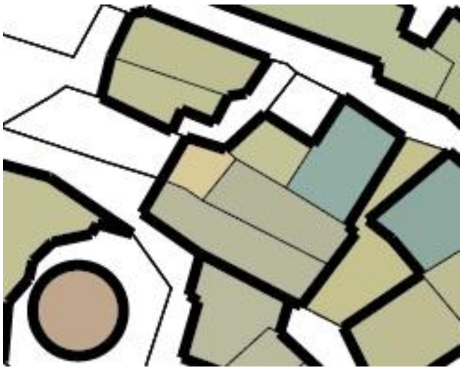
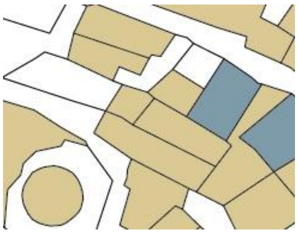


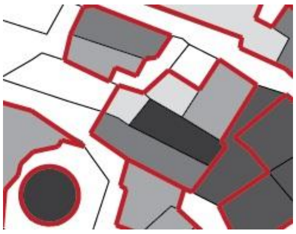
Figure 3.69 Homogeneity Analysis

one structure which is oriented perpendicular to the elevation curves. The greatest disparity regarding collective structural homogeneity is seen in the factors of building height and masonry typology. There is one tower-like structure within the aggregate, as well as several differing heights for the individual structures. Many adjacent structures differ in height by two or more stories. This difference in height increases the chances of the collapse mechanisms of both hammering and out-of-plane overturning. In addition, the aggregate of only five structures is

3.70 BuildingTypology



3.71 Building Orientation



3.72 Building Heights

3.73 Masonry Typology

composed structurally of three separate masonry typologies, including masonry typology one, masonry two as well as one structure with a plaster covering. This lack of collective structural homogeneity in two of the major structural factors puts this particular aggregate in a vulnerable position in the case of a seismic event. Any restorative efforts of the aggregate are advices to increase the connectivity of the individual structures as well as the addition of permanent structural interventions, such as tie rods, that increase the likelihood that the aggregate with function as a single unit in the case of a seismic event.

3.8.3 Negative Collective Homogeneity Example Three

The third negative example of collective structural homogeneity is found in aggregate SSS 067. This particular example is located within the historical center of the village, however the aggregate is located along the divide of the historical center and the area of the village's growth over the last few centuries. As seen in the figures below, this particular aggregate is extremely irregular in both plan and elevation. In addition, of the eight structures within the aggregate, five of the structures are oriented perpendicular to the elevation curves while the remaining three of oriented

Figure 3.74 Aggregate within Santo Stefano

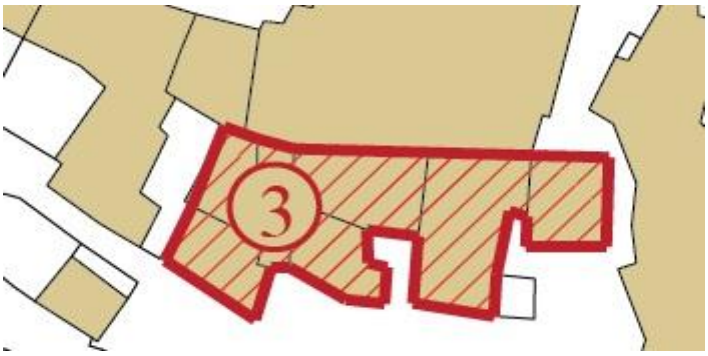


Figure 3.75 Location of Aggregate SSS 067

parallel to the elevation curves. This creates a vulnerable structural mechanisms within the aggregate due to the differing tendencies of movement during aseismic event of the separate structures. In addition, the heights of the individual structures vary substantially, in some cases as much as by two or three stories between adjacent structures. Finally, there are three different masonry typologies present within the aggregate. These include masonry typology one, masonry typology two and plaster covered. This aggregate is one of the least homogeneous within Santo Stefano di Sessanio. In the case of restorative efforts, the aggregate required the addition of stronger connections between the individual structures. In addition, buttresses should be considered due to the high vulnerability to the collapse mechanism of out-of-plane wall overturning.

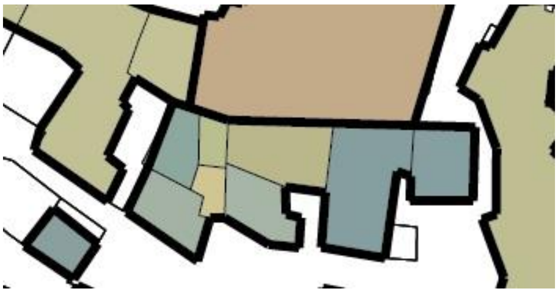
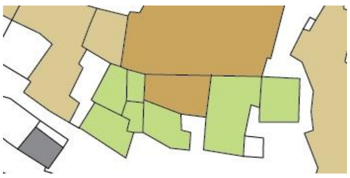
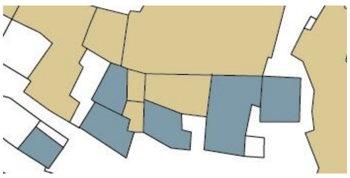


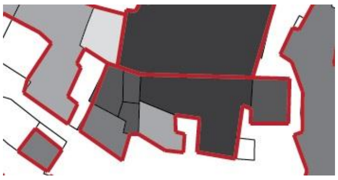
Figure 3.76 Collective Homogeneity Analysis



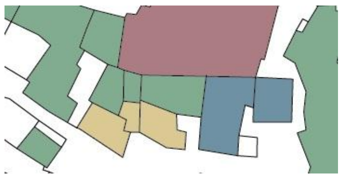
3.77 Building Typology



3.78 Building Orientation



3.79 Building Height



3.80 Masonry

3.8.4 Negative Collective Homogeneity Example Four

\The fourth example of negative collective structural homogeneity is found in aggregate SSS 023. This example is located outside of the original historical center of the village. This particular aggregate is more or less regular in plan but irregular in elevation. The entire aggregate is oriented

Figure 3.81   Aggregate within Santo Stefano

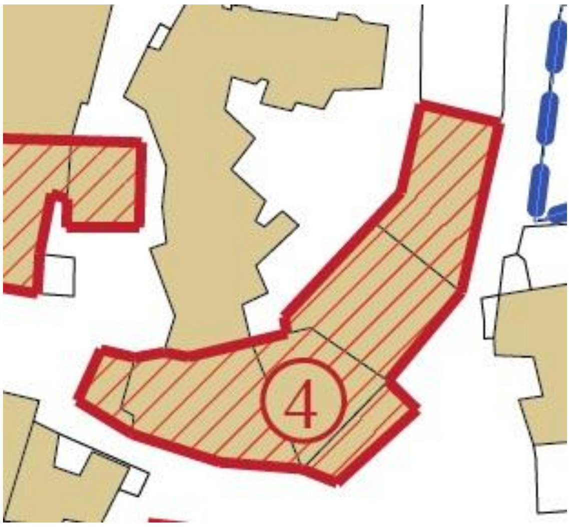


Figure 3.82   Location of Aggregate SSS 023

parallel to the elevation curves. In addition, the entire aggregate is characterized under the building typology of the historical boundary wall, with the except of one structure which is characterized as a

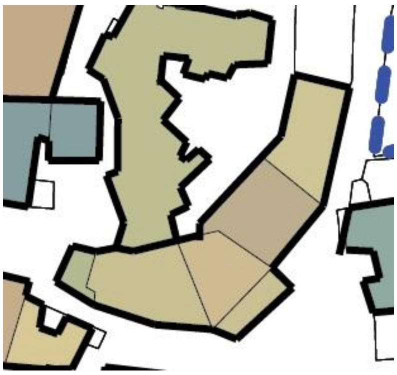
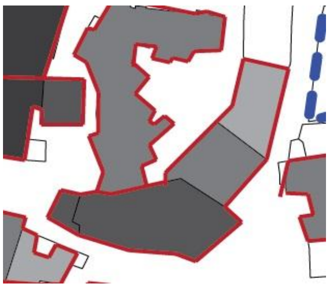


Figure 3.83   Homogeneity Analysis

tower house. The lack of homogeneity of this aggregate is the most present in the building heights as well as in the masonry typologies. The heights within the aggregate vary by no more than one story, but increase in height from the Northern portion of the aggregate to the Southern. Regarding the masonry typology, the aggregate is composed of three different masonry typologies, including masonry

3.84 Building Typology

3.85 Building Orientation



3.86 Building Heights

3.87 Masonry Typology

typology one, masonry typology three and the plaster cover typology. While this aggregate lacks in homogeneity, very little structural intervention is necessary. The most vulnerable portion of the aggregate is the tower house. In this case, additional support and reinforced connections between the tower and the adjacent structures would be necessary as well to ensure proper structural reactions in the case of a seismic event.

3.8.5 Negative Collective Homogeneity Example Five

The fifth negative example of collective structural homogeneity is located outside of the historical center, in aggregate SSS 060. The aggregate is extremely irregular in plan, as seen in the figure below. The shape of the aggregate's plan ispresumably the result of several additions to the original structure. This is also supported by the lack of regularity in both the building heights as well as the masonry typologies. Of the nine buildings present within the aggregate, all of the building are categorized as building oriented parallel to the elevation curves, with the only exception being one structure oriented perpendicular to the elevation curves. The majority of the structures within the aggregate are of similar heights, with the exception of a two structures that are more than two stories higher than their adjacent structures. Finally, the lack of homogeneity is seen the most in the makeup of the masonry typology. While the aggregate is composed of only two different masonry typologies, including masonry typology one and plaster covering, they are randomly placed within the structure of the aggregate. Overall the structure's vulnerability primarily derives from the diversified placement of the two present masonry typologies. This is caused by several structures additions added since the original construction. Thus any restorative effort should be focused on improving the connection of additions to the original units.

Figure 3.88 Aggregate within Santo Stefano

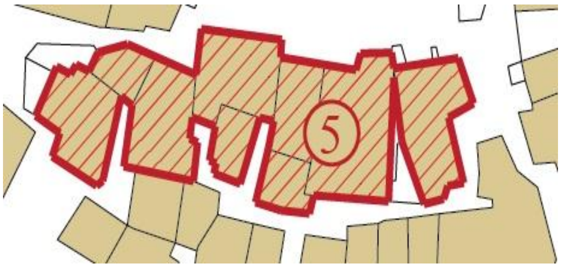


Figure 3.89 Location of Aggregate SSS 060

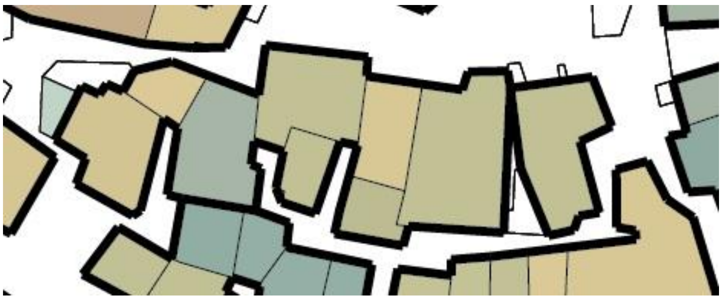


Figure 3.90 Collective Homogeneity Analysis

Figure 3.91 Building Typology

Figure 3.92 Building Orientation

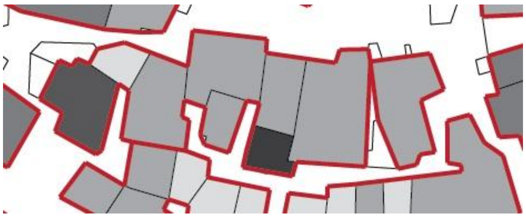


Figure 3.93 Building Heights

Figure 3.94 Masonry Typology

3.8.6 Negative Collective Homogeneity Example Six

The six and final example of collective structural homogeneity is located outside of the historical center and is found in aggregate SSS 045. The aggregate is irregular in plan and is *Figure*

3.95 Aggregate within Santo Stefano

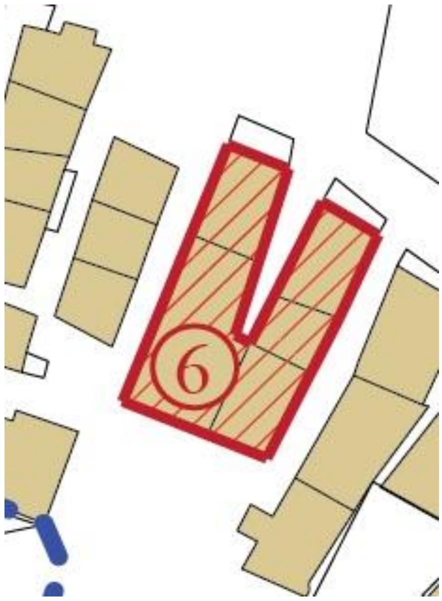


Figure 3.96 Location of Aggregate SSS

*045*primarily considered to be a negative example of collective structural homogeneity is the fact that the aggregate functions as two separate sections regarding several of the primary four structural factors. The Southern portion of the aggregate is oriented perpendicular to the elevation curves, while the Northern portion is oriented perpendicular to the elevation curves. This division of the aggregate is also seen in the building heights. Half of the aggregate is one story higher than the other half. Finally, the masonry typology of the aggregate is composed of two different

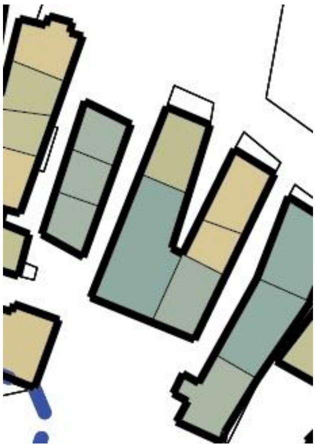
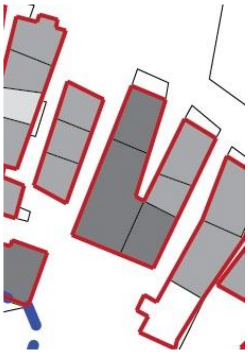


Figure 3.97 Homogeneity

typologies,including masonry typology one and plaster covering. While the lack of collective homogeneity is not extreme in any of the four structural factors, the aggregate is considered to be a negative example due to the overall differences between the two portions of the aggregate. Any restorative effort should be directed at the improved connection between these two portions in order to prevent any negative effects a seismic event, due to their irregularity from one portion of the unit to the other.

3.98 Building Typology

3.99 Building Orientation



3.100 Building Heights

3.101 Masonry Typology

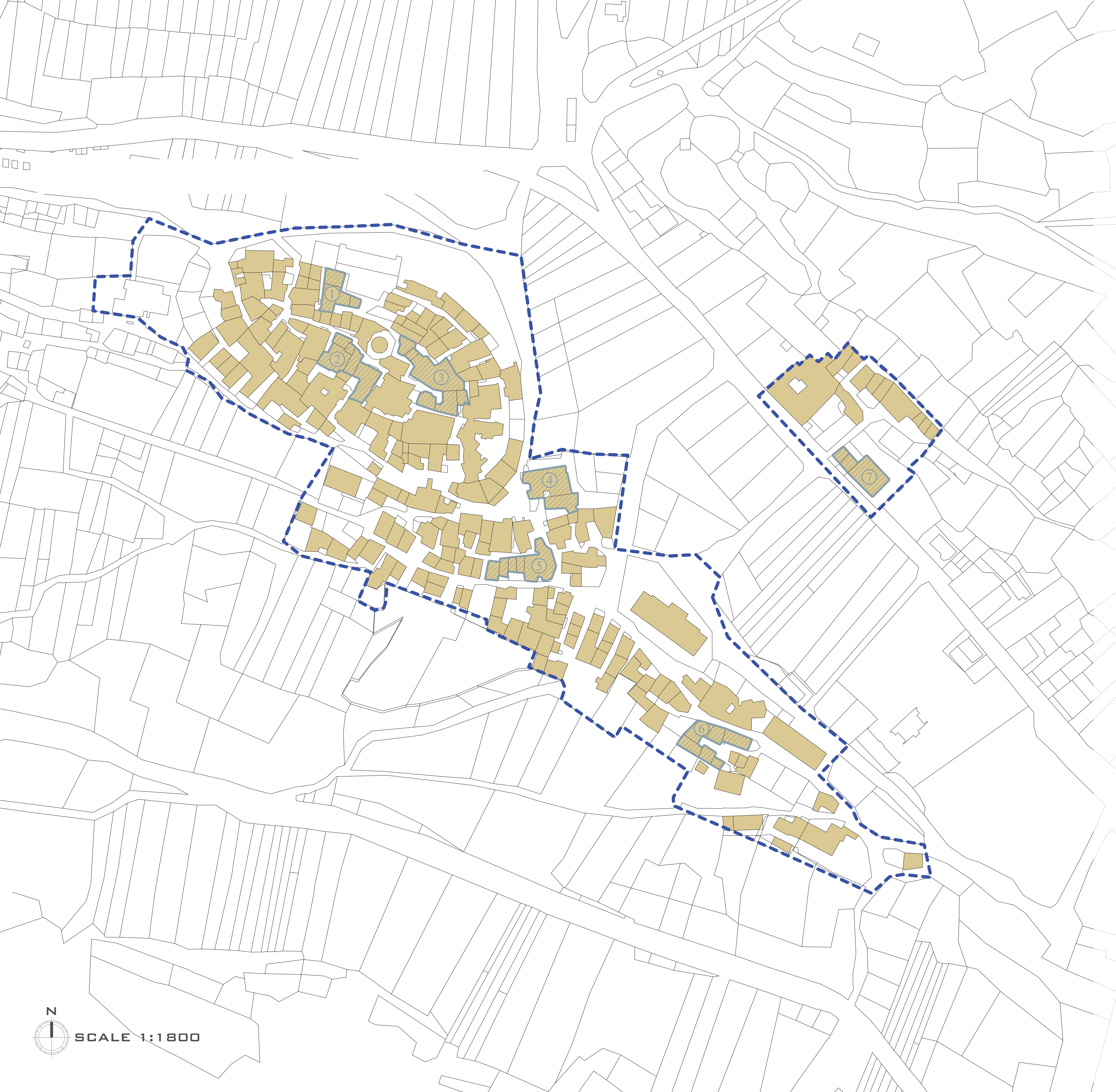


Table 3.9 Location of Positive Examples

KEY:

Typical Building

Aggregate Boundary

Positive Homogenous Example

INFORMATION:

Number of Examples: 7

Example 1: SSS 014

Example 2: SSS 064

Example 3: SSS 009

Example 4: SSS 063

Example 5: SSS 058

Example 6: SSS 043

Example 7: SSS 054

DESCRIPTION:

These positive examples showing homogeneity were chosen based on the "Combined Homogeneity analysis" map for Santo Stefano di Sessanio. The previously mentioned map was created by combining the following maps:

Building Heights

Building Typologies

Masonry Typologies

Orientation to the Elevation Curves

All of these maps were laid on top of one another. Then several examples of aggregates were chosen back on their homogeneity regarding these four principal elements. These examples will be further analyzed within the text of the thesis.

DEFINITION:

A "positive example of homogeneity", in the context of this thesis, is defined as an aggregate made up of several buildings. These buildings will be of the same height and made from the exact same type of masonry, without restorations made of different masonry from that of the original constructions. In addition, the building typologies of all of the buildings within the aggregate are the same and the orientation to the elevation curves will be the same. All or several of them will also be oriented parallel to the elevation curves. It is all of these qualities, or variations of them, that make a specific aggregate a "positive example of homogeneity"

Comune: Santo Stefano si Sessanio
Location of Positive Examples

3.9 Positive Examples of Collective Homogeneity in Aggregates

As described in the previous Collective Homogeneity section 3.7, the final positive examples have been chosen considering the structural homogeneity of each aggregate within Santo Stefano di Sessanio. The overall structural homogeneity was determined by the analysis of four key structural factors including the building typology, orientation to elevation curves, building height and masonry typology. In the case of Santo Stefano di Sessanio, seven positive examples of structural homogeneity within a single aggregate have been chosen, considering the collective homogeneity of all 71 aggregates present in the historical center of Santo Stefano di Sessanio.

3.9.1 Positive Collective Homogeneity Example One

The first positive example of collective structural homogeneity is found in aggregate SSS 014., which is located within the historical center of Santo Stefano di Sessanio. The aggregate is

Figure 3.102 Aggregate within Santo Stefano

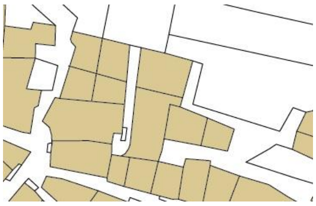
Figure 3.103 Location of Aggregate SSS 014

irregular in plan but not in elevation. This particular elevation is notable due to its placement within the historical boundary wall of Santo Stefano di Sessanio. The aggregate is composed of only four separate structures, of which only one is directly located within the historical boundary wall. The building typologies mirror this sentiment, as the entire aggregate is identified as buildings oriented parallel to

Figure 3.104 Collective Homogeneity Analysis

the elevation curves, with one structure being classified as a historical boundary wall house. The building heights are almost entirely even, with the exception of one structure shorter than the others, but separated by only a single story. Finally the masonry typology is completely homogeneous. The entire aggregate is composed of masonry typology one. Overall this entire aggregate is an excellent


3.105 Building Typology


3.106 Building Orientation


3.107 Building Heights


3.108 Masonry Typology

example of a positive collective homogeneity. This amount of homogeneity within this aggregate is also notable due to location of the aggregate within the historical boundary wall, which typically varies structurally from the rest of the structures within the historical center of Santo Stefano di Sessanio.

3.10 Openings

While generally disregarding, openings can play a large role in the structural stability of a building if improperly placed. The ideal location of punctures of the façade surface are far apart from one another as well as offset in order to avoid creating a vertical instability transcending the separate levels. In addition, openings in order to avoid breaking the continuity of the diaphragm chord of the structural supports. There are several examples of both proper and improper opening placement within Santo Stefano di Sessanio.

This first negative example is found in aggregate SSS 001. In this particular case, the placement of the opening is unfavorable for several reasons. The first issue is the vicinity of several openings to oneanother. As seen with the window and smaller opening on the upper floor, they are placed extremely close to one another which puts the structure between them in a vulnerable position. Also seen on the ground floor in the bottom of the image are two doors who are also extremely close to one another, this weakens the structure between, which in this case is highly dangerous due to the placement of the corner element. The second issue with these opening placements is their vicinity to the corner. Corners or other major structural elements should be continuous and not broken up by the placement of an opening or similar puncture in the surface of the façade.

Figure 3.109 Negative Openings

The second negative example within Santo Stefano di Sessanio is found in the aggregate SSS 019. In this case, the placement of the openings creates substantial structural instability. As seen in the photo, addition temporary structural interventions have been put into place to avoid further damages. Damages have ensued in this case due to the improper placement of openings within the façade. First and foremost, the openings are located too close to the present structural corner element. This not only hinders the structural stability of the corner but of the openings as well. In

Figure 3.110 Negative Opening

addition, the structure between the openings and the corner has also been compromised. The second deficiency with the placement of the openings in this structure is that they are immediately on top of one another. This vertical connection can naturally producing several potential collapse mechanisms, specifically the out-of-plane wall overturning between the present openings. In this case, despite the structural strength of the primary structure of the building, the building's overall stability has been challenged due to the placement of openings.

Despite the presence of several negative examples of openings with Santo Stefano di Sessanio. The majority of the structures within the village showcase positive examples of openings. The two positive examples to be discussed are found in aggregates SSS 002 and aggregate SSS016 respectively. These particular structures are positive examples of opening placements due to the lack of a vertical instability created by stacking the windows. Instead, as seen in both examples, the

Figure 3.111 Positive Opening

Figure 3.112 Positive Opening

openings are staggered from one story to the next. In addition, both structures have their openings placed at a proper distance from all major structural elements including the roof, columns and corners. These are the ideal placements of openings within a structure in order to minimize any negative effect punctures within a façade may produce, if at all.

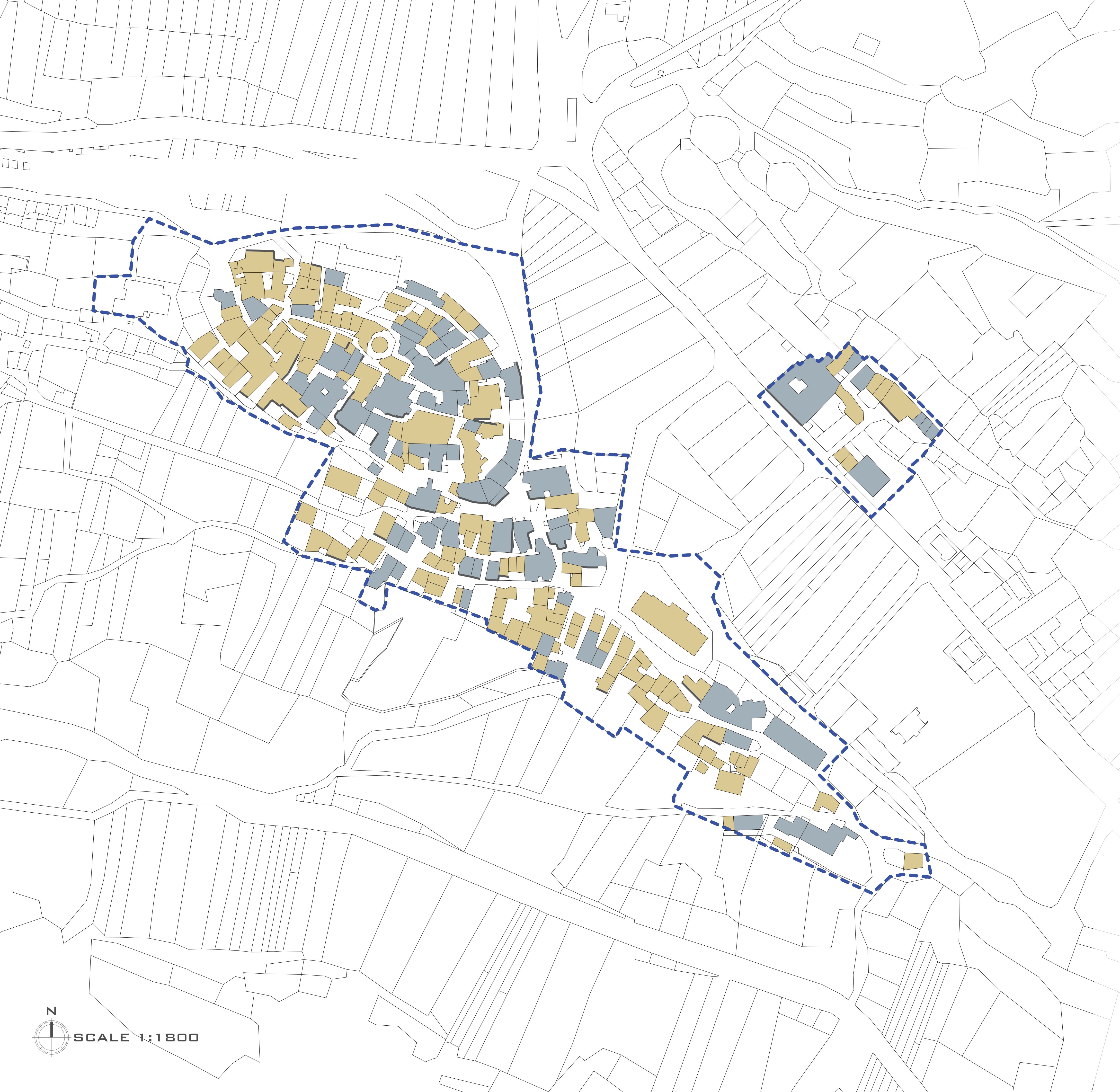


Table 3.11.1 Permanent Interventions

KEY:

- Typical Building
- Buttress Location
- Building with Tie Rods in Place

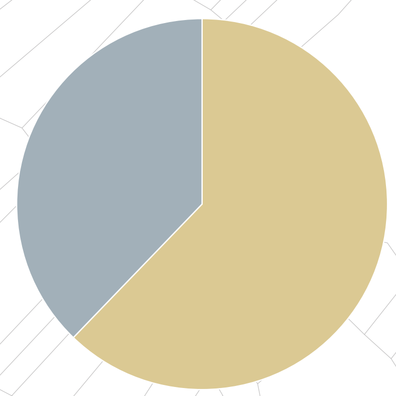
DEFINITION:

Buttress - A mass of masonry or brick work projecting from or built against a wall to give additional strength, usually to counteract the lateral thrust of an arch, roof or vault. There are several different types of buttresses, including angle, clasping, diagonal, flying, lateral, pier and setback buttresses.

Tie Rod - A slender structural unit used as a tie and capable of carrying tensile loads only. Tie Rods are generally used on opposite facades, meant to literally tie the building together in order to prevent facade overturning.

INFORMATION:

Number of Buildings with Tie Rods:	75
Number of Buildings with Buttresses:	37
Total Number of Buildings:	206



EXAMPLES:


Tie Rod


Buttress

Comune: Santo Stefano di Sessanio
Permanent Intervention Locations

Table 3.11.2 Arched Overpass Locations

KEY:

- Typical Building
- Arched Overpass

DEFINITION:

Any arched overpass, that is considered to be either a structural or non-structural element. Any arched overpass, referred to as a "sporto" in the Abruzzo-Italian dialect, is an arched overpass with one or more stories of interior space above the arch. However there are also standard arches included here, that hold no structural weight but themselves.

INFORMATION:

Total Number of Arched Overpasses: 26
Total Number of Buildings: 206




NOTE:

Castel del Monte is famous for their large amount of "sporti", or arched overpasses. However all four regions have at least a few arched overpasses present. Castelvecchio di Calvisio also has a substantial amount of arched overpasses. This characteristic of the four communes is a special construction typology, common in the Abruzzo region's architecture.

Comune: Santo Stefano di Sessanio
Arched Overpass ("Sporto") Locations

3.11 Permanent Structural Interventions

Within the Baronia collective, there is a strong presence of permanent structural interventions, added after the original construction. These interventions include scarp buttresses, typical buttresses and tie rods, and showcase the knowledge of anti-seismic design within the region of Abruzzo. There are four main points when considering the criteria for interventions. The first is that interventions are meant to reduce accidental loads and live loads that caused previous damages. The second is rehabilitation of the load capacity. The third is to remove the causes of material degradation. The fourth and final criteria for interventions is modification of the static scheme. The improvement of the bearing capacity can be made by regenerating of the structural element, increasing the section resistance of the floor supporting structure and replacing degraded elements with other similar elements.

Santo Stefano di Sessanio, similar to the other villages within the Baronia collective, has several types of permanent structural interventions present within the village. These include both buttresses, arches, sporti, and tie rods. Of the 206 buildings present within the village, 75 have tie rods in place, which makes up 37 percent of the buildings within Santo Stefano di Sessanio. There are also several structures within the village with buttresses in place, specifically in the historical center. As seen in figures 3.11a and 3.11b, there are two different typologies of buttresses present within Santo Stefano di Sessanio. The first typology is a partial buttress that only

Figure 3.113 Partial Buttress

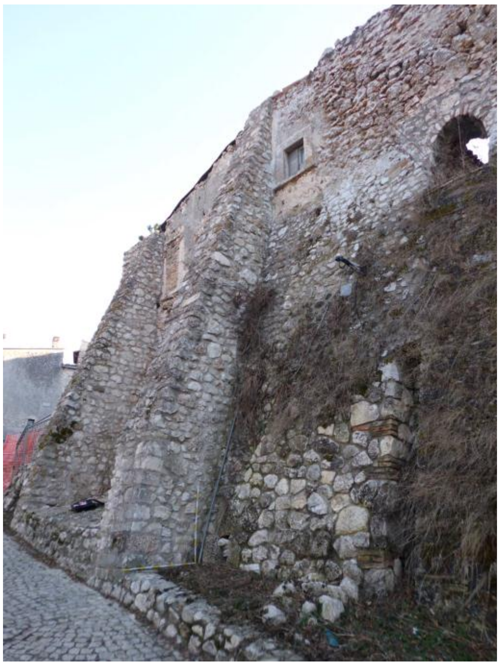


Figure 3.114 Complete Buttress

partial covers the height of the wall being supported. Typically this typology of buttress was not present in the original construction, but instead added later due to the need for additional structural support. The second typology however, the complete buttress, spans the height of the entire supported wall. The example, seen in figure 3.11b, is located within the historical boundary wall and was therefore a part of the original construction. This is typically the case for complete buttresses. It is important to note that due to the size of the buttress structure and the narrow streets within Santo Stefano di Sessanio, in many conditions within the historical center of the village, the addition of a complete buttress is impossible after the initial construction. In this case, either tie rods can be utilized, or partial buttresses, if the space allows for such a structural addition.

There are also several tie rods present within Santo Stefano di Sessanio. There are several typologies of tie rods utilized as well, more so than in any of the other three villages discussed in this


Figure 3.115 Tie Rod


Figure 3.116 Tie Rod

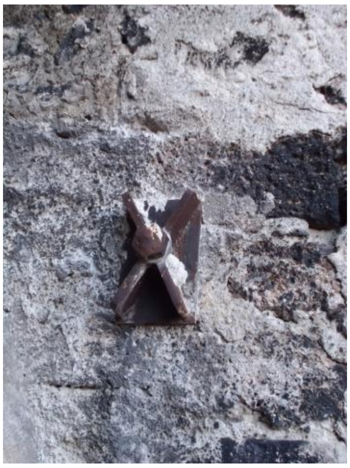


Figure 3.117 Tie Rod


Figure 3.118 Tie Rod

thesis. There are two general categories for tie rods, the first being a bar tie rod, as seen in figures 3.11c and 3.11d. The second category is of plate tie rods, as seen in figure 3.11e and 3.11f. In general, plate tie rods can be considered less damaging to the surface of the structure, while bar tie rods have a tendency of puncturing the surface, although this is only in rare occasions. Tie rods are an extremely efficient strengthening tool in seismic areas, however their placement and tensioning must be considered thoroughly. The example seen in figure 3.11g is found in the ruins of aggregate SSS 020. In this particular case, the tie rod was tensioned too strongly and was the cause of a crack within the structural façade. This crack can have devastating effects because it can produce a lack of


Figure 3.119 Tie Rod Crack

connection between the load bearing walls and also increase the likelihood of out-of-plane wall overturning. It is important to note however that damages due to tie rods are rare. In general, both the placement and implementation of tie rods, within both Santo Stefano di Sessanio as well as the other villages within the Baronia collective, are efficient. There is a clear history of construction knowledge specific to masonry within seismically active historical centers.

The third and final type of permanent structural intervention present in Santo Stefano di Sessanio is the arch or "sporto". In the case of an arch, they are added solely for the purpose of anti-seismic protection. "Sporti" however serve a dual purpose of both anti-seismic protection as well as an interior programmatic function. In both cases, the addition of an arch or "sporto" aid in separating two adjacent structures in the case of a seismic event. This separation can deter the occurrence of the hammering between the two structures. It is important to note that high density "sporti" can create minor structural damages to the attached façade, or collapse on their own. This however is a rare occurrence and is general only applicable for "sporti", instead of for single arches.


Figure 3.120 Sporto

Table 3.12 Temporary Intervention Locations

KEY:

- Surface Rendering Intervention
- Wooden Grid and Ties Intervention
- Traditional Prop Intervention
- Arch/Opening Support Intervention
- Shoring System Intervention

Comune: Santo Stefano di Sessanio
Temporary Intervention Locations

3.12 Temporary Structural Interventions

Both before and after the 2009 seismic event in L'Aquila, temporary structural interventions have been put into place to minimize the collapse mechanisms in several structures that have shown signs of structural instability. There are several types of temporary interventions present in the four villages of the Baronia collective. These include surface rendering, wooden grid and tie, traditional prop, arch/opening support and shoring system interventions. There are several typologies of temporary structural interventions present in Santo Stefano di Sessanio, however only three of these typologies will be discussed in this section.

The first typology of temporary structural interventions present in Santo Stefano di Sessanio is that of the arch/opening support intervention, which is the most common temporary intervention within the Baronia collective. The first example is an arch support intervention, located beneath a "sporto" between aggregates SSS 001 and SSS 068. Both of these aggregates are located within the historical center, unattached from the historical boundary wall. This particular arch support intervention has several flaws. First and foremost, the intervention touches the existing arch unevenly, thus creating increased stress within the vulnerable masonry arch. In addition, the right side of the intervention is supported by the same wall as the arch, thus unnecessarily increasing the load of the structural member. However it is important to note that this particular intervention does allow for circulation access beneath the arch. A large more structurally sound temporary intervention would have to prohibit access underneath the arch, due to the limited space available. However this particular intervention could be of a higher quality, better supported the given arch while minimizing the collapse mechanisms already in place in the arch and the supporting walls.

Figure 3.121 Arch Support Intervention

The second example of an arch/opening support intervention in Santo Stefano di Sessanio is located within aggregate SSS 065. This particular example is specifically an opening support intervention, as seen in the figures below. This intervention allows for passage beneath the opening while still properly supporting the opening, preventing future damage. It is important to not the way in which the opening support intervention interacts with the masonry. In this case, the *Figure 3.122* intervention's force upon the masonry is separated by five wood planks. This formation aids in avoiding the accumulation of stress within the supported opening. In addition, the support is not leaning or supported by the damaged masonry. Overall, this is an effective temporary wooden structural intervention.

Opening Support

Figure 3.123 Opening Support

The third and best example of an arch support intervention is located beneath a "sporto" in aggregate SSS 019. The intervention is composed of high quality wood and evenly distributes the stress added to the existing arch by the addition of the temporary intervention. In addition, the vertical support of the actually intervention is structurally efficient at accepting possible loads produced by the failure of the arch. In addition, the intervention, due to efficient spacing and placement, allows for circulation access beneath the system, which is extremely important due to the use of this particular street by the local inhabitants. As seen in the photo, the intervention interacts with the surface of the arch on seven different points, which are distributed along long horizontal wooden bars. Beneath this arch supporting

Figure 3.124 Arch Support

system is also a triangular shape support system which safely transfers the forces present in the arch support system to the columns of the temporary intervention. Due to the efficient use of space as well as a proper structural support system beneath the primary arch support, this example can be considered the best example of an arch/opening support intervention within SantoStefano di Sessanio. However despite the high quality of the temporary structural intervention, it is important to note that this intervention is only temporary and will need to be replaced in the near future with a thorough permanent structural intervention.

The second typology of temporary structural intervention to be discussed in Santo Stefano di Sessanio is that of wooden grid and tie interventions. An example of this typology of temporary intervention is found in aggregate SSS 061. These interventions are utilized in buildings vulnerable to out-of-plane wall overturning. The support system aids in maintaining the connection of the structural walls to one another. However this is solely a temporary intervention and should eventually be replaced with more permanent interventions such as tie rods and buttresses. In addition, this typology of structural intervention typically does not allow for the use of the building in question, as seen in the figure 3.11e. Similar to arch/opening support interventions, these interventions, if not attached carefully, can increase stress within the façade surface, furthering the damage mechanisms already in place. However in this particular structure, the intervention interacts with the structure through long horizontal and vertical wooden elements that help to disperse the stress produced by the temporary structural intervention. There is also wires in place in order to further support the temporary wooden structure. Based on observational analysis alone, this example is efficient in minimizing the collapse mechanisms in place and well as minimizing the likeliness of future damages before a permanent structural intervention can be put in place.

Figure 3.125 Wooden Grid

The third and final typology of temporary structural interventions to be discussed in Santo Stefano di Sessanio is surface rendering interventions. The first example is located in aggregate SSS 017, which is located within the historical center along the historical boundary wall. These interventions are typically made from steel, as is the case in this example. Similar to the wooden grid or tie interventions, this typology of temporary intervention aids in minimizing the effects of the collapse mechanism of out-of-plane wall overturning. This typology however is typically placed in the façade of the structure facing the narrow street way. Due to the use of steel instead of wood, the intervention has the propensity to last longer, however they still we need to eventually be replaced with permanent structural interventions that prohibit the possible collapse mechanisms within the façade.

Figure 3.126 Surface Rendering

Another example of a surface rendering intervention is found in the aggregate SSS 020. This particular example is important to note due to the fact that the building in question is in ruin. As mentioned in the previous example of surface rendering, the intervention is located on the single façade oriented towards the narrow street. The date of the implementation of the intervention is unknown, however it is presumed that this intervention was put in place after the partial collapse of

Figure 3.127 Surface Rendering

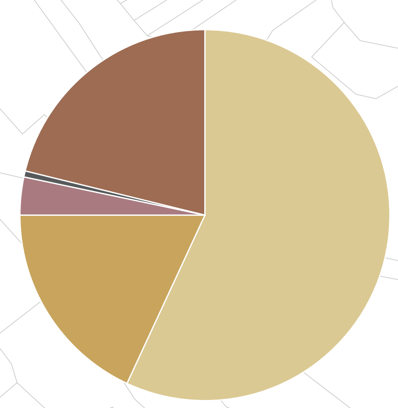
Figure 3.128 Surface Rendering

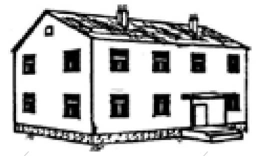
the structure. If this is the case, the temporary intervention's primary utility is to minimize further damages, specifically out-of-place turning of the primary façade onto the usable street space. In this particular case, the temporary structural intervention can remain until the ruins are dismantled and a new structure is built in the same location. Therefore no permanent structural interventions are necessary in this example.

Table 3.13 Immediate Post-Seismic Damages

KEY:

- Damage Level A
- Damage Level B
- Damage Level C
- Damage Level E



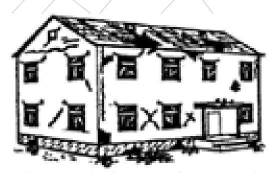


Grade 1 Damage (Level A, B)

Negligible to slight damage, no structural damage slight non-structural damage.

Grade 2 Damage (Level C)

Moderate damage, slight structural damage, moderate non-structural damage

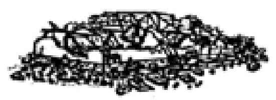


Grade 3 Damage (Level E)

Substantial to heavy damage, moderate structural damage, heavy non-structural damage.

Grade 4 Damage

Very heavy damage, heavy structural damage, very heavy non-structural damage



Grade 5 Damage (Ruins)

Destruction, very heavy structural damage

Comune: Santo Stefano di Sessanio

Immediate Post-Seismic Damages

3.13 Post Seismic Damages

3.13.1 General Damages

Considering the other villages, Santo Stefano di Sessanio had very little extreme damages. The two most notable damages including the collapse of the Medicea tower as well as severe damage to one of the churches within the historical center. The remainder of the structures experienced very little damage with 56% of the 206 buildings within the village being characterized as maintaining level A damage. However 20.5% were characterized as level E, which is defined as substantial to heavy damages. The majority of these structures were located within the historical center, however there appears to be no substantial connection between location and damage levels within Santo Stefano di Sessanio. This implies generally regular terrain characteristics throughout the village, however this has not been officially verified.

3.13.2 The Collapse of the Medicea Tower

Santo Stefano, of the four village discussed in this thesis, suffered the worst patrimonial loss due to the 2009 seismic event. The symbol of the village, the Medicea tower, collapsed due to the earthquake. However it is important to note the role that a twentieth century structural restoration played in the eventual collapse of the tower. The tower was initially constructed approximately in the

Figure 3.129 Pre-Seismic Medicea Tower

Figure 3.130 Medicea Tower

fifteenth century, along with the remainder of the historical center. The name of the tower derives from the Medici family, who founded the village in the fourteenth century. The tower is isolated, unlike the other towers present in Santo Stefano di Sessanio. The original tower was characterized by an overall height of 18 meters, and an internal and external diameter of 4 and 5 meters

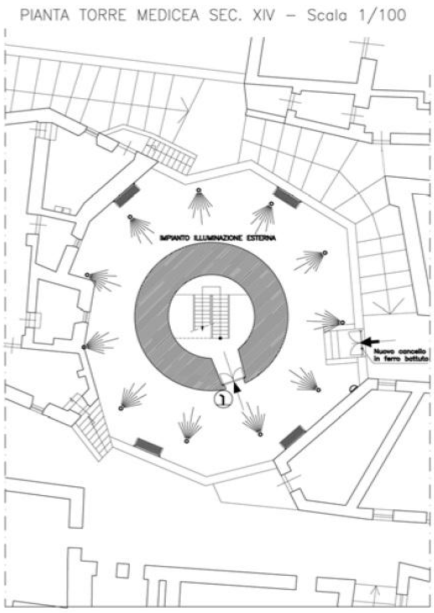


Figure 3.131 Medicea Tower Plan (Marchetti, 2009)

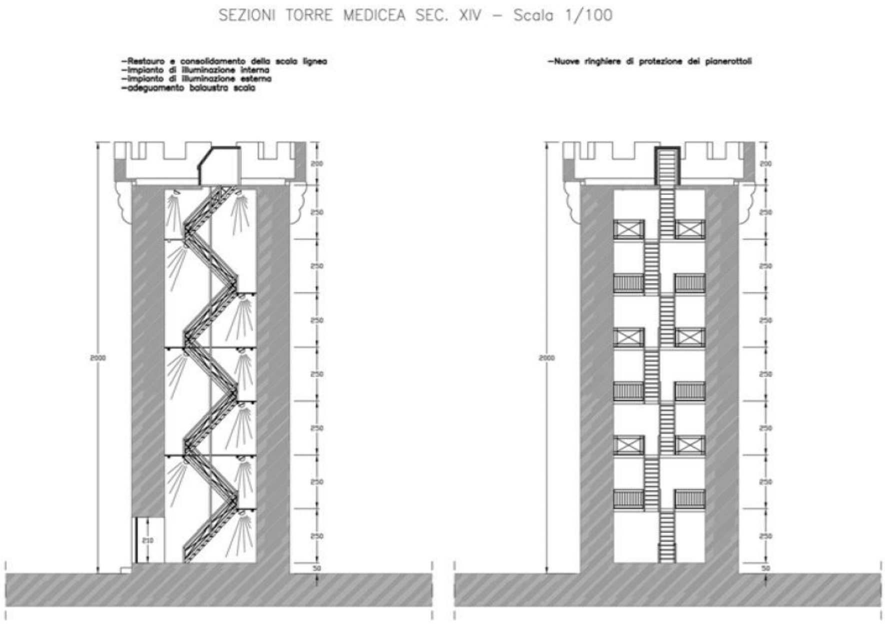


Figure 3.132 Medicea Tower Sections (Marchetti, 2009)

respectively. In addition, the tower was originally constructed with four interior wooden slabs, the fourth and highest being an observational platform. The masonry, before the collapse, was considered not resistant to traction but of high quality. The circular section of the tower also guaranteed a conventional mechanical efficiency that provided no evidence of a possible structural vulnerability. While there was some decay within the interior wooden slabs, the tower had survived thousands of seismic events during its more than six hundred year lifetime, until the implementation of a twentieth century restoration that led to the total collapse of the structure in April of 2009.

While the exact year of the most recent restoration of the tower is unknown, the structural intervention is dated to the twentieth century. The restorative effort aimed at replacing the existing fourth and highest wooden slab that was programmed as an observational platform atop the tower. The existing wooden slab, from the original construction of the tower weighed 900 kg. The slab to be substituted for the wooden slab was of reinforced concrete and weighed 6000 kg, more than six times the weight of the original slab. Similar to the original slab however, the reinforce concrete restoration was circular in shape. In addition it was characterized by a diameter of 6 meters, a thickness of 15 cm and steel reinforcement bars ranging in diameter from 10-12 mm. In general, the restoration can be considered an additional element to the tower that failed to respect the materials, weight or structural dynamics of the tower.

On April 6th, 2009, an earthquake struck the area of L'Aquila, approximately 30 kilometers from Santo Stefano di Sessanio. The seismic event led to minor damages throughout the village and produced the motion that would destroy the Medicea tower. After substantial lateral movements due to the seismic event, the tower completely collapsed and damaged several of the surrounding structures as well. After extensive analysis, it was determined that the masonry structure failed in crushing due to an extremely high loading. This was determined to be due to the reinforced concrete slab, added in the most recent renovation of the twentieth century. The top-heavy quality of the

Figure 3.133 Post-Seismic Medicea Tower

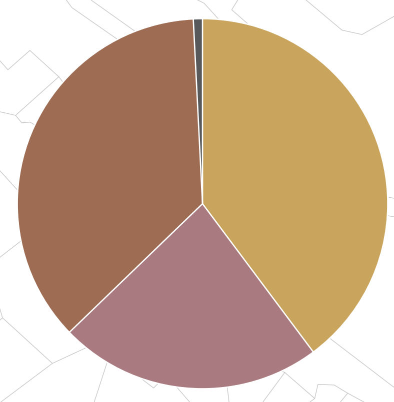
Figure 3.134 Medicea Tower

tower due to this restoration create an off balance structure, which aiding in amplifying the period of movement of the tower, initiated by the seismic event. In addition, these conclusions are supported by the state of the reinforce concrete clab post collapse. The slab remained in a single piece due to its high weight of 6000 kg. The slab only suffered minor lesions of the surface. While the tower of Medicea may have suffered substantial damage due to the 2009 seismic event, it can be concluded with absolute certainty that the collapse of the Medicea tower was a direct effect of the restorative intervention of the twentieth century.

Table 3.14 Post-Seismic Intervention Priorities

KEY:

- Priority 3
- Priority 2
- Priority 1
- Public Buildings with Financing



Priority 3 (Low Priority)
Aggregates not entered in following priority

Priority 2 (High Priority)
Aggregates with primary residences inhabitable
Isolated Buildings

Priority 1 (Highest Priority)
Aggregates with primary residences inhabitable

Public Building with Financing

Comune: Santo Stefano di Sessanio
Post-Seismic Intervention Priorities

3.14 Post Seismic Priorities

3.14.1 General Priorities

Immediately following the post-seismic damage assessment, the villages of the Baronia collective defined post-seismic priorities regarding the location of possible interventions. These priorities have been localized by aggregates and not individual buildings. The highest priority is given to public buildings with financing, such as churches and the Tower of Medicea. The remainder of the aggregates has been given a priority rating of 1, 2 and 3. The priority rating of 1 is the highest priority while rating 3 is the lowest. The priorities relate roughly to the post-seismic damage assessment. The areas with dispersed higher damages have been given the highest priority. This is specifically the case of the aggregates contained within the historical boundary wall. The aggregates have been divided almost equally between the three separate priority levels. It is important to note that these priority levels do not consider the habitation of the structures in question, which will be taken into consideration in the following "Vulnerability Conclusion".

3.14.2 Restoration of Medicea Tower

The Medicea tower, which collapsed in 2009 due to the L'Aquila seismic event, was considered to the architectural symbol of the village of Santo Stefano di Sessanio. The original tower of the village has substantial patrimonial value and its collapse was a substantial loss to the inhabitants of Santo Stefano di Sessanio. Therefore the restoration and rebuilding process of the Medicea tower is of high priority. The approximate cost of the restoration has been set at one million euro and should last approximately two years to complete the intervention. Currently, as seen in figure 3.14.2a, temporary scaffolding has been set in place, however substantial restorative or structural work has yet to begin. This particular tower will be an important point when considering the use of the limited public funds for restoration within the Baronia collective. While the

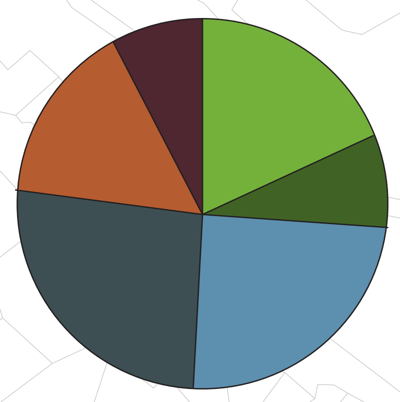
Figure 3.135 Medicea Tower

collapsed tower poses no immediate dangers to the surrounding structures, the rebuilding of the tower will be integral in the reconstruction and restoration of Santo Stefano di Sessanio, post 2009 L'Aquila earthquake.

Table 3.15.1: Vulnerability Conclusion

KEY:

- Priority 6
- Priority 5
- Priority 4
- Priority 3
- Priority 2
- Priority 1



Priority 6 (Lowest Priority)
NOT CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 5
NOT CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 4
CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 3
CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 2
INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

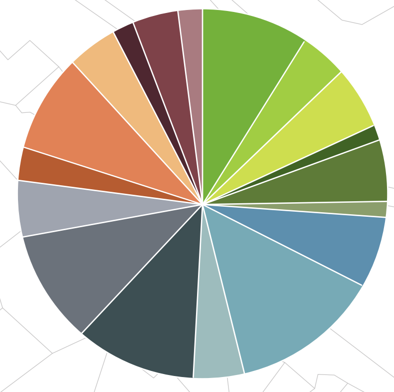
Priority 1 (Highest Priority)
INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Comune: Santo Stefano di Sessanio
Vulnerability Conclusion

Table 3.15.2: Vulnerability Conclusion

KEY: (TOTAL)

Priority 6a (20)	Priority 6b (7)	Priority 6c (10)
Priority 5a (3)	Priority 5b (11)	Priority 5c (4)
Priority 4a (14)	Priority 4b (30)	Priority 4c (7)
Priority 3a (11)	Priority 3b (10)	Priority 3c (5)
Priority 2a (6)	Priority 2b (17)	Priority 2c (8)
Priority 1a (4)	Priority 1b (7)	Priority 1c (4)



Priority 6: 37 Total (18%)

Priority 5: 18 Total (8%)

Priority 4: 51 Total (25%)

Priority 3: 54 Total (26%)

Priority 2: 31 Total (16%)

Priority 1: 15 Total (7%)

Total Buildings: 206

Priority 6 (Lowest Priority)
NOT CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 5
NOT CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 4
CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 3
CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 2
INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 1 (Highest Priority)
INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Comune: Santo Stefano di Sessanio
Vulnerability Conclusion

3.15 Vulnerability Conclusion

3.15.1 Overall Vulnerability Conclusion

The vulnerability conclusion is a cumulative result of the previous fourteen sections of analysis. However it is important to note that these conclusions have been based strongly on four separate analyzed factors, all of which have been previously discussed in the Castel del Monte analysis. These factors have then been subdivided to include a more complete and thorough conclusion to the vulnerability of all of the structures within this village.

The first and most important factor, when determining the vulnerability and therefore priorities within the aggregate, is the inhabitation of the individual structures and aggregates. When considering anti-seismic design and post-seismic structural interventions, both permanent and temporary, the two goals should be to protect both cultural patrimony and human life. While both are essential when protecting a village, such as Santo Stefano di Sessanio, human life should always be given the highest priority. Therefore when considering the six final priority levels to be introduced in this section, the first two priority levels are reserved solely to inhabited structures and the third and fourth priority levels are reserved for structures within the near vicinity or within the aggregate of an inhabited structure.

The second most important factor considered when determining the vulnerability of the aggregate is the collective structural homogeneity of each aggregate and structure. This analysis, as previously discussed, has been determined through the collective evaluation within an aggregate of the building typologies, orientations to the elevation curves, building heights and masonry typologies present. While the cause of potential collapse mechanisms during a seismic event varies, at the foundation of all of these causes is a lack of homogeneity. This lack of homogeneity can be seen in plan, elevation, masonry composition, distribution of stresses, etc. This lack of homogeneity, either in separate elements or factors, or as a whole can lead to collapse mechanisms such as hammering, out of plane wall overturning, torsion and many more. This information was therefore used as a primary source when considering the vulnerability conclusion of each aggregate.

The third and last important factor considered was the existing vulnerability of the aggregate, based on both the post 2009 seismic damages as well as the presence of permanent structural interventions such as tie rods and buttresses. The existing damages imply an inherent vulnerability as well as a need for immediate interventions. Therefore this factor is considered crucial when determining the level of vulnerability in an aggregate. In addition, buildings with existing permanent structural interventions are better protected than those without and therefore are noted in order to diminish the vulnerability priority of an aggregate with these types of interventions present. It is the presence of post-seismic damages and permanent structural interventions that determine the subcategories within the previously mentioned six priority levels.

Each of the six priority levels are split into three separate subsections, which are described on the attached vulnerability conclusion maps. The first subdivision, for all six priority levels, is of the highest priority because it is reserved for structures with post-seismic damages as well as a lack of permanent structural interventions. The second subdivision is for buildings with either no post-seismic damages but a lack of permanent interventions, or with post-seismic damages but with permanent interventions. The third and final subdivision is only for buildings with no post-seismic damages and that also have permanent interventions in place. These structures, within any of the six major priority levels, is considered to be of little priority and requires only observational on-site analysis to determine the extent of the vulnerability, which is presumably minimal. However all structures within the first two subcategories of the six priority levels require more thorough analysis to determine the amount of restoration interventions needed.

In the following sections, specific examples of these vulnerability levels will be discussed. These examples come from aggregates and structures within the higher priority levels. These examples will be used to better describe the priority categories as well as to showcase what higher priority structures are like. This will aid in determining what type of restorative efforts may be necessary for the higher priority aggregates. It is important to note however that these priority levels do not inherently mean there is a need for restoration, but instead they imply the likeliness that

structural interventions are necessary. Each aggregate and building should be taken on a case by case basis following additional on-site observation (interior as well as exterior) to determine the exact need of every structure within the priority levels.

3.15.2 Specific Vulnerability Example One

The first example of one of the more vulnerable aggregates is found in the heart of the historic center, near the San Marco church, specifically in aggregate SSS 001. This example, unlike

Figure 3.136 Aggregate SSS 001

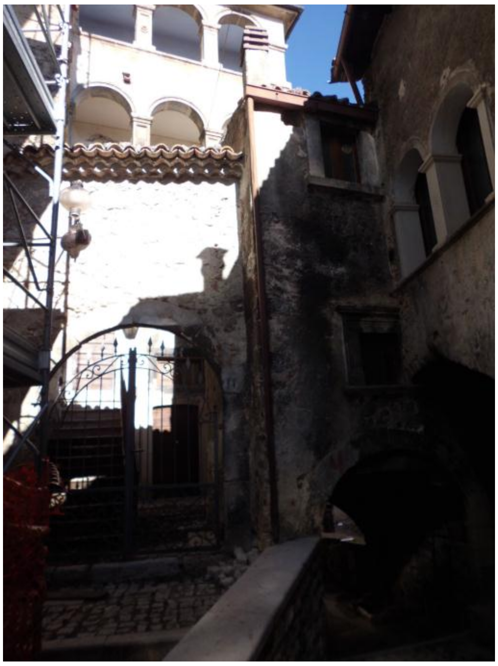


Figure 3.137 Aggregate SSS 001

the other example chosen for further analysis in the vulnerability conclusion, was also chosen as one of the previously discussed negative examples. This example has been chosen for several reasons.

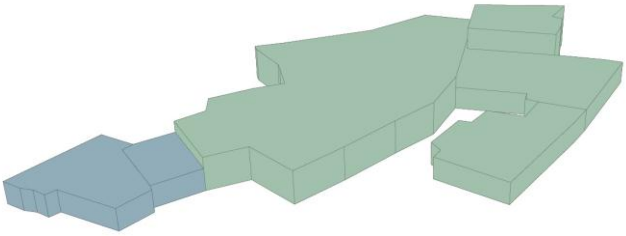


Figure 3.138 Aggregate SSS 001 Model

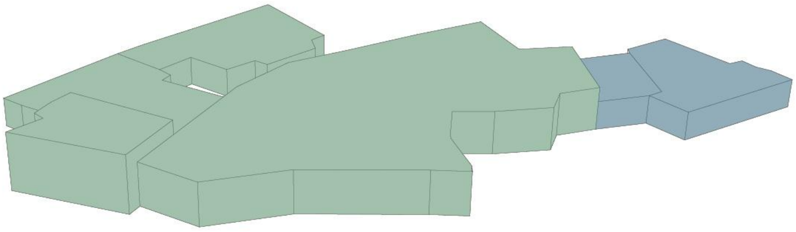


Figure 3.139 Aggregate SSS 001 Model

First and foremost this aggregate was chosen due to the fact that two of the six structures are inhabited. In addition, as previously mentioned, this aggregate has been determined to be negative regarding its collective homogeneity. As seen in the models above, the aggregate is extremely irregular regarding the building heights and masonry typology composition. There were also damages in the aggregate after the 2009 L'Aquila seismic event and not all of the structures within the aggregate have permanent structural interventions in place. As seen in both figures 3.136 and 3.137, there is also irregularity in both additions to the structures as well as openings. Openings have been placed too close to structural elements such as the roof or corners. It is also important to note the extreme changes of the aggregate over time, with elements of different masonry composition, has contributed to the determination of this particular aggregate as a high priority level. Regarding a future for this aggregate, there are several restoration options available. First and foremost, additional permanent and temporary structural interventions need to be added to better control the reactions between the irregular units within the aggregate. These interventions should specifically be placed in vulnerable areas such as fulcrum points between two attached structures of different heights. In addition, any damages sustained during the most recent seismic event of 2009 need to be thoroughly analyzed and resolved to better protect the inhabitants of the aggregate.

3.15.3 Specific Vulnerability Example Two

The second example of a high priority structure is found in the historical center, specifically in aggregate SSS 060. This example has been previously discussed as one of the negative examples within Santo Stefano di Sessanio. This aggregate has been chosen for several reasons, the first of which is that four of the nine structures within the aggregate in currently inhabited. In addition, as previously mentioned, the aggregate has been considered to be negative regarding its overall collective homogeneity. This particular aggregate is extremely irregular in both masonry typology composition and the building heights of the individual units within the aggregate. This aggregate is unique considering its masonry composition due to high quantity of masonry additions and restorations that failed to respect the existing structural masonry typology or homogeneity of the plan. The aggregate is also irregular in both plan and elevation. There were also damages in the aggregate after the 2009 L'Aquila seismic event and not all of the structures within the aggregate have permanent structural interventions in place. Regarding a future for this aggregate, there are several restoration options available. Additional permanent and temporary structural interventions

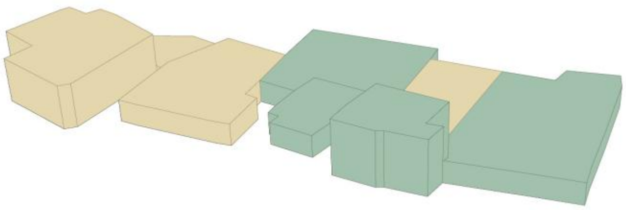


Figure 3.140 Aggregate SSS 060 Model

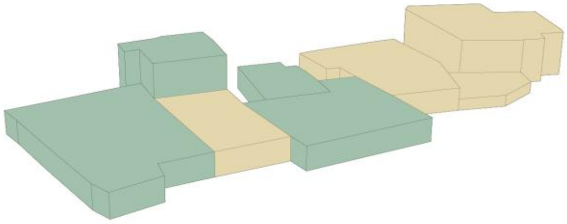


Figure 3.141 Aggregate SSS 060 Model

need to be added to better control the reactions between the irregular units within the aggregate. These interventions should specifically be placed in vulnerable areas such as fulcrum points between two attached structures of different heights. In addition, any damages sustained during the most recent seismic event of 2009 need to be thoroughly analyzed and resolved to better protect the inhabitants of the aggregate. This is especially the case in this particular aggregate due to the high amount of damages after the 2009 seismic event.

3.16 Conclusion

The earthquake of April 2009 in L'Aquila resulted in the destruction of the symbol of the village, the Medicea tower, in Santo Stefano di Sessanio. In addition, several other major buildings sustained extensive damages. This seismic event should be utilized as a reminder of the vast vulnerability of masonry structures within the historical center of the village, in order to avoid future disasters as seen in 2009. It is also important to learn from the past mistakes that led to those damages, such as the twentieth century renovation that led to the destruction of the Medicea tower. The village is the third most vulnerable of those discussed within this thesis. This is due in part to more structures with existing post 2009 seismic minor damages. Fortunately several of the structures have permanent structural interventions in place and very few structures are currently inhabited due to the low population size. However the village is still in dire need of additional reinforcements as well as seismic retrofitting measures. It is important to note that the higher priority structures within the center of the historical center, or just outside of this center. This distribution requires extensive additional analysis, both interior and exterior, to better determine the aggregates that are the most deserving of the limited public funds available for restoration. An initial visual analysis should be the first step of any restoration process, followed by more invasive analysis to determine the structural vulnerability of the masonry elements. Finally the most vulnerable aggregates should be prepared for restorative efforts as soon as possible, in order to protect the existing population.

While restorations are costly efforts, they are always the most economical choice over the reconstruction of structures damaged or destroyed after a major seismic event. Now is the time to protect both the architectural patrimony and populations of the village of Santo Stefano di Sessanio, as well as the rest of the Baronia collective. More specifically, time between seismic events, such as now following the 2009 earthquake, is the opportune time to analyze the existing architecture, regarding collective homogeneity, structural vulnerability and building inhabitations to be better prepared for the next seismic event to come. Any analysis completed now can be utilized in both immediate earthquake aftermath, regarding finding citizens who may be hurt, as well as in the long term aftermath, regarding which structures are more dangerous and should remain vacant until restoration efforts can ensure the safety of the building's inhabitants during a seismic event.

Table 4.1.1 Orientation to Overall Elevation

Comune: Castelvecchio di Calvisio
Orientation to Overall Elevation

Table 4.1.2 Photographic Introduction

KEY:

Location of Photograph

Site Boundary

Comune: Castelvecchio di Calvisio

Photographic Introduction

Table 4.1.3 Aggregate Locations

KEY:

Buildings

Aggregate Boundaries

DEFINITION:

An aggregate is made of one or more houses that are separate houses that are joined together to make a whole, single unit.

PHOTO EXAMPLES:

Aggregate CvC 1.01

Aggregate CvC 1.17

FACTS:

Total Number of Aggregates:	50
Total Number of Churches:	1
Total Number of Municipalities:	1
Total Number of Towers	0

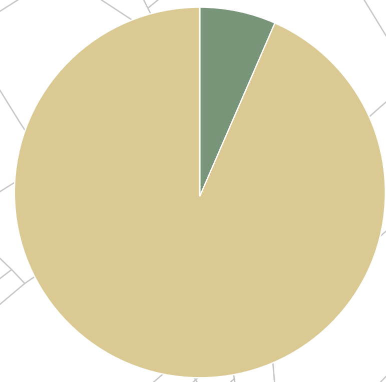
Comune: Castelveccio di Calvisio

Aggregate Locations

Table 4.1.4 Pre 2009 Seismic Building Uses

KEY:

- Private Property Buildings
- Public Property Buildings



Private:
265 Total (95%)

Public:
13 Total (5%)

Total Buildings: 278

EXAMPLES:

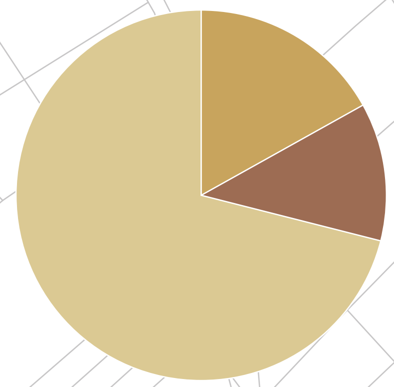

Public Use Building Types
-Church (Above Right)
-Municipality


Private Use Building Types
-Uninhabited Residence
-Inhabited Residence (Above left)
-Uninhabitable Residence (Above right)

Table 4.1.5 Building Inhabitation

KEY:

- Uninhabited Building
- Inhabited Building
- Uninhabitable/Ruined Building



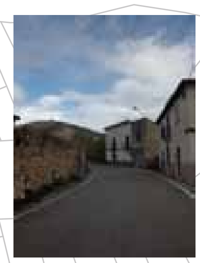
DEFINITIONS:

Uninhabited Building
Building that may or may not be in use, but is currently uninhabited. These may imply a public use building or one that is not lived in full-time.

Inhabited Building
Building that is currently being lived in and is therefore a priority regarding the restorative efforts, along with public use buildings.

Uninhabitable Building
Building that is in ruins, crumbling or structurally instable and therefore uninhabitable. These building are crucual to the restoratvie effort if their structural instability can damage adjacent buildings or create significant damages in the case of a future seismic event.

EXAMPLES:



Inhabited Building Example
This is one of the few inhabited buildings in the area. These buildings are primarly on the outskirts of the city, in buildings that are more stable.

Uninhabited Building Example
This building on the right is one of the many buildings in Castelvecchio di Calvisio that is uninhabitable. As you can see, there is major temporary structural interventions in place, due to the structural instability.

Comune: Castelvecchio di Calvisio
Building Inhabitation

4 CASTELVECCHIO DI CALVISIO

4.1 Introduction:

The village of Castelvecchio di Calvisio, with a population of 187 people, is located within the National Park of the Gran Sasso mountain. In addition, the village is a part of the four village collective, known as Baronia. The village is particular and easily recognizable due to its oval-shaped

Figure 4.1 View of Castelvecchio di Calvisio (provided by University of Padova)

defense wall, that surrounds the historical center. In addition, similar to Castel del Monte, the village has a strong presence of both arches and "sporti" above the small pedestrian streets, throughout the historical center. The first historical sources of Castelvecchio di Calvisio are dated to 779 AD, that attests to the existence of a "Castel of San Lorenzo", which is a section of the current village. The village originated from four quarters or houses, including the aforementioned San Lorenzo as well as San Martino, San Ciripiano and San John. These original sources also mention the churches of San Ciripiano and San Lorenzo. The next historical account reveals the governance of Castelvecchio di Calvisio by the Counts of Valva, as early as 972 AD. Similar to many villages in the region of Abruzzo, Castelvecchio di Calvisio experienced several invasions and rule changes during

Figure 4.2 Four original quarters of Castelvecchio di Calvisio (castelvecchio-calvisio.it)

their long history. Over the years, the village was ruled by several prominent historical figures including the Duke of Amalfi (Antonia Piccolomini), the Grand Duke of Toscany (Don Francesco dei Medici) and Ferdinand the Second of Bourbon. After several changes of power during village's more than nine hundred year history, the village finally became the autonomous municipality of Castelvecchio di Calvisio in 1906.

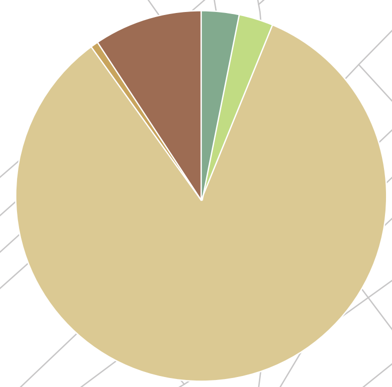
During the village's long history, the architecture of the territory has rarely changed. However many of the structures have seen several forms of restoration or renovation during the village's lifetime. The most notable of the structures within Castelvecchio di Calvisio is the Church of San Cipriano, located within the vicinity of the historical center of the village. The first documented reports of the church date back as far as 779. The church remained a cultural symbol of the village as well as the only place of worship until 1478. This structure has experienced the most restorations of any building within Castelvecchio di Calvisio but has still been able to retain a simple structural form until now.

The village of Castelvecchio di Calvisio has been witness to thousands of seismic events during its lifetime. However despite the location of the village within a zone two seismic area, the village has seen few collapses during its history. The most recent seismic event in L'Aquila in 2009 rendered many of the structures within the village heavily damaged, but the ruins within the village were not due to the most recent earthquake. Due to the current state of disrepair, many of the structures specifically within the historical center would need to be restored to minimize the possibility of future damages.

Table 4.2 Building Typology

KEY:

- Historical Boundary Wall House
- Block House
- Tower House
- Buidling Oriented Perpendicular to the Elevation Curve
- Building Oriented Parallel to the Elevation Curve
- Religious Building
- Ruins



- Wall House: 13 Total (4%)
- Block House: 0 Total (0%)
- Tower House: 0 Total (0%)
- Perpendicular: 12 Total (4%)
- Parallel: 222 Total (81.5%)
- Religious: 1 Total (.5%)
- Ruins: 30 Total (10%)

Total Buildings: 278

Historical Boundary Wall House
Row of houses, oriented in a line

Block House
Single builings, unattached to other buildings

Tower House
Building significantly taller than all buildings it touches

Buidling Oriented Perpendicular to the Elevation Curve
Buidling Unit set in a row, perpendicular to the elevation curve (partially underground with a rock foundation)

Building Oriented Parallel to the Elevation Curve
Building Unit set in a row, parallel to the elevation curve (partially underground with a rock foundation)

Religious Building
Any religious based building such as a church or convent

Ruins
Any building with significant damage to the point of being uninhabitable

Comune: Castelveccio di Calvisio
Building Typology

4.2 Building Typology

4.2.1 Historical Boundary Wall Houses

Similar to many of the other villages within the Baronia collective, Castelvecchio di Calvisio is characterized by its historical boundary wall. However due to modifications of the village since its original construction, very few of the structures within the historical center are currently classified as historical boundary wall houses. Within the entire villages, there are a total of 13 historical boundary walls present, all of which are located within the historical center. All of these examples are divided between two separate aggregates, CvC 1.17 and CvC 1.09. In the case of aggregate CvC 1.17, the entire aggregate is characterized as being historical boundary wall houses. In the case of aggregate CvC 1.09, every building within the aggregate except for one is defined as being a historical boundary wall house.

Figure 4.3 Historical Boundary Wall House

As seen in figure 4.2.1a, the historical boundary wall houses within Castelvecchio di Calvisio are characterized by massive heights and in general, higher quality masonry and construction as well. This higher quality is due to the importance of the boundary wall to the village, especially in the past. Unlike in Castel del Monte or Santo Stefano di Sessanio, there are no towers present within the historical boundary wall of Castelvecchio di Calvisio. The buildings within this historical boundary wall can be considered to be among the oldest buildings within the village and therefore have experienced several restorative and structural interventions over their lifetimes. As seen in figure 4.2.1a, this particular example of a boundary wall house has recently been restored with the addition of a plaster covering as well as possible structural interventions as well. In general, historical boundary wall houses, due to their size, have several permanent structural interventions present. The most common intervention is that of exterior buttress, traditional placed on the outermost wall of the

4.4 Buttress

Figure 4.5 Buttress

historical boundary wall. Due to the massive heights of these structures, buttresses aid in offsetting the collapse mechanism of out-of-plane wall overturning, which is common for historical boundary wall houses. Depending on the height of the building in *Figure* question, these buttresses can extend 1-2 meters from the surface of the building, as seen in figures above. Another important structural aspect of historical boundary wall houses is the presence of large masonry bases for added support of the overall structure. As seen in figures 4.2.1d and 4.2.1e, these base elements are

Figure 4.6 Base of Historical Boundary Wall

Figure 4.7 Base

characterized by larger masonry stones In general, these bases are a separate element from the overall structural masonry system present. These however are extremely important structural elements when considering the vulnerability of a historical boundary wall house. The final permanent structural intervention present within the building typology of historical boundary wall houses is tie rods. These interventions are typically placed along several important points of the façade, with a concentration on the higher floors. These are an integral intervention when considering the elimination of the collapse mechanism of out-of-plane wall overturning. It is important to note that while all of these elements present in historical boundary wall houses are important, it is their combination that makes them the most effective in minimizing the vulnerability of the overall historical boundary wall house in question.

4.2.2 Buildings Oriented Parallel to the Elevation Curves

The most common building typology present in Castelvecchio di Calvisio is buildings oriented parallel to the elevation curves. Of the 278 building present within the village, 222 of them are categorized as buildings oriented parallel to the elevation curves. This building typology thus makes up 81.5 percent of the structures within Castelvecchio di Calvisio. This building typology is located throughout the village with a concentration in the historical center. On-site analysis has revealed that many of the ruins within the Baronia collective were originally buildings oriented perpendicular to the elevation curves. While this is solely a tendency, it is important to note. This building typology includesbuildings of varying masonry typologies, building heights and general construction types. While no particular preference is given to structures oriented parallel to the elevation curves, it is important that all of the structures within a single aggregate are oriented the same to the elevation curves. In the case of aggregates lacking in homogeneity regarding the orientation to the elevation curves, additional connections between these structures as well as permanent structural interventions are needed in order to counteract their potential collapse mechanisms. Due to the commonness of this building typology within Castelvecchio di Calvisio, it is difficult to characterize the overall structural quality of this typology in general. However in almost all cases, structures oriented parallel to the elevation curves are oriented directly parallel, instead of at an angle. It is important to note if a structure is oriented perectly parallel to the elevation curves. When oriented at a large angle, the force of torsion

Figure 4.8 Building Oriented Parallel to the Elevation Curves

acting on the structure is increased and is likely to increase several collapse mechanisms or induce collapse with this force alone, if strong enough.

4.2.3 Buildings Oriented Perpendicular to the Elevation Curves

Of the four villages discussed within this thesis, Castelvecchio di Calvisio has one of the least amount of buildings oriented perpendicular to the elevation curves. Behind only Church or religious structures, this building typology is the least common within the village. In total, there are 12 structures within Castelvecchio di Calvisio characterized as buildings oriented perpendicular to the elevation curves. This makes up only four percent of the buildings 278 buildings within the village. Two of these structures are located within the historical center with the remainder located outside of the original confines of the village. As mentioned in the previous section, a connection has been noted between ruins and building oriented perpendicular to the elevation curves. As seen in figure 4.2.3a, this is the case for the example given. However without further analysis this can only be considered conjecture/ However it is noted that these buildings are structurally vulnerable when placed within an aggregate with structures oriented parallel to the elevation curves. Buildings under these two conditions respond very differently in the case of a seismic event. Thus the combination of these two buildings within an aggregate can induce several collapse mechanisms, the most likely of which is hammering between the structures. Due to the low amount of buildings oriented perpendicular to the elevation curves within Castelvecchio di Calvisio, this is of little concern for this particular village. There are very few aggregates within the village where this is the case, only one of which is within the historical center. Damages due to these diverse orientations to the elevation curves within a

Figure 4.9 Building Oriented Perpendicular to Elevation Curves

single aggregate can be diminished through the strategic use of permanent structural interventions, such as tie rods and exterior buttresses.

4.2.4 Churches or Religious Structures

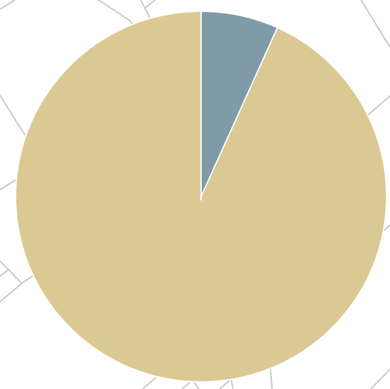
Within Castelvecchio di Calvisio, there is only one church or religious structural present. As mentioned in section 4.1, this structure is the Church of San Cipriano. This church is located just outside of the historical center, specifically within aggregate CvC 2.34. The first evidence of this church comes from the year 779. This particular church has witnessed several restorations and renovations since its original construction, however has maintained regularity in plan. However, as see in figure 4.2.4a, the church is irregular in elevation due to the bell system in system in place. This higher portion of the front façade is the most vulnerable portion of the structure. The structure, besides this point, has very few structural vulnerabilities. As is typical in churches within the Baronia collective, the presence of interior vaults can render the structure vulnerable to seismic events. The structure is composed of the highest quality masonry, masonry typology three, present in Castelvecchio di Calvisio. As seen in figure 4.2.4a, there are also several permanent structural interventions present which aid in minimizing the collapse mechanisms common to churches, such as out-of-plane wall overturning. It is also important to note that due to the cultural and social importance of the structure, the building is in high use and therefore its restoration, even if not highly necessary, should be given priority over several other aggregates or structures present within the village.

Figure 4.10 Church within Castelvecchio di Calvisio

Table 4.3 Building Orientation to Elevation

KEY:

- Building unit positioned parallel to the elevation curves
- Building unit positioned perpendicular to the elevation curves



EXAMPLES:

PARALLEL
These building units are positioned parallel to the elevation curves

PERPENDICULAR
These building units are positioned perpendicular to the elevation curves

Comune: Castelvecchio di Calvisio
Building Orientation to Elevation Curves

4.3 Orientation to Elevation Curves

As thoroughly discussed in the building typology sections 4.2.3 and 4.2.4, the orientation of a group of connected structures, such as an aggregate, is extremely important to the overall structural stability of each of the individual structures. The orientation of a structure to the overall elevation curves can greatly affect the force of torsion or possible collapse mechanism of out-of-plane wall overturning. Although not seen in Castelvecchio di Calvisio, structures oriented at an angle to the elevation curves are extremely vulnerable to the force of torsion and can experience several structural failures due to this force. All of the structures within Castelvecchio di Calvisio have been divided into two difference categories regarding their orientation to the overall elevation curves; parallel or perpendicular. While both orientations are structurally acceptable, it is their combination within a single aggregate that makes a structure vulnerable to several collapse mechanisms.

Of the 278 structures present within Castelvecchio di Calvisio, 264 of these buildings are oriented parallel to the elevation curves, which makes up 95 percent of the buildings within the village. This is highly important because this minimizes the mixing of two different orientations to the elevation curves in a single aggregate. Within the entire village, only fourteen structures are oriented perpendicular to the elevation curves. Of these fourteen, only two are located within the historical center. The remainder are spread into two groups within the most recently added section of the village. In total, six aggregates have both buildings oriented parallel and perpendicular to the elevation curves. Due to the small amount of structures oriented perpendicular to the elevation curves, this particular structural factor is of little concern in Castelvecchio di Calvisio. Therefore the remaining three primary structural factors discussed become more important regarding the overall vulnerability of the village.

Table 4.4 Building Heights by Aggregate

KEY:

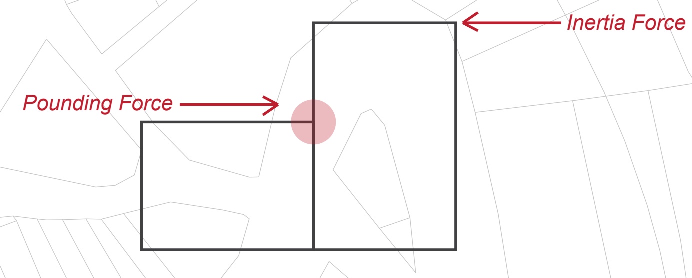
- 5 Floors Equivalent (or above)
- 4 Floors Equivalent
- 3 Floors Equivalent
- 2 Floors Equivalent
- 1 Floor Equivalent
- Aggregate Border

DESCRIPTION:

All building heights indicated on this map are distinguished by aggregate, which is why all heights are "equivalent" and not to be compared between aggregates. These heights are meant to distinguish which aggregates are the most and least homogeneous, regarding building height. Aggregates that are less homogeneous in height are more likely to suffer seismic damage due to pounding, which is described below.

TALLER ADJACENT BUILDING POUNDING:

Pounding is created between two buildings of differing heights due to different moments created in each structure, when they shake due to a seismic force. This creates different dynamic responses in each structure. The point where they meet, the fulcrum point, is the point of the most vulnerability. It is here where most damages can happen. This damage is due to irregularity in elevation, but can also happen between buildings of equal height.



POSITIVE/NEGATIVE EXAMPLES:


Negative Example


Positive Example

Comune: Castelvecchio di Calvisio
Building Heights by Aggregate

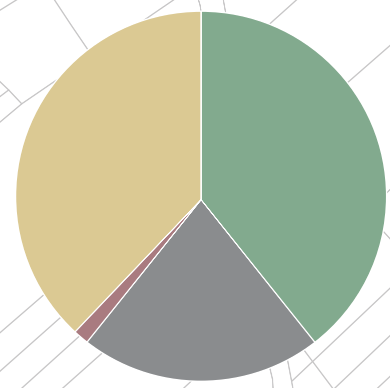
4.4 Building Heights

The building heights within Castelvecchio di Calvisio are failry even regarding each individual aggregate. There are no tower structures within the village, as noted in section 4.2. The most differences in heights are located within the historical center, however in most of these cases these structures differ in height by no more than one story. This is similar to height differences outside of the historical center as well, where structures rarely differ in height by more than a story. This highly homogeneous situation of building heights in aggregates throughout the village limits the potential damage mechanisms due to a lack of homogeneity in building heights, such as hammering and torsion. This is important to note in combination with the homogeneous nature of the orientations of buildings to the elevation curves. Therefore vulnerabilities within Castelvecchio di Calvisio are more likely to be connected to the structural factors of masonry typology and building typology. However, as will be seen in the sections 4.8 and 4.9, which include examples of negative and positive homogeneity, the building height should still be taken into consideration when determining the potential vulnerability of a structure or aggregates in the case of a seismic event.

Table 4.5 Masonry Typology

KEY:

- Irregularly formed masonry (regarding shape, dimensions and materials) stone
- Subhorizontal masonry with roughly cut stones (of varying dimensions)
- Horizontal masonry courses with roughly cut stones (well interlocked)
- Plaster Covered



Low Quality: 113 Total (40%)

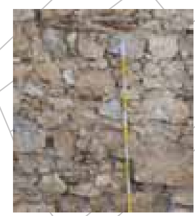
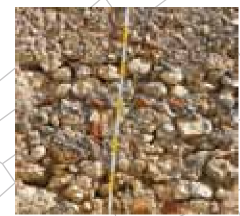
Medium Quality: 59 Total (21%)

High Quality: 3 Total (1%)

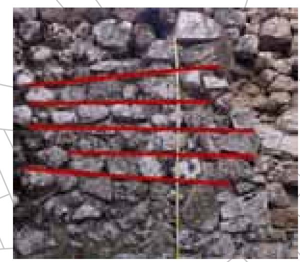
Plaster: 103 Total (38%)

Total Buildings: 278

EXAMPLES:

Low Quality




Medium Quality


High Quality

Comune: Castelvecchio di Calvisio

Masonry Typology

4.5 Masonry Typology

Within the analyzed portion of Castelvecchio di Calvisio, all four of the previously introduced masonry typologies are present. Masonry typology one, masonry typology two and plaster covered structures are located throughout both the historical center as well as the recently added section of the village. The presence of masonry typology two is exclusively in the only church of the village as well as two surrounding structures related to the church. While all four of the masonry typologies are present within Castelvecchio di Calvisio, they are unevenly dispersed through the four building typologies present in the village.

4.5.1 Masonry Typology One

Masonry typology one, defined as irregularly formed masonry stones, regarding shape, dimensions and matrials, is the most common masonry typology within Castelvecchio di Calvisio.

Figure 4.11 Masonry Typology One

Figure 4.12 Masonry Typology One

This typology, considered to be of the lowest quality make up 40 percent of the 278 structures present in the village. Approximately half of the historic center is composed of masonry typology one and a majority of the structures outside of the historical center are also composed of masonry typology one. Figure 4.5.1a and 4.5.1b are two examples of this particular masonry typology. As seen in both examples above, the masonry lacks continuous horizontal bonds and have no visible vertical structural system. This particular masonry typology is the majority in both Castelvecchio di

Calvisio, as well as in the other three villages discussed in this thesis. Masonry typology one is present within only two building typologies; buildings oriented parallel to the elevation curves and building oriented perpendicular to the elevation curves.

The most common combination of masonry typology and building typology is that of masonry typology one within building oriented parallel to the elevation curves. The example to be discussed is located within aggregate CvC 2.27. This particular aggregate is located outside of the historical center of the village. The aggregate is currently of private use and uninhabited. In addition, the buildings within

the aggregate have been inhabited for a substantial amount of time, which is the case of several structures within Castelvecchio di Calvisio. In most cases, structures composed of masonry typology one were originally covered in a plaster covering in order to protect the masonry structure below. As seen in figure 4.5.1c and 4.5.1d, the masonry typology one in this particular structure was once covered in plaster. However this plaster has almost completed decayed and therefore the masonry typology below is almost completely revealed. Due to the amount of visible decay both of the masonry stones as well as the mortar, it can be determined that this plaster covering has been absent for a substantial amount of time. This particular example of masonry typology one is unique due to the large quantity of brick pieces among the more substantial masonry stones. However as to be expected for masonry typology one, there are no distinctive horizontal or vertical structural systems within the masonry, which is what categorizes the masonry as the lowest quality present n Castelvecchio di Calvisio.

Figure 4.13 Type 1 Parallel House

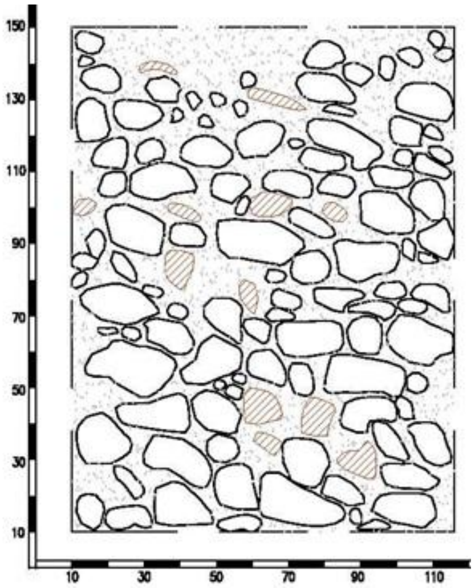


Figure 4.14 Type 1 Parallel House

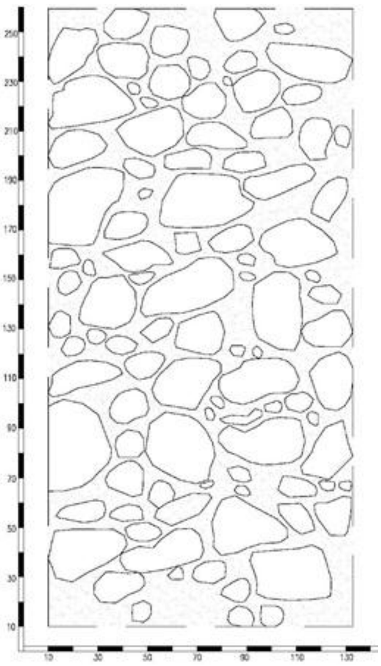
However it is important to note that this masonry has survived several seismic events in its lifetime and can be considered structurally sufficient.

The second and final example of masonry typology one within Castelvecchio di Calvisio is seen in the case of a building oriented perpendicular to the elevation curves. This particular example

Figure 4.15 Aggregate CvC 2.08

is found in aggregate CvC 2.08. This aggregate is located outside of the historical center and is currently of private use and is uninhabited. As seen in figure 4.5.1e, there was once a plaster covering to protect the masonry structure beneath, however it has almost complete decayed due to weathering and human traffic. This implies that an intervention of the structure has not occurred within the recent past. Similar to the previous example of masonry typology one within the parallel orientation to the elevation curves building typology, the masonry present in this example if of high quality. Structurally speaking, there is no

4.16 Type 1 Perpendicular



4.17 Type 1 Perpendicular

significant presence of either a horizontal or vertical structure system within the masonry. However it is important to note that the masonry stones are of high quality, coming from the surrounding area, and the overall masonry system is structurally sound and in general does not render the building vulnerable. This particular masonry typology is however the lowest quality within Castelvecchio di Calvisio. This particular example masonry is characterized by a combination of both large and small stones. Observational analysis also reveals a large amount of mortar which helps to stabilize the masonry in the case of a seismic event.

4.5.2 Masonry Typology Two

Masonry typology two is the second most common distinguishable masonry typology in Castelvecchio di Calvisio. Out of the 278 buildings, 59 are composed of masonry typology two. This typology therefore makes up 21 percent of the buildings within the area of analysis. Masonry typology two is of higher quality than that of masonry typology one. There is a presence of a horizontal structural system within the masonry, which is not present in masonry typology one. More importantly, the stones are slightly larger and of higher quality. The legal definition of this masonry typology, as defined by the RELUIS system, is sub-horizontal masonry with roughly cut stones (of varying dimensions). Despite the higher percentage of structures within Castelvecchio di Calvisio composed of masonry typology two, this particular masonry typology is present in only two of the four building typologies present within the village. In almost all cases, the masonry is of high quality and the original plaster covering has decayed substantially over time without interventions.

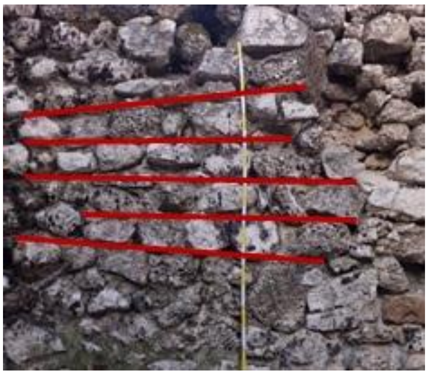


Figure 4.18 Typology Two

Figure 4.19 Typology Two

The first example of masonry typology two in Castelvecchio di Calvisio comes from a structural within the historical boundary wall building typology. This example is located within aggregate CvC 1.17. This aggregate is one of two aggregates within the historical center of Castelvecchio di Calvisio where all of the buildings within the aggregates are defined as historical boundary wall houses. The entire aggregate as well is privately owned with two of the eight structures within the aggregate currently inhabited. Similar to several

4.20 Type2 Boun. Wall

structures within the historical boundary wall, the masonry is of higher quality due to the social importance of the defensive wall, especially in the past. As seen in the masonry analysis below, thee are little to no traces of the once existent plaster covering of the masonry, which has

Figure 4.21 Typology 2 Boundary Wall

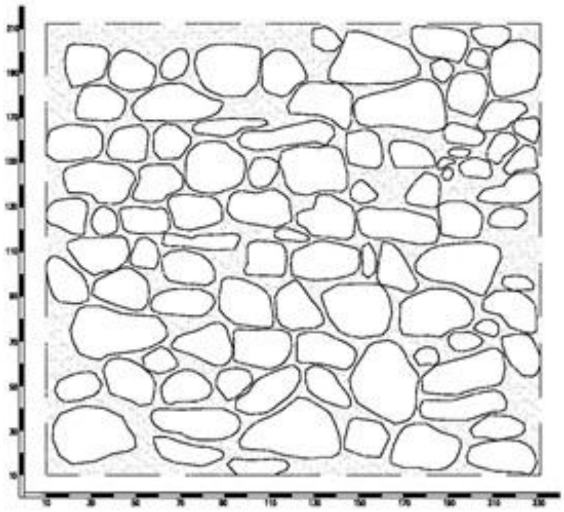


Figure 4.22 Typology 2 Boundary Wall

now almost entirely decayed away. The revealed masonry has a presence of horizontal rows of stones. The masonry is also of higher quality due to the proper spacing between stones as well as the varying sizes of the stones which provide a stronger structural stability. Due to the massive heights of the structures within the historical boundary wall, the masonry becomes extremely important regarding the structure's vulnerability in the case of a seismic event. The structure is also supported with the addition of buttresses in order to prevent the out-of-plane overturning tendencies of taller structures such as those within this particular aggregate. It is however important to note that the masonry typology, while of higher quality, is a single element when considering the overall vulnerability of both a single building as well as an aggregate.

The second example of masonry typology two in Castelvecchio di Calvisio is located within a structured characterized by the building typology of buildings oriented parallel to the elevation curves. This particular example is located within the historical center, within aggregate CvC 1.02. The aggregate is composed of four structures, two of which are privately owned and three of which are currently inhabited. This example however comes from a privately owned uninhabited structure within the aggregate. This example has a slight presence of the once existent plaster covering and therefore is accessible to observation analysis of the exposed masonry structure. As seen in figure 4.5.2f and figure 4.5.2g, the masonry composition is fairly regular, with a subtly visible presence of horizontal rows. In addition, the masonry typology is composed of stones of varying sizes that are

Figure 4.23   Typology 2   Parallel Building

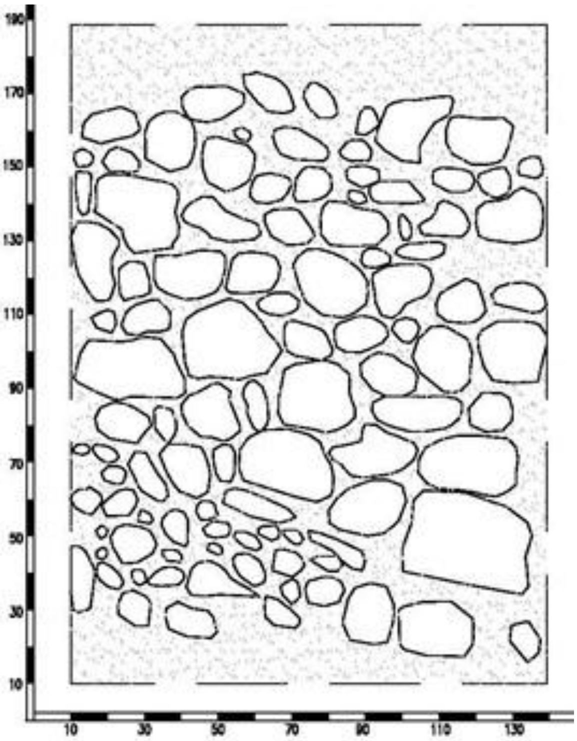


Figure 4.24   Typology 2   Parallel Building

properly placed apart. The quality of the masonry is particularly important due to the placement of the building on the end of the aggregate. In this example, it is also important to note the stones which are the typical size of stones found within the surrounding region. These stones are of high quality and have been constructed with precision as well, which is expected for structures within the historical center of the village.

4.5.3   Masonry Typology Three

The final masonry typology present in Castelvecchio di Calvisio is masonry typology three. This masonry is of the highest quality present in all four of the villages discussed in this thesis. Within the Baronia collective, this masonry typology is typically reserved for churches or religious structures due to their social and cultural importance in the area. In addition, these structures are typically subsidized by the Catholic church, which allowed for high quality materials and construction. The masonry is legally defined, by the RELUIS system, as horizontal masonry courses with roughly cut

Figure 4.25 Typology 3

Figure 4.26 Typology 3

stones, which are well interlocked. In the case of Castelvecchio di Calvisio, masonry typology three is only present in three buildings, all of which are either within or in the surrounding area of the historical center. These structures make up only one percent of the 278 structures within Castelvecchio di Calvisio. The most well-known of these structures is the Church of San Cipriano, who's construction dates back as far as 770 AD.

The first and only example of masonry typology three within Castelvecchio di Calvisio to be discussed is found on the edge of the historical center, within aggregate CvC 2.34. The aggregate which is composed solely of the Church of San Cipriano is privately owned and although not currently inhabited, the church is still in public use within the community for religious purposes. The masonry present in this particular church is one of the highest quality masonries present in Castelvecchio di Calvisio. As seen in the sample elevations in figures 4.5.3d and 4.5.3e, the stones as well as their arrangement are extremely regular. There is no plaster covering present to protect the bricks and there is no evidence to suggest that there was a cover at one time. This appears to be an aesthetical choice. In addition, it is important to note the slight variation in the masonry stone sizes and well as the proper

Figure 4.27 Aggregate CvC 2.34

spacing between each stone. Due to the social importance of both churches and religious structures in both Csastelvecchio di Calvisio as well as the remainder of the villages within the Baronia collective, these structures are of the highest masonry and construction quality. This particular structure is composed of the highest quality version of masonry three present within the four villages discussed in this thesis. However while these church and religious structures, specifically this example, are composed of more structurally sound masonry, they are still extremely vulnerable in the case of a seismic event due to their interior vaults, lack of homogeneity in building heights and propensity for out-of-plane wall overturning.

Figure 4.28 Typology 3 Church

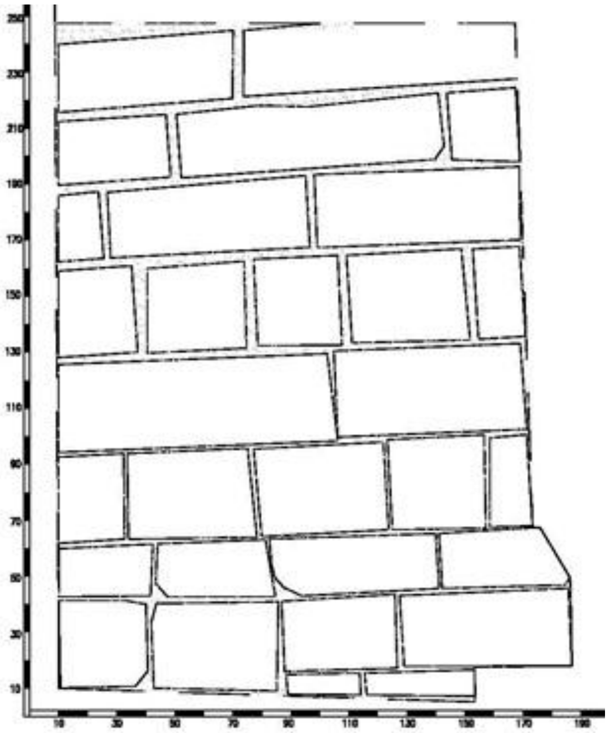


Figure 4.29 Typology 3 Church

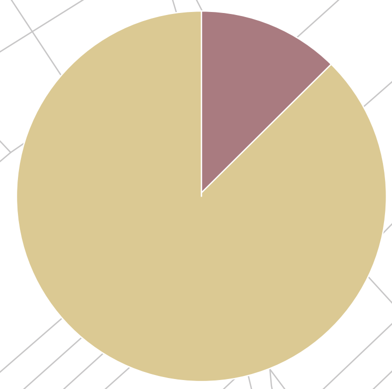
Table 4.6 Location of Ruins

KEY:

Usable Building

Building in Ruins

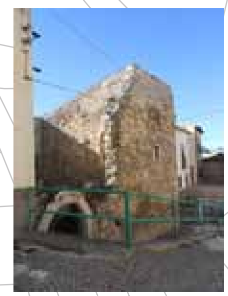
Total Number of Ruins: 29
Total Buildings: 311

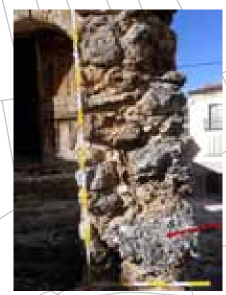


DEFINITION:

"Ruins" are considered any building that is beyond uninhabitable, but instead is to the point of having lost all structural stability. The building will in general have collapsed entirely or at least partially. It is important to note these structures because they can hint at a particular vulnerability of an aggregate or area of buildings. They also, if not properly controlled, create damage to surrounding buildings or structures.

EXAMPLES:





Comune: Castelvecchio di Calvisio
Location of Ruins

4.6 Existing Ruins

Within Castelvecchio di Calvisio, there are several examples of ruins, the most of any of the four villages discussed in this thesis. Within the village there are 29 examples of ruins, 7 of which are located within the historical center and 22 in the addition area outside of the historical center. Seven of the twenty-nine ruins present in the village will be discussed, through the use of sectional and elevation analysis based on observational investigations.

The first example of a ruin within the historical center is located in aggregate CvC 1.07. This particular aggregate lacks in structural homogeneity regarding the four primary structural elements that will be discussed in the section 4.7. The ruined building in question is characterized as being composed of masonry typology one, the weakest of the masonry typologies present within Castelvecchio di Calvisio.

Figure 4.30 CvC 1.07 Ruins

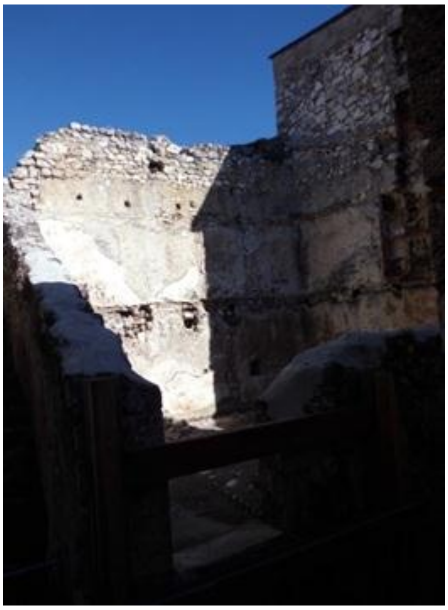


Figure 4.31 CvC 1.07 Ruins

Unfortunately due to security measures in place, it was impossible to complete a more complete observational analysis of the ruins in question. However the mode of failure of the structural masonry walls does imply a failure of the strength of the masonry elements. It is important to note that this conclusion is solely conjecture and would need to be verified via more extensive analysis both on-site and in a laboratory.

The second example of a ruin within Castelvecchio di Calvisio is, similar to the previous example, also located within the historical center of the village. Specifically this particular examples is comes from aggregate CvC 1.08. This particular aggregate is composed of five structures and lacks in structural homogeneity regarding the four primary structural factors that have been analyzed.

The building currently in ruins was structurally composed of masonry typology two. The higher

Figure 4.32 CvC 1.08 Ruins

Figure 4.33 CvC 1.08 Ruins

quality of masonry utilized as well as the observed mode of failure suggests the structure of the roof or the higher floors were the cause of the damage that led to the collapse of the entire structure. The location of vegetation and recently added elements suggest that the collapse of the structure was not a recent event. However all of these conclusions are conjecture due to the lack of masonry sections available for thorough observational analysis. Therefore the all of these conclusion would need to be verified through further analysis both on-site and in a laboratory.

The third and final example of a ruin within the historical center of Castelvecchio di Calvisio is located between two aggregates, specifically aggregates CvC 1.13 and CvC 1.14. Both of the

Figure 4.34 CvC 1.13/14 Ruins

Figure 4.35 CvC 1.13/14 Ruins

aggreagtes involved are irregular when considering the collective homogeneity analysis, to be introduced in section 4.7. The masonry composition of the ruin in question, which is specifically located in aggregate CvC 1.14, is masonry typology two. While this is solely conjecture, the higher quality masonry may imply other structural factors led to the collapse of the structure. Due to the inaccessibility of the site due to security reasons, further observational analysis was made impossible. Therefore any conclusions for this particular example are based solely on conjecture. Any verification of these conclusions would have to be based on further analysis both on-site and in a laboratory.

The first example outside of a ruin outside of the historical center of Castelvecchio di Calvisio is located in aggregate CvC 2.02. Due to the accessibility of the site as well as an available section for observational analysis, this is the best example of a ruin within the village and will therefore have the most thorough analysis. This particular aggregate lacks in homogeneity considering the four primary structural factors considered when determining the collective homogeneity of the aggregate. In addition, the masonry of the building is that of masonry typology one. When considering the wall section, seen below in figure 4.6i, it is presumed that this section is exemplary of the entire structure's masonry composition.

Figure 4.36 Aggregate CvC 2.02

Initial observational analysis has indicated that the brickwork has been assembled with a certain effectiveness. Despite the size of the analyzed section, it can be deduced that the masonry is comprised of two partially clamed leaves with a total thickness of 50 cm. The masonry consists of both large and medium stones, with the presence of some larger stones that connect the two leaves together to ensure a better connection between the two sides of the wall section. Also present are very porous limestone wedges. The

Figure 4.37 CvC 2.02 Ruins

Figure 4.38 CvC 2.02 Ruins

mortar used within the section is in good condition, with light gray coloration, firm consistency, with both large and small aggregates within the mortar. It is also important to note that there were no voids within the section. It can therefore be presumed that the masonry quality was not a major factor in the collapse of the structure. Again, as in the previous examples, all of these conclusions are based solely on observational analysis and would therefore need to be verified through further analysis both on-site and in a laboratory.

The second example of a ruin outside of the historical center of Castelvecchio di Calvisio is located within aggregate CvC 2.03. This particular aggregate is fairly irregular regarding collective

Figure 4.39 CvC 2.03 Ruins

Figure 4.40 Ruins

Figure 4.41 Ruins

structural homogeneity and the individual ruined structure is composed of masonry typology two. Due to the inaccessibility to the site due to security reasons, observational analysis was extremely limited. However a recent renovation, pre-collapse, that did not respect the existing masonry typology, appears to have played a part in the eventual collapse. However this again is a conclusion based solely on observations and therefore needs to be verified through further analysis.

The third example of a ruin outside of the historical center of Castelvecchio di Calvisio is located within aggregate CvC 2.07. This aggregate is homogeneous regarding the four primary structural fsctors analyzed in order to determine the collective structural homogeneity of the aggregate. However all of the three structures within the aggregate are in ruins. In addition, all three of these structures are

Figure 4.42 Aggregate CvC 2.07

composed of masonry typology one, the lowest quality masonry present in Castlevecchio di Calvisio. As seen in figure 4.6m, there appears to have been an addition that failed to respect the masonry typology of the existing structure. This may have played a large role in the eventual collapse of the structure. This conclusion is based solely on minimal observational analysis due to a lack of accessibility to the site due to security reasons. Therefore further analysis would be necessary to determine the validity of this statement.

The fourth and final example of a ruin outside of the historical center of Castelvecchio di Calvisio is located in aggregate CvC 2.13. The aggregate in which this example is located in lacks in

Figure 4.43 Aggregate CvC 2.13

collective homogeneity as determined through the analysis of four primary structural factors. However all six buildings within the aggregate are composed of masonry typology one, the lowest quality masonry typology present in Castelvecchio di Calvisio. The collapse of the structure is concentrated solely to the upper floors, however due to a lack of access into the site, it is difficult to determine a possible cause of the eventual collapse. Therefore, especially in this case, further analysis is required, both on-site and in a laboratory.

Table 4.7 Collective Homogeneity Analysis

DESCRIPTION:

This collective homogeneity map includes all major structural characteristics that influence the homogeneity of an aggregate. This includes building height, building typology, masonry typology and orientation to the elevation curves. All of the previously mentioned maps have been overlaid over each other to emphasize the aggregates that are the best positive and negative examples of structural homogeneity. This was underlined in the following maps and then analyzed within the text of the thesis to better understand the vulnerability or lack of vulnerability of certain aggregates.

GENERAL KEY:

- Buildings
- Aggregate Boundaries

BUILDING HEIGHTS:

- 5 Floors Equivalent (or above)
- 4 Floors Equivalent
- 3 Floors Equivalent
- 2 Floors Equivalent
- 1 Floor Equivalent

BUILDING TYPOLOGIES:

- Historical Boundary Wall House
- Block House
- Tower House
- Buidling Oriented Perpendicular to the Elevation Curve
- Building Oriented Parallel to the Elevation Curve
- Religious Building
- Ruins

MASONRY TYPOLOGIES:

- Irregularly formed masonry (regarding shape, dimensions and materials) stone
- Subhorizontal masonry with roughly cut stones (of varying dimensions)
- Horizontal masonry courses with roughly cut stones (well interlocked)
- Plaster Covered

ORIENTATION TO ELEVATION CURVES:

- Building unit positioned parallel to the elevation curves
- Building unit positioned perpendicular to the elevation curves

Comune: Castelvecchio di Calvisio
Collective Homogeneity Analysis

4.7 Collective Homogeneity Analysis

The collective homogeneity analysis is primary based on four specific factors, all of which have been determined through on-site analysis. These include the topics of the previous four sections, including building typology, orientation to elevation curves, building height and masonry typology. As seen in the attached map of Castelvecchio di Calvisio for “Collective Homogeneity”, the four previously mentioned factors’ maps have been overlaid to located the aggregates with an extremely uniform or non-uniform structure, regarding all four elements. The aggregates that present the least and most uniformly regarding these four elements will be discussed in the following two sections, entitled “Negative Homogeneous Examples” and “Positive Homogeneous Examples”.

Overall, Castelvecchio di Calvisio is one of the more collectively homogeneous, considering these structural factors, of the villages of the Baronia collective. An initial analysis of the attached map reveals that more homogeneous aggregates are located within the historical center, while the areas outside of the historical center are more irregular in their overall structural makeup. A lack of structural homogeneity can create several types of damages because an aggregate is more likely to act as separate elements instead of a single unit in the case of a seismic event. This can increase the chances of several collapse mechanisms within the individual aggregates as well as those that are adjacent to one another. In these case of Castelvecchio di Calvisio, there are several aggregates that are vulnerable to seismic events due to their lack of structural homogeneity and will therefore be strongly considered as structures to be restores with the limited public funds available. These structures will be discussed in the “Negative Homogeneous Examples” section, while in the “Positive Homogeneous Examples” section, aggregates of homogeneous construction will be used as a guide for possible restoration work for the aggregates considered to not be homogeneous and therefore possibly structurally instable.

Table 4.8 Location of Negative Examples

KEY:

Typical Building

Aggregate Boundary

Negative Homogenous Example

INFORMATION:

Number of Examples: 7

Example 1: CvC 1.01

Example 2: CvC 1.13

Example 3: CvC 1.06

Example 4: CvC 1.10

Example 5: CvC 1.08

Example 6: CvC 2.04

Example 7: CvC 2.10

DESCRIPTION:

These negative examples showing a lack of homogeneity were chosen based on the “Combined Homogeneity analysis” map for Castelvecchio di Calvisio. The previously mentioned map was created by combining the following maps:

Building Heights

Building Typologies

Masonry Typologies

Orientation to the Elevation Curves

All of these maps were laid on top of one another. Then several examples of aggregates were chosen back on their lack of homogeneity regarding these four principal elements. These examples will be further analyzed within the text of the thesis.

DEFINITION:

A “negative example of homogeneity”, in the context of this thesis, is defined as an aggregate made up of several buildings. These buildings will be of different heights and made from several different types of masonry possibly with restorations made of different masonry from that of the original constructions. In addition, the building typologies of all of the buildings within the aggregate are different and the orientation to the elevation curves will be different. All or several of them will also be oriented perpendicular to the elevation curves. It is all of these qualities, or variations of them, that make a specific aggregate a “negative example of homogeneity”

Comune: Castelvecchio di Calvisio
Location of Negative Examples

4.8 Negative Examples of Collective Homogeneity in Aggregates

Overall seven examples of negative collective homogeneity have been determined within Castelvecchio di Calvisio. Five of these examples are located within the historical center and two are located outside of the historical center. As described in the previous Collective Homogeneity Analysis section 4.7, these examples are based on the collective homogeneity, a combination of the overall homogeneity of the building typology, orientation to elevation curves, building heights and masonry typology. These examples will be later further analyzed when considering the most vulnerable aggregate within the four villages discussed.

4.8.1 Negative Collective Homogeneity Example One

The first negative example of collective structural homogeneity of Castelvecchio di Calvisio is found within the historical center. The example is the entirety of aggregate CvC 1.01. This aggregate

Figure 4.44 Aggregate within Castelvecchio di Calvisio

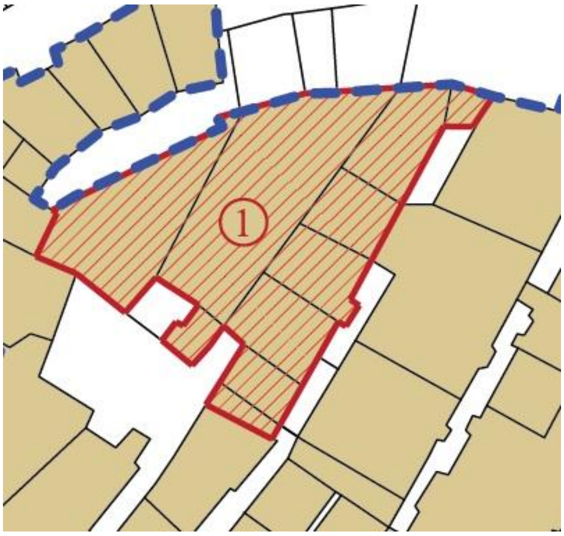


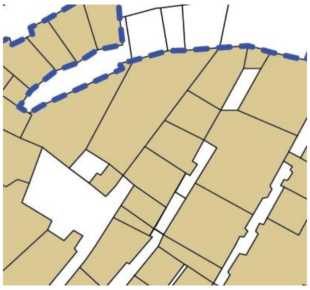
Figure 4.45 Location of Aggregate CvC 1.01

is composed of nine structures, five of which are publically owned and all of which are currently uninhabited. In addition, the aggregate is extremely irregular in plan and only slightly irregular in elevation. This particular aggregate is completely homogeneous regarding the building typologies and building orientations of the separate structures within the aggregate. This aggregate has been categorized as a negative example of collective structural homogeneity however due to the lack of

Figure 4.46 Homogeneity

homogeneity of both the building heights and especially the masonry typologies. As seen in figure 4.8.1f, all of the structures within the aggregate are homogenous with the exception of two shorter structure and one tower-like structure. These are important due to the possible collapse mechanisms


4.47 Building Typology


4.48 Building Orientation


4.49 Building Height


4.50 Masonry Typology

that they create. The most important aspect of the aggregate to note is the lack of homogeneity among the structures in the aggregate. All four of the masonry typologies present in Castelvecchio di Calvisio are also present in this aggregate. In addition, all four of these masonry typologies are fairly spread out in the aggregate. There is one structure of masonry typology three, two structures of masonry typology two, three structures of masonry typology one and finally three structures with a plaster covering. This highly irregular use of differing masonry can poorly effect the aggregate in the case of a seismic event, specifically regarding the aggregate's vulnerability to hammering between the separate structures. Restorative efforts would therefore need to be aimed at a reinforcement of the structural connections between the buildings of differing masonry typologies. In addition, the connections between the structures of heights should also be considered for restorative work.

4.8.2 Negative Collective Homogeneity Example Two

The second negative example of collective structural homogeneity in the historical center of Castelvecchio di Calvisio comes from aggregate CvC 1.13. The aggregate is composed of 11 separate structures. All of the eleven structures are privately owned. Currently two of the


Figure 4.51 Aggregate within CvC

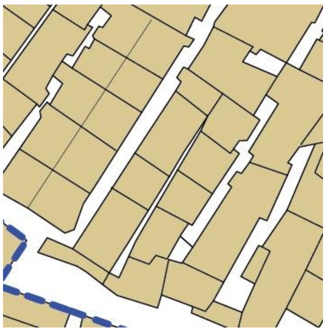
Figure 4.52 Aggregate CvC 1.13

structures are inhabited and two other structures within the aggregate have been determined to be uninhabitable. All of the structures within the aggregate have been categorized as buildings oriented

parallel to the elevation curves, with only the two ruins within the aggregate as exceptions. The building heights of the structures within the aggregate are fairly homogeneous. There are only two cases in which adjacent structures differ by more than two stories. As seen in the previous example, the lack of homogeneity of the overall structure is primarily a product of the masonry typologies present within the aggregate. There are three masonry typologies present including masonry typology one, masonry typology two and plaster covered. Each typology is generally grouped in

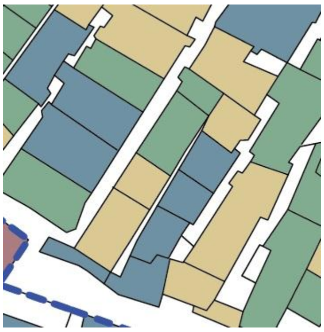
structures of the same masonry typology. This irregularity is extremely important considering the possibility of hammering between the structures with differing structural characteristics. In order to minimize these possible collapse mechanisms, additional structural

4.54 Building Typology



4.55 Building Orientation

4.56 Building Heights



4.57 Masonry Typology

Structure reinforcement is necessary to improve the connection between the individual structures.

4.8.3 Negative Collective Homogeneity Example Three

The third negative example of collective structural homogeneity within the historical center of Castelvecchio di Calvisio is found in aggregate CvC 1.06. There are 12 structures present within the aggregates. Of these 12 structures, all 12 are privately owned and currently only two are inhabited. This aggregate is more irregular in plan that most of the aggregates within the historical center, however it can still be considered fairly regular. Regarding the building typology, ten of the 12

Figure 4.58   Aggregate within Castelvecchio di Calvisio

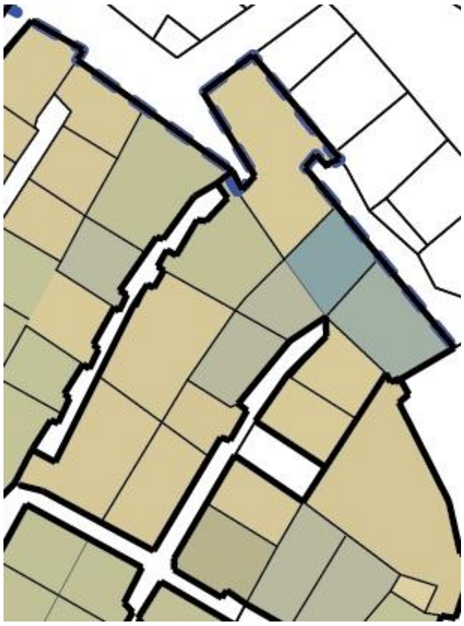
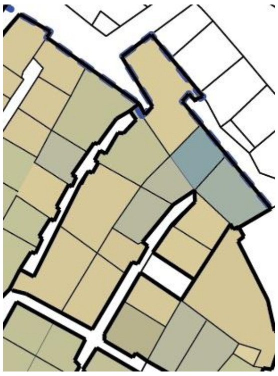


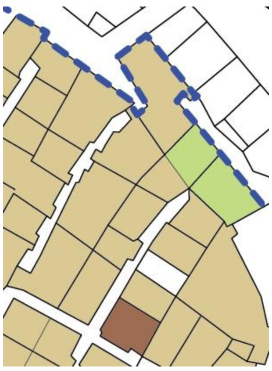
Figure 4.59   Location of Aggregate CvC 1.06

structures are oriented parallel to the elevation curves while the remaining two structures are

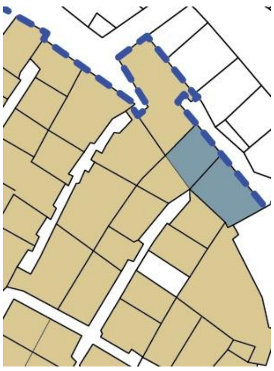


4.60 Homogeneity

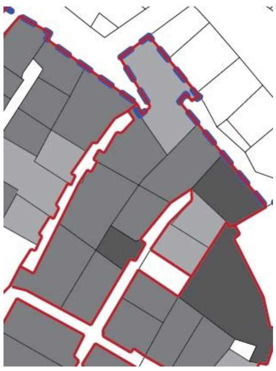
oriented perpendicular to the elevation curves. The two structures oriented perpendicular are located together on the edge of the historical center. The building heights within the aggregate are regular with no adjacent structures differing by more than a single story. The lack of homogeneity in the aggregate stems almost exclusively from the masonry typology. There are three masonry typologies present within the aggregate, including masonry typology one, masonry typology two and plaster covered. The majority of the structures are composed of plaster covered structures. The structures with exposed masonry structures are located



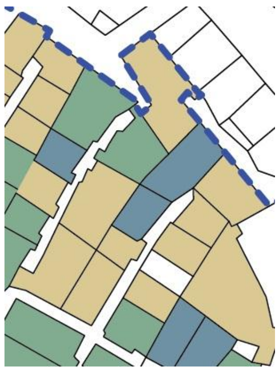
4.61 Building Typology



4.62 Building Orientation



4.63 Building Height



4.64 Masonry Typology

on the outer most portion of the aggregate. This characteristic along with the two structures oriented perpendicular to the elevation curves render this area more vulnerable than the remainder of the aggregate. This region of the aggregate this deserves the most attention regarding restorative efforts. This can be seen in the forms of several permanent structural interventions including tie rods, buttresses and even arches or “sporti”.

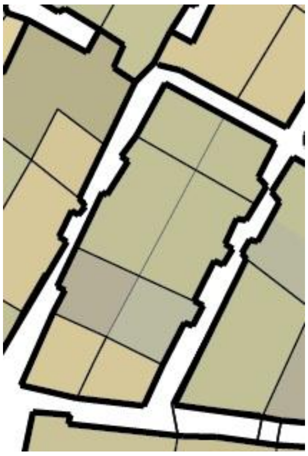
4.8.4 Negative Collective Homogeneity Example Four

The fourth negative example of collective structural homogeneity within the historical center of Castelvecchio di Calvisio is found in the entirety of aggregate CvC 1.10. The aggregate is

Figure 4.65 Aggregate within Castelvecchio di Calvisio

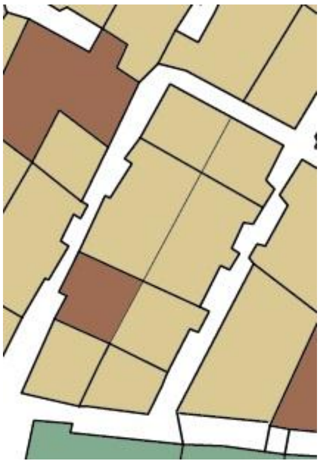
Figure 4.66 Location of CvC 1.10

composed of eight separate structures. Two of these eight structures are publically owned, all are

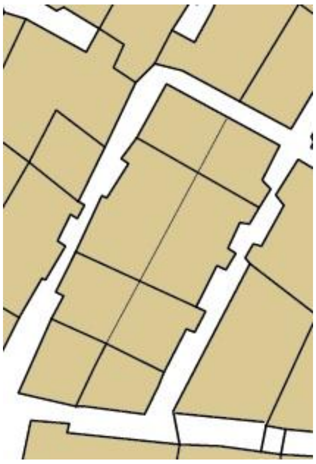


4.67 Homogeneity

currentlyuninhabited and one is considered to be uninhabitable. All of the buildings within the aggregate have been categorized as buildings oriented parallel to the elevation curves, with the only exception being the previously mentioned building in ruins. Regarding the building heights, the aggregate is almost completely homogeneous with the exception of one structure which is one story taller than the adjacent buildings. As seen in the previous three examples within the historical center, the lack of homogeneity of the overall structure derives primarily from the masonry typology. The eight structures are composed of three masonry typologies, which are grouped together in three separate groups. These typologies include masonry typology one, masonry typology two and plaster covered.



4.68 Building Typology



4.69 Building Orientation

4.70 Building Height

4.71 Masonry Typology

The northernmost section of the aggregate is composed of masonry typology one, the center of the aggregate is composed of two structures of masonry typology two and the Southernmost structures are plaster covered. This composition of the aggregate implies that these three sections of the aggregate have very different structural dynamics and therefore the connection between the three groups as well as the stability of the end buildings should be reinforced in the case of possible restorative work.

<u>4.8.5 Negative Collective Homogeneity Example Five</u>

The fifth and final negative example of collective structural homogeneity within the historical

Figure 4.72 Aggregate within Castelvecchio di Calvisio

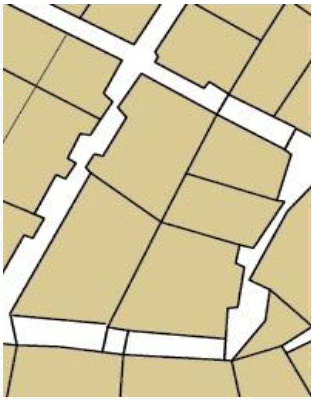
Figure 4.73 Location of Aggregate CvC 1.08

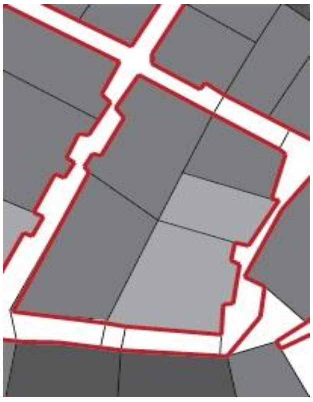
center of Castelvecchio di Calvisio is located in aggregate CvC 1.08. The aggregate is composed of only five structures. All of these five structures are privately owned and only one is currently inhabited. All of the buildings within the aggregate are classified as being buildings oriented


4.74 *Homogeneity*

parallel to the elevation curves, with the exception of the one ruin within the aggregate. The overall aggregate is fairly homogeneous regarding the building heights with no adjacent structures differing by more than one story. The lack of homogeneity within the aggregate, as seen in all of the negative examples present in Castelvecchio di Calvisio, derives from the masonry typology, which in this case is split into two different masonry typologies. The two typologies present are masonry typology one, which are almost perfectly divided into two


4.75 Building Typology


4.76 Building Orientation


4.77 Building Height


4.78 Masonry Typology

sections in the aggregate, masonry typology one on the West side and masonry typology two on the East side. This results in very different structural dynamics for the two halves of the aggregate, thus rendering the aggregate vulnerable to several collapse mechanisms in the case of a seismic event. These mechanisms include hammering, torsion and out-of-plane wall overturning. Permanent structural interventions could help to minimize or eliminate these potential collapse mechanisms.

4.8.6 Negative Collective Homogeneity Example Six

The first negative example of collective structural homogeneity outside of the historical center of Castelvecchio di Calvisio is found in aggregate CvC 2.04. This particular aggregate is composed of eight separate structures. All of these eight structures are privately owned and currently only two are inhabited. All of the structures within the aggregate have been categorized as buildings oriented parallel to the elevation curves. Regarding the building heights, the aggregate is quite

Figure 4.79 Aggregate within Castelvecchio

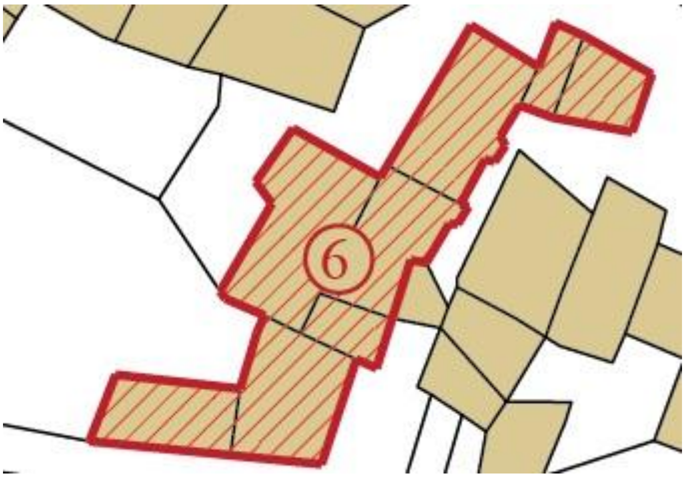


Figure 4.80 Location of Aggregate CvC 2.04

regular with all adjacent structures differing by no more than a single story. However it is important to not that the aggregate has been divided into two regarding the building heights, with the taller structures lying on the Eastern side of the aggregate. The major structural factor for the lack of homogeneity within the aggregate is the masonry typology. There are three masonry typologies present in the eight structures, including masonry typology one, masonry typology two and plaster covered. The masonry is spread out in the plan, that is also irregular in its plan formation. The exposed masonry is located within the

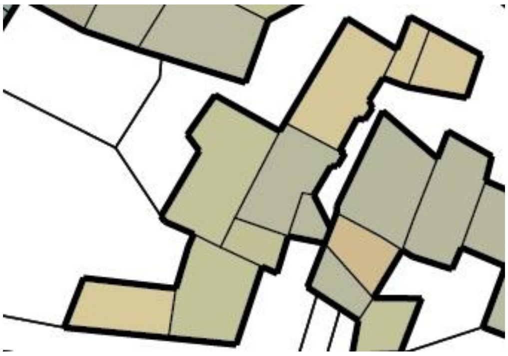
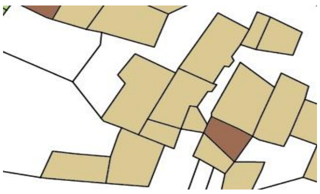
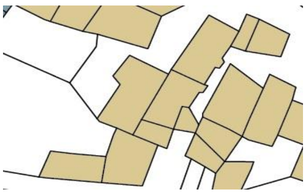


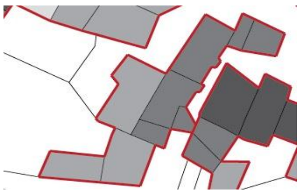
Figure 4.81 Collective Homogeneity



4.82 Buidling Tyology



4.83 Building Orientation



4.84 Building Height

4.85 Masonry Typology

center of the aggregate. This is important to note for restorative work, which should be concentrated on this particular area regarding its connection to the extremities of the aggregate.

4.8.7 Negative Collective Homogeneity Example Seven

The second and final negative example of collective structural homogeneity outside of the historical center of Castelvecchio di Calvisio is found in aggregate CvC 2.10. There are eight structures within the aggregate. All of these eight buildings are privately owned and of these eight,

Figure 4.86 Aggregate within Castelvecchio

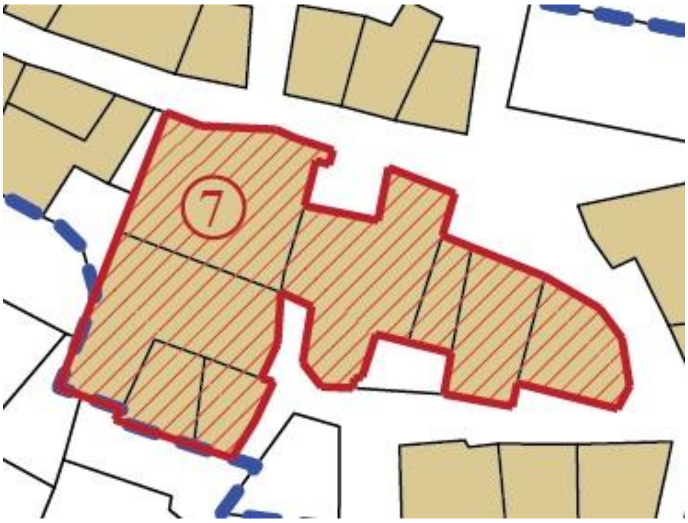


Figure 4.87 Location of Aggregate CvC 2.10

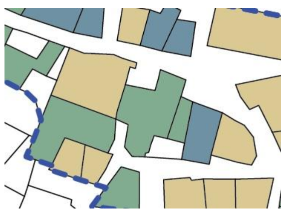
four are currently inhabited and one is considered to be uninhabitable. All of the structures within the aggregate are considered to be buildings oriented parallel to the elevation curves, with the exception of one ruin. Regarding the building heights, the aggregate is almost perfectly homogeneous, with the exception of one structure that is a story taller than its adjacent structures. The lack of homogeneity in the aggregates is primarily a result of the masonry typology. There are three different typologies present in the aggregate, including masonry typology one, masonry typology two and plaster covered. The location of these masonry typologies is irregular as well. This is important to note considering the possible collapse mechanisms related to a lack of homogeneity in the structural dynamics of an aggregate. In order to minimize these possible damages

Figure 4.88 Collective Homogeneity

4.89 Building Typology

4.90 Building Orientation

4.91 Building Height



4.92 Masonry Typology

in the case of a seismic events, emphasis for restorative efforts should be placed on the connection between these structures composed of different masonry typologies.

Table 4.9 Location of Positive Examples

KEY:

- Typical Building
- Aggregate Boundary
- Positive Homogenous Example

INFORMATION:

Number of Examples: 7

Example 1: CvC 1.02

Example 2: CvC 1.04

Example 3: CvC 1.12

Example 4: CvC 1.09

Example 5: CvC 2.01

Example 6: CvC 2.27

Example 7: CvC 2.20

DESCRIPTION:

These positive examples showing homogeneity were chosen based on the “Combined Homogeneity analysis” map for Castelvecchio di Calvisio. The previously mentioned map was created by combining the following maps:

Building Heights

Building Typologies

Masonry Typologies

Orientation to the Elevation Curves

All of these maps were laid on top of one another. Then several examples of aggregates were chosen back on their homogeneity regarding these four principal elements. These examples will be further analyzed within the text of the thesis.

DEFINITION:

A “positive example of homogeneity”, in the context of this thesis, is defined as an aggregate made up of several buildings. These buildings will be of the same height and made from the exact same type of masonry, without restorations made of different masonry from that of the original constructions. In addition, the building typologies of all of the buildings within the aggregate are the same and the orientation to the elevation curves will be the same. All or several of them will also be oriented parallel to the elevation curves. It is all of these qualities, or variations of them, that make a specific aggregate a “positive example of homogeneity”

Comune: Castelvecchio di Calvisio
Location of Positive Examples

4.9 Positive Examples of Collective Homogeneity in Aggregates

Overall seven examples of positive collective homogeneity have been determined within Castelvecchio di Calvisio. Four of these examples are located within the historical center and three are located outside of the historical center. As described in the previous Collective Homogeneity Analysis section 4.7, these examples are based on the collective homogeneity, a combination of the overall homogeneity of the building typology, orientation to elevation curves, building heights and masonry typology. These examples will be later further analyzed when considering the least vulnerable aggregate within the four villages discussed. Specifically these examples will be used as examples to following when beginning restorative work to improve the structural stability of the village.

4.9.1 Positive Collective Homogeneity Example One

The first positive example of collective structural homogeneity within the historical center of Castelvecchio di Calvisio is located in aggregate CvC 1.02. The aggregate is composed of only four

Figure 4.93 Aggregate within Castelvecchio di Calvisio

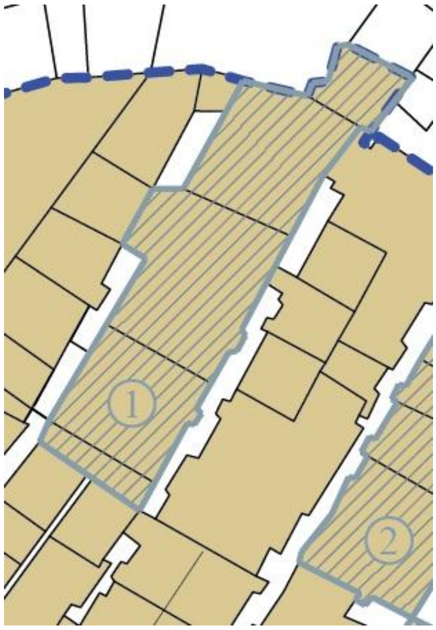
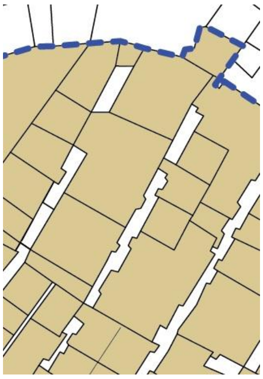


Figure 4.94 Location of CvC 1.02

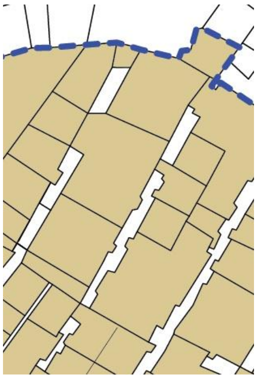
structures. Two of these four structures are publically owned and three are currently inhabited. All of these structures within the aggregate are characterized as buildings oriented parallel to the elevation curves. Regarding the building height, the aggregate is almost perfectly homogeneous, with only one structure being a story shorter than the remainder of the structures within the aggregate. Regarding

4.95 Homogeneity

the masonry typology, the aggregate is again almost perfectly homogenous with all but one structure being plaster covered masonry. The other building is composed of masonry typology one. However due to the inability to determine the structure beneath the plaster cover, it is impossible to determine properly how homogeneous the masonry typology is within the aggregate. This aggregate is considered to be a positive example of collective homogeneity also because of the regularity of the overall aggregate in both plan and elevation.



4.96 Building Typology



4.97 Building Orientation

4.98 Building Height

4.99 Masonry Typology

4.10 Openings

While generally disregarded, openings can play a large role in the structural stability of a building if improperly placed. The ideal location of punctures of the façade surface are far apart from one another as well as offset in order to avoid creating vertical instability transcending the separate floors. In addition, openings should be placed near the center of the wall in order to avoid breaking the continuity of the diaphragm chord or the structural supports. There are several examples of both proper and improper opening placements within Castelvecchio di Calvisio.

The first negative example is found in aggregate CvC 2.03. In this particular case, the placement of the openings has several faults. Specifically on the front façade, the openings are placed extremely close to another and therefore compromise not only the stability of each opening but also the entire façade by increasing the stresses between the openings. On the side of the façade, as seen in figure 4.10a, the openings are also placed in a vertical line, creating a vulnerable portion of the façade where potentially a partial out-of-plane wall overturning can happen. However one of the more severe issueswith the placement of the openings in this particular structure is the proximity of one of the openings to the roof structure. This again increases the likeliness of the roof's failure, specifically at the point of the opening. Overall this particular building has been rendered vulnerable due to the improper placements of the openings within the façade, many of which appear to have been added after the initial construction of the structure. This is seen in the lack of use of masonry window or door frames that help to better reinforce the opening. In many of the openings in this case, the openings have either no frame at all or a wooden frame that is more likely to suffer damages due to general decay.

Figure 4.100 Negative Openings

The negative example of an opening placement within Castelvecchio di Calvisio is found

Figure 4.101 Negative Openings

within the historical center in aggregate CvC 1.01. This particular structure showcases several improperly placed openings within the surface of the façade. First and foremost, the openings within the structure are places extremely close to one another. Due to these close proximities vertically, these openings can compromise the structural strength of both the façade as well as the floor slabs within the structure. This is due to the fact that stresses will accumulate between these openings and therefore render these areas vulnerable to collapse or damage in the case of a seismic event. It is also important are located close to the corner of the structure. This characteristic can also render the connection between the two facades vulnerable, thus effected major structural elements within the building.

Despite the presence of several negative examples of openings within Castelvecchio di Calvisio, the majority of the structures within the village showcase positive examples of openings.

Figure 4.102 Positive Openings

Figure 4.103 Positive Openings

The two positive examples to be discussed are both found within the historical center of the village.

These particular structures are positive examples of openings due to the lack of vertical instability produced by the stacking of the openings. Instead, as seen in both examples, the openings are staggered from one story to the next. In addition, both structures have their openings placed at a proper distance from all major structural elements including the roof, columns and corners. These are the ideal placements of openings within a structure in order to minimize any negative effect punctures within a façade may produce, if at all.

Table 4.11.1 Permanent Interventions

KEY:

- Typical Building
- Buttress Location
- Building with Tie Rods in Place

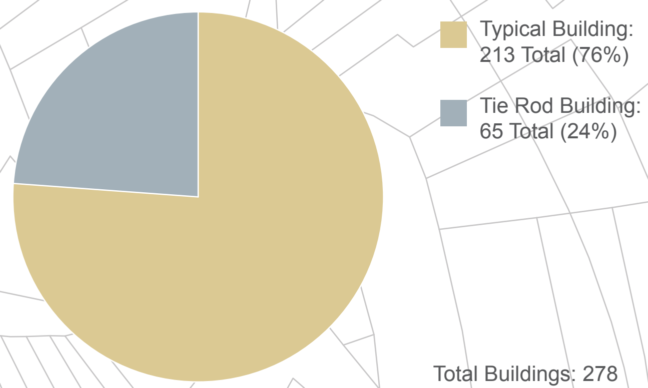
DEFINITION:

Buttress - A mass of masonry or brick work projecting from or built against a wall to give additional strength, usually to counteract the lateral thrust of an arch, roof or vault. There are several different types of buttresses, including angle, clasping, diagonal, flying, lateral, pier and setback buttresses.

Tie Rod - A slender structural unit used as a tie and capable of carrying tensile loads only. Tie Rods are generally used on opposite facades, meant to literally tie the building together in order to prevent facade overturning.

INFORMATION:

Number of Buildings with Tie Rods:	65
Number of Buildings with Buttresses:	25
Total Number of Buildings:	278



EXAMPLES:

Tie Rod

Buttress

Comune: Castelvecchio di Calvisio
Permanent Intervention Locations

Table 4.11.2 Arched Overpass Locations

KEY:

Typical Building

Arched Overpass

DEFINITION:

Any arched overpass, that is considered to be either a structural or non-structural element. Any arched overpass, referred to as a “sporto” in the Abruzzo-Italian dialect, is an arched overpass with one or more stories of interior space above the arch. However there are also standard arches included here, that hold no structural weight but themselves.

INFORMATION:

Total Number of Arched Overpasses: 25
Total Number of Buildings: 278




NOTE:

Castel del Monte is famous for their large amount of “sporti”, or arched overpasses. However all four regions have at least a few arched overpasses present. Castelvecchio di Calvisio also has a substantial amount of arched overpasses. This characteristic of the four communes is a special construction typology, common in the Abruzzo region’s architecture.

4.11 Permanent Structural Interventions

Within the Baronia collective, there is a strong presence of permanent structural interventions, specifically added after the original construction of the village. These interventions include scarp buttresses, typical buttresses and tie rods, and showcase a significant knowledge of anti-seismic design within the region of Abruzzo. There are main points when considering the criteria for interventions. The first is that interventions are meant to reduce accidental loads and live loads that caused previous damages. The second is the rehabilitation of load capacity. The third is to remove the causes of material degradation. The fourth and final criteria for interventions is the modification of the static scheme. The improvement of the bearing capacity can be made by regenerating the structural element, increasing the sectional resistance of the floor supporting structure and replacing degraded elements with other similar elements.

Castelvecchio di Calvisio, similar to the other villages within the Baronia collective, has several types of permanent structural interventions present within the village. These include buttresses, arches, “sporti”, and tie rods. Of the 278 buildings present within the village, 65 have tie rods in place, which makes up 24 percent of the buildings within Castelvecchio di Calvisio. with buttresses in place, There are also several structures within the village specifically within the historical center. As seen in figures 4.11a and 4.11b, there are two different typologies of buttresses present within Castelvecchio di Calvisio. The first typology is a partial buttress that only partially covers the height of the wall being supported. Typically this typology of buttress was not present in original construction, but

Figure 4.104 Partial Buttress

Figure 4.105 Complete Buttress

instead was added later due to the need for additional structural support. The second typology however, the complete buttress, spans the height of the entire supported wall. The example, as seen in figure 4.11b, is located within the historical boundary wall and was therefore a part of the original construction. This is typically the case for complete buttresses. It is important to note that due to the size of the buttress structure and the narrow streets within the historical center of Castelvecchio di Calvisio, in many conditions, the addition of a complete buttress is impossible after the initial construction. In this case, either tie rods can be utilized or partial buttresses, if the space allows for such a structural addition.

As previously mentioned, there are several tie rods present within Castelvecchio di Calvisio. There are also several typologies of tie rods utilized. There are two general categories for tie rods,

Figure 4.106 Tie Rod

Figure 4.107 Tie Rod

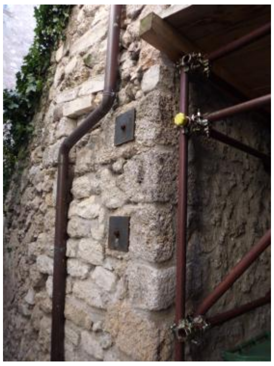


Figure 4.108 Tie Rod

Figure 4.109 Tie Rod

the first being a bar tie rod, as seen in figures 4.11c and 4.11d. The second category is of plate tie rods, as seen in figure 4.11e and 4.11f. In general, plate tie rods can be considered less damaging to the surface of the structure, while bar tie rods have a tendency of puncturing the surface, although this is only the case in rare occasions. Tie rods are an extremely efficient strengthening tool in seismic areas, however their placement must be considered thoroughly. In general, both the placement and implementation of tie rods, within Castelvecchio di Calvisio as well as the other villages within the Baronia collective, are efficient. There is a clear history of construction knowledge specific to masonry within seismically active historical centers.

The third and final type of permanent structural interventions present in Castelvecchio di Calvisioís the arch or “sporto”. In the case of an arch, they are added solely for the purpose of anti-seismic protection. “Sporti” however serve a dual purpose of both anti-seismic design as well as an interior programmatic function. In both cases, the addition of an arch or “sporto” aid in separating two adjacent structures in the case of a seismic event. This separation can deter the occurrence of the hammering between the two structures. It is important to note that high density “sporti” can create minor structural damages to the attached façade, or collapse on their own. This however is a rare occurrence and is generally only applicable for “sporti”, instead of for single arches. Castelvecchio di Calvisio is specifically notable due to the high amount of both arches and “sporti” present in the historical center of the village.

Figure 4.110 Arch

Figure 4.111 “Sporto”

Table 4.12 Temporary Intervention Locations

Comune: Castelvecchio di Calvisio
Temporary Intervention Locations

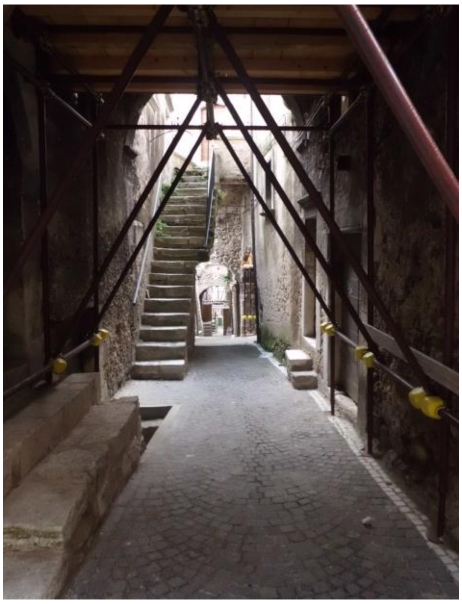
4.12 Temporary Structural Interventions

Both before and after the 2009 seismic event in L'Aquila, temporary structural interventions have been put into place to minimize the collapse mechanisms in several structures that have shown signs of structural instability. There are several types of temporary interventions present in the four villages discussed in this thesis. These include surface rendering, wooden grid and tie, traditional prop, arch/opening support and shorting system interventions. There are several typologies of temporary structural interventions present in Castelvecchio di Calvisio, however only three of these typologies will be discussed in this section.

The first typology of temporary structural interventions to be discussed, present in Castelvecchio di Calvisio, is that of the arch/opening support intervention, which is the most common temporary intervention within the Baronia collective. The first example is an arch support intervention, located beneath a "sporto" between aggregates CvC 1.01 and CvC 1.16. Both are these aggregates are located within the historical center, unattached from the historical boundary wall. This particular arch support intervention is extremely effective. The intervention distributes its influence on the "sporto" across the entire length of the arch in order to avoid the accumulation of stresses that can further the damage mechanisms in place. In addition, the intervention is supported solely by the ground and not by either of the adjacent aggregates. This placement also allows for access under the "sporto" which is preferable considering the importance of this major access way of the village. This intervention can therefore be considered quite successful and should be used as a model for future temporary interventions to be placed through the historical center of this village.

Figure 4.112 Arch Support Intervention

The second example of an arch/opening support intervention within the historical center of Castelvecchio di Calvisio is located between aggregates CvC 1.04 and CvC 1.13. Both of these



4.113 Opening Support Intervention

aggregates are unattached from the historical boundary wall. This particular support intervention has several flaws. The first and most important of these instabilities is that the intervention is supported by the adjacent structures' facades. This thus renders them vulnerable as well. In addition, the support system concentrates the stress of the support onto the center of the opening, thus increasing the stresses present within the opening. This example however is positive due to available access beneath the opening, allowing for continued circulation on the major street way of the village. Overall, this intervention can be thoroughly improved to better support the opening.

The second typology of temporary structural interventions present within the historical center of Castelvecchio di Calvisio is surface rendering interventions. The example to be discussed of this particular typology of intervention is located in aggregate CvC 1.06. These interventions are typically

Figure 4.114 Surface Rendering

Figure 4.115 Surface Rendering

made from steel, however this particular case is a combination of both steel and wood. Similar to the wooden grid or tie interventions, this typology of temporary intervention aids in minimizing the effects of the collapse mechanisms of out of plane wall overturning. This typology however is typically placed on the façade of the structure facing the narrow street way. Due to the use of steel instead of wood, the intervention has the propensity to last longer, however they still need to eventually be replace with permanent structural interventions that prohibit the possible collapse mechanisms within the façade.

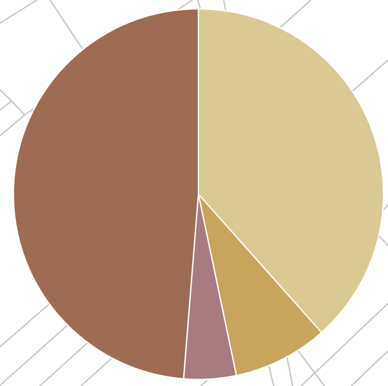
The third and last typology of temporary structural interventions present in Castelvecchio di Calvisio. This is a shoring system intervention and the example to be discussed is located outside of the historical center in aggregate CvC 2.01. This particular intervention aims at prospering up the façade of a structure as well as increasing the connection between both the façade and the roof structures. While these structures are helpful they are only temporary interventions and need to be replaced with more permanent interventions to better support the structure in question. These are appropriate interventions immediately following damage or a seismic event due to their small stature and limited spatial requirements on the narrow street ways

Figure 4.116 Shoring System

Table 4.13 Immediate Post-Seismic Damages

KEY:

- Damage Level A
- Damage Level B
- Damage Level C
- Damage Level E



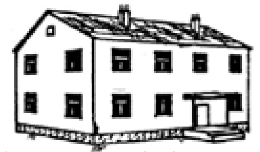
Level A:
112 Total 40%)

Level B:
18 Total (8%)

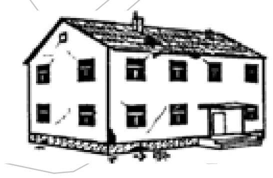
Level C:
10 Total (3%)

Level E:
138 Total (49%)

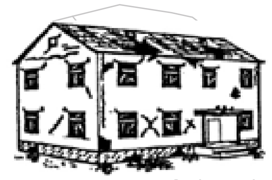
Total Buildings: 278



Grade 1 Damage (Level A, B)
Negligible to slight damage, no structural damage slight non-structural damage.



Grade 2 Damage (Level C)
Moderate damage, slight structural damage, moderate non-structural damage



Grade 3 Damage (Level E)
Substantial to heavy damage, moderate structural damage, heavy non-structural damage.

Grade 4 Damage
Very heavy damage, heavy structural damage, very heavy non-structural damage

Grade 5 Damage (Ruins)
Destruction, very heavy structural damage

Comune: Castelvecchio di Calvisio
Immediate Post-Seismic Damages

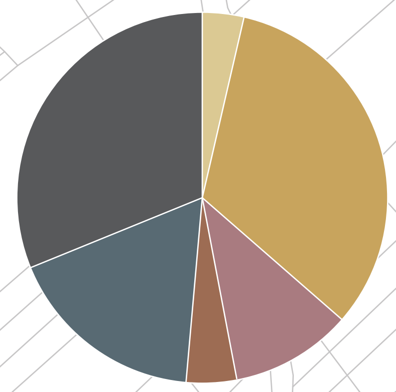
4.13 Post Seismic Damages

Immediately following the 2009 L'Aquila seismic event, the four communities discussed in this thesis of the Baronia collective surveyed the structures within the four separate villages to determine the post-seismic damages. These damages have been defined to four different levels. These include level A,B,C and E. Level A is approximately equivalent to the legal damage level 1, where there is negligible to slight damage. There is no structural damage with limited non-structural damages. Level B and C are approximately equivalent to damage grade 2. This grade includes moderate damage, specifically with slight structural damage and moderate non-structural damage. The final damage category is level E, which is approximately equivalent to damage grade 3. In this case, there is substantial to heavy damage that includes moderate structural damage and heavy non-structural damage. In most cases, these damage assessments are slightly exaggerated. As seen in the attached "Post-Seismic Damages" map of Castelvecchio di Calvisio, the varying degrees of damage are equally spread throughout the historical center and the area outside of the historical center. This implies that there is no terrain feature in the area that amplifies the force of a seismic event. There was no major structural damages that need to be noted. It however is important to note the vast amount of structure categorized as sustaining level E damage. More than 49% of the 278 buildings within the village sustained level E damage. Very few structures were categorized as sustaining damage levels B and C. The remainder of the village, 40 percent of the structures, were including in the category of level A damages. It is also important to note that a large amount of the structures within the historical center were considered to have level E damages.

Table 4.14 Post-Seismic Intervention Priorities

KEY:

- Priority 3b
- Priority 3a
- Priority 2
- Priority 1c
- Priority 1b
- Priority 1a



- Priority 3b: 12 Total (4%)
- Priority 3a: 87 Total (31%)
- Priority 2: 33 Total (12%)
- Priority 1c: 14 Total (5%)
- Priority 1b: 52 Total (18%)
- Priority 1a: 80 Total (30%)

Total Buildings: 278

Priority 3b (Lowest Priority)
Aggregates comprised of only dilaped buildings or buildings damaged before the recent seismic event

Priority 3a (Low Priority)
Aggregates not entered in the following priorities

Priority 2 (Low Medium Priority)
Aggregates with primary residences inhabitable
Isolated Buildings

Priority 1c (High Medium Priority)
Aggregates with primary residences tha does not obstruct the major road system

Prioruty 1b (High Priority)
Aggregates with primary residences inhabitable
Immediate Post-Seismic Damage Level B-C-E

Priority 1a (Highest Priority)
Aggregates with primary residences uninhabitable with easy work availability
Immediate Post-Seismic Damage Level E

Comune: Castelvecchio di Calvisio
Post-Seismic Intervention Priorities

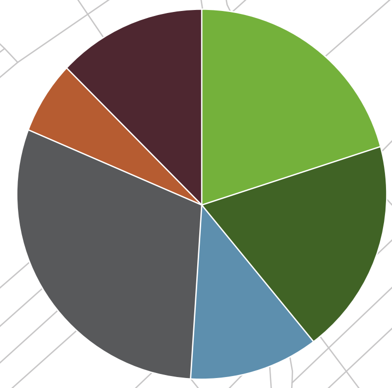
4.14 Post Seismic Priorities

Immediately following the post-seismic damage assessment, the villages of the Baronia collective defined post-seismic priorities regarding the location of possible interventions. These priorities have been localized by aggregates and not individual buildings. The highest priority is given to more severely damaged structures in the historical center. The remainder of the aggregates have been given a priority of 1a, 1b, 1c, 2, 3a and 3b. The priority rating of 1a is the highest priority while 3b is the lowest. The priorities relate roughly to the post-seismic damage assessment. The area with dispersed higher damages have been given the highest priority. This is specifically the case of the aggregate contained within the historical boundary wall. The aggregates have been divided between the six separate priority levels. It is important to note that these priority levels due not consider the habitation of the structures in question, which will be taken into consideration in the following section 4.15, vulnerability conclusion.

Table 4.15.1: Vulnerability Conclusion

KEY:

- Priority 6
- Priority 5
- Priority 4
- Priority 3
- Priority 2
- Priority 1



Priority 6 (Lowest Priority)
NOT CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 5
NOT CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 4
CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 3
CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 2
INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

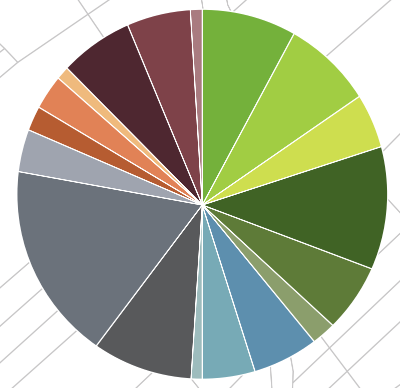
Priority 1 (Highest Priority)
INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Comune: Castelvecchio di Calvisio
Vulnerability Conclusion

Table 4.15.2: Vulnerability Conclusion

KEY: (TOTAL)

Priority 6a (25)	Priority 6b (22)	Priority 6c (12)
Priority 5a (38)	Priority 5b (17)	Priority 5c (5)
Priority 4a (11)	Priority 4b (11)	Priority 4c (3)
Priority 3a (25)	Priority 3b (49)	Priority 3c (8)
Priority 2a (7)	Priority 2b (9)	Priority 2c (2)
Priority 1a (17)	Priority 1b (15)	Priority 1c (2)



Priority 6 (Lowest Priority)
NOT CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 5
NOT CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 4
CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 3
CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 2
INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 1 (Highest Priority)
INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Comune: Castelvecchio di Calvisio
Vulnerability Conclusion

4.15 Vulnerability Conclusion

4.15.1 Overall Vulnerability Conclusion

The vulnerability conclusion is a cumulative result of the previous fourteen sections of analysis. However it is important to note that these conclusions have been based strongly on four separate analyzed factors, all of which have been previously discussed in the Castel del Monte analysis. These factors have then been subdivided to include a more complete and thorough conclusion to the vulnerability of all of the structures within this village.

The first and most important factor, when determining the vulnerability and therefore priorities within the aggregate, is the inhabitation of the individual structures and aggregates. When considering anti-seismic design and post-seismic structural interventions, both permanent and temporary, the two goals should be to protect both cultural patrimony and human life. While both are essential when protecting a village, such as Castelvecchio di Calvisio, human life should always be given the highest priority. Therefore when considering the six final priority levels to be introduced in this section, the first two priority levels are reserved solely to inhabited structures and the third and fourth priority levels are reserved for structures within the near vicinity or within the aggregate of an inhabited structure.

The second most important factor considered when determining the vulnerability of the aggregate is the collective structural homogeneity of each aggregate and structure. This analysis, as previously discussed, has been determined through the collective evaluation within an aggregate of the building typologies, orientations to the elevation curves, building heights and masonry typologies present. While the cause of potential collapse mechanisms during a seismic event varies, at the foundation of all of these causes is a lack of homogeneity. This lack of homogeneity can be seen in plan, elevation, masonry composition, distribution of stresses, etc. This lack of homogeneity, either in separate elements or factors, or as a whole can lead to collapse mechanisms such as hammering, out of plane wall overturning, torsion and many more. This information was therefore used as a primary source when considering the vulnerability conclusion of each aggregate.

The third and last important factor considered was the existing vulnerability of the aggregate, based on both the post 2009 seismic damages as well as the presence of permanent structural interventions such as tie rods and buttresses. The existing damages imply an inherent vulnerability as well as a need for immediate interventions. Therefore this factor is considered crucial when determining the level of vulnerability in an aggregate. In addition, buildings with existing permanent structural interventions are better protected than those without and therefore are noted in order to diminish the vulnerability priority of an aggregate with these types of interventions present. It is the presence of post-seismic damages and permanent structural interventions that determine the subcategories within the previously mentioned six priority levels.

Each of the six priority levels are split into three separate subsections, which are described on the attached vulnerability conclusion maps. The first subdivision, for all six priority levels, is of the highest priority because it is reserved for structures with post-seismic damages as well as a lack of permanent structural interventions. The second subdivision is for buildings with either no post-seismic damages but a lack of permanent interventions, or with post-seismic damages but with permanent interventions. The third and final subdivision is only for buildings with no post-seismic damages and that also have permanent interventions in place. These structures, within any of the six major priority levels, is considered to be of little priority and requires only observational on-site analysis to determine the extent of the vulnerability, which is presumably minimal. However all structures within the first two subcategories of the six priority levels require more thorough analysis to determine the amount of restoration interventions needed.

In the following sections, specific examples of these vulnerability levels will be discussed. These examples come from aggregates and structures within the higher priority levels. These examples will be used to better describe the priority categories as well as to showcase what higher priority structures are like. This will aid in determining what type of restorative efforts may be necessary for the higher priority aggregates. It is important to note however that these priority levels do not inherently mean there is a need for restoration, but instead they imply the likeliness that

structural interventions are necessary. Each aggregate and building should be taken on a case by case basis following additional on-site observation (interior as well as exterior) to determine the exact need of every structure within the priority levels.

4.15.2 Specific Vulnerability Example One

The first example of one of the more vulnerable aggregates is found in the heart of the historic center, near the San Marco church, specifically in aggregate CvC 1.08. This example, was

Figure 4.117 Aggregate CvC 1.08

Figure 4.118 Aggregate CvC 1.08

also chosen as one of the previously discussed negative examples. This example has been chosen for several reasons. First and foremost, this aggregate was chosen due to the fact that one of the five

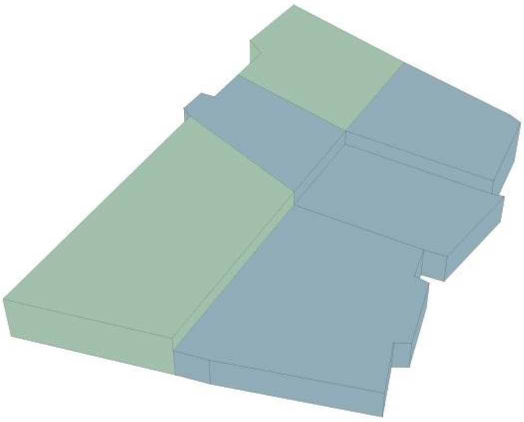


Figure 4.119 Aggregate CvC 1.08 Model

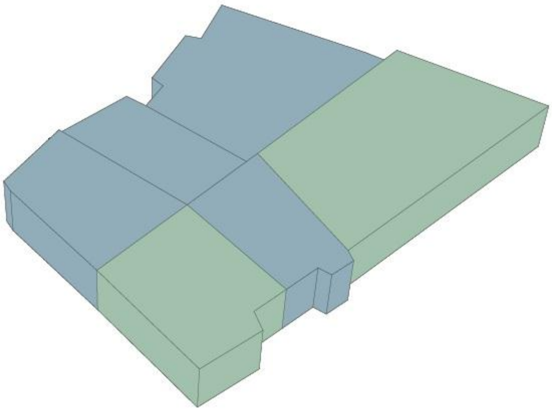


Figure 4.120 Aggregate CvC 1.08 Model

structures are currently inhabited. In addition, as previously mentioned, this aggregate has been determined to be negative regarding its collective homogeneity. As seen in the models above, the aggregate is extremely irregular regarding masonry typology composition and also has a ruin within the aggregate as seen in figures 4.117 and 4.118. There were also damages in the aggregate after the 2009 L'Aquila seismic event and not all of the structures within the aggregate have permanent structural interventions in place. As seen in figuree 4.118, there is also irregularity in both additions to the structures as well as openings. Openings have been placed too close to structural elements such as the roof or corners. It is also important to note the extreme changes of the aggregate over time, with elements of different masonry composition, has contributed to the determination of this particular aggregate as a high priority level. Regarding a future for this aggregate, there are several restoration options available. First and foremost, additional permanent and temporary structural interventions need to be added to better control the reactions between the irregular units within the aggregate. These interventions should specifically be placed in vulnerable areas such as fulcrum points between two attached structures of different height. In addition, any damages sustained during the most recent seismic event of 2009 need to be thoroughly analyzed and resolved to better protect the inhabitants of the aggregate. It is also extremely important to resolve the existing within the aggregate due to its possibly negative effect on the surrounding structures as well as the threat it poses to the current inhabitants of both the specific aggregate as well as of all of Castelvecchio di Calvisio. This aggregate also maintains "sporti" and arch connections to separate aggregates which can create partial damage to adjacent aggregates if not properly maintained, as they aren't now.

4.15.3 Specific Vulnerability Example Two

The second example of a high priority structure is found in the historical center, specifically in aggregate CvC 1.15. This aggregate has been chosen for several reasons, the first of which is that five of the nine structures within the aggregate are currently inhabited. In addition, as previously mentioned, the aggregate has been considered be negative regarding its overall collective homogeneity. This particular aggregate is extremely irregular in both masonry typology composition and the building heights of the individual units within the aggregate. The aggregate is also irregular in

Figure 4.121 Aggregate CvC 1.15

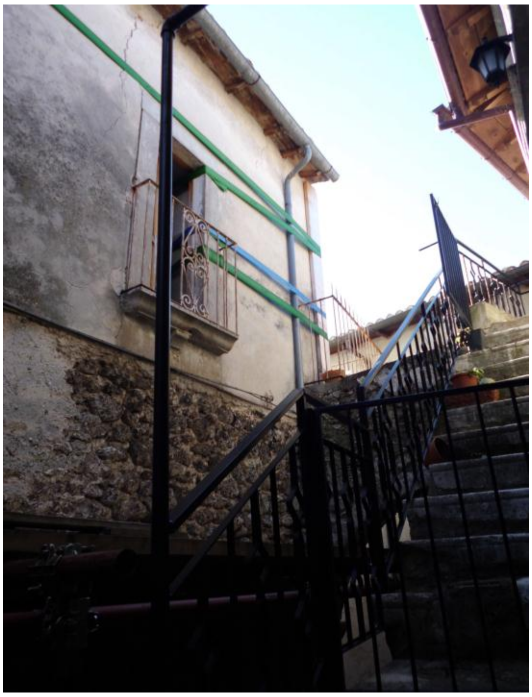


Figure 4.122 Aggregate CvC 1.15

both plan and elevation. There were also extensive damages in the aggregate after the 2009 L'Aquila seismic event and not all of the structures within the aggregate have permanent structural

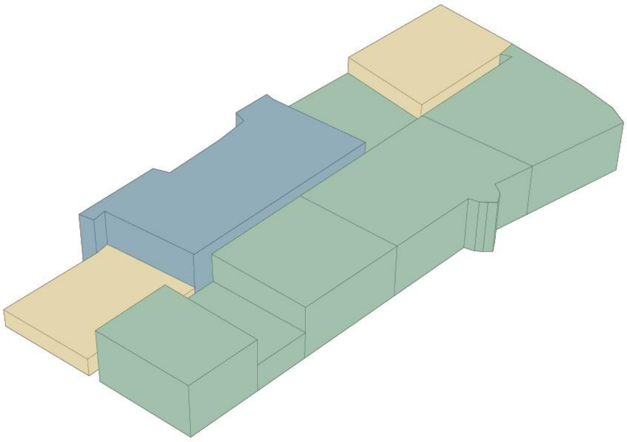


Figure 4.123 Aggregate CvC 1.15 Model

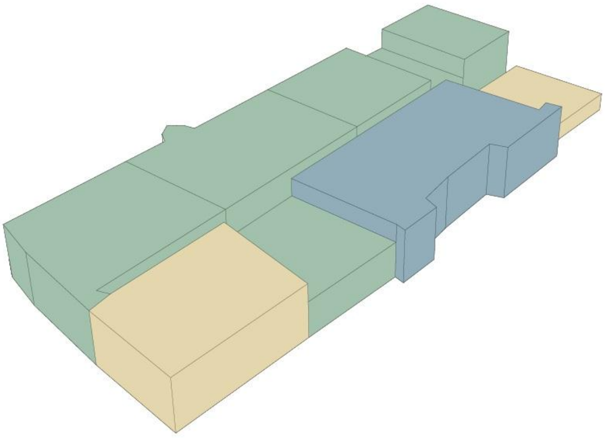


Figure 4.124 Aggregate CvC 1.15 Model

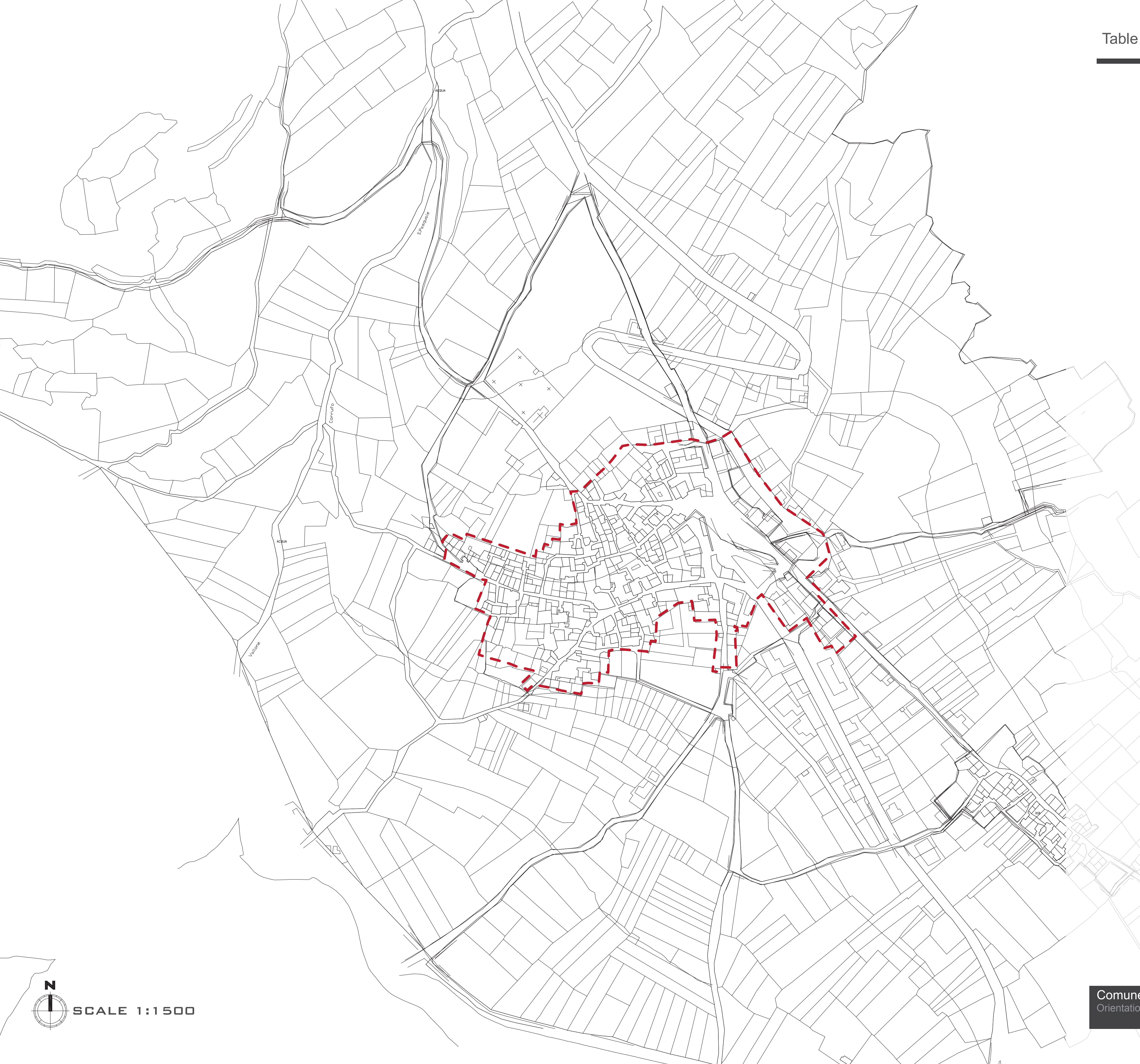
interventions in place. Regarding a future for this aggregate, there are several restoration options available. Additional permanent and temporary structural interventions need to be added to better control the reactions between the irregular units within the aggregate. These interventions should specifically be placed in vulnerable areas such as fulcrum points between two attached structures of different heights or between buildings of different masonry composition. In addition, any damages sustained during the most recent seismic event of 2009 need to be thoroughly analyzed and resolved to better protect the inhabitants of the aggregate.

4.16 Conclusion

While the earthquake of April 2009 in L'Aquila resulted in little to no major structural damages in Castel del Monte, the seismic event should be utilized as a reminder of the vast vulnerability of masonry structures within the historical center. The village is the second most vulnerable of those discussed within this thesis. This is due in part to more structures with existing post 2009 seismic minor damages. Few of the structures have permanent structural interventions in place, which has led to the increased damages. The village is still in dire need of additional reinforcements as well as seismic retrofitting measures. It is important to note that the higher priority structures within the village are located almost exclusively within the ancient historical center. This distribution requires additional analysis, both interior and exterior, to better determine the aggregates that are the most deserving of the limited public funds available for restoration. An initial visual analysis should be the first step of any restoration process, followed by more invasive analysis to determine the structural vulnerability of the masonry elements. Finally the most vulnerable aggregates should be prepared for restorative efforts as soon as possible, in order to protect the existing population.

While restorations are costly efforts, they are always the most economical choice over the reconstruction of structures damaged or destroyed after a major seismic event. Now is the time to protect both the architectural patrimony and populations of the village of Castelvecchio di Calvisio, as well as the rest of the Baronia collective. More specifically, time between seismic events, such as now following the 2009 earthquake, is the opportune time to analyze the existing architecture, regarding collective homogeneity, structural vulnerability and building inhabitations to be better prepared for the next seismic event to come. Any analysis completed now can be utilized in both immediate earthquake aftermath, regarding finding citizens who may be hurt, as well as in the long term aftermath, regarding which structures are more dangerous and should remain vacant until restoration efforts can ensure the safety of the building's inhabitants during a seismic event.

Table 5.1.1 Orientation to Overall Elevation



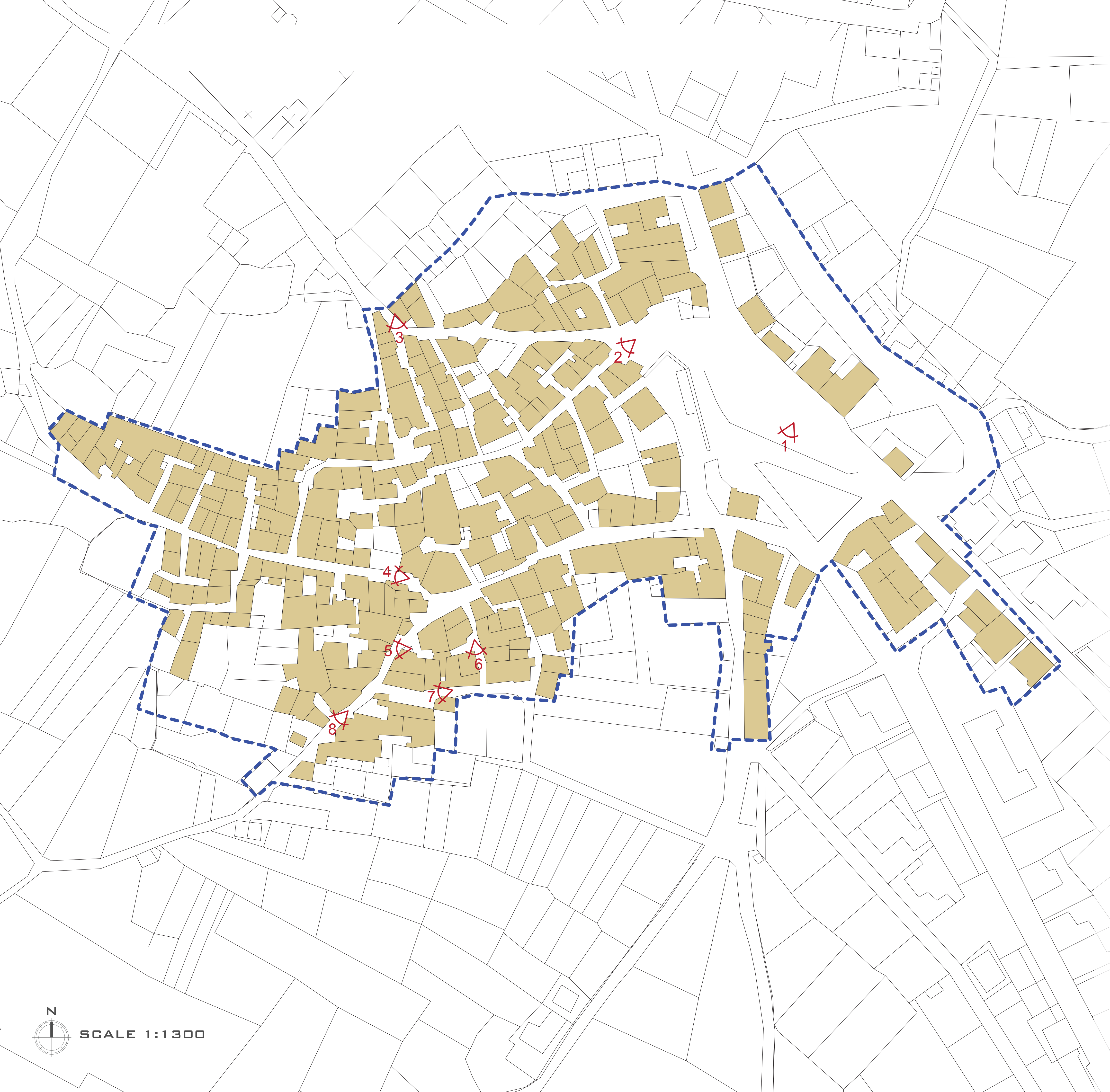
Comune: Villa Santa Lucia degli Abruzzi
Orientation to Overall Elevation

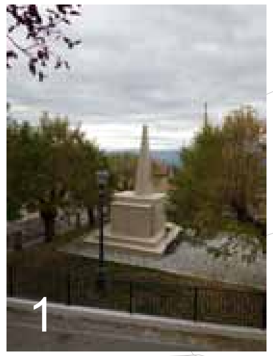
Table 5.1.2 Photographic Introduction

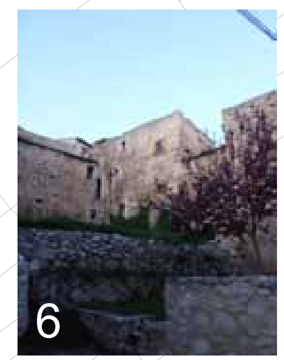
KEY:

Location of Photograph

Site Boundary







Comune: Villa Santa Lucia degli Abruzzi

Photo Introduction

Table 5.1.3 Aggregate Locations

KEY:

Buildings

Aggregate Boundaries

DEFINITION:

An aggregate is made of one or more houses that are separate houses that are joined together to make a whole, single unit.

PHOTO EXAMPLES:

Aggregate VSL 012

Aggregate VSL 003

FACTS:

Total Number of Aggregates:	52
Total Number of Churches:	1
Total Number of Municipalities:	0
Total Number of Towers	0

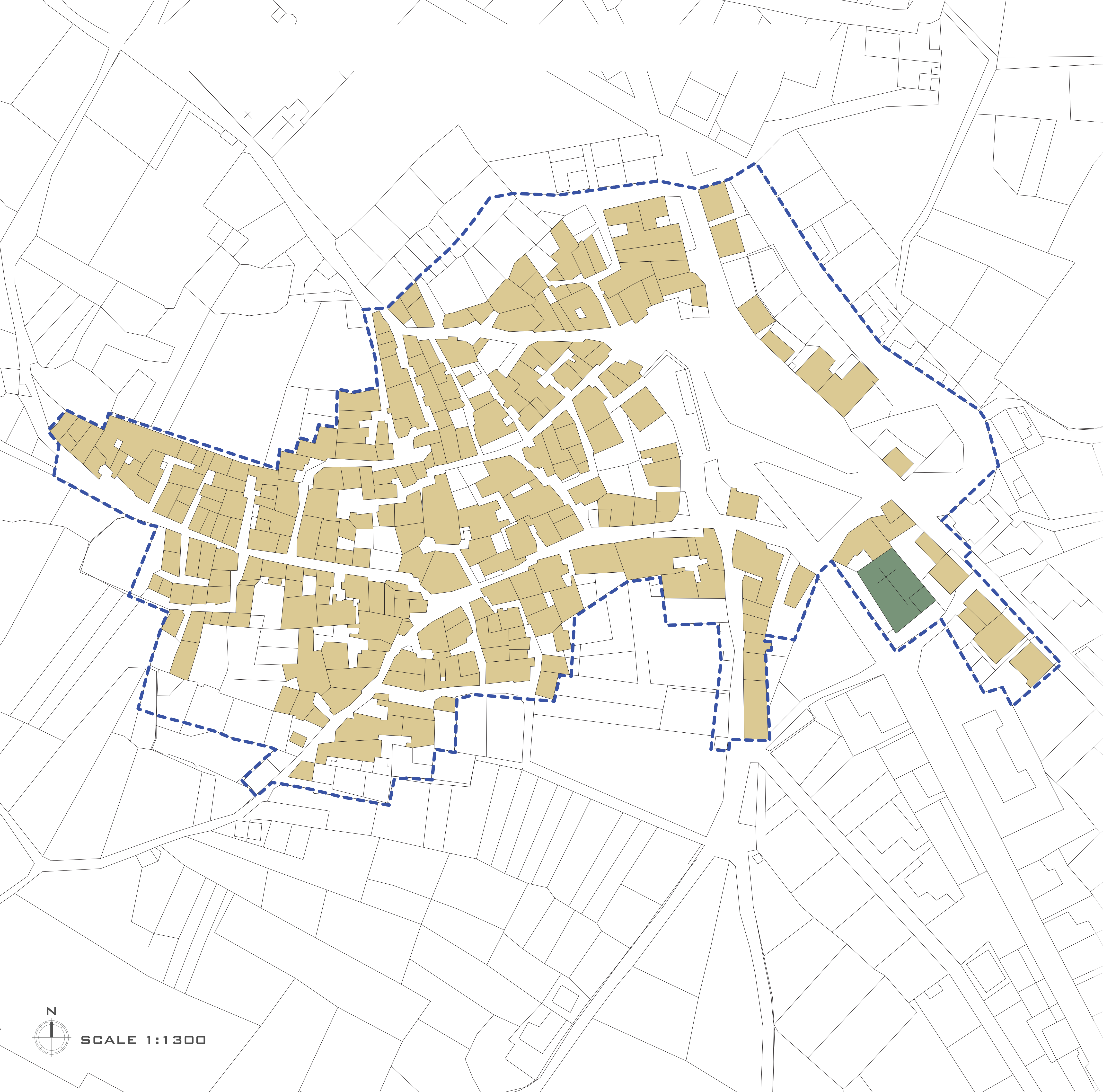
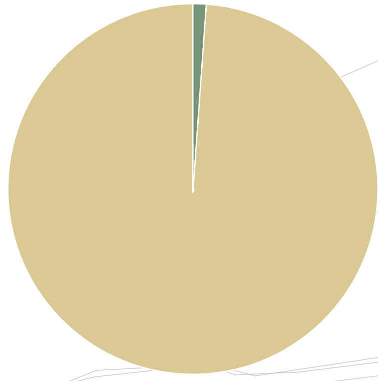


Table 5.1.4 Pre 2009 Seismic Building Uses

KEY:

- Private Property Buildings
- Public Property Buildings



EXAMPLES:

Public Use Building Types
-Church (Above left and right)

Private Use Building Types
-Uninhabited Residence (Above left)
-Inhabited Residence
-Uninhabitable Residence (Above right)

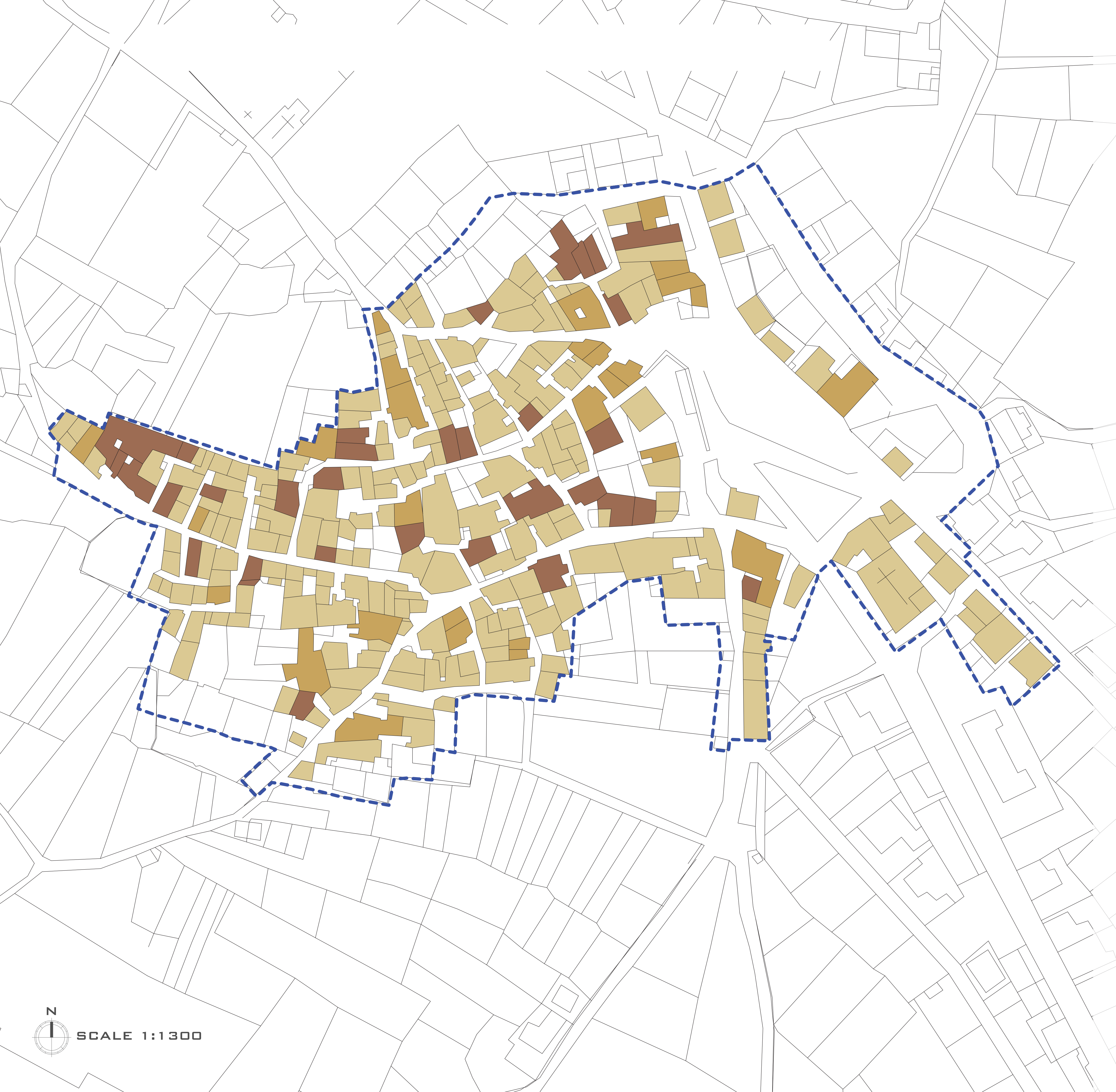
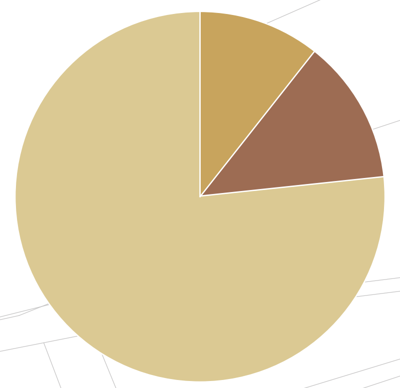


Table 5.1.5 Building Inhabitation

KEY:

- Uninhabited Building
- Inhabited Building
- Uninhabitable/Ruined Building



DEFINITIONS:

Uninhabited Building

Building that may or may not be in use, but is currently uninhabited. These may imply a public use building or one that is not lived in full-time.

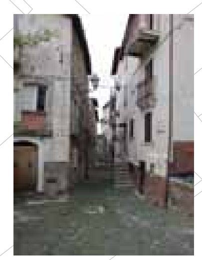
Inhabited Building

Building that is currently being lived in and is therefore a priority regarding the restorative efforts, along with public use buildings.

Uninhabitable Building

Building that is in ruins, crumbling or structurally instable and therefore uninhabitable. These building are crucual to the restoratvie effort if their structural instability can damage adjacent buildings or create significant damages in the case of a future seismic event.

EXAMPLES:



Uninhabited Building Example

These are a few of the uninhabited buildings in the village center. They were once inhabited in the past but are now currently uninhabited.

Uninhabitable Building Example

This is a clear example of one of the many uninhabitable buildings within Villa Santa Lucia degli Abruzzi. The building has obvious exterior damage and is therefore considered unlivable.

5 VILLA SANTA LUCIA DEGLI ABRUZZI

5.1 Introduction:

The hillside village of Villa Santa Lucia degli Abruzzi, with a population of 174 people, is located just beneath the Gran Sasso mountain within the National Park of the Gran Sasso mountain. The village is currently a member of the Baronia political collective, which includes the three previously mentioned villages as well as several others. The village is sprawling in nature and is the lowest, regarding sea level, of the four villages presented in this thesis.

Figure 5.1 View of Villa Santa Lucia degli Abruzzi (Provided by the University of Padova)

The villages, similar to the rest of the Baronia collective, maintains a rich history. The occupation of this area dates as far back as the tenth to fourth century BC. The village known today would not be settled until 775 AD, when warrior King Desiderio reached the area known, at that time, as Villocchera. King Desiderio would eventually settle there along with his troops. From 950 until 1000, Cillocchera expanded and changed its name first to Villa and then to Villa Santa Lucia. The village would continue to grow in population until the end of the 19th century and beginning of the 20th century. During this time period, a large amount of the population began to emigrate to other countries, such as the United States and Canada, due to the first war as well as a lack of work. Still today, the population's economy is dependent on agriculture and pastoral goods, as well as the production of oil, wine and wheat. In the village's past, the economy was also heavily dependent on the manufacturing of charcoal In addition, due to the village's location within the Baronia collective, the economy has benefited from tourism as well.

The most recent earthquake of 2009 in L'Aquila effected the village but led to no major structural damages within the commune. However due to the high risk of seismic events in the region of Abruzzo, Villa Santa Lucia degli Abruzzi, along with all of the Baronia village communities have begun restorative analysis, along with the University of Padova. The goal of this analysis is to prioritize the structural vulnerabilities within the historical center in order to afford the best best possible use of the limited public resources available for seismic retrofitting. This retrofitting will be aimed at respecting the existing structural typology in order to avoid compromising the structural stability further. However due to the lack of available funds, strong consideration is being given to areas of the historical area that are inhabited or commonly used by the existing population of Villa Santa Lucia degli Abruzzi. Seismic events have occurred in this area repeated since its initial settlement and will continue to do so for the foreseeable future. Thus now is the time to protect both the cultural patrimony and lives present in the village of Villa Santa Lucia degli Abruzzi, before future seismic events make that impossible.

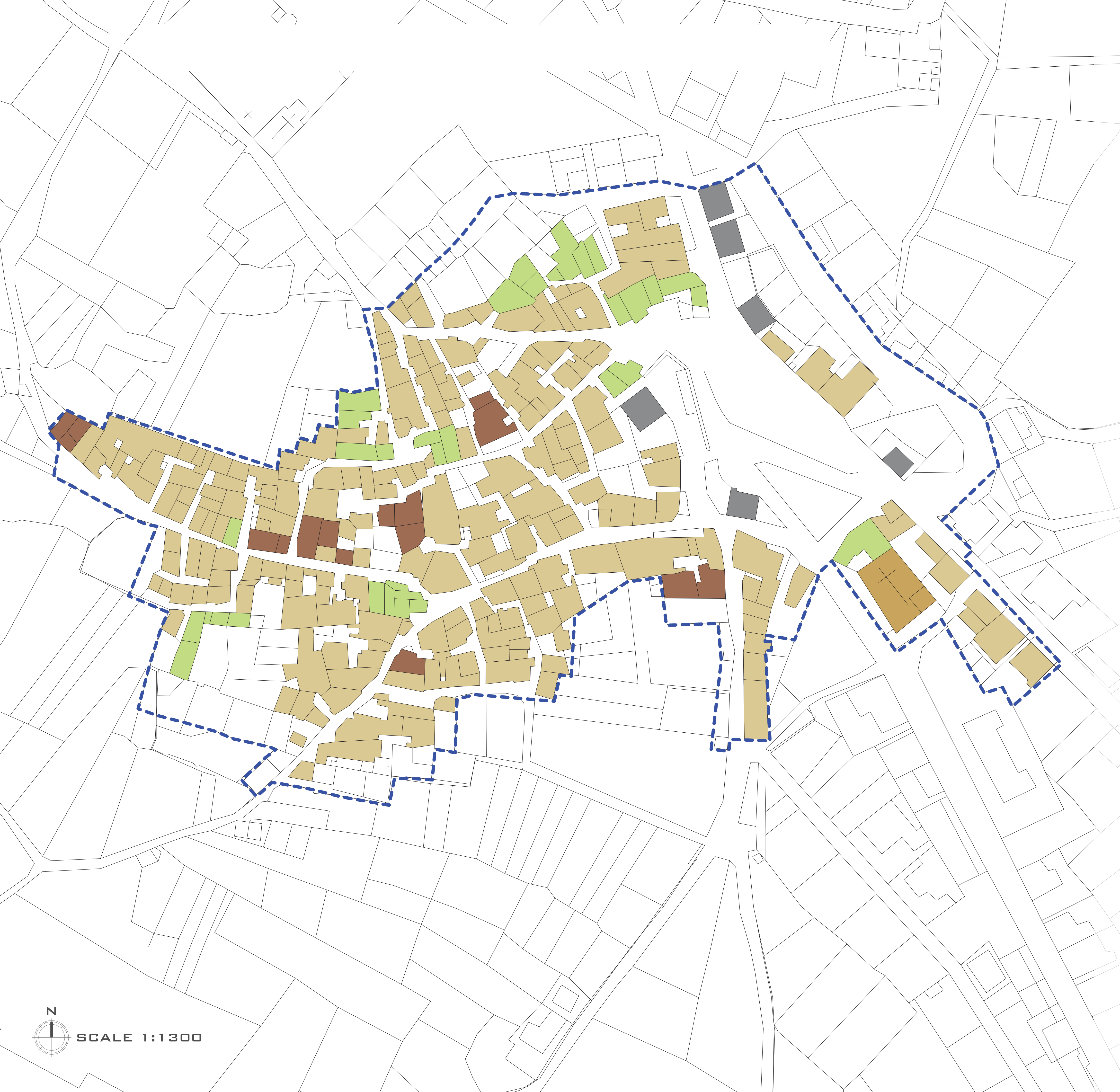
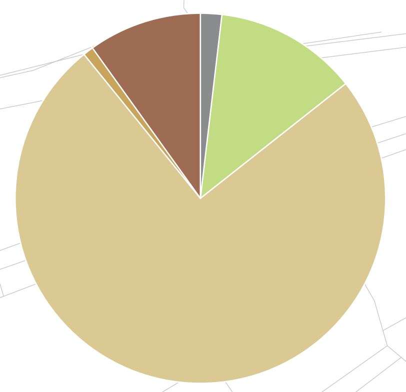


Table 5.2 Building Typology

KEY:
- Line House
- Block House
- Tower House
- Buidling Oriented Perpendicular to the Elevation Curve
- Building Oriented Parallel to the Elevation Curve
- Religious Building
- Ruins



Line House:
0 Total (0%)

Block House:
6 Total (2%)

Tower House:
0 Total (0%)

Perpendicular:
34 Total (12%)

Parallel:
211 Total (79%)

Religious:
1 Total (.5%)

Ruins:
16 Total (6.5%)

Total Buildings: 268

Line House
Row of houses, oriented in a line

Block House
Single builings, unattached to other buildings

Tower House
Building significantly taller than all buildings it touches

Buidling Oriented Perpendicular to the Elevation Curve
Building Unit set in a row, perpendicular to the elevation curve (partially underground with a rock foundation)

Building Oriented Parallel to the Elevation Curve
Building Unit set in a row, parallel to the elevation curve (partially underground with a rock foundation)

Religious Building
Any religious based building such as a church or convent

Ruins
Any building with significant damage to the point of being uninhabitable

Comune: Villa Santa Lucia degli Abruzzi
Building Typology

5.2 Building Typology

5.2.1 Building Oriented Parallel to the Elevation Curves

The first and most common of the building typologies present in Villa Santa Lucia degli Abruzzi are buildings oriented parallel to the elevation curves. This is also the most common of the building typologies in all of the four villages of the Baronia collective presented in this thesis. 211 of the 268 buildings within Villa Santa Lucia degli Abruzzi are within this building typology category. This building typology therefore makes up 79 percent of the buildings within the village. This typology is distributed throughout the entire village. On-site analysis has revealed that many ruins within the Baronia collective were originally buildings oriented perpendicular to the elevation curves. While this is soley a tendency, it is important to note. In general, these structures vary in masonry typology, building heights, and general construction type. However their similar parallel orientation to the elevation curves is important because when located within a single aggregate, it is important that structures be oriented evenly across the aggregate regarding the elevation curves.

Figure 5.2 Building Oriented Parallel to the Elevation Curves

Differing orientations can lead to several collapse mechanisms, most commonly out of plane wall overturning. In the case of aggregates lacking in homogeneity regarding the orientation of the individual structure, additional connections between these structures as well as permanent interventions are needed in order to counteract these potential collapse mechanisms. Due to commonness of this building typology, it is difficult to characterize their other structural qualities. For structures and aggregates within this particular typology, it therefore becomes essential, when analyzing collective homogeneity, to emphasize the consideration of the two other major structural qualities; masonry typology and building heights within the aggregate. It is also important to note if a structure is oriented perfectly to the elevation curves or at an angle. When oriented at a large angle, the force of torsion acting on the structure is increased and is likely to increase several collapse mechanisms or induce collapse with this force alone, if strong enough.

5.2.2 Buildings Oriented Perpendicular to the Elevation Curves

While buildings oriented perpendicular to the elevation curves are present in all of the villages within the Baronia collective, they are typically a small percentage of the buildings within the village. This is the case in Villa Santa Lucia degli Abruzzi. Of the 268 buildings within the village, only 34 are categorized within this building typology. This typology therefore makes ups 12 percent of the total buildings within Villa Santa Lucia dfegli Abruzzi. The location of the these buildings is throughout the village, with a slight concentration in the historical center. As noted in the previous section 5.2.1, after thorough on-site analysis in four of the villages of the Baronia collective, a connection between buildings oriented perpendicular to the elevation curves with partially or completely collapsed structures has been observed. While this is just an on-site observation, it is important to note that perpendicularly oriented structures are in the minority within hillside historical centers of Abruzzo, specifically in the villages of the Baronia collective. Despite the connection made between ruins and structures oriented perpendicular to the hillside, these structures are only considered structurally vulnerable when places within an aggregate with structures oriented parallel to the elevation curves. Buildings under these two conditions react structurally in very different ways during a seismic event. Thus the combination of these two buildings within an aggregate can induce several collapse mechanisms, the most likely

Figure 5.3 Perpendicular Orientation

Figure 5.4 Perpendicular Orientation

of which is hammering. This is the case in several aggregates within the historical center of Villa Santa Lucia degli Abruzzi. These damages along with out of plan wall overturning can be diminished through the strategic use of permanent structural interventions, such as tie rods and exterior buttresses.

5.2.3 Block Houses

The presence of block houses are scattered in the Baronia collective, seen in all four of the communities discussed in this thesis except Castelvecchio di Calvisio. The block houses in Villa Santa Lucia degli Abruzzi however are located within the same area, in the heart of the historic center of the village. Out of the 268 buildings present in the village, only 6 have been categorized in this particular building typology. This typology therefore makes up only 2 percent of the buildings within Villa Santa Lucia degli Abruzzi. These structures tend to be either governmental or private

Figure 5.5 Block Houses

residential use. Structurally speaking, block houses are dependent solely upon themselves. Similar to isolated towers, these structures are separate from any aggregate structure and therefore many of their characteristics are negligible. For example, their orientation to the elevation curves can be considered of little structural significance unless the structure is oriented to the elevation curves can be considered of little structural significance unless the structure is oriented at an angle to the surrounding typography. The height of block houses can be important in the case of a tower-like structure due to the period of movement in the case of a seismic event. The most structurally notable characteristics in all cases of block houses is therefore the masonry typology, specifically the homogeneity of the masonry composition. As seen in the composition of aggregates within the Baronia collective, structural additions and renovations are commonly present in block houses as well. These modifications to the original structure are integral to the stability of the overall structure. These changes should respect the existing structure and most importantly, the existing structural dynamics. Improper modifications can lead to soft story failure, out of plan wall overturning or increase the effects of forces of torsion and shear failure.

5.2.4 Churches or Religious Structures

There is only one church or religious structure present in Villa Santa Lucia degli Abruzzi, which is located on the edge of the historical center. This example is found in aggregate VSL 012. This particular church is extremely regular in plan but irregular in elevation. Similar to many churches within the region of Abruzzo, this church, although constructed with higher quality materials, is extremely vulnerable to seismic activity. The addition of several temporary structural interventions supports this claim. Renaissance or Roman churches are characterized by changing heights and volumes of varying sizes and shapes. In addition, they are popular in use fue to their cultural and societal importance within Italy. Despite their higher construction, as is the case of thisparticular church, permanent structural interventions are recommended in order to minimize damage to the cultural patrimony of the village as well as to minimize the casualties in the case of the next seismic event to come. As seen in figure 5.6 and 5.7, there are permanent structural interventions in place. However the additional of post-seismic temporary structural interventions implies a need for additional permanent interventions such as tie rods or exterior buttresses Luckily this church has a rectangular and regular façade, which can help to minimize the common out of plane wall overturning in church facades.

Figure 5.6 Church of Aggregate VSL 012

Figure 5.7 Church of Aggregate VSL 012

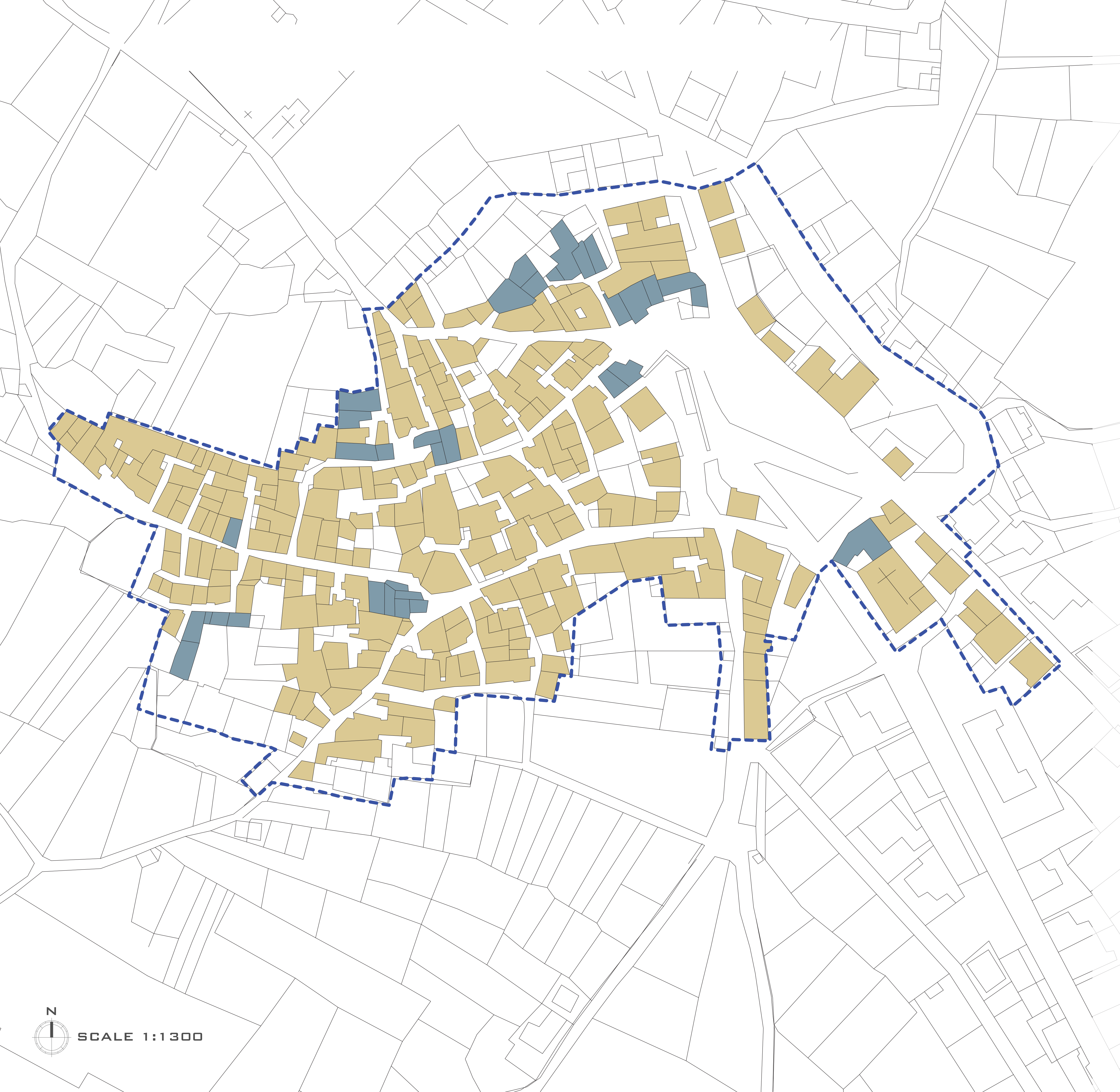
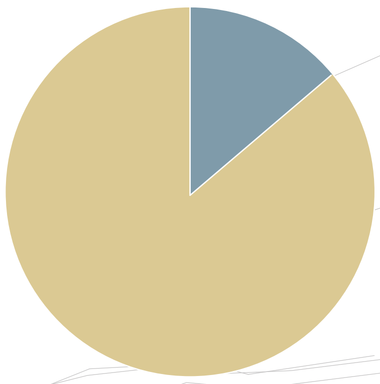


Table 5.3 Building Orientation to Elevation

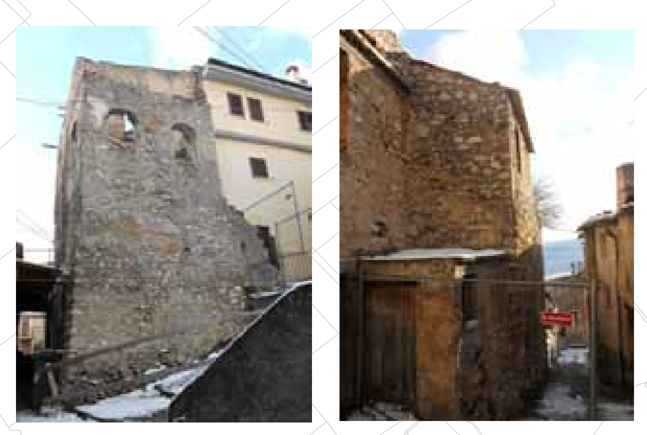
KEY:

- Building unit positioned parallel to the elevation curves
- Building unit positioned perpendicular to the elevation curves



EXAMPLES:

PARALLEL
These building units are positioned parallel to the elevation curves



PERPENDICULAR
These building units are positioned perpendicular to the elevation curves

Comune: Villa Santa Lucia degli Abruzzi
Building Orientation to Elevation Curves

5.3 Orientation to Elevation Curves

As thoroughly discussed in the building typology sections 5.2.1 and 5.2.2, the orientation of a group of connected structures, such as an aggregate, is extremely important to the overall structural stability of each of the individual structures. The orientation of a structure to the overall elevation curves can greatly affect the force of torsion or possible collapse mechanisms of out of plane wall overturning. Although not seen in Villa Santa Lucia degli Abruzzi, structures oriented at an angle to the elevation curves are extremely vulnerable to the force of torsion and can experience several structural failures due to this force. All of the structures within Villa Santa Lucia degli Abruzzi have been divided into two different categories regarding their orientation to the overall elevation curves; parallel or perpendicular. While both orientations are structurally acceptable, it is their combination within a single aggregate that makes a structure vulnerable to several collapse mechanisms.

Of the 268 structures present in Villa Santa Lucia degli Abruzzi, 234 of these buildings are oriented parallel to the elevation curves, which makes up for 87 percent of the buildings within the village. This is highly important because this minimizes the mixing of two different orientations to the elevation curves in a single aggregate. Within the entire village, 34 structures are oriented perpendicular to the elevation curves. In only seven aggregates is there a combination of both buildings oriented parallel and perpendicular to the elevation curves. Due to the small amount of structures oriented perpendicular to the elevation curves, this particular structural factor is of little concern in Villa Santa Lucia degli Abruzzi. Therefore the remaining three primary structural factors discussed become more important regarding the overall vulnerability of the village.

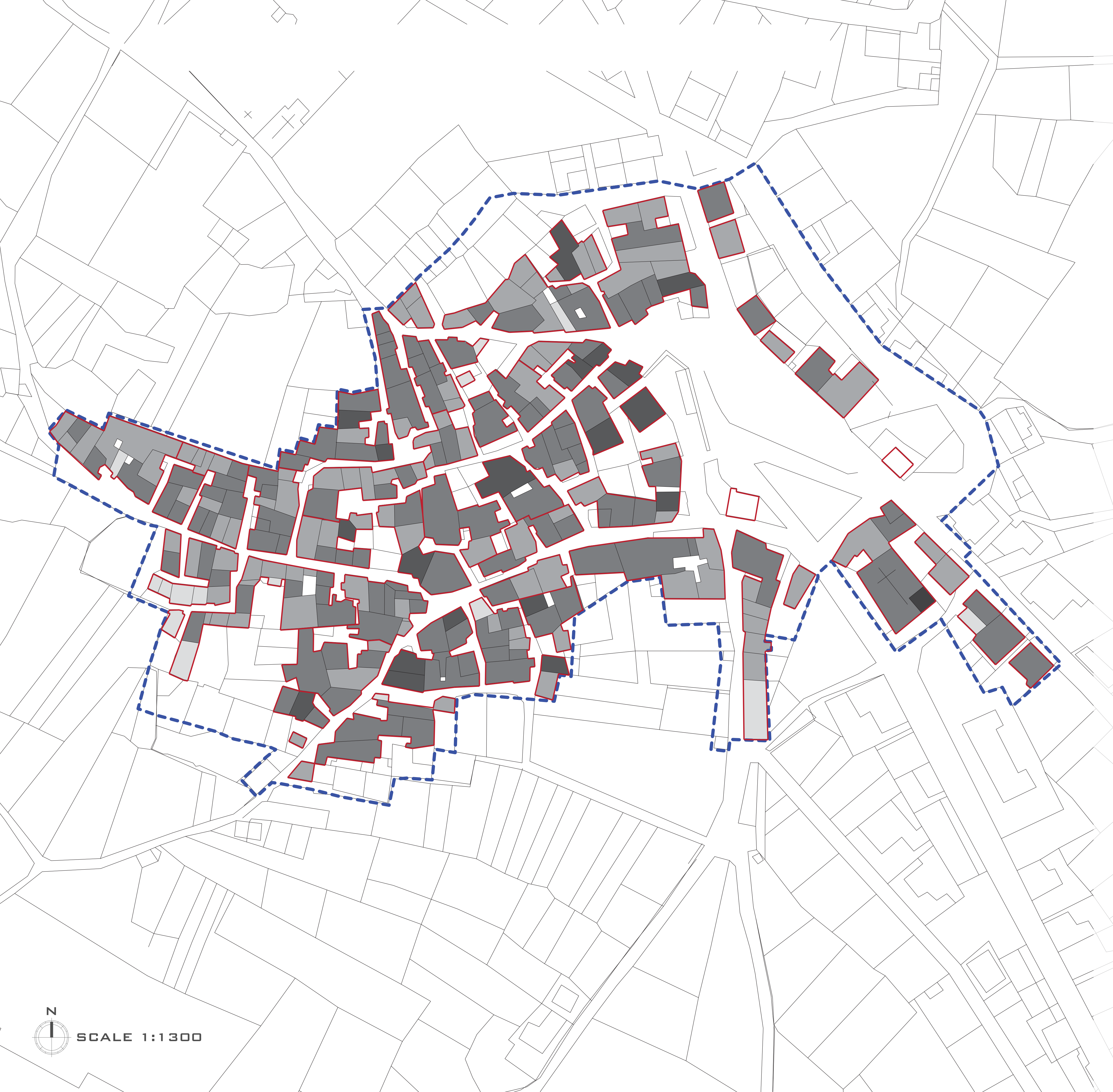


Table 5.4 Building Heights by Aggregate

KEY:

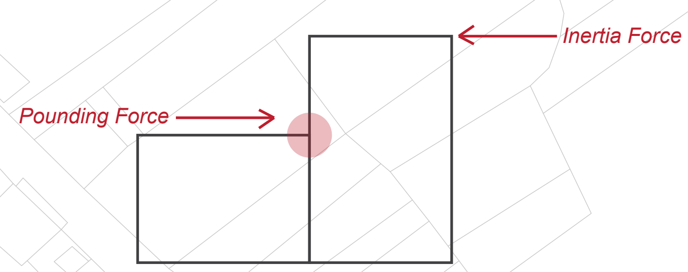
- 5 Floors Equivalent (or above)
- 4 Floors Equivalent
- 3 Floors Equivalent
- 2 Floors Equivalent
- 1 Floor Equivalent
- Aggregate Border

DESCRIPTION:

All building heights indicated on this map are distinguished by aggregate, which is why all heights are “equivalent” and not to be compared between aggregates. These heights are meant to distinguish which aggregates are the most and least homogeneous, regarding building height. Aggregates that are less homogeneous in height are more likely to suffer seismic damage due to pounding, which is described below.

TALLER ADJACENT BUILDING POUNDING:

Pounding is created between two buildings of differing heights due to different moments created in each structure, when they shake due to a seismic force. This creates different dynamic responses in each structure. The point where they meet, the fulcrum point, is the point of the most vulnerability. It is here where most damages can happen. This damage is due to irregularity in elevation, but can also happen between buildings of equal height.



POSITIVE/NEGATIVE EXAMPLES:

Negative Example

Positive Example

5.4 Building Heights

The building heights within Villa Santa Lucia degli Abruzzi is fairly uneven regarding each individual aggregate. There are no tower structures within the village, as noted in 5.2, however several adjacent structures differ in height by more than two stories. The most important differences in heights are located within the heart of the historical center. Outside of the historical center, on the edges of the village, adjacent units rarely differ by more than a story. This homogeneous situation of building heights in aggregates outside the village center limits the potential damage mechanisms due to a lack of homogeneity in building heights, such as hammering and torsion. However in the center of village, these damages become a significant concern regarding the structural vulnerability of the village. As will be seen in the sections 5.8 and 5.9, which include examples of negative and positive homogeneity, the building heights should still be taken into consideration when determining the potential vulnerability of a structure or aggregates in the case of a seismic event. Many of these negative examples are located in the historic center where building heights differ the most.

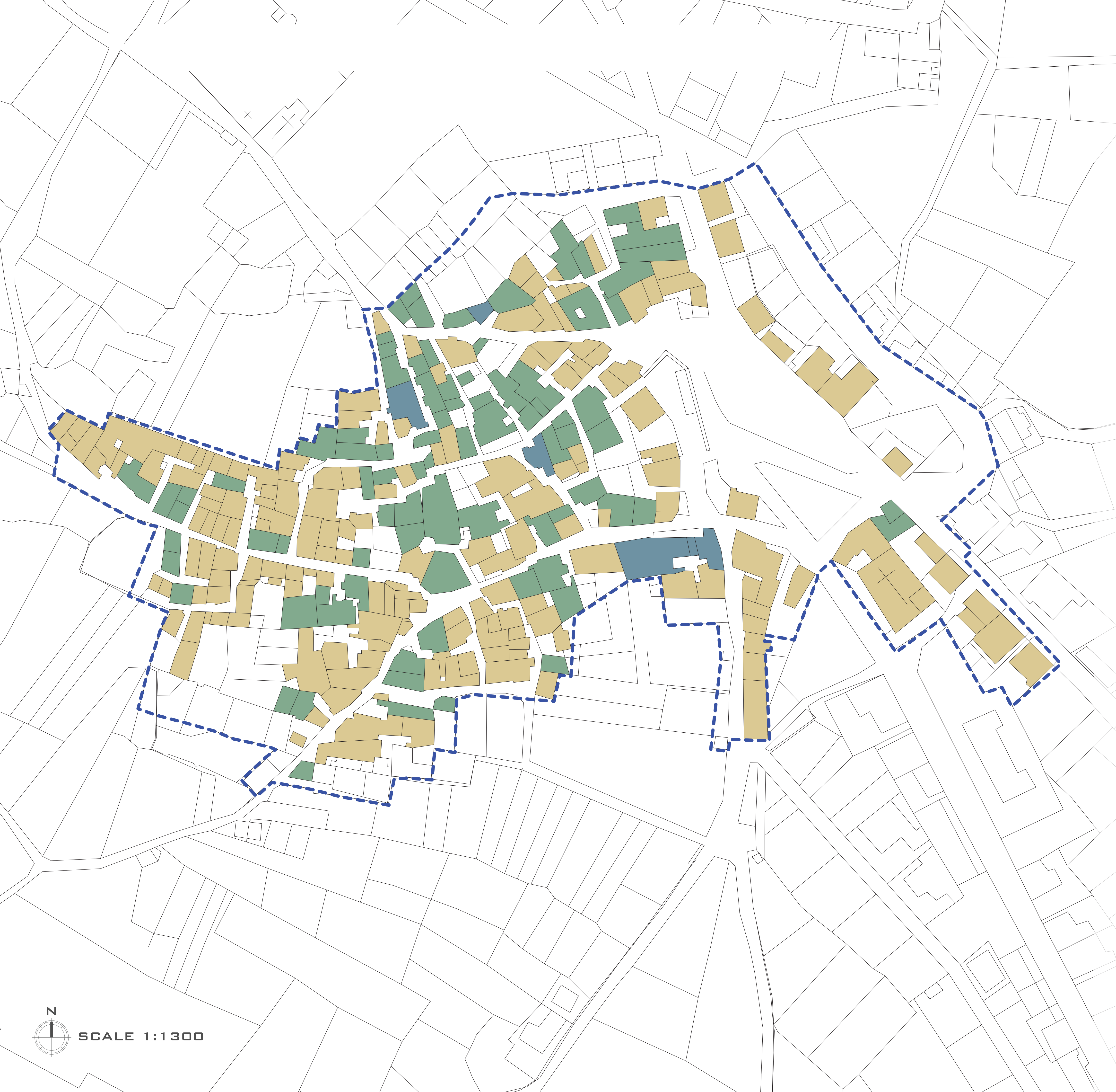
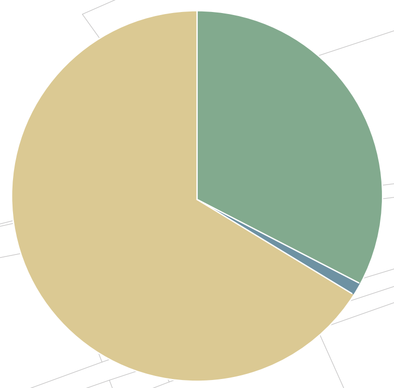


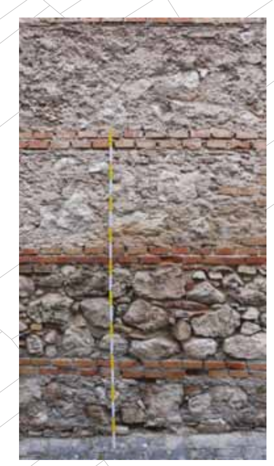
Table 5.5 Masonry Typology

KEY:

- Irregularly formed masonry (regarding shape, dimensions and materials) stone
- Subhorizontal masonry with roughly cut stones (of varying dimensions)
- Horizontal masonry courses with roughly cut stones (well interlocked)
- Plaster Covered



EXAMPLES:

Low Quality


Medium Quality

Comune: Villa Santa Lucia degli Abruzzi

Masonry Typology

5.5 Masonry Typology

Within the analyzed portion of Villa Santa Lucia degli Abruzzi, only three of the previously introduced masonry typologies are present. Masonry typology one, masonry typology two and plaster covered structures are located throughout the entire village. While these three masonry typologies are present in Villa Santa Lucia degli Abruzzi, they are unevenly dispersed through the four building typologies present in the village.

5.5.1 Masonry Typology One

Masonry typology one, defined as irregularly formed masonry stones, regarding shape, dimensions and materials, is the most common masonry typology within Villa Santa Lucia degli

Figure 5.8 Masonry Typology One

Figure 5.9 Masonry Typology One

Abruzzi. This typology, considered to the lowest quality, makes up 31 percent of the 268 structures present in the village. This particular typology is concentrated in the center of the village where it makes up the majority of the buildings. Figures 5.8 and 5.9 are two examples of this particular masonry typology present in Villa Santa Lucia degli Abruzzi. As seen in both examples above, the masonry lacks continuous horizontal bonds and have no visible vertical structural systems. This particular masonry typology is the majority in both Villa Santa Lucia degli Abruzzi and the remainder of the villages discussed in this thesis. Masonry typology one is present within only two building typologies; buildings oriented parallel to the elevation curves and buildings oriented perpendicular to the elevation curves.

The most common combination of masonry typology and building typology is that of masonry typology one within buildings oriented parallel to the elevation curves. The example to be discussed is located within aggregate VSL 005. This particular aggregate is located in the historical center of the village. The aggregate is currently or private use and uninhabited. In addition, the buildings within the aggregate have been uninhabited for a substantial amount of time, which is the case of several structures within Villa Santa Lucia degli Abruzzi. In most cases, structures composed of masonry typology one were originally covered in a plaster covering in order to protect the masonry structure below. As seen in figure 5.11 and 5.12, the masonry typology one in this particular structure was once covered in plaster. However this plaster has almost been completed decayed and therefore the masonry typology below is almost completely revealed. Due to the amount of visible decay both of the masonry stones as well as the

Figure 5.10 Aggregate VSL 005

Figure 5.11 Typology One Parallel

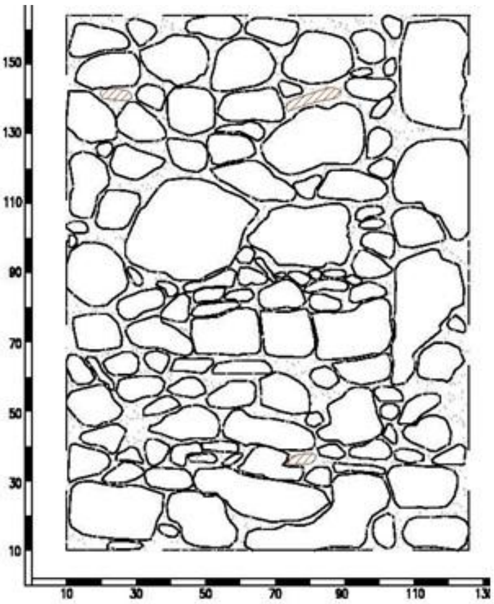


Figure 5.12 Typology One Parallel

mortar, it can be determines that this plaster covering has been absent for a substantial amount of time. This particular example of masonry typology one is unique due to the large quantity of brick pieces among the more substantial masonry stones. However as is to be expected for masonry typology one, there are no distinctive horizontal or vertical structural systems within the masonry, which is what categorizes the masonry as the lowest quality present in Villa Santa Lucia degli Abruzzi. However it is important to note that this masonry has survived several seismic events in its lifetime and can be considered structurally sufficient.

The second and final example of masonry typology one within Villa Santa Lucia degli Abruzzi is seen in the case of a building oriented perpendicular to the elevation curves. This particular

Figure 5.13 Aggregate VSL 025

example is found in aggregate VSL 025. This aggregate is located within the historical center and is currently of private use and is uninhabited. As seen in figure 5.13, there was once a plaster covering to protect the masonry structure beneath, however it is almost completed decayed away due to weathering and human traffic. This implies that an intervention of the structure has not occurred within the recent past, since the initial construction of the building. This particular example is of lower quality than the previous example. Structurally speaking

Figure 5.14 Type 1 Perpendicular

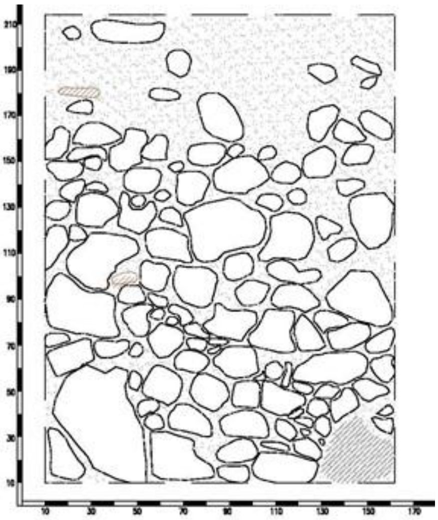


Figure 5.15 Type 1 Perpendicular

there is no significant presence of either a horizontal or vertical structural system within the masonry. However it is important to note that the masonry stones are of high quality, coming from the surrounding area, and the overall masonry system is structurally sound and in general does not render the building vulnerable. This particular masonry typology however is the lowest quality present in Villa Santa Lucia degli Abruzzi. The masonry, analyzed in figures 5.14 and 5.15 is characterized by a combination of both large and small stone. Observational analysis also reveals a large amount of mortar which helps to stabilize the masonry in the case of a seismic event.

5.5.2 Masonry Typology Two

Masonry typology two is the second most common distinguishable masonry typology in Villa Santa Lucia deglia Abruzzi. Out of the 268 buildings, only 6 are composed of masonry typology teo.

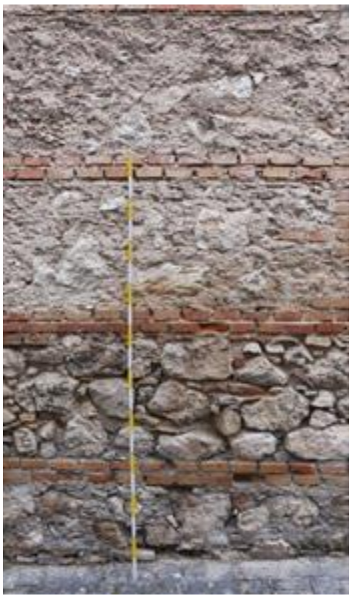


Figure 5.16 Typology Two

This typology therefore makes up 2 percent of the buildings within the area of analysis. Masonry typology two is of higher quality than that of masonry typology one. There is a presence of a horizontal structural system within the masonry, which is not present in masonry typology one. More importantly, the stones are slightly larger and of higher quality. The legal definition of this masonry typology, described by the RELUIS system, is sub-horizontal masonry with roughly cut stones (of varying dimensions). Due to the low percentage of masonry typology two within the village, the typology is only present in the typology of buildings oriented parallel to the elevation curves. In almost all cases, the masonry is of high quality and the original plaster covering has decayed substantially over time without interventions.

The first and only example of masonry typology two in Villa Santa Lucia degli Abruzzi comes from a building oriented parallel to the elevation curves. This examples is located within aggregate VSL 025. This aggregate is located within the historical center of the village. The entire aggregate is of private use and currently uninhabited. The example, as seen in figure 5.18, comes from a structure with a plaster covering. Due to the high quality of the plaster, it can be induced that this cover was recently added through restorative efforts or interventions. As seen in figures 5.18 and 5.19, the masonry composition is fairly regular with a subtly visible presence of horizontal rows. In

Figure 5.17 Aggregate VSL 025

addition, the masonry typology is composed of stones of varying sizes that are properly place apart. The quality of the masonry is particularly important due to the placement of the building on the end of an aggregate, where was the potential collapse mechanisms of out of plane wall overturning is highly prevalent. In this example, it is also important to note the stones which are the typical size of stones found within the surrounding region. These stones are of high quality and have been constructed with precision as well, which is expected for structures within the historical center of the village. The

Figure 5.18 Typology Two Parallel Typology

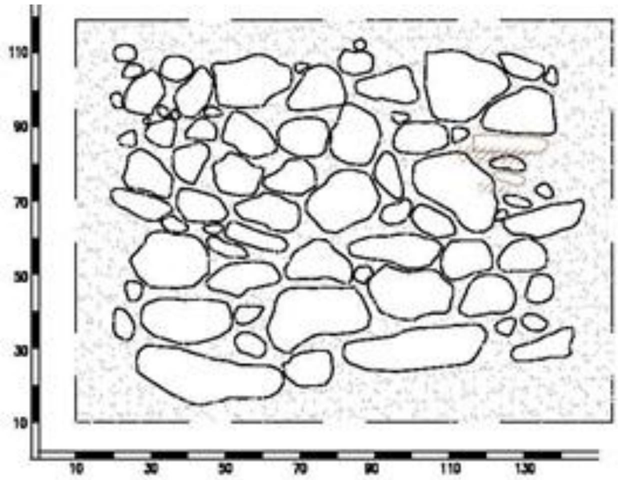


Figure 5.19 Typology Two Parallel Typology

presence of the plaster cover has also aided in the continued quality of the masonry stones by avoiding decay due to environmental factors or human interference.

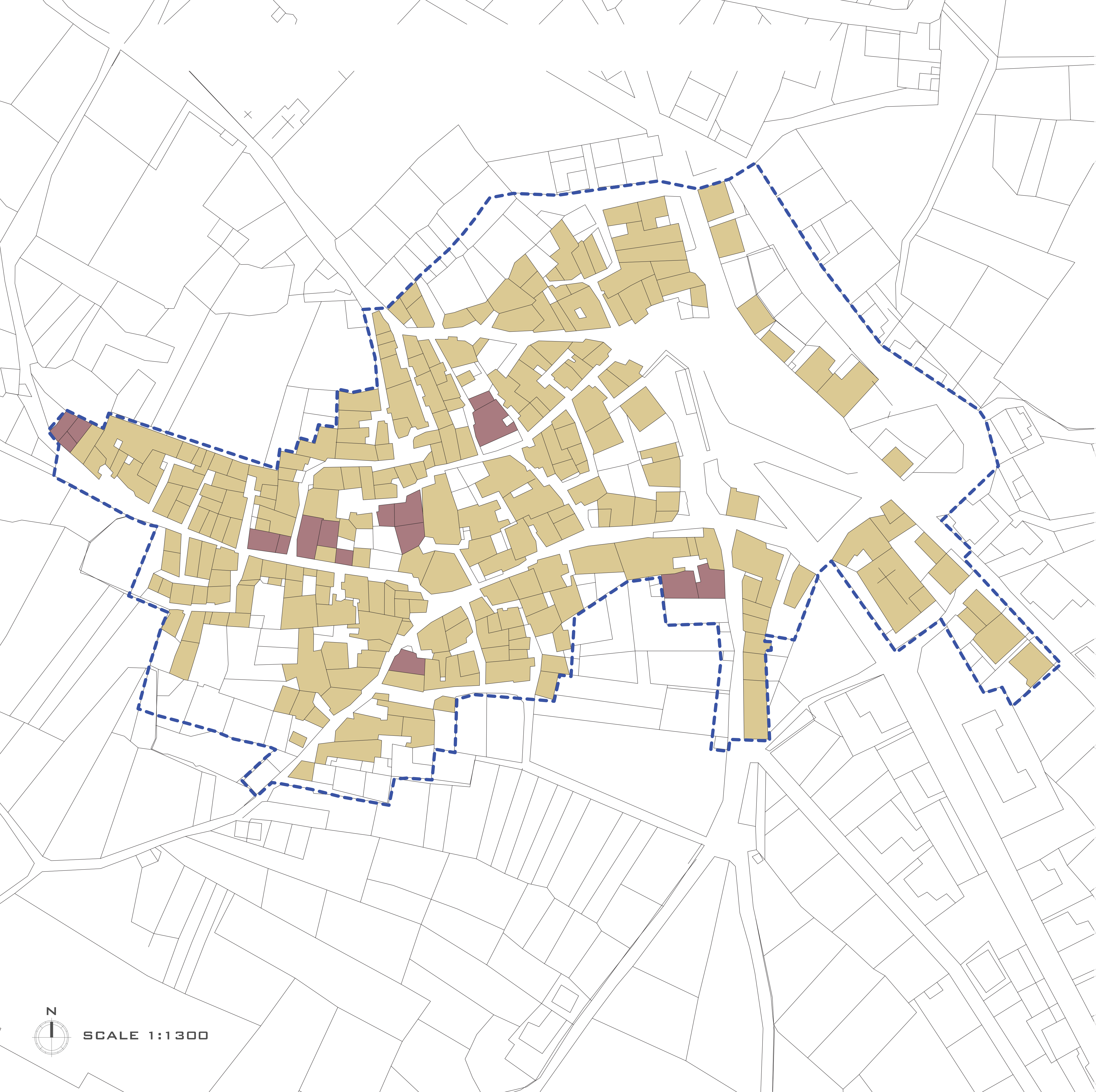


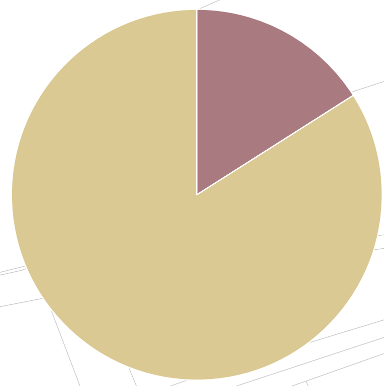
Table 5.6 Location of Ruins

KEY:

- Usable Building
- Building in Ruins

Total Number of Ruins: 16

Total Buildings: 311



Other Buildings 252 (94%)

Ruins: 16 Total (6%)

Total Buildings: 268

DEFINITION:

"Ruins" are considered any building that is beyond uninhabitable, but instead is to the point of having lost all structural stability. The building will in general have collapsed entirely or at least partially. It is important to note these structures because they can hint at a particular vulnerability of an aggregate or area of buildings. They also, if not properly controlled, create damage to surrounding buildings or structures.

EXAMPLES:

Comune: Villa Santa Lucia degli Abruzzi

Location of Ruins

5.6 Existing Ruins

Within Villa Santa Lucia degli Abruzzi, there are several examples of ruins, the second most of the four villages discussed in this thesis. Within the village, there are 16 examples of ruins, 7 of which will be discussed, through the use of sectional and elevation analysis based on observational investigations.

The first example of a ruin within the historical center of Villa Santa Lucia degli Abruzzi is located in aggregate VSL 006. This particular aggregate lacks in structural homogeneity regarding

Figure 5.20   VSL 006   Ruins

Figure 5.21   VSL 006   Ruins

the four primary structural elements that will be discussed in the section 5.7. In addition, the aggregate is very irregular in both plan and elevation. The ruined building in questioned is characterized by being composed of masonry typology one, the weakest of the masonry typologies present in Villa Santa Lucia degli Abruzzi. Unfortunately due to security measures in place, it was impossible to complete a more complete observational analysis of the ruins. However the mode of failure does not appear to imply a failure in the strength of the masonry elements. It is important to note that this conclusion is solely conjecture and would need to be verified through additional extensive analysis done both on-site and in a laboratory.

The second example of ruins within Villa Santa Lucia degli Abruzzi is found on the edge of the analyzed are of the village, specifically in aggregate VSL 011-A. This particular aggregate is composed of five buildings and lacks in structural homogeneity regarding the four primary structural factors that have been analyzed. In addition, the aggregate is irregular in both plan and elevation. Due to the accessibility of the site as well as an available section for observational analysis, this is one of the best examples of a ruin within the village and will therefore have the most thorough analysis. This masonry present corresponds to masonry typology two and is characterized by larger

Figure 5.22 Aggregate VSL 011-A Ruins

Figure 5.23 Masonry Typology 1 Ruins

Stones than typically seen in masonry typology two samples. It is important to note that the masonry structure shows extensive decay and lacks any evidence of a plaster covering. As seen in figures 5.24

Figure 5.24 VSL 011-A Masonry Section One

Figure 5.25 VSL 011-A Masonry Section Two

and 5.25, there are two masonry sections exposed for observational analysis. Assuming these sections are a portion of the building in ruins, it can be said that the brickwork has been assembled, in both cases, with a certain effectiveness. Despite the size of the sections under examination, it can be deduced that the masonry is comprised of two leaves, partially clamped with the presence of larger stones, holding the two leaves together. Approximately every 70 centimeters, we find one of these stones, as is indicated by the red arrow in figure 5.25. It is also important the presence of limestone wedges. The mortar within the sections is also in good condition and of good consistency. There were no voids found in either section. Observational analysis can conclude that the masonry quality was not a major factor in the initial collapse of this particular structure. This is a conclusion based solely on observational analysis and would need to be verified through additional analysis.

The third example of a ruin in Villa Santa Lucia degli Abruzzi is located in aggregate VSL 015. This aggregate is located on the edge of the village center, within the historical center. The aggregate is extremely irregular regarding plan and has been considered to be homogeneous regarding the four primary structural factors except in the section of the aggregate where the ruins are located. The masonry typology of the ruins is categorized as masonry typology one. Due to the inaccessibility of the site due to security reasons, observational analysis was extremely limited. Therefore concluding a potential cause of collapse is impossible. Further analysis both on-site and in a laboratory is required to verify the cause or causes of collapse.

Figure 5.26   Aggregate VSL 015   Ruins

The fourth example of ruins within the village comes from aggregate VSL 020-A. This particular is fairly regular in both plan and elevation. The entire aggregate is plaster covered expect for the ruins which are categorized as masonry typology one regarding the structural masonry. This is lowest quality masonry present in Villa Santa Lucia degli Abruzzi. The collapse of the structure seems to be isolated from the adjacent structures and suggests this structure was built after the initial construction of the village. In addition, the collapse mechanisms present appear to be connected to

Figure 5.27 Aggregate VSL 020-A Ruins

Figure 5.28 Aggregate VSL 020-A Ruins

masonry structure present. It is important that this conclusion is based solely on observational analysis and must be verified with further analysis and investigations.

The fifth example of ruins in Villa Santa Lucia degli Abruzzi is located in aggregate VSL 025.

Figure 5.29 Aggregate VSL 025 Ruins

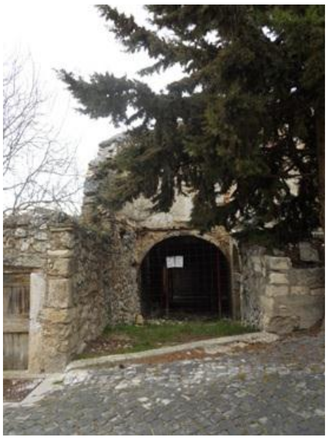


Figure 5.30 Aggregate VSL 025 Ruins

The aggregate is located within the center of the village and is extremely irregular in plan, specifically where the ruins are located within the aggregate. However the aggregate is fairly regular regarding the four major structural factors analyzed. This particular structure in question is composed of masonry typology two. Observational analysis as well as the high quality of masonry implies that the initial collapse was not related to the masonry. However this can only be considered conjecture, due to inability to further investigate the ruins. Further analysis both on-site and in a laboratory are required to verify these conclusions.

The sixth example of a ruins within the village is located in aggregate VSL 110. Due to the access available to the site as well as a section, this example will be analyzed in further detail. The aggregate in which the ruins is irregular in plan and partially lacks homogeneity regarding the four

Figure 5.31 Aggregate VSL 110

Figure 5.32 Aggregate VSL 110

Figure 5.33 Ruins Section

major structural factors. It is also important to note that the majority of the buildings within the aggregate are in ruins. In addition, the structure has been categorized as masonry typology one. Due to the access to the site as well as the presence of an exposed masonry section, the observational analysis in this particular case is more detailed than other examples of ruins within Villa Santa Lucia degli Abruzzi. Assuming that the section, seen in figure 5.33, is a portion of the building in ruins, it can be said that the brickwork has been assembled with a certain effectiveness. Despite the size of the section under examination, it can be deduced that the masonry is comprised of two leaves partially clamped by larger stones. One of these stones is pointed out by the red arrow in figure 5.33.

The masonry structure consists of stones of both medium and large size, implying a higher quality masonry. It is also important to note the presence of very porous limestone wedges. The mortar within the section is also in good condition, with light gray coloration and firm consistency. The aggregates within the mortar in the section are larger than those present in the mortar visible on the surface of the masonry wall. There were no voids present in the sample. It can therefore be presumed that the masonry quality was not a major structural factor in the collapse of the structure. Again, as in the previous examples, all of these conclusions are based solely on observational analysis and would therefore need to be verified through further analysis.

The seventh and final example of ruins within Villa Santa Lucia degli Abruzzi is located in aggregate VSL Y, which is located outside of the analyzed area of the village. Due to this fact, very

Figure 5.34 Aggregate Y Ruins

Little information on the aggregate in question in available. However due to the presence of an

Figure 5.35 Ruins Section

Figure 5.36 Ruins Section

Figure 5.37 Ruins Section

exposed and accessible masonry section, detailed observational analysis was possible. Assuming that the wall section is a portion of the building in ruins, it has been noted that the masonry is composed of three leaves: two outer masonry leaves and an internal filling layer. The outer two leaves are composed of limestone of both medium and large sizes. There is also a presence of small stones and line mortar to support the larger stones. It is also important to note the presence of very porous limestone wedges. Within the section, the mortar is in good condition, with light gray-brown color and is well compacted. The aggregates in the mortar are larger in the section than they appear on the surface of the masonry wall. There are no voids present within the section. Based on this analysis of masonry of the section and the definitions given in the table of NTC C8A2.1 and 14.01.08, the masonry can be categorizes in masonry typology one, the weakest of those present in Villa Santa Lucia degli Abruzzi. The above analysis and well as the mode of collapse apparent in the figures above indicates that the masonry may have played a major role in the collapse of the structure in question. However this conclusion is based solely on observational analysis and would need further analysis in order to verify these assessments.

Table 5.7 Collective Homogeneity Analysis

DESCRIPTION:

This collective homogeneity map includes all major structural characteristics that influence the homogeneity of an aggregate. This includes building height, building typology, masonry typology and orientation to the elevation curves. All of the previously mentioned maps have been overlaid over each other to emphasize the aggregates that are the best positive and negative examples of structural homogeneity. This was underlined in the following maps and then analyzed within the text of the thesis to better understand the vulnerability or lack of vulnerability of certain aggregates.

GENERAL KEY:

- Buildings
- Aggregate Boundaries

BUILDING HEIGHTS:

- 5 Floors Equivalent (or above)
- 4 Floors Equivalent
- 3 Floors Equivalent
- 2 Floors Equivalent
- 1 Floor Equivalent

BUILDING TYPOLOGIES:

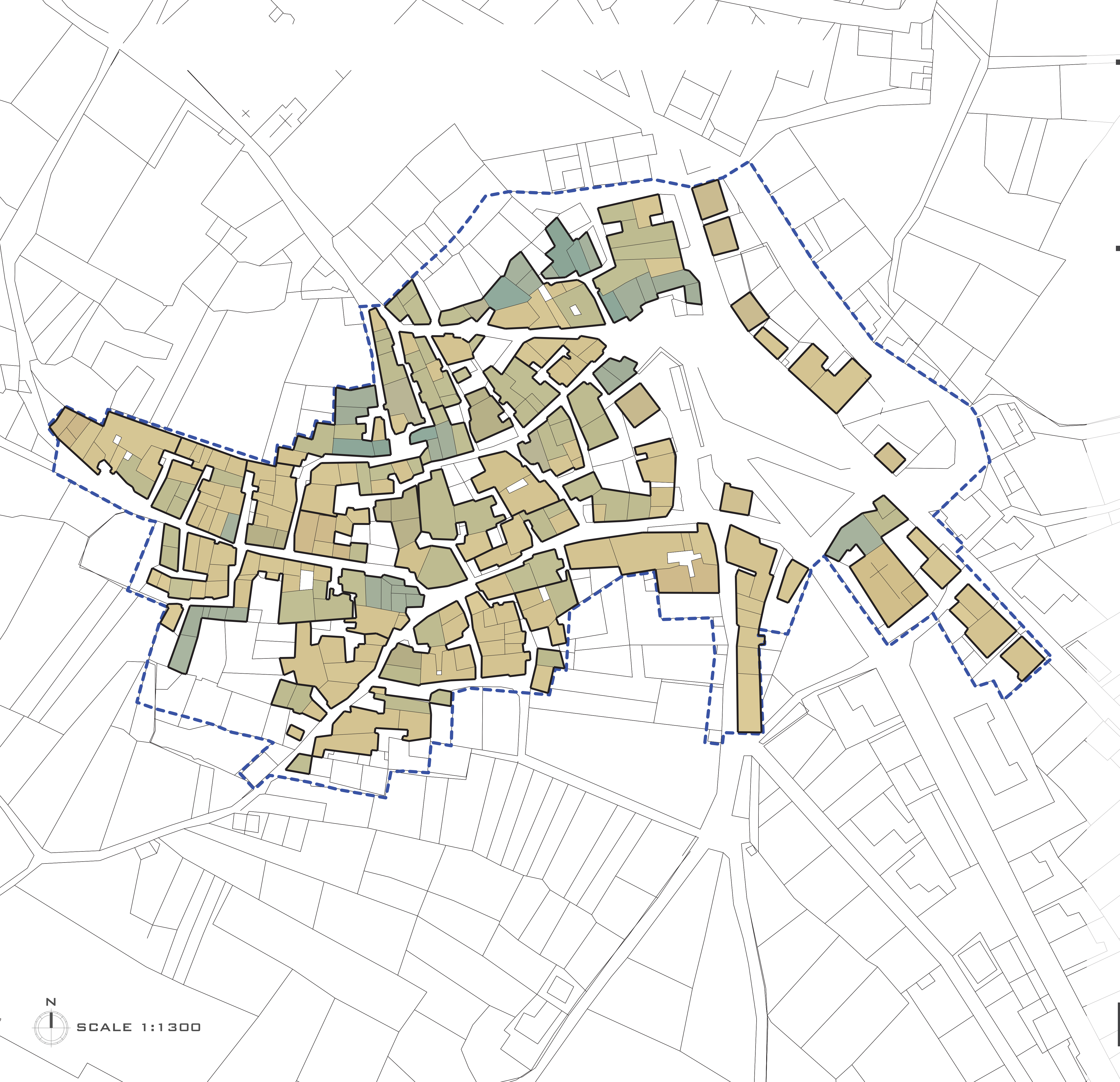
- Historical Boundary Wall House
- Block House
- Tower House
- Buidling Oriented Perpendicular to the Elevation Curve
- Building Oriented Parallel to the Elevation Curve
- Religious Building
- Ruins

MASONRY TYPOLOGIES:

- Irregularly formed masonry (regarding shape, dimensions and materials) stone
- Subhorizontal masonry with roughly cut stones (of varying dimensions)
- Horizontal masonry courses with roughly cut stones (well interlocked)
- Plaster Covered

ORIENTATION TO ELEVATION CURVES:

- Building unit positioned parallel to the elevation curves
- Building unit positioned perpendicular to the elevation curves



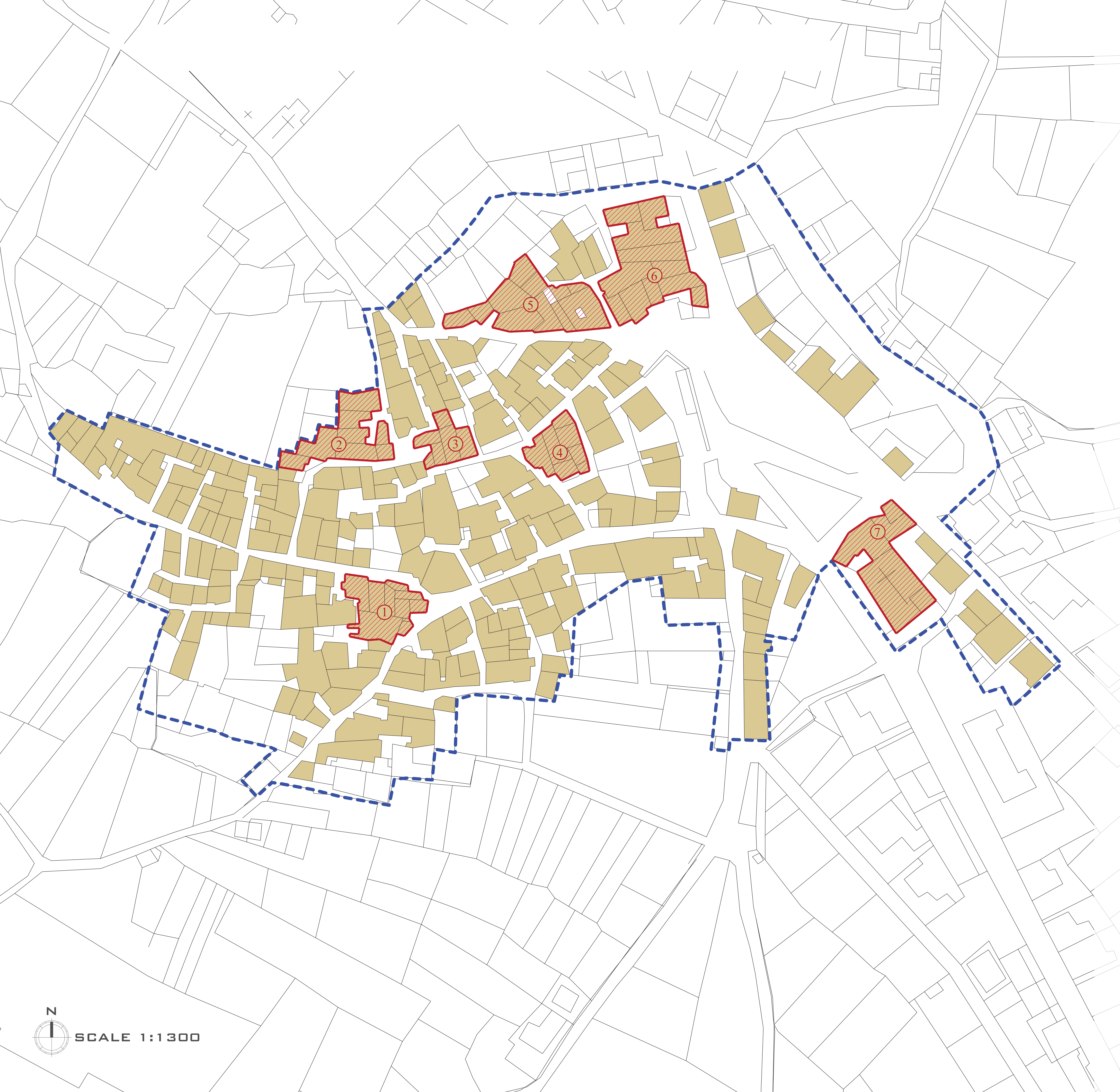
Comune: Villa Santa Lucia degli Abruzzi
Collective Homogeneity Analysis

5.7 Collective Homogeneity Analysis

The collective homogeneity analysis is primarily based on four specific factors, all of which have been determined through on-site analysis. These include the topics of the previous four sections, including building typology, orientation to elevation curves, building height and masonry typology. As seen in the attached map of Villa Santa Lucai degli Abruzzi for “Collective Homogeneity”. The four previously mentioned factors’ maps have been overlaid to located the aggregates with an extremely uniform or non-uniform structure, regarding all four elements. The aggregates that present the least and most uniform regarding these four elements will be discussed in the following two sections, entitled “Negative Homogeneous Examples” and “Positive Homogeneous Examples”.

Overall, Villa Santa Lucia degli Abruzzi is fairly homogeneous, except in the center of the village where the collective homogeneity is generally lower than in the remainder of the village. The location of the areas lacking in collective homogeneity are important to note considering the structure consequences. A lack of structural homogeneity can create several types of damages because an aggregate is more likely to act as separate elements instead of a single unit in the case of a seismic event. This can increase the chance of several collapse mechanisms within the individual aggregates as well as those that are adjacent to one another. In the case of Villa Santa Lucia degli Abruzzi, there are several aggregates that are vulnerable to seismic events due to their lack of structural homogeneity and will therefore be strongly considered as structures to be restores with the limited public funds available. These structures will be discussed in the “Negative Homogeneous Examples” section, while in the “Positive Homogeneous Examples” section, aggregates of homogeneous construction will be used as a guide for possible restoration work for the aggregates considered to not be homogeneous and therefore possibly structurally instable.

Table 5.8 Location of Negative Examples



KEY:

Typical Building

Aggregate Boundary

Negative Homogenous Example

INFORMATION:

Number of Examples: 7

Example 1: VSL 010

Example 2: VSL 020-B

Example 3: VSL 018

Example 4: VSL 032

Example 5: VSL 004

Example 6: VSL 003

Example 7: VSL 012

DESCRIPTION:

These negative examples showing a lack of homogeneity were chosen based on the “Combined Homogeneity analysis” map for Villa Santa Lucia degli Abruzzi. The previously mentioned map was created by combining the following maps:

Building Heights

Building Typologies

Masonry Typologies

Orientation to the Elevation Curves

All of these maps were laid on top of one another. Then several examples of aggregates were chosen back on their lack of homogeneity regarding these four principal elements. These examples will be further analyzed within the text of the thesis.

DEFINITION:

A “negative example of homogeneity”, in the context of this thesis, is defined as an aggregate made up of several buildings. These buildings will be of different heights and made from several different types of masonry possibly with restorations made of different masonry from that of the original constructions. In addition, the building typologies of all of the buildings within the aggregate are different and the orientation to the elevation curves will be different. All or several of them will also be oriented perpendicular to the elevation curves. It is all of these qualities, or variations of them, that make a specific aggregate a “negative example of homogeneity”

Comune: Villa Santa Lucia degli Abruzzi
Location of Negative Examples

5.8 Negative Examples of Collective Homogeneity in Aggregates

Overall seven examples of negative collective homogeneity have been determined within Villa Santa Lucia degli Abruzzi. All of these examples are located within the historical center of the village. As described in the previous Collective Homogeneity Analysis section 5.7, these examples are based on the collective homogeneity, a combination of the overall homogeneity of the building typology, orientation to elevation curves, building heights and masonry typology. These examples will be later further analyzed when considering the most vulnerable aggregates within the four villages discussed.

5.8.1 Negative Collective Homogeneity Example One

The first example of collective structural homogeneity of Villa Santa Lucia degli Abruzzi is found within the center of the village. The example is the entirety of aggregate VSL 010. The aggregate is composed of nine structures, all of which are privately owned and one that is currently inhabited. In addition, the aggregate is irregular in plan. The aggregates is fairly regular in elevation as seen in figure 5.43. There is no case within the aggregate where two adjacent structures differ in height by more than a single story. All of the buildings within the aggregate are typical aggregate houses. The structural factor that makes this aggregate a negative example of structural homogeneity is the orientation of the buildings to the elevation curves. As is seen in figure 5.42, the Northern

Figure 5.38 Aggregate within Villa Santa Lucia

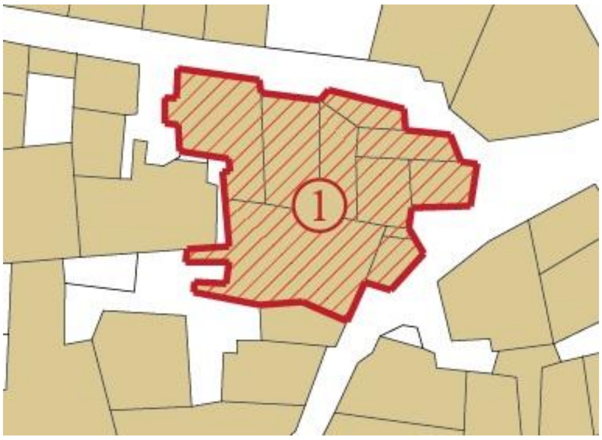


Figure 5.39 Location of Aggregate VSL 010

portion of the aggregate is oriented perpendicular to the elevation curves, while the Southern portion is oriented parallel to the elevation curves, This major differing of the buildings' orientations forces the aggregate to function as two separate units in the case of a seismic event. This can lead to several potential collapse mechanisms such as torsion within the individual aggregate, hammering between the structures and out of plane wall overturning as well. In order to minimize these effects, extensive connections are required between these two separate sections of the aggregate. The final factor that is fairly homogeneous within the aggregate is masonry typology. All nine structures, with the exception of **o** in masonry typology one, are plaster covered and therefore the masonry structure is impossible to determine. Due to the fact that one of these buildings in currently inhabited, this particular aggregate will be given emphasis when considering the priorities for restorative efforts.

Figure 5.40 Collective Homogeneity Analysis

5.41 Building Typology

5.42 Building Orientation

5.43 Building Heights

5.44 Masonry Typology

5.8.2 Negative Collective Homogeneity Example Two

The second negative example of collective structural homogeneity is found in aggregate VSL

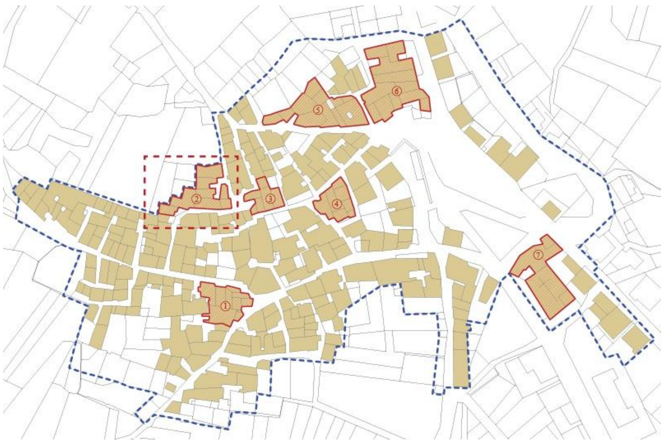


Figure 5.45 Aggregate within Villa Santa Lucia

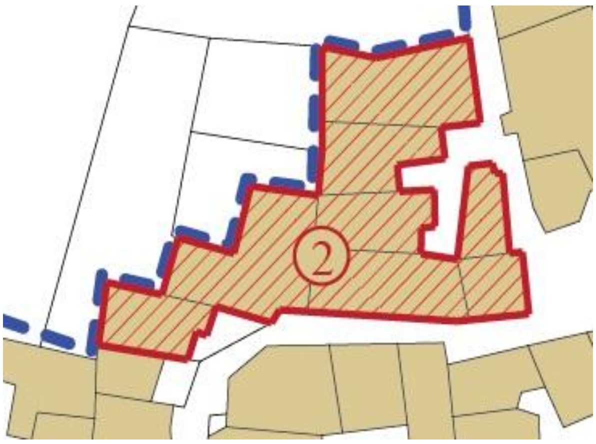


Figure 5.46 Location of Aggregate VSL 020-B

020-B, which is located on the edge of the historical center of the village. The particular example is extremely irregular in plan and can be considered one of the least homogeneous examples within Villa Santa Lucia degli Abruzzi. All of the buildings within the aggregate are typical aggregate houses. However their orientation to the elevation curves vary throughout the aggregate. Unlike in the previous example, the aggregates oriented perpendicular to the elevation curves are not grouped together as a single unit, but instead are placed throughout the aggregate. This increases the likeliness of several collapse mechanisms, which can occur in several locations in the aggregate. These potential collapse mechanisms include torsion, out of wall overturning and hammering. These potential damages are also magnified by the lack of homogeneity

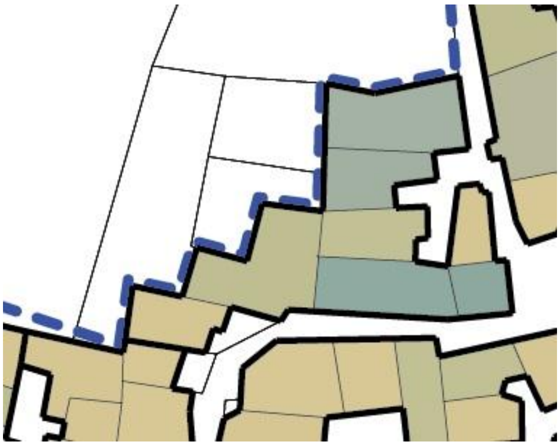
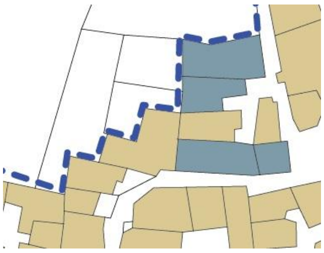


Figure 5.47 Collective Homogeneity Analysis

5.48 Building Typology



5.49 Building Orientation

5.50 Building Heights

5.51 Masonry Typology

in both the building heights and masonry typologies present. The building heights within the aggregate are variable and in some occasions adjacent structures differ in height by more than two stories. Finally one third of the aggregate is revealed to be masonry typology one while the remainder of the buildings within the aggregate are indistinguishable due to a plaster cover. The location of this revealed section implies additions to the original structure that occurred after the initial construction of the village, however this is solely conjecture. Overall this particular aggregate is extremely inhomogeneous and therefore very vulnerable in the case of a seismic event. Therefore this aggregate will be further analyzed and evaluated in section 5.15; the vulnerability conclusion.

5.8.3 Negative Collective Homogeneity Example Three

The third negative example of collective structural homogeneity within Villa Santa Lucia degli Abruzzi is found in aggregate VSL 018. This particular aggregate is located on the edge of the

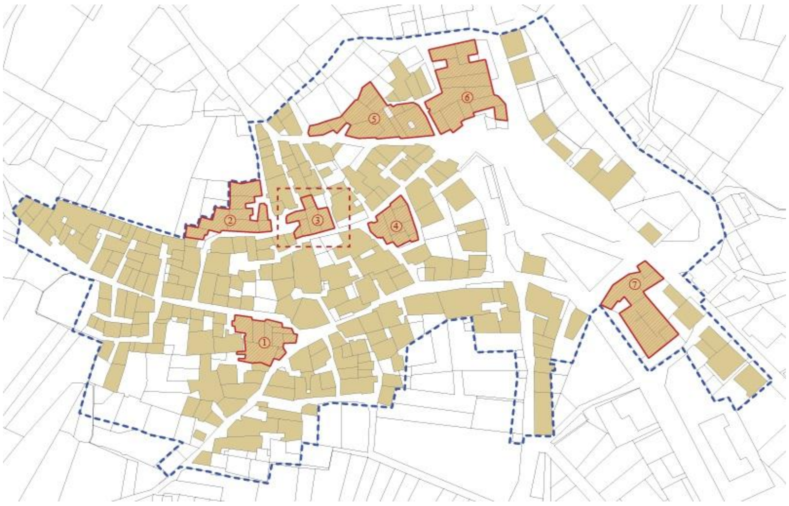


Figure 5.52 Aggregate within Villa Santa Lucia degli Abruzzi

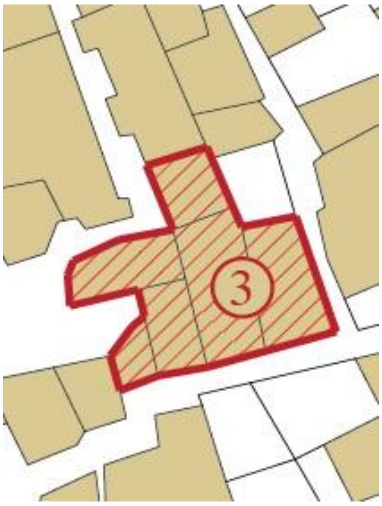


Figure 5.53 Location of VSL 018

historical center of the village. This aggregate is composed of six units, all of which are both

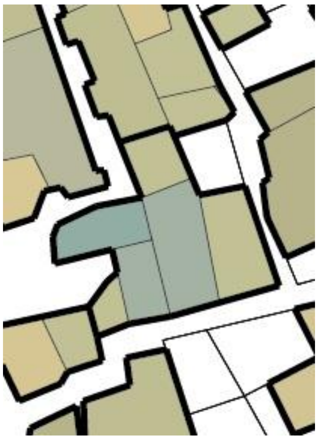
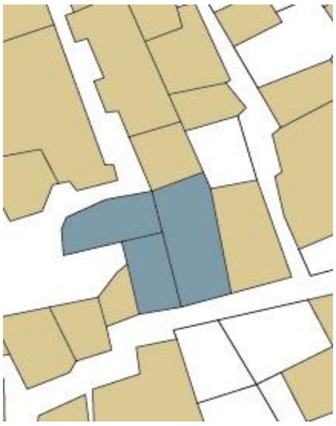


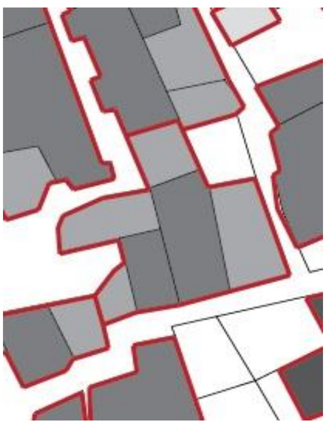
Figure 5.54 Homogeneity

privately owned and currently uninhabited. In addition, two of the six structures have been deemed uninhabitable after the post 2009 L'Aquila earthquake assessment of the village. The aggregate is irregular in plan as well as in elevation. As seen in the Collective homogeneity analysis, in figure 5.54, the aggregate has a fairly homogeneous central core with several extremities that differ structurally from that core. All of the units within the aggregate are typical aggregate houses, however this core is oriented perpendicular to the elevation curves while the remainder of the aggregate is oriented parallel to the elevation curves. This extremely important to note because this creates fulcrum points

5.55 Building Typology



5.56 Building Orientation



5.57 Building Heights

5.58 Masonry Typology

of possible rotation at the connections between the core of the aggregate and the extremities of the aggregate. This relates to several potential collapse mechanisms as well. Regarding the building heights within the aggregate, there is a lack of homogeneity, however adjacent buildings never differ in height by more than a single story. The building heights therefore create few potential collapse mechanisms. Finally the masonry typology within aggregate is fairly irregular. Most of the units are composed of masonry typology one, while the remainder of plaster covered, therefore it is impossible to distinguish their masonry typology. Due to this lack of information, it is difficult to conclude the vulnerability of the aggregate based on the masonry typology.

5.8.4 Negative Collective Homogeneity Example Four

The fourth negative example of collective structural homogeneity is located in aggregate VSL 032, which is located in the very core of the historical center. The aggregate is composed of seven units, all of which are privately owned and currently uninhabited. The aggregate is fairly regular in both plan and elevation. All of the six units within the aggregate are typical aggregate houses and all are oriented parallel to the elevation curves. This is extremely important to note, considered the amount of potential collapse mechanisms that are related to the combination of structures oriented parallel and perpendicular to the elevation curves in a single aggregate. Almost all of the buildings within the aggregate are of similar height, with the exception of a single unit which differs by no

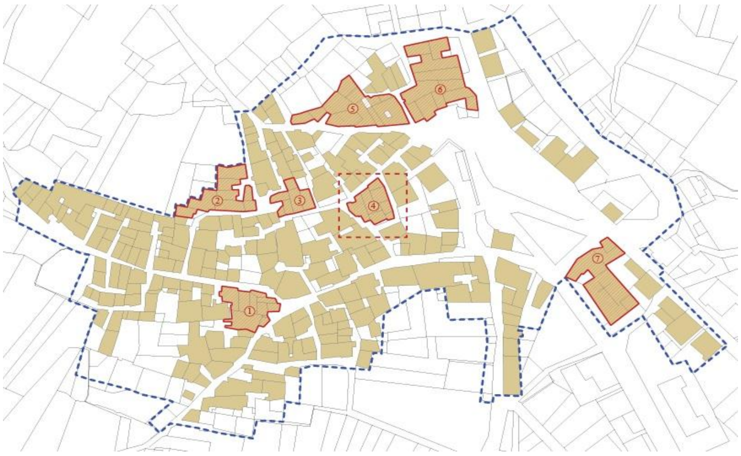


Figure 5.59 Aggregate within Villa Santa Lucia degli Abruzzi

Figure 5.60 Location of Aggregate VSL 032

more than a single story from its adjacent structures. What makes this particular aggregate a negative example of collective structural homogeneity is the masonry typologies present within the

5.61 Collective Homogeneity

aggregate. In the six structures there are three masonry typologies present. These include masonry typology, masonry typology two and structures whose structure cannot be distinguished due to a plaster cover. The presence of a plaster covering on a select few units implies a recent renovation of the aggregate that was not completed on the entire aggregate or structures added to the aggregate after the initial construction of the village. This lack of homogeneous does not allow the aggregate to function as a single unit in the case of a seismic event and therefore increases the

5.62 Building Typology

5.63 Building Orientation

5.64 Building Heights

5.65 Masonry Typology

possibility of several potential collapse mechanisms such as hammering. These mechanisms can be minimized through the addition of permanent structural interventions that aid in connecting the separate masonry typologies through the use of tie rods or similar interventions.

5.8.5 Negative Collective Homogeneity Example Five

The fifth negative example of collective structural homogeneity is located in aggregate VSL 004. This aggregate is located on the edge of the core of the historical center. The aggregate is

Figure 5,66 Aggregate within Villa Santa Lucia

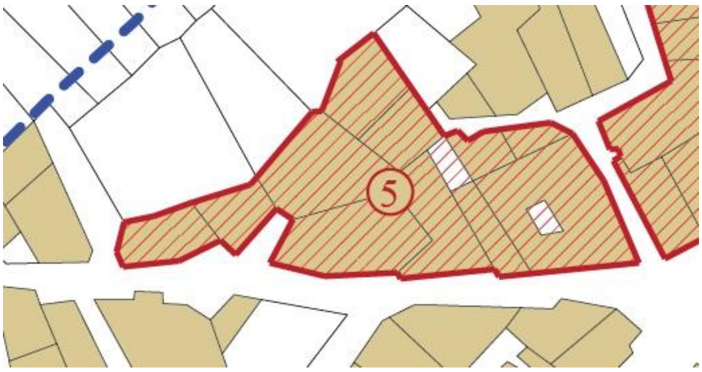


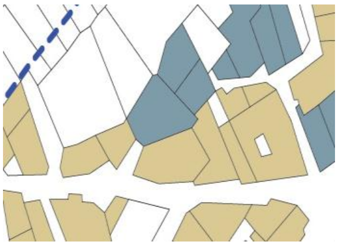
Figure 5.67 Location of Aggregate VSL 004

composed of eleven units, all of which are privately owned , one is currently inhabited and one other is considered to be uninhabited following the post 2009 L'Aquila earthquake assessment of the

Figure 5.68 Collective Homogeneity Analysis

village. The aggregate lacks regularity in both plan and elevation. All of the buildings within the aggregate have been identified as typical aggregate houses. The orientation of these houses however to elevation curves however differs. Three of the Northern most units of the aggregate are oriented perpendicular to the elevation curves while the remainder of the adjacent surrounding structures are oriented parallel to the elevation curves. This lack of homogeneity regarding orientation, especially in this more extreme case, can produce several

5.69 Building Typology



5.70 Building Orientation

5.71 Building Heights

5.72 Masonry Typology

potential collapse mechanisms such as torsion, hammering and out of plan wall overturning. The building heights within the aggregate are fairly homogeneous however, with no adjacent structures differing in height by more than a single story. Finally the masonry typology within the aggregate strongly lacks in homogeneity. There are three typologies present within the aggregate, including masonry typology one, masonry typology two, and plaster covered. Masonry typology one, the most common of the exposed masonry in this aggregate, is intermixed with masonry typology two as well as plaster covered structures. This disparity of organization within the aggregate, regarding the presence of differing masonry typologies can lead to several damage and collapse possibilities. These can minimized through the use of additional connection between the differing units, this is also the case regarding structures that differ in terms of their orientation to the elevation curves.

5.8.6 Negative Collective Homogeneity Example Six

The sixth negative example of collective structural homogeneity within the village is located in aggregate VSL 003. This aggregate is located in the very center of the historical center and is

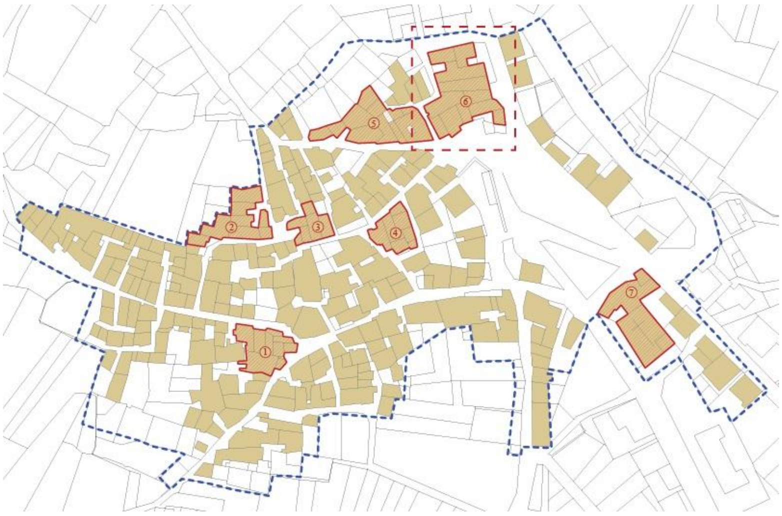


Figure 5.73 Aggregate within Villa Santa Lucia degli Abruzzi

Figure 5.74 Aggregate VSL 003

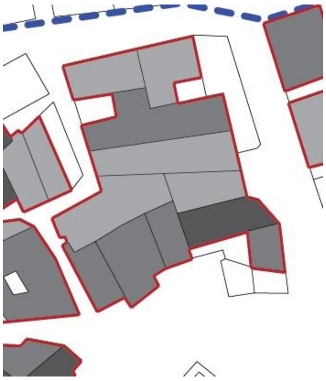
made up of eleven structures. Of these eleven structures, all of them are privately owned, four of

5.75 Collective Homogeneity

them are currently inhabited and two have been categorizes as uninhabited following the post seismic damage assessment. The aggregate is irregular in both plan and elevation. It is also one of the more negative examples to be presented in this section. All of the units within the aggregate have been categorized as typical aggregate houses. However these houses differ in their orientation to the elevation curves. The aggregate is separated into two sections. The

5.76 Building Typology

5.77 Building Orientation



5.78 Building Heights

5.79 Masonry Typology

Southern most five aggregates are oriented perpendicular to the elevation curves. The remainder of the aggregates, in the Central and Northern sections of the aggregate, are oriented parallel to the elevation curves. This is extremely important because of the potential collapse mechanisms realted to differing orientations in a single aggregate. Regarding building heights, the aggregate is fairly homogeneous, however there is one case where adjacent structures differ in height by more than two stories. The connection point between these two structures is therefore extremely vulnerable to collapse and should be substantially reinforced in order to avoid damages. This is especially the case because of the high number of inhabited units within the aggregate. Finally the masonry typology consists of either masonry typology one or plaster covered structures. Due to the plaster covering on many of the structures, it is impossible to determine their masonry structure and therefore their potential vulnerability due to the masonry typologies. However it is important to note that a plaster covering generally implies recent renovations or interventions, which were therefore not completed on the entire aggregate. This can lead to an increased lack of homogeneity within the aggregate, leading to further potential collapse mechanisms.

5.8.7 Negative Collective Homogeneity Example Seven

The seventh and final negative example of collective structural homogeneity within Villa Santa Lucia degli Abruzzi is located in aggregate VSL 012. This aggregate is located in the very core of the historical center and is extremely important due to the presence of the only church of the village. The aggregate is composed of five structures. One of these units is of public use and all of them are currently uninhabited. As seen in the collective homogeneity analysis, seen in figure 5.82,

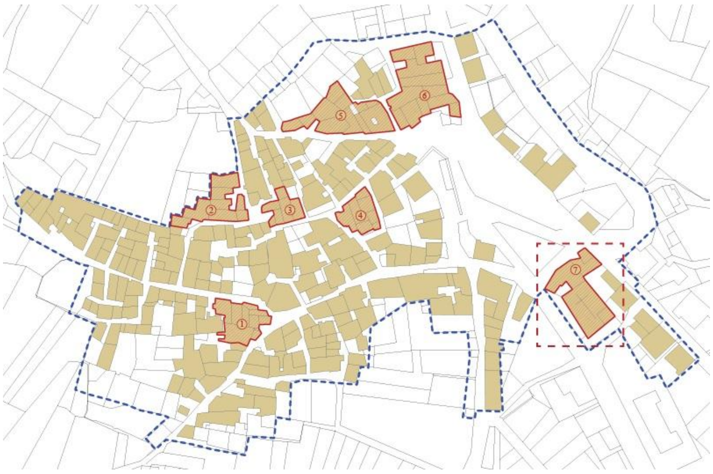


Figure 5.80 Aggregate within Villa Santa Lucia

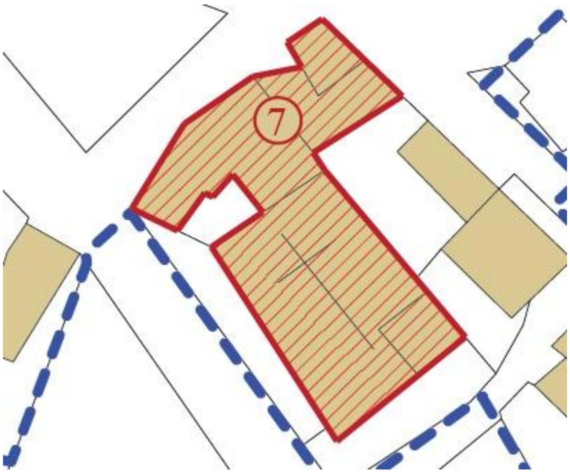


Figure 5.81 Location of Aggregate VSL 012

the aggregate is split into three separate sections and therefore lacks collective homogeneity within the aggregate. Three of the four buildings have been categorized as being typical aggregate houses.

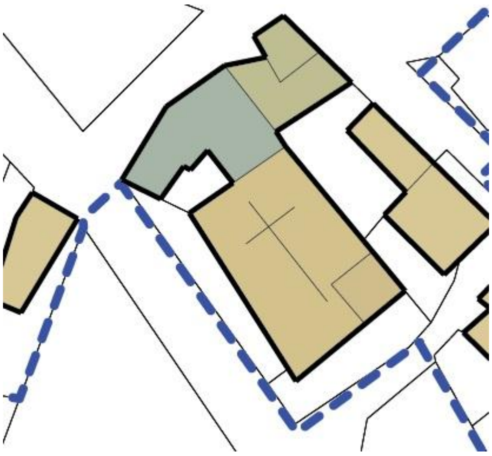
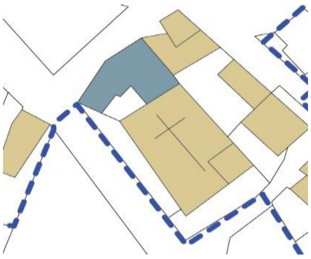


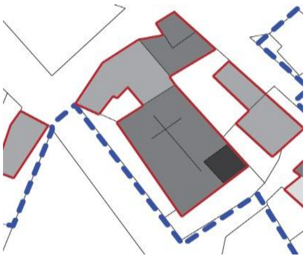
Figure 5.82 Collective Homogeneity

The remaining structure is a church or religious structure. Regarding the separate units orientation to elevation curves, all of the structures are oriented parallel with the exception of the central unit which is oriented perpendicular to the elevation curves. This orientation and the placement of the building in the center of the aggregate has many structural consequences. These consequences include the increased propensity for several potential collapse mechanisms related to torsion and hammering. The building heights within the aggregate are fairly regular with no adjacent structures differing in height by more

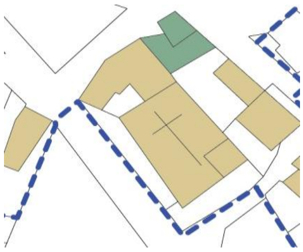
5.83 Building Typology



5.84 Building Orientation



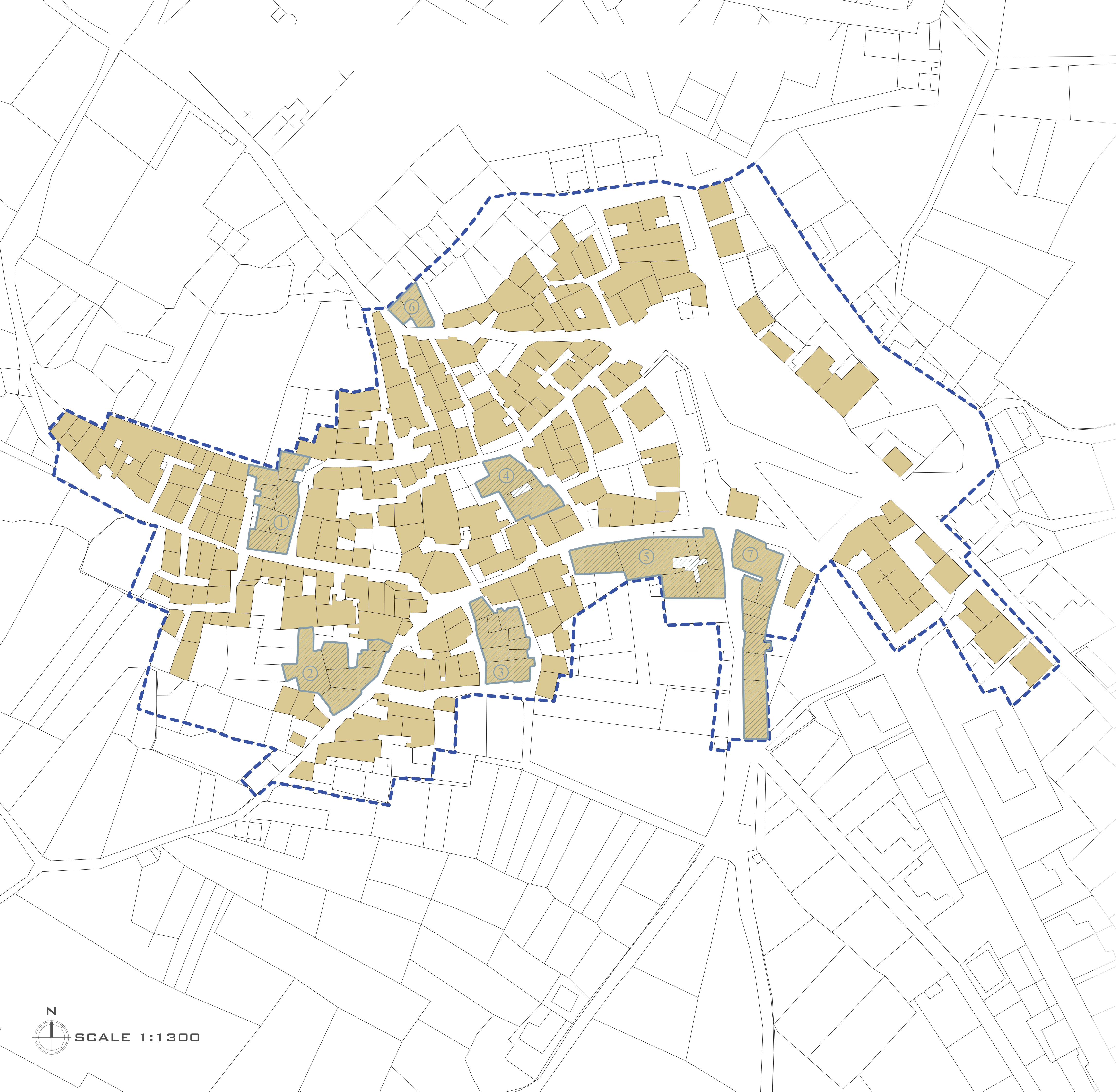
5.85 Building Heights



5.86 Masonry Typology

than a single story, except in the case of the tower-like unit within the church structure. There are many potential collapse mechanisms related to tower-like structures within an aggregate as well as potential damage to the surrounding structures. The fulcrum points or connection points between the tower and the remainder of the aggregate is extremely important. Several permanent structural interventions can aid in minimizing damages related to tower-like structures. Finally, the masonry within the aggregate is composed of masonry typology one and plaster covered. Due to the amount of structures covered in plaster it is impossible to complete a thorough observational analysis and determine the vulnerability of the masonry within the aggregate. Further investigations and studies both on-site and in a laboratory would be necessary to complete the vulnerability analysis of both the aggregate as a whole as well as the individual units.

Table 5.9 Location of Positive Examples



KEY:

Typical Building

Aggregate Boundary

Positive Homogenous Example

INFORMATION:

Number of Examples: 7

Example 1: VSL 020-A

Example 2: VSL 009

Example 3: VSL 036

Example 4: VSL 007-B

Example 5: VSL 025

Example 6: VSL 000

Example 7: VSL 001

DESCRIPTION:

These positive examples showing homogeneity were chosen based on the “Combined Homogeneity analysis” map for Villa Santa Lucia degli Abruzzi. The previously mentioned map was created by combining the following maps:

Building Heights

Building Typologies

Masonry Typologies

Orientation to the Elevation Curves

All of these maps were laid on top of one another. Then several examples of aggregates were chosen back on their homogeneity regarding these four principal elements. These examples will be further analyzed within the text of the thesis.

DEFINITION:

A “positive example of homogeneity”, in the context of this thesis, is defined as an aggregate made up of several buildings. These buildings will be of the same height and made from the exact same type of masonry, without restorations made of different masonry from that of the original constructions. In addition, the building typologies of all of the buildings within the aggregate are the same and the orientation to the elevation curves will be the same. All or several of them will also be oriented parallel to the elevation curves. It is all of these qualities, or variations of them, that make a specific aggregate a “positive example of homogeneity”

Comune: Villa Santa Lucia degli Abruzzi

Location of Positive Examples

5.9 Positive Examples of Collective Homogeneity in Aggregates

While seven positive examples of collective homogeneity within aggregates have been chosen, as seen in table 5.9, many of these examples are extremely similar. Therefore in order to more efficiently describe a positive example of collective homogeneity, only one positive example will be introduced. The example chosen is marked as example seven in table 5.9.

5.9.1 Positive Collective Homogeneity Example One

The first and only positive example of collective structural homogeneity to be discussed is found in the historic center of Villa Santa Lucia degli Abruzzi, specifally in aggregate VSL 001.

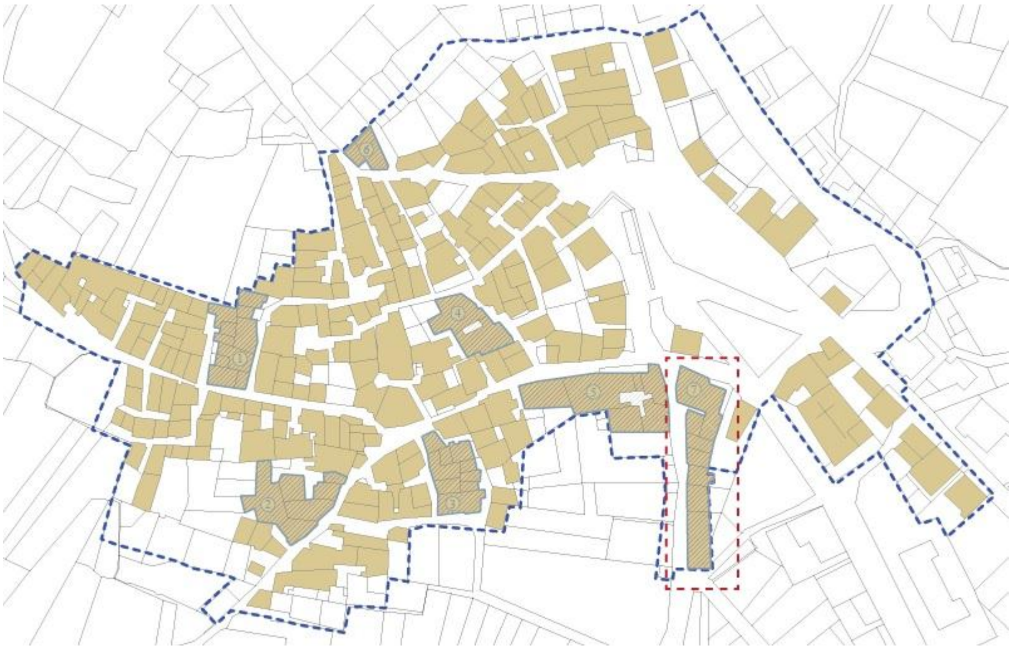
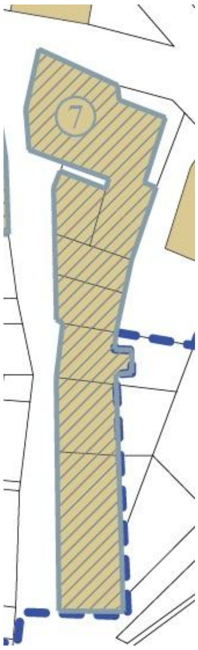
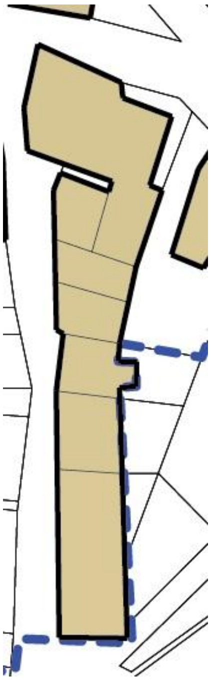


Figure 5.87 Aggregate within Villa Santa Lucia degli Abruzzi

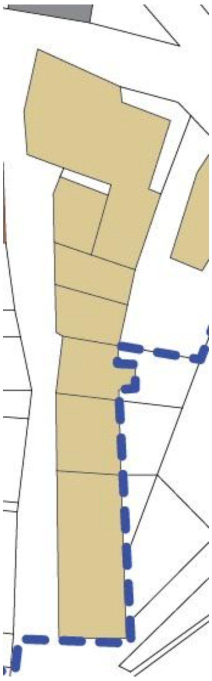


5.88 VSL 001

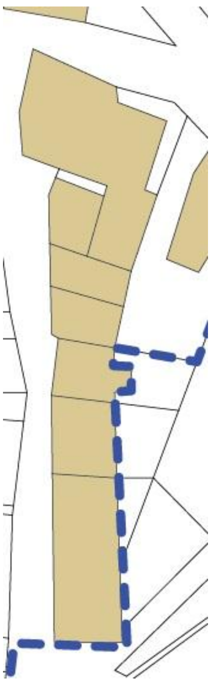
This particular aggregate is composed of seven units, all of which are privately owned, one of which has been deemed uninhabitable and one that is currently inhabited. The aggregate is extremely regular in both plan and elevation. It is important to note that this aggregate appears to have been constructed at the same time as the original village although that must be verified. As seen in the collective homogeneity analysis in figure 5.89, the aggregate is one of the most homogeneous of the aggregates within the village. All of the units within the aggregate have been categorized as typical aggregate houses. In addition all of the structures within the aggregate are oriented parallel to the elevation curves. This characteristic of the aggregate is crucial considering the amount of potential



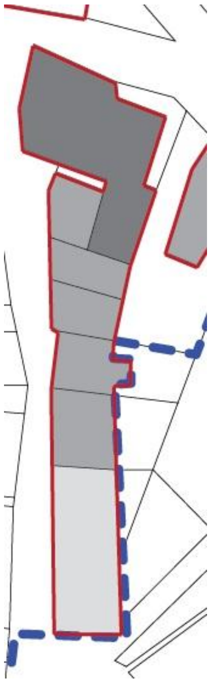
5.89 Homogeneity



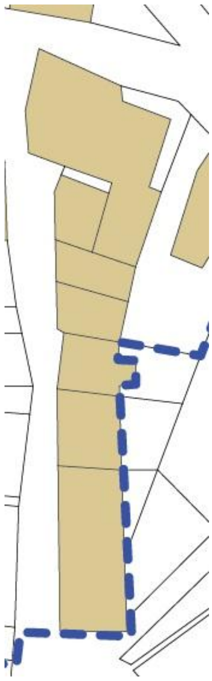
5.90 Building Type



5.91 Orientation



5.92 Building Heights



5.93 Masonry Type

collapse mechanisms that are related to irregularity of orientation to the elevation curves in a single aggregate. The main point of irregularity within the aggregate is from the building heights. The building height’s follow the topography, but in no case do adjacent units differ in height by more than a single story. Finally the entire aggregate, regarding the masonry typology, is plaster covered. While it is impossible to properly determine the vulnerability of the structure regarding the masonry typology due to this plaster cover, it is important to note that all of the units within the aggregate have the cover. This implies a recent restorative effort that took all of the buildings within the aggregate into account, which is essential when attempting to maintain structural homogeneity within an aggregate. Overall this aggregate is a good model for future restorative efforts to be performed within the village that hope to keep structural homogeneity a primary goal

5.10 Openings

While generally disregarding, openings can play a large role in the structural stability of a building if improperly placed. The ideal location of punctures of the façade surface are ar apart from one another as well as within a single line in order to minimize the area of effect of the openings. In addition, openings should be placed near the center of the wall in order to avoid interrupting corner conditions within the masonry. There are several examples of both proper and improper openings within Villa Santa Lucia degli Abruzzi that will be discussed.

The first negative example is found within the historical center, specifically in aggregate VSL 004. In this particular case, there are several faults in the placement of the openings on the surface of the façade. Many of the openings are quite close in proximity and can therefore damage the structure of the entire façade, specifically in the weakened areas between the punctures. As is the case on the first floor, the placement of a window near to an arch can in fact disrupt the structural continuity of the arch and potentially cause damages or collapse. It is also important to note that many of the openings are extremely close to both the roof structure as well as to the corners of the building. These are important points structurally and can be weakened due to the placement of an adjacent opening such as a window. In addition, these openings are offset or staggered on the surface of the façade, this increasing the area of the façade that they affect, thus increasing the potential collapse mechanisms. Overall this is an extremely negative example regarding the placement of openings within a structure.

Figure 5.94 Negative Openings

The second negative example to be discussed is also found in the historical center of Villa Santa Lucia degli Abruzzi. The example specifically comes from aggregate VSL 010. This particular building is a negative example of an opening for several reasons. The first reason is the close

Figure 5.95 Negative Openings

placement of many of the openings to one another. These placements weaken the structure of the façade, increasing the chance of the potential collapse mechanisms of out of plane wall overturning. In addition, an exterior masonry stairway has been added, which also contains an opening. This opening breaks the masonry continuity between the original structure and the additional stairway. As seen in the photo, this has led to major vertical cracks on the façade surface, as well as a necessary temporary structural intervention in order to avoid collapse of the additional element. While the opening is not the leading cause of these potential collapse mechanisms, it is important to note the role the placement of the opening played on the structural stability.

There are two positive examples of openings to be discussed that are found in Villa Santa Lucia degli Abruzzi. These examples are found in the church aggregate and the aggregate VSL 003.

Figure 5.96 Positive Openings

Figure 5.97 Positive Openings

In both of these cases, the openings are properly places apart and are aligned into vertical columns which minimize the area of influence of the openings on the masonry structure. These are the ideal placements of openings within a structure in order to minimize the negative effects of punctures.

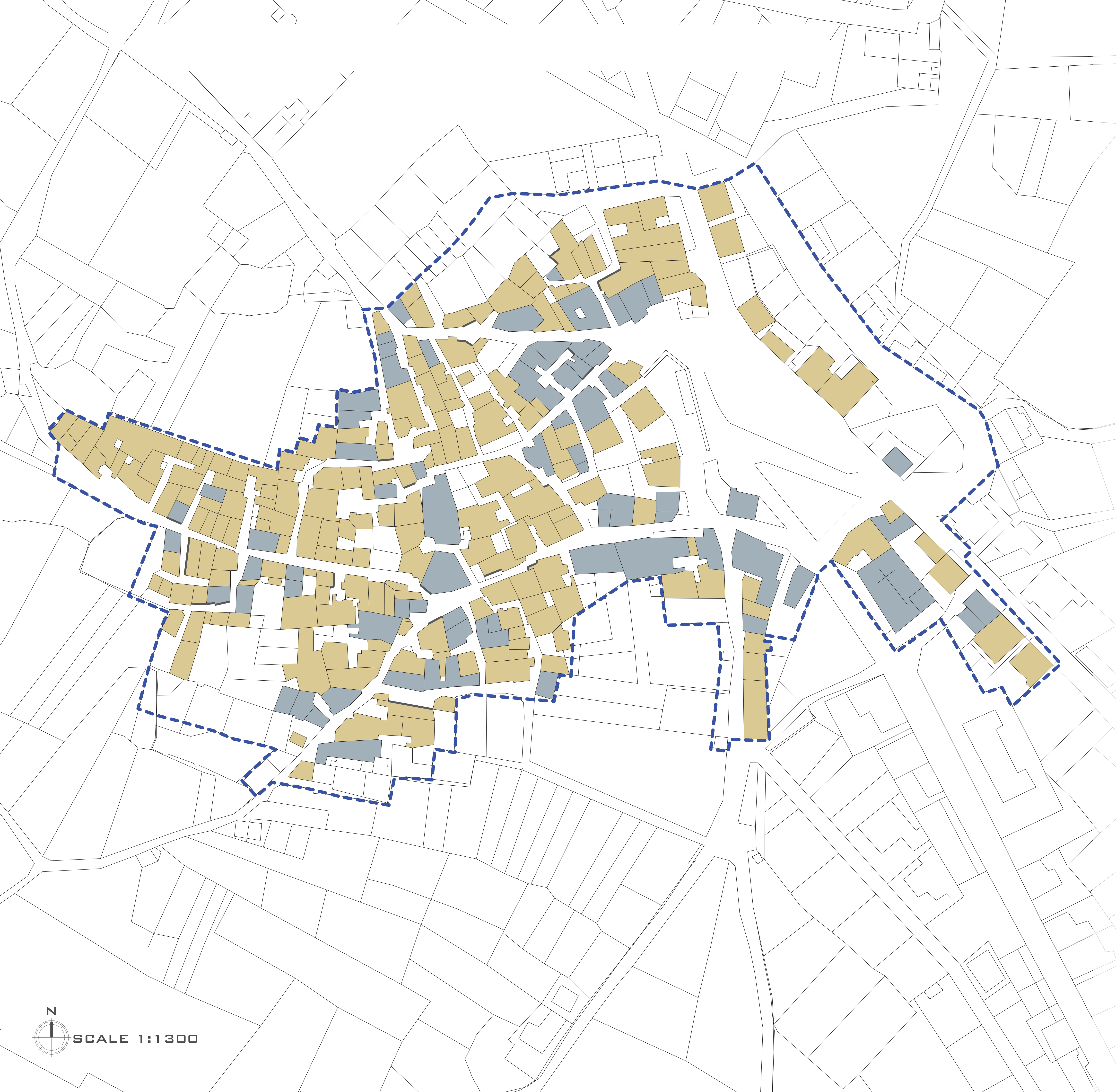


Table 5.11.1 Permanent Interventions

KEY:

- Typical Building
- Buttress Location
- Building with Tie Rods in Place

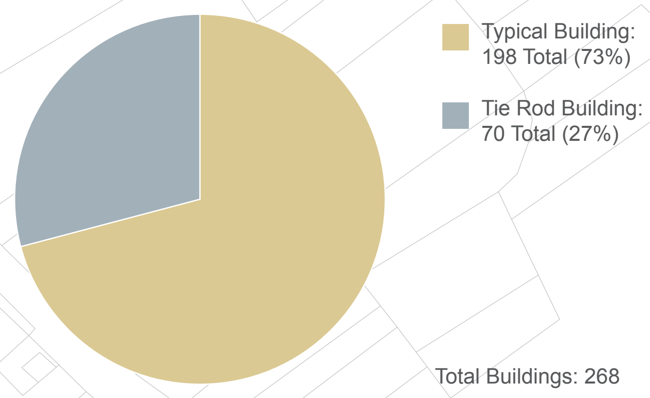
DEFINITION:

Buttress - A mass of masonry or brick work projecting from or built against a wall to give additional strength, usually to counteract the lateral thrust of an arch, roof or vault. There are several different types of buttresses, including angle, clasping, diagonal, flying, lateral, pier and setback buttresses.

Tie Rod - A slender structural unit used as a tie and capable of carrying tensile loads only. Tie Rods are generally used on opposite facades, meant to literally tie the building together in order to prevent facade overturning.

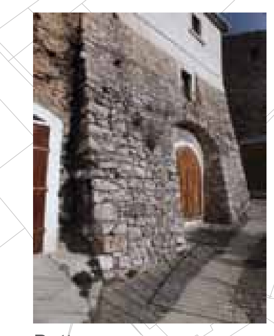
INFORMATION:

Number of Buildings with Tie Rods:	70
Number of Buildings with Buttresses:	21
Total Number of Buildings:	268



EXAMPLES:

Tie Rod



Buttress

Comune: Villa Santa Lucia degli Abruzzi

Permanent Intervention Locations

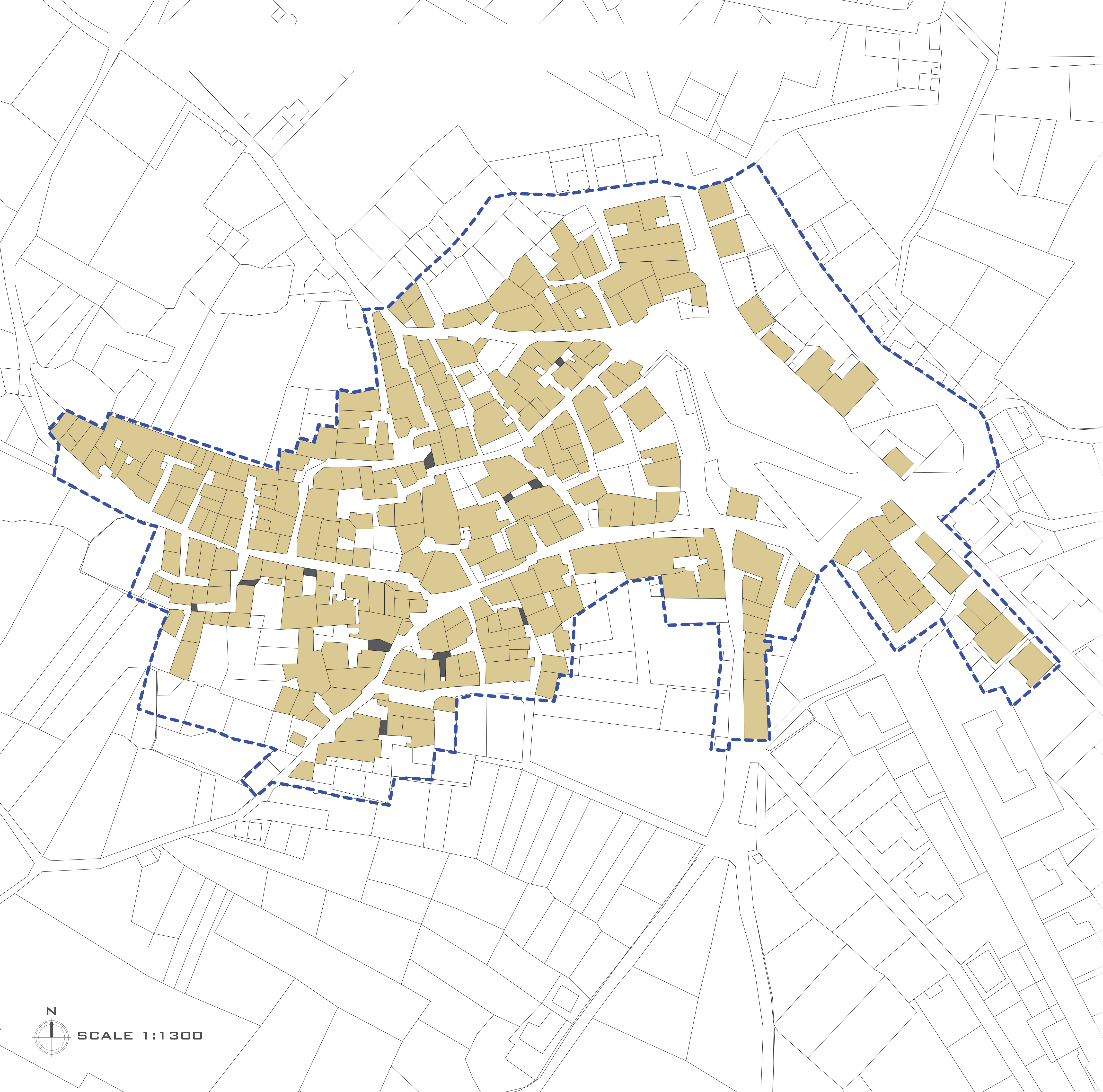


Table 5.11.2 Arched Overpass Locations

KEY:

Typical Building

Arched Overpass

DEFINITION:

Any arched overpass, that is considered to be either a structural or non-structural element. Any arched overpass, referred to as a “sporto” in the Abruzzo-Italian dialect, is an arched overpass with one or more stories of interior space above the arch. However there are also standard arches included here, that hold no structural weight but themselves.

INFORMATION:

Total Number of Arched Overpasses: 11
Total Number of Buildings: 268

NOTE:

Castel del Monte is famous for their large amount of “sporti”, or arched overpasses. However all four regions have at least a few arched overpasses present. Castelvecchio di Calvisio also has a substantial amount of arched overpasses. This characteristic of the four communes is a special construction typology, common in the Abruzzo region’s architecture.

Comune: Villa Santa Lucia degli Abruzzi
Arched Overpass (“Sporto”) Locations

5.11 Permanent Structural Interventions

Within the Baronia collective, there is a strong presence of permanent structural interventions, specifically after the original construction of the village. These interventions include scarp buttresses, typical buttresses, and tie rods. In addition, these interventions showcase a significant knowledge of anti-seismic design within the region of Abruzzo. There are four main points when considering the criteria for interventions The first is that interventions are meant to reduce accidental loads and live loads that caused previous damages. The second is the rehabilitation of load capacity. The third is to remove the causes of material degradation. The fourth and final criteria for interventions is the modification of the static scheme. The improvement of the bearing capacity can be made by regenerating the structural element, increasing the sectional resistence of the floor supporting system and replacing degraded elements with other similar elements.

Villa Santa Lucia, similar to other villages within the Baronia collective, has several types of permanent structure interventions present within the village. These include buttresses, arches, "sporti", and tie rods. Of the 268 building present within the village, 70 buildings have tie rods in place, which makes up 27 percent of the buildings within Villa Santa Lucia degli Abruzzi. There are also several structures within the village with buttresses in place, approximately 21 buildings. As seen in figures 5.98 and 5.99, there are two different typologies of buttresses present within Villa Santa Lucia deglia Abruzzi. The first typology is a partial buttress that only partially covers the height of the wall being supported. Typically this typology of buttress was not present in the original construction, but

Figure 5.98 Partial Buttress

Figure 5.99 Complete Buttress

instead was added later due to the need for additional structural support. The second typology however, the complete buttress, spans the height of the wall being supported. The example, as seen in figure 5.99, is located in the heart of the historical center and was therefore presumably a part of the original construction of the village. This is typically the case for complete buttresses. It is also important to note that due to the size of the buttress structure and the narrow streets within the historical center of Villa Santa Lucia degli Abruzzi, in many conditions, the addition of a complete buttress is impossible after the initial construction. In this case, either tie rods can be utilized of partial buttresses, if the space allows for such a structural addition.

As previously mentioned, there are several tie rods present within Villa Santa Lucai degli Aburzzi. There are also several typologies of tie rods utilized. There are two general categories for


Figure 5.100 Tie Rod


Figure 5.101 Tie Rod


Figure 5.102 Tie Rod


Figure 5.103 Tie Rod

tie rods, the first being a bar tie rods, as seen in figure 5.100 and 5.101. The second categoru is pf plate tie rods, as seen in figures 5.102 and 5.103. In general, plate tie rods can be considered pless damaging to the surface of the structure, while bar tie rods have a tendency to puncture the surface, although this is only the case in rare occasions. Tie rods are extremely efficient strengthening toold in seismic area, however their placement must be considered thoroughly. In general, both the placement and implementation of tie rods, within Villa Santa Lucai deglia Abruzzi as well as other villages within the Baronia collective, are efficient. There is a clear history of construction knowledge specific to masonry within seismically active historical centers.

The third and final type of permanent structural interventions present in Villa Santa Lucia degli Abruzzi is the arch or “sporto”. In the case of an arch, they are added solely for the purpose of anti-seismic protection. “Sporti” however serve a dual purpose of both anti-seismic deign as well as an interior programmatic function. In both cases, the addition of an arch or “sporto” can aid in separating two adjacent structures in the case of a seismic event. This separation can deter the occurance of the hammering between the two structures. It is important to note that high density “sporti” can create minor structural damages to the attached façade, or collapse on their own. This however is a rare occurrence and is generally only applicable for “sporti”, instead of for single arches. Villa Santa Lucia is specifically notable due to the medium amount of both arches and “sporti” present in the historical center of the village.

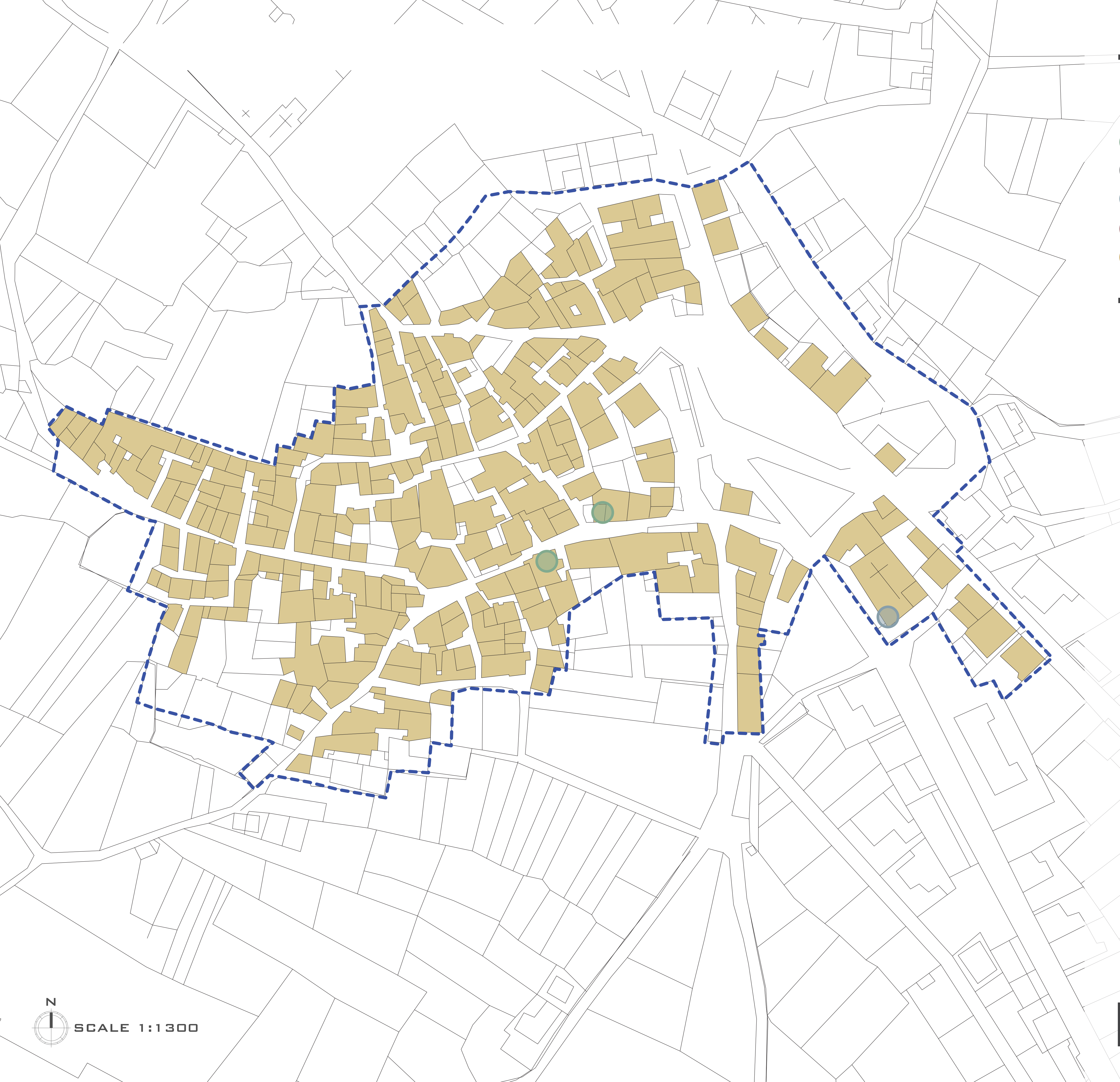
Figure 5.104 “Sporto”

Figure 5.105 Arch

Table 5.12 Temporary Intervention Locations

KEY:

- Surface Rendering Intervention
- Wooden Grid and Ties Intervention
- Traditional Prop Intervention
- Arch/Opening Support Intervention
- Shoring System Intervention



Comune: Villa Santa Lucia degli Abruzzi

Temporary Intervention Locations

5.12 Temporary Structural Interventions

Both before and after the 2009 seismic event in L'Aquila, temporary structural interventions have been put into place to minimize the collapse mechanisms in several structures that have shown signs of structural instability. There are several types of temporary interventions present in the four villages discussed in this thesis. These include surface rendering, wooden grid and tie, traditional prop, arch/opening support and shoring system interventions. There are several typologies of temporary structural interventions present in Villa Santa Lucia degli Abruzzi, however only two of these typologies will be discussed in this section.

The first typology of temporary structural interventions to be discusses, present in Villa Santa Lucia degli Abruzzi, is that of the traditional prop intervention, which is an extremely common temporary intervention, specifically in the region of Abruzzo. The first and only example of this typology to be discussed is located in aggregate VSL 012. The example to be discussed is located on the only church within the village. Traditional prop interventions aim at preventing one of the most common potential collapse mechanisms; out of plane wall overturning. This particular collapse mechanism is common in churches due to their typically irregular facades and building heights within a single aggregate. This particular example is fairly efficient, with the aim of better supporting two of the façade walls. However the intervention touches the façade at only four separate point, although the wooden beams allow for better distribution of the stress. However to better interact with the façade, additional connection points to the façade are necessary. However this traditional prop intervention is a good example for temporary structural interventions. It is important to note that this intervention should be seen as only a temporary intervention and permanent interventions should be implemented as soon as possible in order to prevent further damage or collapses.

Figure 5.106 Wall Prop Intervention

The second and final temporary structural intervention to be discusses within Villa Santa Lucai degli Abruzzi is that of the surface rendering intervention. The two examples of this typology

Figure 5.107 Surface Rendering

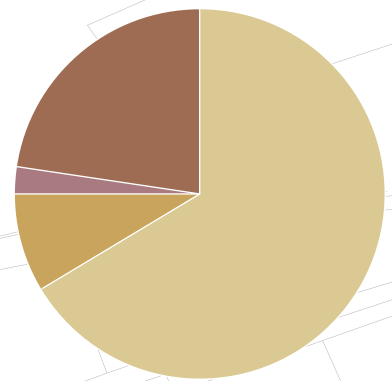
Figure 5.108 Surface Rendering

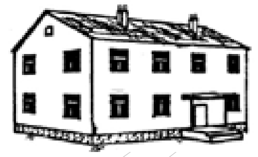
of temporary intervention are located in aggregates VSL 002 and VSL 013-B. Both of these examples of located within the core of the historical center of the village. In both cases, steel and wood compose the intervention. Similar to the traditional wall prop intervention, this typology of intervention aids in minimizing the effects of the collapse mechanisms of out of plane wall overturning. This typology however is typically placed on the façade of the structure facing the narrow street way and never on the sides. Due to the use of steel instead of wood, the intervention has the propensity to last longer, however these temporary interventions will still eventually need to be replaced with permanent structural interventions that prohibit the possible collapse mechanisms of the façade. In both cases, the interventions present are of high quality and have little effect on the existing structural dynamics of the surface due to distribution of the stresses put on the façade by the connections to the intervention. These can both be considered to be efficient temporary structural interventions, however these conjectures would have to be verified through further analysis on-site.

Table 5.13 Immediate Post-Seismic Damages

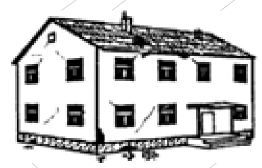
KEY:

- Damage Level A
- Damage Level B
- Damage Level C
- Damage Level E





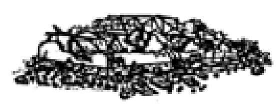
Grade 1 Damage (Level A, B)
Negligible to slight damage, no structural damage slight non-structural damage.



Grade 2 Damage (Level C)
Moderate damage, slight structural damage, moderate non-structural damage

Grade 3 Damage (Level E)
Substantial to heavy damage, moderate structural damage, heavy non-structural damage.

Grade 4 Damage
Very heavy damage, heavy structural damage, very heavy non-structural damage



Grade 5 Damage (Ruins)
Destruction, very heavy structural damage

Comune: Villa Santa Lucia degli Abruzzi
Immediate Post-Seismic Damages

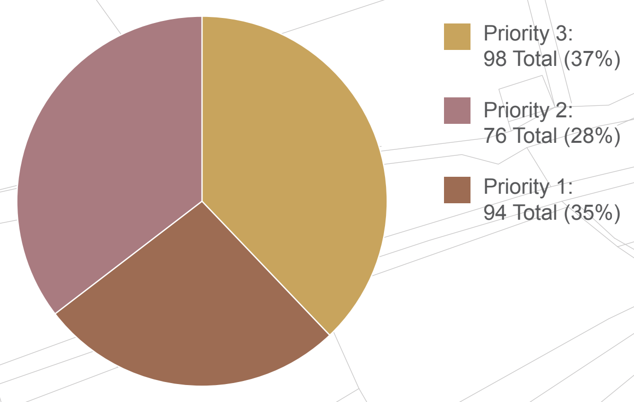
5.13 Post Seismic Damages

Immediately following the 2009 L'Aquila seismic event, the four communities discussed in this thesis of the Baronia collective surveyed the structures within the four separate villages to determine the post-seismic damages. These damages have been defines to four different levels. These include level A,B,C and E. Level A is approximately equivalent to the legal damage grade 1, where there is negligible to slight damage. There is no structural damage with limited non-structural damages. Level B and C are approximately equivalent to damage grade 2. This grade includes moderate damage, specifically with slight structural damage and moderate non-structural damage. The final damage category is level E, which is approximately equivalent to damage grade 3. In this case, there is substantial to heavy damage that includes moderate structural damage and heavy non-structural damage. In most cases, these damage assessments are slightly exaggerated. As seen in the attached "Post Seismic Damages" map of Villa Santa Lucia degli Abruzzi, the varying grades of damage are equally spread throughout the historical center. This implies that there is no terrain feature in the area that amplifies the force of a seismic event. There was no major structural damages to be notes. It is however important to note the amount of structures categorized as sustaining level E damage. More than 23 percent of the 268 buildings within the village sustained level E damage. Very few structures were categorized as sustaining damage levels B and C. The remainder of the village, 64 percent of the structures, was included in the category of level A damages. It is also important to note that a large amount of the structures in the center of the village were considered to be have level E damages.

Table 5.14 Post-Seismic Intervention Priorities

KEY:

- Priority 3
- Priority 2
- Priority 1

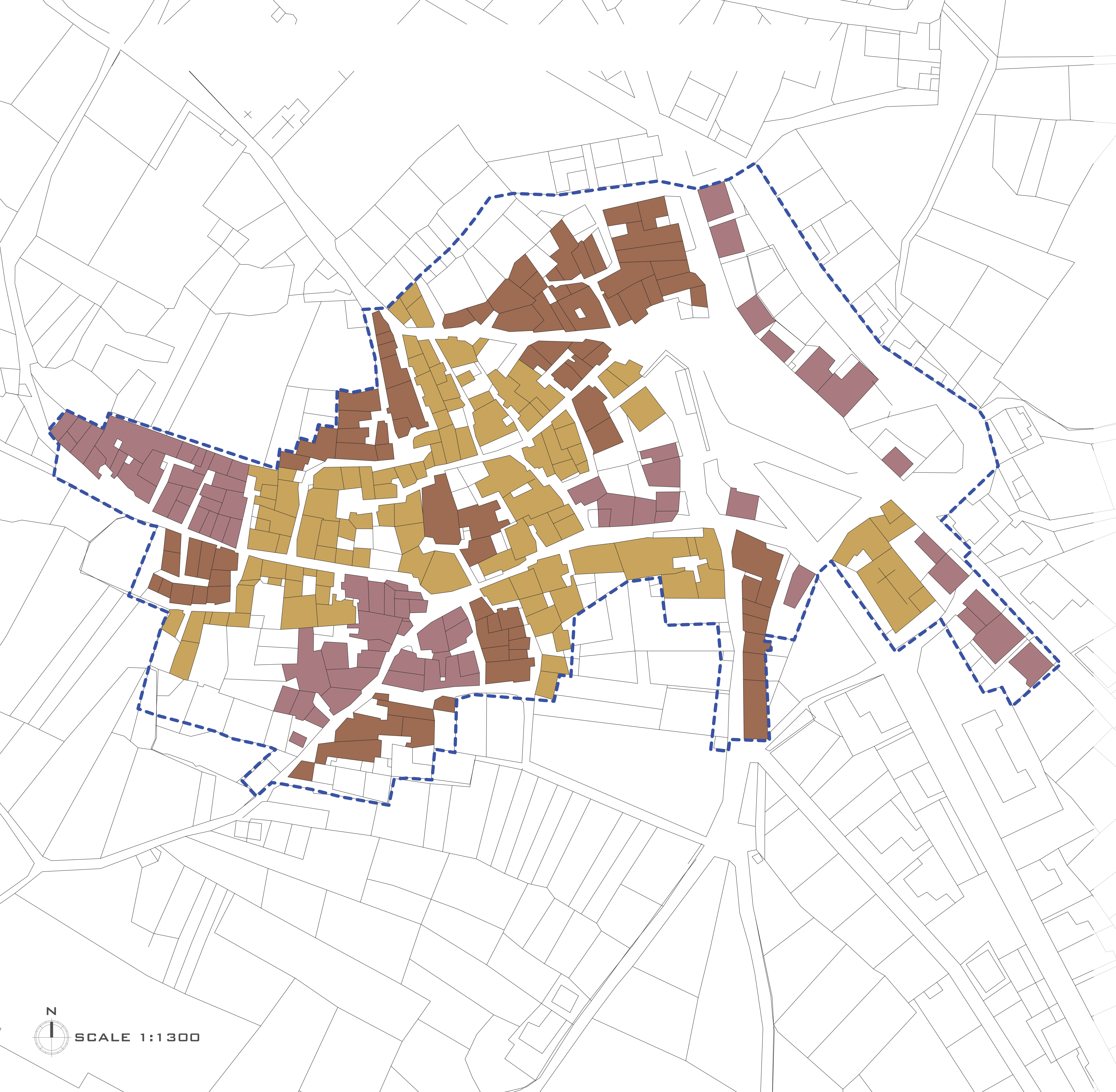


Total Buildings: 268

Priority 3 (Low Priority)
Aggregates not entered in the following priorities

Priority 2 (High Priority)
Aggregates with primary residences inhabitable
Isolated Buildings

Priority 1 (Highest Priority)
Aggregates with primary residences inhabitable



Comune: Villa Santa Lucia degli Abruzzi
Post-Seismic Intervention Priorities

5.14 Post Seismic Priorities

Immediately following the post-seismic damage assessment, the villages of the Baronia collective defined post-seismic priorities regarding the location of possible interventions. These priorities have been localized by aggregates and not individual buildings. The highest priority is given to more severely damaged structures on the edge of the historical center. The remainder of the aggregates have been given a priority of 1, 2 and 3. The priority of 1 is the highest while 3 is the lowest. The priorities relate roughly to the post-seismic damage assessment. The area with dispersed higher damages has been given the highest priority. In is important to note that these priority levels due not consider the habitation of the structures in question, which will be taken into consideration in the following section 5.15,on the vulnerability conclusion.

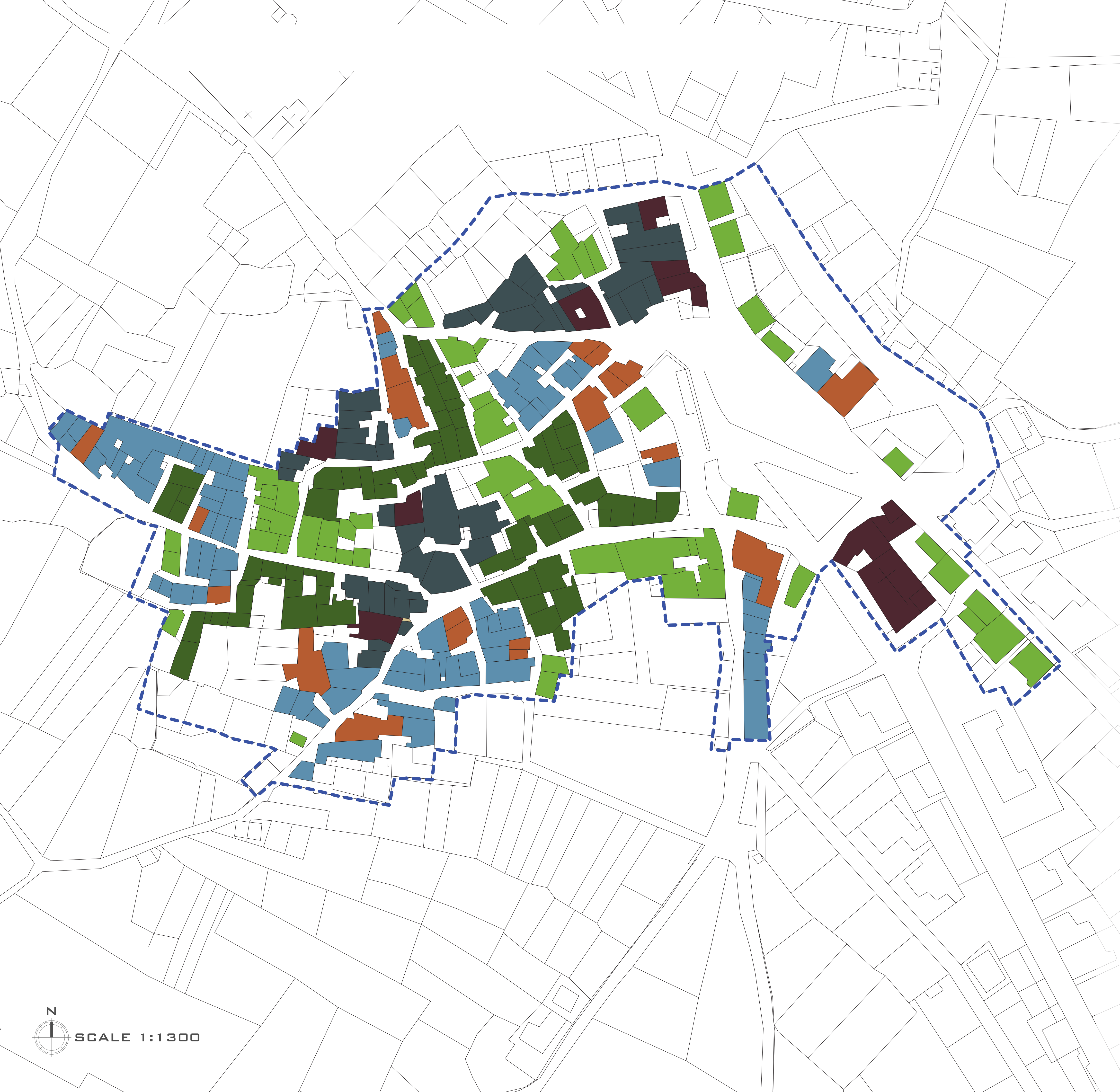
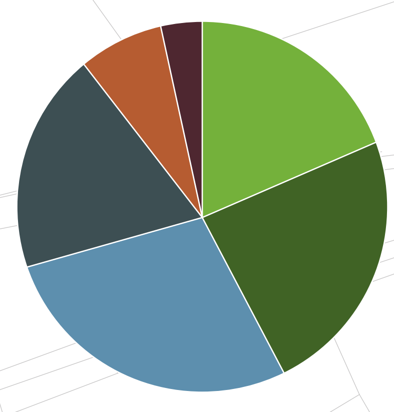


Table 5.15.1: Vulnerability Conclusion

KEY:

- Priority 6
- Priority 5
- Priority 4
- Priority 3
- Priority 2
- Priority 1



Priority 6 (Lowest Priority)
NOT CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 5
NOT CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 4
CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 3
CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 2
INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

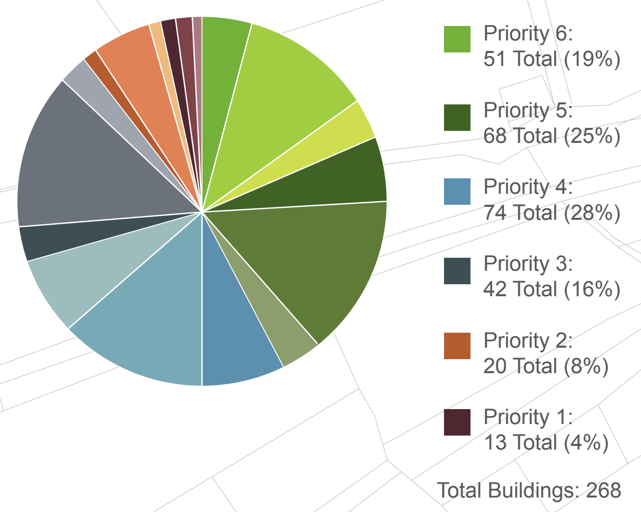
Priority 1 (Highest Priority)
INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Comune: Villa Santa Lucia degli Abruzzi
Vulnerability Conclusion

Table 5.15.2: Vulnerability Conclusion

KEY: (TOTAL)

Priority 6a (9)	Priority 6b (35)	Priority 6c (7)
Priority 5a (18)	Priority 5b (41)	Priority 5c (9)
Priority 4a (14)	Priority 4b (46)	Priority 4c (14)
Priority 3a (8)	Priority 3b (28)	Priority 3c (6)
Priority 2a (4)	Priority 2b (13)	Priority 2c (3)
Priority 1a (5)	Priority 1b (6)	Priority 1c (2)



Priority 6 (Lowest Priority)
NOT CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 5
NOT CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 4
CLOSE TO INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 3
CLOSE TO INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 2
INHABITED-POSITIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Priority 1 (Highest Priority)
INHABITED-NEGATIVE HOMOGENEITY
a. No interventions and Post Seismic Damages
b. No interventions and no Post Seismic Damages
c. Interventions and no Post Seismic Damages

Comune: Villa Santa Lucia degli Abruzzi
Vulnerability Conclusion

5.15 Vulnerability Conclusion

5.15.1 Overall Vulnerability Conclusion

The vulnerability conclusion is a cumulative result of the previous fourteen sections of analysis. However it is important to note that these conclusions have been based strongly on four separate analyzed factors, all of which have been previously discussed in the Castel del Monte analysis. These factors have then been subdivided to include a more complete and thorough conclusion to the vulnerability of all of the structures within this village.

The first and most important factor, when determining the vulnerability and therefore priorities within the aggregate, is the inhabitation of the individual structures and aggregates. When considering anti-seismic design and post-seismic structural interventions, both permanent and temporary, the two goals should be to protect both cultural patrimony and human life. While both are essential when protecting a village, such as Villa Santa Lucia degli Abruzzi, human life should always be given the highest priority. Therefore when considering the six final priority levels to be introduced in this section, the first two priority levels are reserved solely to inhabited structures and the third and fourth priority levels are reserved for structures within the near vicinity or within the aggregate of an inhabited structure.

The second most important factor considered when determining the vulnerability of the aggregate is the collective structural homogeneity of each aggregate and structure. This analysis, as previously discussed, has been determined through the collective evaluation within an aggregate of the building typologies, orientations to the elevation curves, building heights and masonry typologies present. While the cause of potential collapse mechanisms during a seismic event varies, at the foundation of all of these causes is a lack of homogeneity. This lack of homogeneity can be seen in plan, elevation, masonry composition, distribution of stresses, etc. This lack of homogeneity, either in separate elements or factors, or as a whole can lead to collapse mechanisms such as hammering, out of plane wall overturning, torsion and many more. This information was therefore used as a primary source when considering the vulnerability conclusion of each aggregate.

The third and last important factor considered was the existing vulnerability of the aggregate, based on both the post 2009 seismic damages as well as the presence of permanent structural interventions such as tie rods and buttresses. The existing damages imply an inherent vulnerability as well as a need for immediate interventions. Therefore this factor is considered crucial when determining the level of vulnerability in an aggregate. In addition, buildings with existing permanent structural interventions are better protected than those without and therefore are noted in order to diminish the vulnerability priority of an aggregate with these types of interventions present. It is the presence of post-seismic damages and permanent structural interventions that determine the subcategories within the previously mentioned six priority levels.

Each of the six priority levels are split into three separate subsections, which are described on the attached vulnerability conclusion maps. The first subdivision, for all six priority levels, is of the highest priority because it is reserved for structures with post-seismic damages as well as a lack of permanent structural interventions. The second subdivision is for buildings with either no post-seismic damages but a lack of permanent interventions, or with post-seismic damages but with permanent interventions. The third and final subdivision is only for buildings with no post-seismic damages and that also have permanent interventions in place. These structures, within any of the six major priority levels, is considered to be of little priority and requires only observational on-site analysis to determine the extent of the vulnerability, which is presumably minimal. However all structures within the first two subcategories of the six priority levels require more thorough analysis to determine the amount of restoration interventions needed.

In the following sections, specific examples of these vulnerability levels will be discussed. These examples come from aggregates and structures within the higher priority levels. These examples will be used to better describe the priority categories as well as to showcase what higher priority structures are like. This will aid in determining what type of restorative efforts may be necessary for the higher priority aggregates. It is important to note however that these priority levels do not inherently mean there is a need for restoration, but instead they imply the likeliness that

structural interventions are necessary. Each aggregate and building should be taken on a case by case basis following additional on-site observation (interior as well as exterior) to determine the exact need of every structure within the priority levels.

5.15.2 Specific Vulnerability Example One

The first example of one of the more vulnerable aggregates is found in the heart of the historic center, near the San Marco church, specifically in aggregate VSL 004. This example, as all

Figure 5.109 Aggregate VSL 004

Figure 5.110 Aggregate VSL 004

of the examples chosen for further analysis in the vulnerability conclusion, was also chosen as one of the previously discussed negative examples. This example has been chosen for several reasons. First

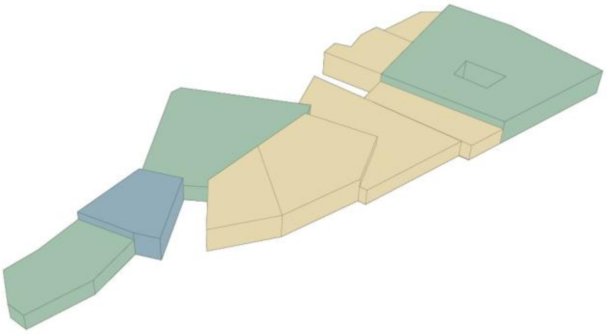


Figure 5.111 Aggregate VSL 004 Model

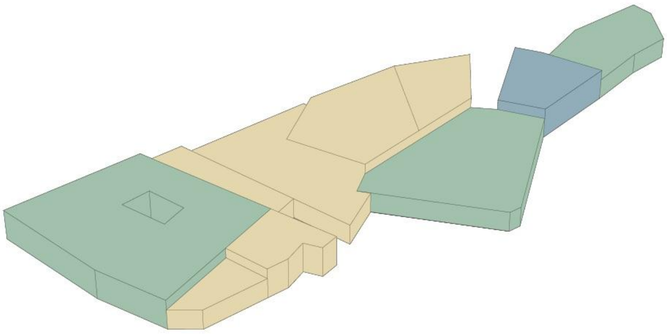


Figure 5.112 Aggregate VSL 004 Model

and foremost this aggregate was chosen due to the fact that one of the eleven structures are inhabited. In addition, as previously mentioned, this aggregate has been determined to be negative regarding its collective homogeneity. As seen in the models above, the aggregate is extremely irregular regarding the building heights and masonry typology composition. There were also damages in the aggregate after the 2009 L'Aquila seismic event and not all of the structures within the aggregate have permanent structural interventions in place. As seen in both figures 5.109 and 5.110, there is also irregularity in both additions to the structures as well as openings. Openings have been placed too close to structural elements such as the roof or corners. This is especially the case in figure 5.110, where an opening is located directly in the corner, compromising the structural integrity of both structural involved. Also additions, such as balconies have been added as cantilevers to the original structure which is extremely vulnerable to collapse in the case of a seismic event due to the uneven mass distribution. It is also important to note the extreme changes of the aggregate over time, with elements of different masonry composition, has contributed to the determination of this particular aggregate as a high priority level. Regarding a future for this aggregate, there are several restoration options available. First and foremost, additional permanent and temporary structural interventions need to be added to better control the reactions between the irregular units within the aggregate. These interventions should specifically be placed in vulnerable areas such as fulcrum point and where there are vulnerable openings. In addition, any damages sustained during the most recent seismic event of 2009 need to be thoroughly analyzed and resolved to better protect the inhabitants of the aggregate.

5.15.3 Specific Vulnerability Example Two

The second example of a high priority structure is found in the historical center, specifically in aggregate VSL 020-B. This example has been previously discussed as one of the negative examples within Villa Santa Lucia. This aggregate has been chosen for several reasons, the first of which is that one of the eight structures within the aggregate in currently inhabited. In addition, as previously mentioned, the aggregate has been considered to be negative regarding its overall collective homogeneity. This particular aggregate is extremely irregular in both masonry typology composition and the building heights of the individual units within the aggregate. The aggregate is also irregular in

Figure 5.113 Aggregate VSL 020-B

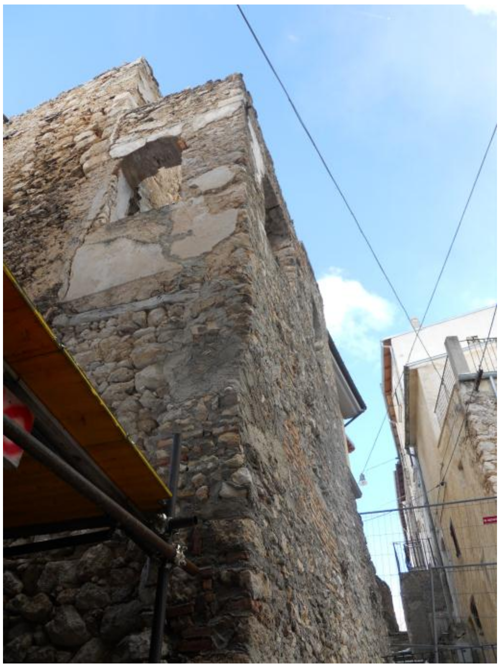


Figure 5.114 Aggregate VSL 020-B

both plan and elevation. There were also damages in the aggregate after the 2009 L'Aquila seismic event and not all of the structures within the aggregate have permanent structural interventions in

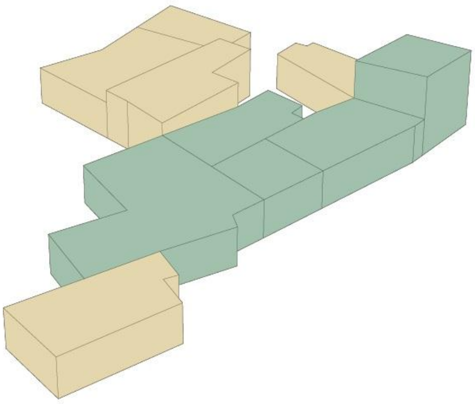


Figure 5.115 Aggregate VSL 020-B Model

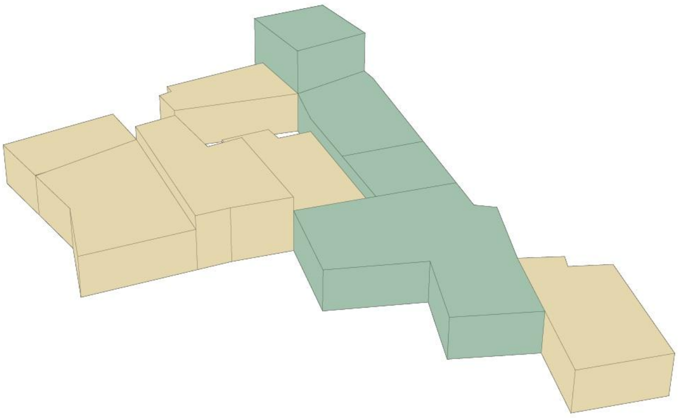


Figure 5.116 Aggregate VSL 020-B Model

place. As seen in figure 5.113, several masonry restorations have taken place that failed to respect the existing masonry composition. Regarding a future for this aggregate, there are several restoration options available. Additional permanent and temporary structural interventions need to be added to better control the reactions between the irregular units within the aggregate. These interventions should specifically be placed in vulnerable areas such as fulcrum points between two attached structures of different heights. In addition, any damages sustained during the most recent seismic event of 2009 need to be thoroughly analyzed and resolved to better protect the inhabitants of the aggregate. Also previously ruined buildings need to be better controlled to avoid more damages.

5.16 Conclusion

While the earthquake of April 2009 in L'Aquila resulted in little to no major structural damages in Villa Santa Lucia degli Abruzzi, the seismic event should be utilized as a reminder of the vast vulnerability of masonry structures within the historical center. The village is the least vulnerable of those discussed within this thesis. This is due in part to the lower population size, as well as less structures with existing post 2009 seismic damages. Fortunately several of the structures have permanent structural interventions in place. However the village is still in dire need of additional reinforcements as well as seismic retrofitting measures, specifically in the currently inhabited aggregates. It is important to note that the higher priority structures within the village are located in very few aggregates. This distribution therefore requires little additional analysis, both interior and exterior, to better determine the aggregates that are the most deserving of the limited public funds available for restoration. An initial visual analysis should be the first step of any restoration process, followed by more invasive analysis to determine the structural vulnerability of the masonry elements. Finally the most vulnerable aggregates should be prepared for restorative efforts as soon as possible, in order to protect the existing population.

While restorations are costly efforts, they are always the most economical choice over the reconstruction of structures damaged or destroyed after a major seismic event. Now is the time to protect both the architectural patrimony and populations of the village of Villa Santa Lucia degli Abruzzi, as well as the rest of the Baronia collective. More specifically, time between seismic events, such as now following the 2009 earthquake, is the opportune time to analyze the existing architecture, regarding collective homogeneity, structural vulnerability and building inhabitations to be better prepared for the next seismic event to come. Any analysis completed now can be utilized in both immediate earthquake aftermath, regarding finding citizens who may be hurt, as well as in the long term aftermath, regarding which structures are more dangerous and should remain vacant until restoration efforts can ensure the safety of the building's inhabitants during a seismic event.

6 GENERAL CONCLUSIONS

6.1 Community Comparison Analysis

While all of the previously mentioned analysis has been village specific, it is important to cross reference the information gained from each specific commune to better comprehend where they differ and what qualities they share. This cross referencing will provide a better opportunity to adequately restore the four villages with the limited public funds available. It important to note that the differences in vulnerability among the four villages are primarily based on population size. Castel del Monte has been considered to be the most vulnerable, due in part to post-seismic damages as well as structures within permanent interventions, however this is primarily due to the fact that the village has a population almost four times higher than the other three villages. While the restorations of each village will be carried out separately, the distribution of funds should correspond to the population size of each village.

The next most vulnerable villages include Castelvecchio di Calvisio and Santo Stefano di Sessanio. This two villages require less restorative work and further analysis than Castel del Monte, but still should be given priority regarding public funds due to their population sizes, as well as amount of possible tourists. Final the least vulnerable of the four villages is Villa Santa Lucia degli Abruzzi. The village has an extremely low population and very few of the structures are currently inhabited. There are also many permanent interventions in place and very few post-seismic damages. Thus in the case of Villa Santa Lucia degli Abruzzi, the emphasis should be given to better understand the vulnerability of all of the aggregates within the inhabited areas. Additional interior and exterior analysis is necessary to understand the depth of vulnerability in the higher priority structures. In the case of Castel del Monte, restoration is required throughout and while further analysis is required, the emphasis should be given to immediate restorative efforts due to the vast distribution of vulnerable structures. This is also the case for Santo Stefano di Sessanio, where the damages are not heavily localized in a specific area of the village. There are more vulnerable aggregates in the ancient historical center, but there are also extensive vulnerabilities outside of this center as well. In the case of Castelvecchio di Calvisio and Villa Santa Lucia degli Abruzzi, the vulnerable aggregates are located in a smaller area, concentrated to a limited amount of aggregates. This concentration of vulnerable structures allows for more thorough analysis to better gauge the amount of restoration required. In addition the smaller population sizes mean that vast interventions are necessary immediately as is the case for Castel del Monte.

Overall it is important to note not only the placements of vulnerable aggregates in each village, but also the reasons for their vulnerability. Each of these four villages are common in their construction typologies, typical for the region of Abruzzo, however they should be seen as completely separate entities that have their own individual qualities. It is these qualities, that have been thoroughly analyzed in this thesis, that will define the next restorative steps for each of the four communities. Restorations are specific efforts that must be related to all possible factors, including the population size, the types of damages, the presence of structural interventions, the collective homogeneity, etc. So while it is important to compare each of these four villages to understand how they differ and to better determine how to allocate public funds in the most efficient manner, their restorative efforts should be seen as completely separate processes, specific to the characteristics that make each aggregate its own.

6.2 Final Conclusions

The goal of this thesis was to investigate the role of structurally homogeneity in seismically active historic centers of Abruzzo, and then to create a macro guideline for which the four villages discussed in this thesis can follow to have a list of priorities of the most complex and vulnerable buildings. Seismic events are almost impossible to accurately predict but none the less their happening in a specific region is predictable, if not the specific time or location. The earthquake that struck L'Aquila on April 6th, 2009 was devastating. However this earthquake was not the first and will not be the last seismic event in this region. The characteristics of the tectonic plates guarantee there will be future earthquakes. This therefore leaves the opportunity to prepare villages, such as Castel del Monte, Santo Stefano di Sessanio, Castelvecchio di Calvisio and Villa Santa Lucia degli Abruzzi, before the next seismic event to come. The role of this thesis as a potential guide is aimed at kick starting the analysis necessary for not only an efficient restoration but also a practical immediate response following an earthquake. Better understanding not only the building inhabitation but also collective homogeneity and specific vulnerabilities, will allow for a more intelligent, prepared post-seismic response to effectively defend both the architectural patrimony of these villages, but more importantly the human lives.

One of the primary problems encountered in this particular thesis was a lack of specificity. However the role of generality allowed for a more all-encompassing study of all of the structural and inhabitation factors that play a role in accurately determining the specific vulnerabilities of the aggregates within a village. In order to resolve the issue of a lack of specificity, following a general introduction for each commune of all structural factors involved, there are introduced specific examples of both negative/positive collective homogeneity as well as specific examples of high priority structures and aggregates. These examples, as well as the priority levels, was produced in the hope that each village would be able to utilize the information to better continue the analysis of their respective communities in the most cost effective way possible.

The methodology of this particular thesis reflects the aim of maintaining both generality and specificity in the analysis of each village. The initial investigation focused on on-site work, aimed at analyzing four primary structural factors. These factors include building typology, orientation to elevation curves, masonry typology and building heights. All of these four factors were determined for every single building within the four villages through on-site observational analysis. Due to the quantity of structures, the analysis was exclusively restricted to exterior analysis only. All of these four factors were then overlaid to produce a better understanding of the collective homogeneity within individual aggregates of these four structural factors. From this collective homogeneity analysis, both positive and negative examples were then determined. This analysis is then followed by several sections referring to more minor structural influences such as openings, permanent and temporary structural interventions, post seismic damages, etc. To conclude the analysis of each village, the information analyzed is then complied to create an extremely specific map with 18 separate subcategories in six overall categories to define the vulnerabilities and therefore priorities of all of the structures within the villages. The most important factors included in this vulnerability analysis include the combined collective homogeneity analysis, the buildings' inhabitations, the presence of permanent structural interventions and the presence of post seismic damages. The highest emphasis was given to the buildings' inhabitation to maintain the priority of protecting human lives, with protecting architectural patrimony as a second primary goal.

While the analysis is thorough regarding each of the many structural factors considered, there are some limits to the methodology. These specifically include interior analysis of the structures as well as more in depth analysis of the quality of materials and structures, giving more information to reveal the homogeneity of the single structural units of an aggregate and the crack patterns present. While this is a superficial, observationally based, analysis for all factors considered, regarding quality, there is a lack of more specificity. However due to the limited time and shear amount of information presented to provide a general structural view of each village, more specific analysis was rendered impossible. This particular limitation can be easily resolved through continued research on site and analysis as well as through further analysis completed by the municipalities of the communes. In fact this can be a positive attribute to the thesis regarding the manner in which it suggests the villages to continue their own analysis in a more direct fashion. Further analysis will also aid in the seismic evaluation, improving upon the limitation of being unable to verify the structural integrity of the structures determined to be vulnerable. Additional time and analysis would provide these villages with a better understanding of the accuracy of the methodology used in this thesis, which will then determine their possible next courses of action for the future of their communities.

Overall this thesis provides only the start to a long process that will properly prepare all four villages for the next earthquake to come. The quantity of factors analyzed showcases the complexity in determining the vulnerability of both aggregates and individual buildings. This methodology, compared to previous verifications on site, showcases the difficulty of verifying the level of vulnerability due to a lack of interior access in most uninhabited structure. This is the case for all four villages discussed in this thesis as well as similar historical centers. If properly prepared for, through additional verifications, seismic events do not need to render villages damaged or destroyed. A thorough analysis, completed between seismic events, will prepare villages such as these four discussed for a more efficient and effective response, specifically immediately following a seismic event as well as for the long term restoration process. A proactive approach, while costly, is always the more economically efficient option, regarding both the protection of architectural patrimony as well as human life. This proposed methodology could be a guide and a possible beginning to a proactive approach that will protect Castel del Monte, Santo Stefano di Sessanio, Castelvecchio di Calvisio and Villa Santa Lucia degli Abruzzi from future seismic events to come as well as similar historical centers in seismic regions.

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