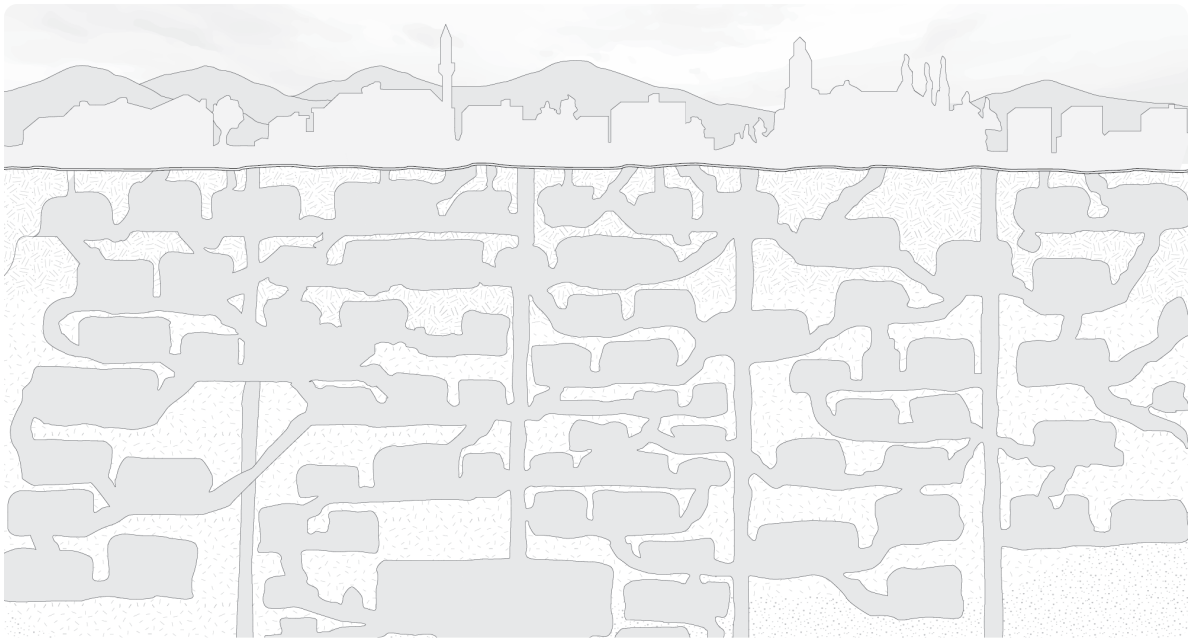
Underground Architecture Typology as Crisis Management

An Analysis Through Derinkuyu Underground City



This paper analyses the features and context of Derinkuyu to create an underground architecture typology focused on crisis management. It explores the following questions: As a precedent for underground architecture, what geological and architectural elements helped Derinkuyu achieve its aim of protection from crises? Considering Derinkuyu as an archetype, what is an underground architecture typology that can protect people from future crises?

Located in central Turkey, Derinkuyu is one of the largest and oldest underground cities in the world. The underground city was carved by people around approximately 1750 BC. in the soft geologic tuffs that are characteristic of the Cappadocia region.

Several elements like location, social conditions, geological features, and structure allowed the residents of Derinkuyu to avoid crises – creating the blueprints for crisis management through architecture. By analyzing these elements and categorizing them to their crisis management functions, this paper creates an underground architecture typology focused on crisis management.

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Introduction

Humans are inherently primed to react to a dangerous world and the need for protection drives their decision-making.[1] During a crisis, the defence mechanism of humans can be triggered to avoid many forms of threat, injury, and attack – and many times, the physical solution is a suitably protective dwelling unit.[2]

A dwelling unit is any room or group of rooms located within a structure to form a single habitable unit with life-sustaining facilities.[3] For millennia, dwelling units in cities have generated power, wealth, creativity, and knowledge, but they have also incubated hunger, violence, war, inequality, and disease.[4] In a time where the world is facing multiple crises simultaneously, proper crisis management has become crucial to minimise their impact(s). Thus, as people contemplate the future of cities, examining their past becomes just as important – since the blueprints of crisis management have been laid out in past civilizations and nature.

Ever since ancient times, crisis management has been a fundamental practice often achieved through the qualities of the dwelling unit. Moreover, for housing and protection within the ecosystem in the early days of human life, the underground dwelling was one of the first known architectural resorts.[5]

This paper explores the following questions: As a precedent for underground architecture, what geological and architectural elements helped Derinkuyu achieve its aim of protection from crises? Considering Derinkuyu as an archetype, what is an underground architecture typology that can protect people from future crises?

A paragon of ancient underground architecture is the Derinkuyu Underground City (Derinkuyu) in Cappadocia, a volcanic plateau region in central Turkey.[6] The structure is part of a UNESCO World Heritage Site where the special geology of the region, unique volcanic rock layers deposited over the past ~10 Myr, made possible the development of a unique vast underground refuge.[7] Inhabited through generations starting in 1750 BC, Derinkuyu was used as a shelter to protect its people from diseases, natural disasters, and attacks – essentially preventing and managing crises. As such, underground architecture like Derinkuyu, was an essential way for crisis management in ancient times – providing its inhabitants a place of refuge.

This paper analyses the features and context of Derinkuyu to create an underground architecture typology focused on crisis management.

1 Stevan E. Hobfoll, "The Primitive Self and the Power of Catastrophic Threat," In *Tribalism* (Palgrave Macmillan, Cham, 2018), 1.
2 Paul Gilbert. *Human nature and suffering* (Routledge, 2016), 42.
3 "Dwelling Unit Definition: 5k Samples," Law Insider, accessed August 23, 2021, https://www.lawinsider.com/dictionary/dwelling-unit.
4 Andrew Robinson, "How Did Ancient Cities Weather Crises?," Nature News (Nature Publishing Group, July 14, 2020), https://www.nature.com/articles/d41586-020-02070-5.
5 Zaher A. Al-shanty, "Towards a Futuristic Underground Cities," *International Journal of Civil Engineering and Technology* 10, no. 3 (2019): 2294, http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=03
6 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," (2016): 3.
7 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," (2016): 1.

1. The Use of Underground Architecture in History

During a crisis, underground was one of the first places to seek shelter due to its hidden and secure nature. The advantages of underground refuge include hiding from a war/different religion; emergency evacuations; or for protecting people, animals, tools, and crops. [8]

Figure 1: Maresha Underground City, Israel. Photo: tripfreakz.com

This common use of underground space suggests how underground living is linked to human history. Caverns and hollows have been used as dwellings and food storage since the Paleolithic era millions of years ago.[9] Hiding in natural caves or digging beneath the surface of the earth for mining, worship, and storage was an innate action.[10] More recently, underground cities in China (Banpo), Turkey (Cappadocia), and Israel (Maresha, Figure 1) two and three thousand years ago, show underground living as a repeating solution to avoid crises in past civilizations (Figure 2).[11]

Figure 2: Underground Perugia, Italy. Photo: www.travelmagma.com

8 John Carmody and Ray Sterling, *Underground Space Design: a guide to subsurface utilization and design for people in underground spaces* (Van Nostrand Reinhold, 1993), 328-333.
9 Francois Mancebo, "Future Cities Live Underground," The Nature of Cities, August 5, 2020, https://www.thenatureofcities.com/2017/01/22/future-cities-live-underground-thats-not-pile-schist/.
10 Khayat M. Arij, "Underground Architecture," *Global Journal on Advances in Pure & Applied Sciences* 00, no. 1 (2014): 1, www.awer-center.org/pit.
11 Francois Mancebo, "Future Cities Live Underground."

2. Derinkuyu Underground City

Located in central Turkey, Derinkuyu is one of the largest and oldest underground cities in the world. The underground city was carved by people around approximately 1750 BC. in the soft geologic tuffs that are characteristic of the Cappadocia region.[12] Derinkuyu is thought to be almost as old as the invention of writing and was discovered by local villagers in 1963 and opened to visitors in 1965.[13]

Though its true size is still unknown, Derinkuyu is thought to be large enough for a stadium full of people to live together. With an estimated total size of 4.5 square kilometers, the underground city's total footprint is equivalent to 1100 football fields.[14] This space for Derinkuyu includes 13 floors underground, covering 7 km on the surface (Figure 3). However, to date, only 8 floors have been discovered. [15]

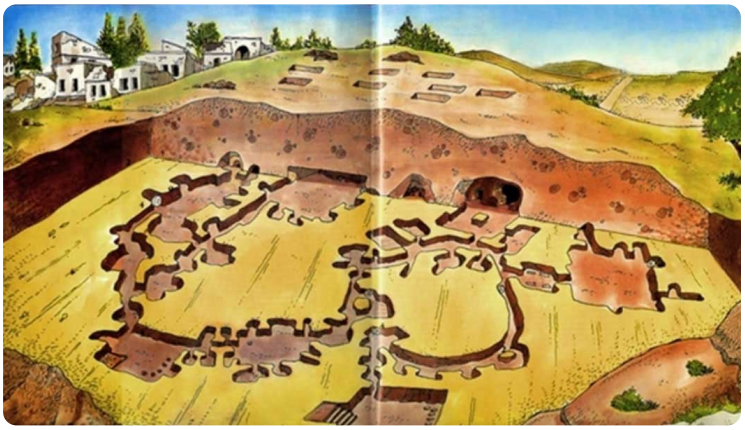

Figure 3: Section of Derinkuyu Underground City. Diagram: https://sometimes-interesting.com/derinkuyu-the-underground-cities-of-cappadocia/

These numbers only show the beginning of how Derinkuyu was intentionally designed as a crisis management structure aimed to protect large civilizations. With its location and social conditions, geological features, and structure, Derinkuyu proves itself not only as a successful underground architecture example, but also as a way of managing crises.

12 K. Dirik, "Geology, geomorphology of Kapadokya region and their effect on the civilizations of the region," *In Abstracts Book of I. Medical Geology Workshop*, vol. 30, (2009), 6.
13 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
14 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
15 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.

2.1 Location and Social Conditions

Since the Paleolithic Age, Turkey has been the home of various civilizations as it sits astride the Asian and European continents.[16] Hosts of cultures from Asia and Europe have migrated through and into the lands of present-day Turkey and these diverse civilizations and ethnicities have shaped the social and cultural history of the region. The Cappadocia region specifically is situated on one of the principal trading routes of the ancient Silk Road from China to Europe and was a meeting place for religions and philosophies – each leaving a historical and cultural impression on the region.[17] Ancient Anatolian tribes, Assyrians, Hittites, Turkic tribes from Central Asia, Mongols, Persians, Syrians, Arabs, Kurds, Armenians, Slavs, Greeks, Romans, and Western Europeans have all passed through Cappadocia.[18] Owing to the numerous raids from different civilizations to the region, early inhabitants recognized the importance of building underground rock shelters against these raids in the relatively flat plateau region of Cappadocia (Figure 4).[19]

Figure 4: Underground Perugia, Italy. Photo: https://mymodernmet.com/derinkuyu-underground-city/

It is estimated by anthropologists that the beginning of Derinkuyu dates to the pre-Hittite period, approximately 1750 BC or 2000 BC.[20] 4000 years ago, the Hatti civilization in Cappadocia had the power and social organization to build cities and were thought to have laid the first foundation of Derinkuyu.[21]

This leads to the intriguing question of how could a civilization that has not yet found writing build a huge underground city whose borders are still unexplored even today?[22] To the Hattis, the first thing needed for this was the right raw material.

16 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," 1.
17 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," 3.
18 Alessandro Bucci and Luigi Mollo, eds. *Regional architecture in the Mediterranean area*, Vol. 8. (Alinea Editrice, 2010), 105.
19 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," 2.
20 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
21 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
22 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.

2.2 Geological Features and Material

The geology and geomorphology of Cappadocia are two of the factors controlling the activity of civilizations who settled, developed, and disappeared in Derinkuyu.[23] The landforms of the Cappadocia Region were formed by volcanic, tectonic activities and erosion of running water.[24]

Geologically the region is dominated by relatively recent volcanic activity. The episodic eruption of Erciyes, Hasandağ, and Melendiz volcanos over the past several million years to present has covered Cappadocia with layers of ignimbrites, ash units (tuffs) that have welded into solid rock.[25] Over millennia, these soft tuff layers were eroded to produce earth formations that carry the imprint of ancient civilizations to recent times.[26] In terms of tectonics, "the tectonic evolution of the Mediterranean involves a complex array of subduction, collision, and back-arc spreading events in relation to ongoing northward convergence of Africa towards Eurasia." [27]

Finally for the effects of water, Kızılırmak, the longest river in Turkey, flows through the northern part of the region - this river with its sub-branches was the principal architect of the spectacular morphological features in the region (Figure 5).[28]

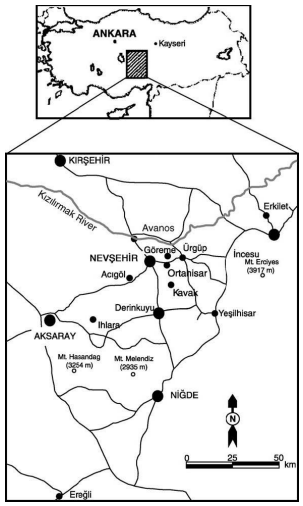

Figure 5: Underground Perugia, Italy. Map: R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," 1.

23 K. Dirik, "Geology, geomorphology of Kapadokya region and their effect on the civilizations of the region," 8.
24 K. Dirik, "Geology, geomorphology of Kapadokya region and their effect on the civilizations of the region," 9.
25 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," 2.
26 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," 2.
27 Göğüş, Oğuz H., Russell N. Pysklywec, A. M. C. Şengör, and Erkan Gün. "Drip tectonics and the enigmatic uplift of the Central Anatolian Plateau." *Nature communications* 8, no. 1 (2017): 1.
28 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," 1.

Derinkuyu was built within this ignimbrite (Figure 6). Although the volcanic rock is solid and stable, it is soft and easy to work with, even with very simple excavation implements.[29] Since the city is beneath the surface, its walls are at a constant temperature of about 20° both summer and winter.[30] The natural thermal insulation of the volcanic tuffs allows the correct adjustment of the temperature to keep a rough thermal balance. This meant that the winters were warm and the summers cool underground– making Derinkuyu suitable for human life. Thus, from the past to the present, easy carving and thermal isolation properties of these soft tuffs have been important reasons for the extensive multi-purpose underground settlement in this region.[31]

Figure 6: Ignimbrite. Photo: https://volcanohotspot.wordpress.com/2020/01/20/tuff-tufa-ignimbrite-pyroclastic-deposits/

2.3 Building Strategies

In classical engineering, buildings are built from the ground up. However, when an underground city like Derinkuyu is desired to be built, reverse engineering methods must be used.[32] Specifically, in building underground, two main problems arise: static and balance.

In classical construction, when you make a mistake on a floor, you have the chance to demolish that floor and build it again, whereas when you make a mistake on a floor while building an underground city, there is a possibility of the whole system crashing.[33] In Derinkuyu, the layers between the floors were thickened to solve this problem.

29 Vedat Toprak and M. C. Göncöoğlu, "Tectonic control on the development of the neogene-quaternary central anatolian volcanic province, Turkey," *Geological Journal* 28, no. 3-4 (1993): 357.
30 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
31 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," 2.
32 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
33 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.

2.4 Structure

The Hattis not only built the city, but also built a living space in Derinkuyu. For thousands of people to live together in a city 85 meters below the ground and carved into rock, several key life-sustaining elements like ventilation, water wells, and passages were necessary (Figure 7).[34]

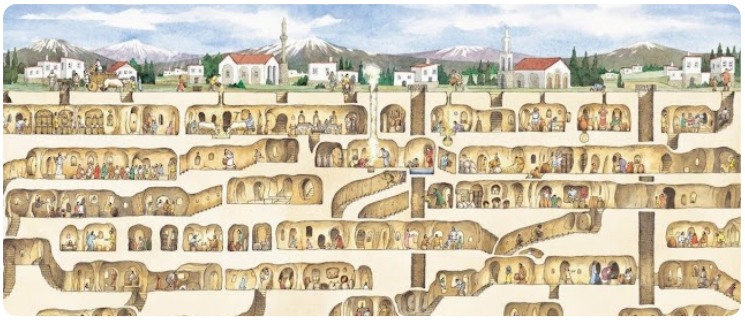

Figure 7: Section of Derinkuyu. Diagram: https://www.vintag.es/2018/11/derinkuyu-underground-city.html

The priority was ventilation – to ensure that the air on the surface would go down through all the floors and be evenly distributed throughout the rooms, Hattis built ventilation shafts (Figure 8).[35] Considering there were ultimately 10-30 thousand people and animals living in this underground city, the number of shafts was significant – approximately 50 chimneys providing 1,200,000 cubic meters of fresh air per hour. It takes considerable calculation and engineering skills to be able to get this much air circulating through this eight-story city.

The water wells were also a part of the ventilation system. The wells worked as a two-way ventilation system with holes drilled on each floor along the shaft line.[36] This way, the residents were able to provide water and ventilation to the city though a single structure. But these shafts were not the city's only connection to the surface.

Figure 8: One of the ventilation shafta in Derkuyu. Photo: https://www.vintag.es/2018/11/derinkuyu-underground-city.html

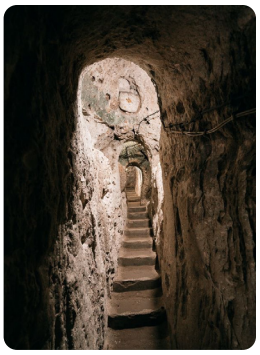

Figure 9: A corridor in Derinkuyu. Photo: https://www.journeyera.com/derinkuyu-underground-city-cappadocia-turkey/

34 R. Ulusay and Ö. Aydan. "Cultural, Historical and Geo Engineering Aspects of the Cappadocia Region," 2.
35 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
36 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.

The third required element was suitable passage and transport through the underground. Most of these people living in Derinkuyu used underground spaces as a substitute for shelter – still using the above tracts of land for growing their crops because the dark city without sunlight was not enough on its own to sustain human life.[37] For instance, a barn is located on the first floor, in the closest part of the surface, to reserve a shelter for livestock – also helping animals enter and exit easily.[38] Kitchens, chimneys, supply rooms, and more were available for residents' use. Since the space was limited, these areas were for common use. Thus, people living in Derinkuyu were never completely cut off their contact with the surface – engaging in agriculture and continuing their livestock activities.

Moreover, the half-human-sized passages (with a height of 1-1.5 meters), interconnected rooms, and tunnels are carved into stone aid and create a connection between residents (Figure 9). Unlike the floor system in a planned building that we know, the underground levels vary in their depth and extent and are connected to each other by tunnels – allowing communication in communal living.[39] The residents also tried to imitate aboveground living with innovative ideas: drilling holes in the walls to talk to each other between rooms and floors, developing a permanent lighting system in corridors by linseed oil into the cavities, and a cemetery (Figure 10).[40] In many religious beliefs, the underground is identified with death since humans have been burying their dead under the ground for tens of thousands of years. However, 4000 years ago, life in Cappadocia was under the ground – for several suitable reasons.

Figure 10: Corridor at Derinkuyu. Photo: https://www.vintag.es/2018/11/derinkuyu-underground-city.html

37 Khayat M. Arij, "Underground Architecture," (2014): 2.
38 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
39 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
40 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.

3. Derinkuyu as a Crisis Management Tool

Although referred to as “cities” the underground communities of Cappadocia like Derinkuyu probably served as temporary shelters rather than as permanently occupied dwellings. The incessant darkness is not highly conducive to life and some of the passageways are little more than crawling spaces that would have been intolerable in long-term situations.[41] These features of Derinkuyu imply that the city was made not for fulltime inhabitation, but as a crisis management system – a way to avoid danger.

In modern-day architecture, crisis management is often achieved through building systems and structures. However, even when technology wasn’t as advanced, people of Derinkuyu took pre-emptive measures to protect their communities – which created the foundation of some of today’s structures and systems that involve crisis management.

3.1 Avoiding Crises in Derinkuyu: Elements and Theories

Even though crisis management wasn’t formalized as a practice at the time, Derinkuyu was inherently built avoid crises. The first example of this is the exterior of the city - when you look at Derinkuyu from the outside, you can only see an ordinary valley and the city appears non-existent. This is because Derinkuyu, like other underground cities, was built on a simple principle: privacy and protection.[42]

Even though Derinkuyu spreads over a large area, all its connections to the surface are skillfully hidden – so well that it was discovered 4000 years after its construction. The city’s entrance is a narrow corridor of five meters, where the daylight disappears after a few meters. Bolt stones, which are locked doors, are carved from bedrock and weigh between 200-500 kilograms (Figure 11).[43] These one-way doors and narrow corridors (where two people could not pass at the same time) served the purpose of defense – making Derinkuyu not only designed for secrecy, but also shelter.

41 Alessandro Bucci and Luigi Mollo, eds. *Regional architecture in the Mediterranean area*, 106.
42 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
43 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.

Figure 11: Bolt stone. Photo: https://www.captivatingcappadocia.com/cappadocia-derinkuyu-underground-city-visitor-guide/

Moreover, floors are connected to each other – so one must pass through the second floor before going to the third.[44] Thus, it was possible to gradually defend the city when faced with a threat. With the help of bolt doors, each floor could survive independently or escape from the escape tunnels on different floors.

There are many theories surrounding the reason behind building Derinkuyu – why did the Hattis abandon their above-ground colonies and build a well-hidden sanctuary? The main theories include epidemics and volcanic eruption.

Epidemics have created great problems for people in every period of history, as they do today. Even today, it is difficult to fight an epidemic or a pandemic (most recently COVID-19), even with advanced medicine technologies. Under the conditions of that time, epidemics would have caused mass deaths at quite frequent intervals.[45] For this reason, those who took refuge in Derinkuyu may have escaped from an outside epidemic such as plague, cholera, or leprosy. [46]

Another theory is that the Hattis escaped from a massive volcanic eruption. The city was only 60 km away from the 4000-meter Mount Erciyes, the largest volcanic mountain in Anatolia.[47] The last eruption of Mount Erciyes is expressed as 250 years BC. Even though experts state that the lava of Erciyes volcanism could not have reached Derinkuyu, its eruption would have scared the locals – making them look for underground refuge.[48]

44 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
45 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
46 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
47 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.
48 *Gizemli Tarih: Derinkuyu* (2020, TRT Documentary), documentary.

3.2 Stages of Crisis Management and the Crisis Management Cycle

A crisis is when a community of people perceives an urgent threat to life-sustaining functions, which must be dealt with under conditions of uncertainty.[49] Subsequently, managing crises involves planning for (pre-crisis), coping with (response), and recovering from the impacts (post-crisis) of unexpected events (Figure 12).[50]

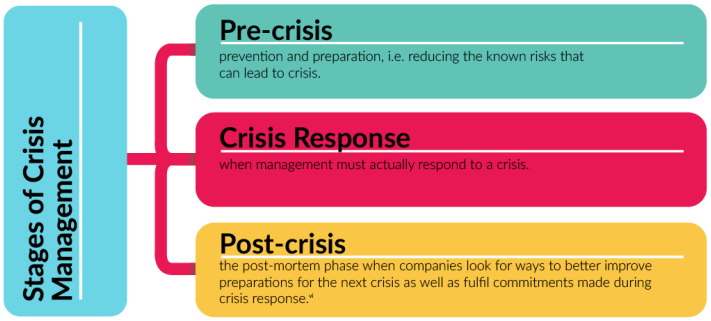

Figure 12: Stages of Crisis Management. Diagram: The Brain, "The Stages of Crisis: Understanding the Crisis Management Lifecycle," Integrated Safety & Security Software Platform, accessed July 10, 2021, https://www.noggin.io/blog/the-stages-of-crisis-understanding-the-crisis-management-lifecycle.

Stages of crisis management can be divided as pre-crisis, crisis response, and post-crisis. Pre-crisis is when prevention and preparations are made to reduce the known risks that can lead to a crisis, whereas crisis response is when the people respond.[51] During post-crisis, people look for ways to better improve preparations for the next crisis as well as fulfill plans made during crisis response. These three stages are further investigated to create the crisis management life cycle: "A life cycle approach to managing crises fortifies an organization's ability to avoid crises by focusing proactively on detection and risk management as well as on readiness and response. It also recognizes that crises can present opportunities for organizations to emerge stronger, enabling them to build more effective capabilities at all stages of the crisis life cycle." [52]

Derinkuyu's features allow its users to follow the crisis management life cycle, as described in Deltoitte's Crisis Management Survey. Their model consists of four main steps: (1) understanding the full implications of your risk landscape, (2) preventing crises, managing issues, and preparing for the worst, (3) responding to, and recovering from, crises and keep the business running, and (4) learning,

49 Arjen Boin and Paul'T. Hart, "The Crisis Approach," In *Handbook of disaster research*, (New York: Springer, 2007), 42.
50 K. Bradley Penuel, Matt Statler, and Ryan Hagen, eds, *Encyclopedia of crisis management* (Sage Publications, 2013), xxv.
51 Institute for PR, "Crisis Management and Communications," Institute for Public Relations, November 19, 2020, https://instituteforpr.org/crisis-management-and-communications/.
52 Junko Kaji, Preetha Devan, Abrar Khan, and Blythe Hurley, *Global Crisis Management Survey*, (2018), distributed by Deloitte Insights, 6.

rebuilding, and emerging stronger (Figure 13).[53]

Figure 13: Crisis Management Life Cycle, Diagram taken Global Crisis Management Survey, (2018), distributed by Deloitte Insights.

The crisis management stages, and crisis management life cycle intersect to best represent Derinkuyu's typology for crisis management (Table 1). Thus, these steps were taken as a basis in identifying the typology.

Table 1: Intersection between crisis management stages and crisis management life cycle

Pre-Crisis		Crisis Response	Post-Crisis
Understand the Full Implications of Your Risk Landscape	Prevent Crises, Manage Issues, and Prepare for the Worst	Respond to, and Recover from Crises and Keep the Business Running	Learn, Rebuild, and Emerge Stronger

4. Underground Architecture Typology for Crisis Management

"Typology in dictionary definition, is "a classification according to general type". In architecture, the word refers to a particular set of characteristics of a building, and it helps in identifying and categorizing buildings into different groups of forms… A typology therefore identifies the function of the space and its most suitable structural composition." (Figure 14) [54]

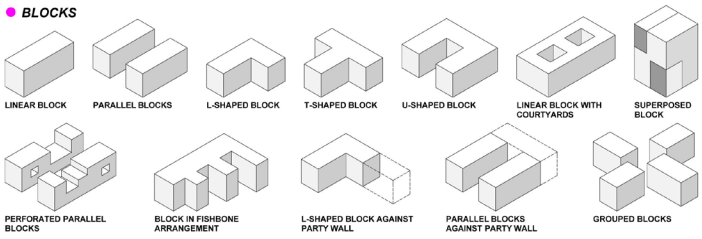

Figure 14: Crisis Management Life Cycle, Diagram taken Global Crisis Management Survey, (2018), distributed by Deloitte Insights.

53 Junko Kaji, Preetha Devan, Abrar Khan, and Blythe Hurley, *Global Crisis Management Survey*, (2018), distributed by Deloitte Insights, 6.
54 Andrea Sooyoun Kim. "Typology and Design."

4.1 Derinkuyu Model and Typology

Considering the previous examples mentioned, Derinkuyu's features can be divided into three main categories: life-sustaining, privatizing/protecting, and surface-living (Table 2). In Table 3, these elements are reorganized according to crisis management models (Table 3).

Table 2: Categorization of Derinkuyu's Features

Life-Sustaining	Privatizing/Protecting	Surface-Living
Material (providing thermal insulation, breathability, and living space)	Hidden Entrance	Barn/livestock
Organization of floors	Tight, Narrow Corridors	Communication tools (holes in walls)
Ventilation and Water Wells	Locked Doors (Bolt Stones with one-way system)	Permanent lighting system
Layers between floors, increased thickness (for static and balance)	Escape Tunnels	Additional rooms (kitchens, supply rooms, cemetery, etc.)

Table 3: Typological Arrangement of Derinkuyu's Features According to Crisis Management Models

Pre-Crisis		Crisis Response	Post-Crisis
Understand the Full Implications of Your Risk Landscape	Prevent Crises, Manage Issues, and Prepare for the Worst	Respond to, and Recover from Crises and Keep the Business Running	Learn, Rebuild, and Emerge Stronger
Used as a living place for hundreds of years, the residents of Derinkuyu knew the area very well – this can be understood by how efficiently they use the life on the surface and how they built Derinkuyu with their understanding of their landscape.	Material	Escape Tunnels	Permanent lighting system
	Hidden Entrance	Organization of floors	Communication tools
	Tight, Narrow Corridors	Locked Doors	
	Layers between floors		
	Ventilation and Water Wells		
	Barn/livestock		

This reorganization suggests that the elements/features of Derinkuyu serve the intention of crisis management steps and life cycle. Therefore, the organization on this data can be used to derive a typology (Appendix A).

The overarching theme for underground architecture typology for crisis management is privacy and protection from external forces. This way, the design and organization of Derinkuyu was built upon this need and idea.

As an underground city that has been used for thousands of years, and is still useable, Derinkuyu elements are proven to be effective. Thus, the typology derived from it would be able to adapt to future – with changing circumstances and technologies.

4.2 Future Uses

Ancient underground settlements like Derinkuyu set the blueprints of current underground projects. Today, underground space is being diversified for more and more functions, including industrial, commercial, transport, educational, and recreational uses.[55]

Over the next 100 years, many issues like spiking global temperatures and overpopulation are expected, making the aboveground uninhabitable.[56] Moreover, with projected emergence of underground built environments, future populations are expected to spend much more of their working, transit, and recreational time in underground spaces.[57] Underground spaces in Montreal, London, The Netherlands, Helsinki, Beijing, Shanghai, Hong Kong, Seoul, Taipei and Tokyo identified three drivers for future cities to explore their basement resource as: topology/geography, climate, and land shortage (Table 4). [58]

Usage	Examples
Rail infrastructure	Seoul wins with more than 400km of rail below ground.
Roads and Underground pedestrian networks	15% of Tokyo's urban expressways are below ground, reducing air pollution and helping to remove barriers between neighbourhoods.
Utility tunnels	Taipei has 50km of utility tunnels and some 300km of smaller ducts, which means maintenance can be carried out without digging up roads, so reducing traffic congestion and therefore pollution.
Caverns	Not available to every city, though Hong Kong uses theirs for waste transfer and treatment, and Helsinki boasts the world's most extensive use of rock caverns, turning them into commercial space, car parks, data centres and more. In fact, it was Helsinki that developed the world's first 'Underground Master Plan' to describe how it would extend and employ its subterranean resource in the future.

Table 4: Current common use of underground space. Information from: Wallace, Daniel. "Unearthed: Digital Transformation." Seequent, August 12, 2021. https://www.seequent.com/community/research-reports/unearthed-digital-transformation/.

The above table exemplifies the current common use of underground space. All these structures and their uses rely on experience and forms such as Derinkuyu. Thus, understanding of the successful precedents are essential in creating the ideal underground architecture/city.

55 Chee-Kiong Soh, George Christopoulos, Adam Roberts, and Eun-Hee Lee, "Human-centered development of underground work spaces," *Procedia Engineering* 165 (2016): 242.

56 Thomas Kostigen, "As Disasters Mount, Our Cities May Need to Move Underground," Medium (OneZero, April 9, 2020), https://onezero.medium.com/as-disasters-mount-our-cities-may-need-to-move-underground-f2e7ead9dfbf.

57 Eun H. Lee, George I. Christopoulos, Kian W. Kwok, Adam C. Roberts, and Chee-Kiong Soh, "A psychosocial approach to understanding underground spaces," *Frontiers in psychology* 8 (2017): 452.

58 Daniel Wallace, "Unearthed: Digital Transformation," Seequent, August 12, 2021, https://www.seequent.com/community/research-reports/unearthed-digital-transformation/.

Conclusion

Environmental and anthropological factors of the Cappadocia Region have been the main reasons for extensive subsurface and multi-purpose use in the past and present – including severe daily and seasonal changes of temperature in the region; thermal insulation properties of the volcano-sedimentary units covering the region; self-supporting behavior and construction opportunities in these rocks; easily carved, particularly soft tuffs; provide hiding places and camouflage to provide a defensive advantage and safety against enemy attack; and superior resistance and protection against natural disasters due to earthquake and/or volcanic eruptions in the past.[59]

Thus, Derinkuyu, a paragon of ancient underground architecture in Cappadocia, achieves various functions regarding crisis management through its elements like location, social conditions, geological features, and structure – providing its inhabitants a place of refuge. These elements not only aided in preventing crises at the time, but also created the blueprints of today's structures. The future holds many problems regarding the climate and population, therefore, underground structures might be the way to prevent crises in the future, just like they did in the past.

59 Resat Ulusay, Candan Gokceoglu, Tamer Topal, Harun Sonmez, Ergün Tuncay, Zeynal Abiddin Erguler, and Ozgu Kasmer, "Assessment of environmental and engineering geological problems for the possible re-use of an abandoned rock-hewn settlement in Urgüp (Cappadocia), Turkey," *Environmental Geology* 50, no. 4 (2006): 473.

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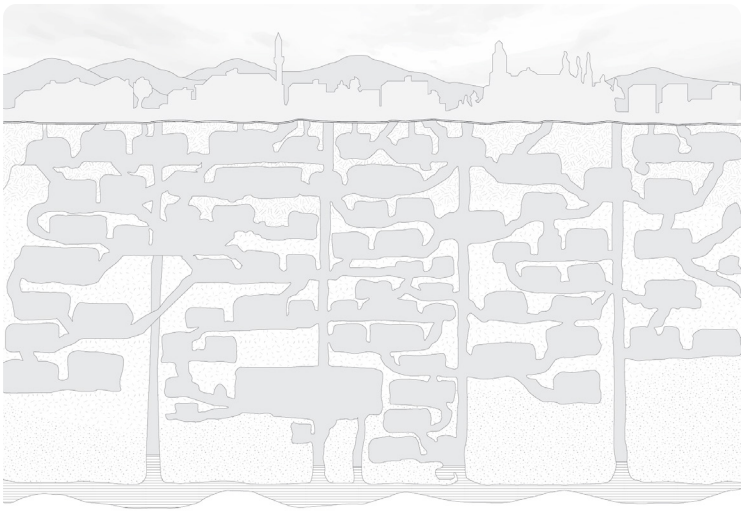
Appendix A: Section of Derinkuyu Underground City

Reference Image: Tourist map of Derinkuyu Underground City (en Español), from Sometimes Interesting. “Derinkuyu & the Underground Cities of Cappadocia.” Sometimes Interesting, January 2, 2021. https://sometimes-interesting.com/derinkuyu-the-underground-cities-of-cappadocia/.



This drawing was made as a base template to analyze typological elements of Derinkuyu underground city. The typological elements listed and organized in Table 3 was used as labels for this drawing The final version of the drawing can be found on the poster.