buildings

MDPI

Article

Integrating Underground Space into the Groundscape Resilience Concept

Nerma Omićević [1], Tamara Zaninović [2,*] and Bojana Bojanić Obad Šćitaroci [3]

[1] Faculty of Engineering and Natural Sciences, International University of Sarajevo, 71210 Sarajevo, Bosnia and Herzegovina; nomicevic@ius.edu.ba
[2] Department of Urban Planning, Spatial Planning and Landscape Architecture, Faculty of Architecture, University of Zagreb, 10000 Zagreb, Croatia
[3] Independent Researcher, 10000 Zagreb, Croatia; bojanic.scitaroci@gmail.com
* Correspondence: tmaric@arhitekt.unizg.hr

Abstract: Underground space has always been used as a resilient solution in addressing the need for safety in terms of climate conditions and defense purposes. This research seeks to recognize the potential of the underground space in the city as a significant urban resilience strategy, with the aim of revealing how contemporary underground architecture is integrated with the public spaces on the surface and how this groundscape integration contributes to the quality of the use of the public spaces to achieve urban resilience. Public spaces have a crucial role in the environmental, social, and sustainable context of the city and are considered urban domains for spatial urban intervention that contribute to urban resilience in its broader understanding. Based on the review of underground space research and the comparative analysis of selected contemporary design projects, the research explores the integration of underground space in correlation with its utilization model based on contemporary design projects. The research results in the systematization of underground utilization among underground infrastructure, underground living settlements, and urban development to offer insights into the enhancement of resilience planning through the contemporary multifunctional usage of underground space. The contribution of this research is reflected in the methodology of developing the criteria for a groundscape resilience concept, in terms of perceiving underground space as an integral urban layer, its multifunctional utilization, and in terms of achieving urban resilience.

Keywords: underground; urban resilience; groundscape; urban integration; underground architecture

check for updates

Citation: Omićević, N.; Zaninović, T.; Bojanić Obad Šćitaroci, B. Integrating Underground Space into the Groundscape Resilience Concept. *Buildings* **2024**, *14*, 2406. https://doi.org/10.3390/buildings14082406

Academic Editor: Guozhu Zhang

Received: 10 June 2024
Revised: 2 July 2024
Accepted: 19 July 2024
Published: 3 August 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Throughout history, people have always felt the need to shape and modify their surroundings, above and below the surface of the Earth. The Earth's surface is continuously evolving and changing as a result of a complex interaction between its external and internal processes [1] (p. 3). These changes are evident in the transformation of the Earth's landscapes and landforms [2] but also as a part of the urban development and urban transformations, which can be observed throughout history. The result of these processes enables us to assume that the environment above ground could be underground tomorrow [1]. Therefore, this paper explores the contemporary architectural form of underground space use that can reinforce urban resilience through the design and quality of use of the public spaces on the surface.

The concept of using underground space has always existed, mainly to reply to the basic human needs in the form of shelter. There are many historical examples of people using underground spaces for different purposes and, due to their cultural value, they fall within the concept of the *underground built heritage*, which comprises the architectural, urban, and landscape heritage below the surface of the earth [1] (p. 2). Despite its universal value, this concept still has no proposed common definition, unlike the *underwater*

cultural heritage [3], which is defined as the heritage layer that has been partially or totally under water, periodically or continuously, for at least 100 years [4] (p. 51). It is necessary to emphasize that underwater cultural heritage was initially a surface layer, but due to the impact of change, it got shifted underwater and as such does not fall within the built heritage framework. The need for protection and preservation of the underwater cultural heritage was not officially recognized until 2001, when the United Nations Educational, Scientific and Cultural Organization adopted the Convention on the Protection of Underwater Cultural Heritage, with the main aim of protecting and preserving the underwater cultural heritage from direct and indirect man-made impact [5] (p. 2).

Although the term *underground built heritage* has no generally accepted definition, its taxonomy has been the subject of recent research [1,3]. From the theoretical approach, its context can be understood in the adopted Convention Concerning the Protection of the World Cultural and Natural Heritage, which shows that among the listed properties, the most common descriptions are related to the word *cave* and the word *underground* [3] (p. 1096). Although the word *cave* relates to different categories, it mostly falls under the use for shelters, followed by the use for art and for religious purposes [3] (p. 1103). Following this taxonomy, the underground built heritage comprises the "*built environment*" defined as "human-made (versus natural) resources and infrastructure designed to support human activity, such as buildings, roads, parks, and other amenities" [1] (p. 3) below the surface of the earth. Despite the divided terminological concepts, the utilization of the underground space and underwater space is recognized as a unified concept. Due to the rapid population growth and increasing transportation problems, the use of the earth layer underwater has become increasingly important. The coherence is best seen through the construction of underground underwater tunnels, considered immersed passages or roadways, beneath a body of water [6] (p. 325).

Based on the complex underground concept of taxonomy, underground space in this research is understood as space that is situated below the ground level of the city, intended for public use. This underground layer can be used in the form of infrastructure, sport and recreational purposes, exhibition and culture facilities, and commercial use.

Underground space is considered the enclosed built environment below the ground, and for this reason, it is perceived as an additional spatial layer of the city [7]. We can visualize this perception in the 1926 film Metropolis, directed by Fritz Lang, which illustrates the division of the society, presenting the society above the ground with the sky, light, and high-rise buildings and the society below the ground with darkness and workers working underneath to support the needs of the society above the ground. This perception evokes many negative associations with and psychological concerns about the use of the underground, such as death, fear of collapse, and feeling of disorientation [8]. This duality and the accompanying concerns are still contemporary relatable motives that are repeatedly artistically reinterpreted in various ways, as filmography keeps reconfirming with films, such as Matrix (1999), Parasite (2019), and Alita: Battle Angel (2019), or the tv series Arcane (2021). The integration of underground space with the surface can influence and mitigate negative associations related to the use of underground space [7]. Therefore, it is important to perceive the underground layer as an integral part of the city with all its benefits along with challenges.

The social usage of underground space was historically noteworthy, through a combination of fear and curiosity from ancient times driven by various social prejudices, religious beliefs, and artistic visions. Christianity referred to the hell as the place underground. This perception can also be seen during the period of Romanesque art, in *The Last Judgement* by the sculptor Gislebertus [9], which illustrates a large figure of Christ enthroned and positioned in the center with four angels. Under Christ's feet, there are the unweighed souls, waiting to be weighed and subsequently chosen as worthy or unworthy. In addition, the human burial practice of both western and eastern societies explains the association of the underground with death [10]. The way people perceive their environment relies mostly on their bodily experience and attachment to the environment [10] (p. 5). For this reason, the

perception of underground space is strongly influenced by the negative aspects of the use of the underground [10]. Underground space has limited access to open outdoor spaces, which leads to the feeling of isolation; the lack of windows leads to the feeling of restriction in terms of evacuation; and the lack of landmarks leads to the feeling of disorientation and eventually lowers the individuals perceived control, which reflects "the extent to which an individual believes that a certain situation is controllable" [10] (p. 3).

Unlike the negative aspects related to social prejudice and religious beliefs connected with the underground, the positive aspects of the use of underground space can be seen in the visionary works of artists and architects throughout history, such as Leonardo da Vinci and Friedensreich Hundertwasser. The Renaissance inventor Leonardo da Vinci designed his *ideal city* at the end of the 15th century. He envisioned the city consisting of various levels. The lower level would be designed for trade and transportation, used by carriages, pack animals, and boats, including an underground sewerage system, while the upper level would be an open space, enjoyed by citizens and designed for pedestrians only [11]. Conceptualizing the city where the horizontal layer belongs to nature and the vertical layer belongs to men is established in Hundertwasser's 1974 depiction of a motorway placed under land. In his work, *The Green Motorway—the invisible, the inaudible*, he envisioned a highway through an open underground tunnel absorbing noise and directing the remaining noise vertically with trees growing within the tunnel and with visible sky [12]. The interpretation of Leonardo da Vinci's design of the *Ideal city* and Hunderwassers's design of The *Green Motorway—the invisible, the inaudible* is presented as a schematic section in Figure 1.

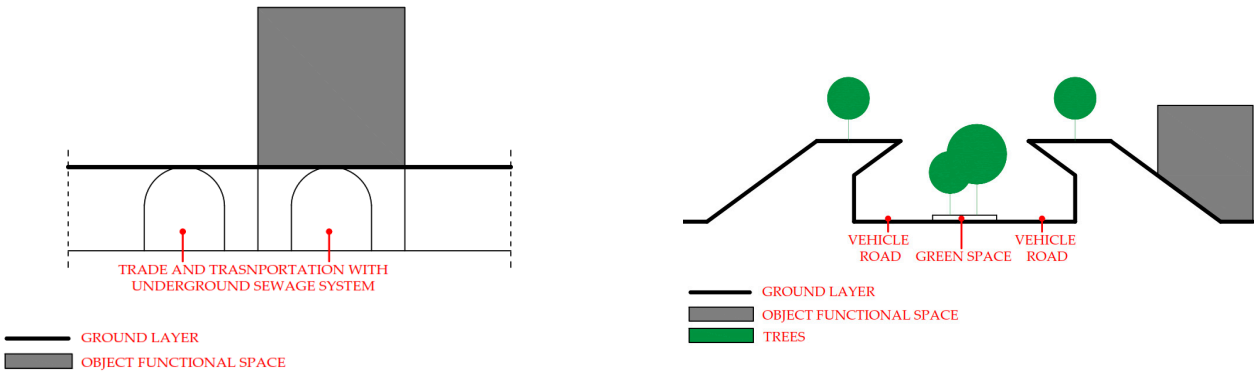


Figure 1. Scheme interpretation of Leonardo da Vinci's design of *The Ideal city* (**left**) and Hunderwassers's design of *The Green Motorway—the invisible, the inaudible* (**right**). Figure drawings by authors.

Over the last century, this perception of recognizing underground space as an integral part of the urban environment and acknowledging its potential in the urban planning process has become increasingly important as a significant resilience strategy to meet the challenges of the future. As Kollarath et al., explain [13] (p. 1757), underground development can become a strategy for evolving urban areas that can cope with unpredictable changes and as such be used effectively in the planning process.

The need for an integrated approach in the use of underground space was also recognized by the French architect Domique Perrault. In his book "*Groundscapes—Other Topographies*" [14], he introduces the concept of groundscapes as a subterranean form of architecture exploring the spatial potentials of the underground space below the surface with the aim of providing a resilient solution to the unpredictable urban challenges. Since 2018, the architect offers an online course about the Groundscape Architecture in collaboration with subLab teachers Richard Nguyen, Ignacio Ferrer Rizzo, and Juan Fernandez Andrino at The Swiss Federal Institute of Technology in Lausanne (The Ecole Polytechnique Fédérale de Lausanne, EPFL), Switzerland. The course offers valuable insights into the contemporary use of underground territory and design of underground architecture [15]. The

aim of the groundscape concept is to rethink the relationship between the underground layer and the urban layer on the surface with a new understanding as an integrated urban layer, which will enable a new form of urban living.

This research seeks to recognize the potential of the underground space as a significant urban resilience strategy, with the aim of revealing how contemporary underground architecture is integrated with the public spaces on the surface and how this groundscape integration contributes to the quality of the use of the public spaces to achieve urban resilience. In the context of this research, resilience is considered the ability to absorb shocks and to adapt, where resilient cities are understood as flexible, resourceful, and integrated [16]. The resilience of cities is reflected by the capacity of cities and society to cope with and adapt to any impact of change [16,17]. Therefore, the analyses are focused on the urban dimension of the concept of resilience, which is a less explored aspect of underground spaces because the engineering point of view is the primary focus of most underground research. Furthermore, public spaces have a crucial role in the environmental, social, and sustainable context of the city and are considered "arenas for urban resilience" [18] (p. 156). Public spaces in this research refer to urban spaces that are open, accessible, and can be used by the public. These public spaces include all categories of the street network, squares, and plazas and all categories of public green spaces and urban spaces along the waterfronts [18] (p. 156). To achieve urban resilience, public spaces need to be designed through specific urban interventions that ensure accessibility and use and be able to cope with unpredictable extraordinary events. The research aims to reveal how groundscape integration contributes to the accessibility and use of public spaces and subsequently to the achievement of urban resilience in cities. The contribution of this research is reflected by developing the criteria for the groundscape resilience concept.

The overall structure of the paper begins with a theoretical context by exploring the resilience and integration aspect of underground space use and the development of its utilization in the city through a brief historical overview (Section 2). The systematization of historical underground utilization in the city provides the basis for the comparative analysis of the multifunctional usage of underground space, through selected contemporary design projects (Section 3). The research summarizes the findings of the analyzed examples and concludes with defining the criteria for the groundscape resilience concept (Sections 3 and 4). The research framework is outlined in a conceptual graph, summarizing the research method sections (Figure 2).

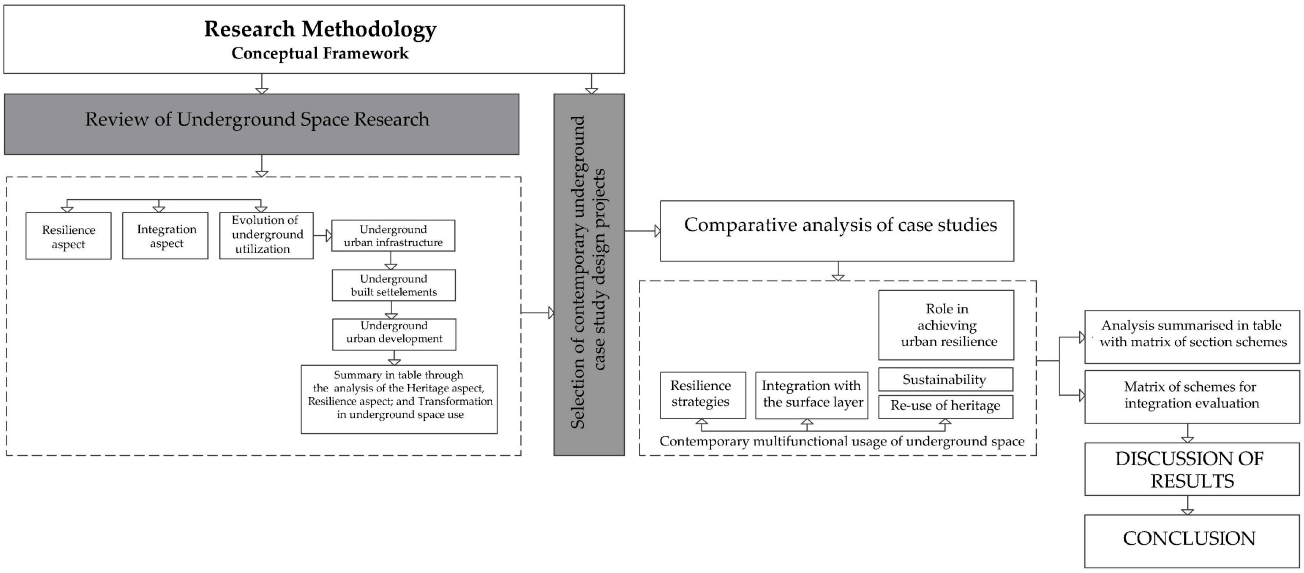


Figure 2. Conceptual framework for research methodology. Scheme by authors.

2. Review of Underground Space Research

The review of the existing research on the concept of underground space is divided into three main sections, referring to the resilience aspect, integration aspect, and the development of the underground space in cities through history. The literature review was conducted during the period of 2023 until 2024 based on interdisciplinary books and journal articles on underground utilization, which included the following disciplines: technology and civil engineering, architecture and planning, economy and management, and sociology and history, together with the history of art and religion. The literature that was used for the research was available online as open access and was found based on a search with the following keywords: underground, built environment, heritage, landscape, underground infrastructure, underground built settlements, urban resilience, social resilience, and underground urbanism.

2.1. Resilience Aspect

The word *resilience* comes from the Latin word *resilire*, "the idea of resisting and rebounding" [19] (p. 2). The concept of resilience was firstly applied in physics to define the capacity of a system to withstand alteration and being able to recover [19] (p. 2), but its modern conceptual framework is grounded in the ecological theory, revealing that a system is more resilient if it manages to recover faster [20] (p. 5). With regard to the city, the concept of resilience is understood as urban resilience, as the ability to adapt, in order to overcome uncertainty, as well as the capacity for self-organization prior to and during times of need [19,21]. Based on this interpretation, the concept of resilience was later introduced in disaster research. Within the context of disaster framework, urban resilience refers to the "the ability of a system and its components to anticipate, absorb and accommodate or recover from the effect of a hazardous event in a timely and efficient manner, through ensuring preservation, restoration and improvement of its essential basic structures and functions" [22,23] (p. 21, p. 18).

Underground space has always been used as a resilient solution. With people seeking shelter, the underground built environment addressed the need for safety, in terms of climate conditions and defense purposes [13], but it also facilitated the development of ancient urban communities and addressed the growing needs for living space, in terms of subterranean infrastructure networks [24]. Subsequently, underground space has become an important part of the city's urban development. Nowadays, cities are facing the consequences of the rapid growth of the world's population and uncontrolled urbanization, environmental changes, and disaster impact, as well as growing demands of the built environment above the ground, in terms of urban infrastructure, land resources, and usable land in urban areas [13,25]. These factors have raised the question of the sustainable urban development of cities and led to an increased use of underground space, as a strategic attempt to increase the value of land use and contribute to economic growth and subsequently to improve the resilience of the city's environment [26]. During the disaster impact, underground space was mostly used for seeking shelter in the underground infrastructure facilities. The potential of the use of underground space is not only evident in addressing the growing needs of the contemporary world but in the preservation of the underground built heritage, below the surface of the earth, crucial for the sustainable development of contemporary cities.

2.2. Integration Aspect

Established psychological barriers of fear and unpleasantness present an issue in the use of underground spaces for developing urban resilience. Negative associations with the underground are strongly influenced by the degree of assimilation of the underground layer and the surface above ground: in terms of functionality, by developing a functional relationship of the surface and the underground space; in terms of spatial context, by creating a physical connection with the above ground; and in terms of visual connectivity, by introducing daylight [7] (p. 38). Like in any other spatial assignment, for people to

use (underground) places, they should be approachable, accessible, and walkable, which means interconnected. Therefore, it is necessary to establish the highest possible degree of groundscape integration [27] with the goal of underground and ground levels together becoming the layer that represents the main public sphere as a whole.

Spatial–Social Aspects of Groundscape Integration

The four main groups of aspects as detected in the literature on underground spaces are physical, psychological, functional, and typological aspects (Table 1). Physical aspects of the underground deal with types of space and spatial characteristics, such as various limitations in size, scale, boundaries, connectivity elements, and layout organization. Psychological aspects of the underground relate to human perception—senses, emotions, and interactivity.

Table 1. Spatial–social aspects of groundscape integration developed by authors.

Aspects	Physical	Psychological
Functional	SPATIAL ELEMENTS AND ROLES	**Activity level** (dynamic, eventful, monotonous, uneventful)
	Infrastructure (canals, drainage, installations, tunnels, cisterns)	
	Basement utility (garage, storage)	**Multisensory and synesthesia level** (visual, olfactory, and tactile experience)
	Urban spaces (shopping centres, stations, denivelations	
	Urban settlement (historical and contemporary)	
Typological	**Vertical connections (nodes)**: stairs, lifts, escalators, buildings	RANGE OF EMOTIONS pleasant-calm-other **positive**
	Networks (line systems): metro, shopping and sewerage systems, mines, caves, cities	scary-disturbing-other **negative**

Functional underground aspects are concerned with how people use underground space and can be related to both physical and psychological aspects as suggested by Table 1. As in general architectural practice, there are (public and private) roles for which places are designed and underground spaces can, in that context, functionally assume the infrastructural role, basement role with primary utility functions, various urban multipurpose roles, such as centers (shopping, metro and theatre centers), and/or the role of urban settlement when the underground network becomes a larger urban area. The underground as an urban settlement can be observed through the historical and contemporary role. The historical role is considered through the heritage aspect as traces of previous forms of life, many of which are part of the recognized UNESCO Cultural Heritage List, which is elaborated on in Section 2.3 of the paper. The contemporary roles of underground cities are plans with an active underground layer where multiple usages merge and these are cities with metro lines and underground shopping malls. Functional aspects can also be explored through human activities in the form of how people engage with underground space. The activity level of usage can vary rhythmically depending on the time of the day and time of the year.

Typological aspects of the underground can also be related to both the physical and psychological integration of underground and ground levels. In the spatial context, this integration is either an element (a node in various scales) or a system (a network of interconnected lines). Psychologically, there are positive and negative types of emotions connected with underground spaces, both with a range of feelings that can be mixed in describing the effect of the underground on people.

Based on the detected problems from the theoretical approach, the research further presents a brief historical overview of the development of underground space in cities. Un-

derground space has a rich history in its diverse forms of utilization. For this reason, the focus of this paper is to understand the historical development of the underground space in cities, by emphasizing the transformative aspect of its utilization. The underground space in cities was firstly utilized in the form of underground urban infrastructure and then further developed by constructing underground built settlements, which subsequently influenced the underground urban development and the contemporary focus on sustainability and resilience planning. Based on the examples from the literature review, the main aim of this analysis is to observe the transformation in the use of underground space and its heritage and resilience aspect.

2.3. Development of Underground Space in Cities—A Brief Historical Overview

2.3.1. Underground Urban Infrastructure

The earliest known example of urban infrastructure is the underground sewerage channels from **Mesopotamia (ca. 4000-2500 BCE)**. Mesopotamian cities had effective drainage systems for stormwater control and sanitary sewer systems. Storm water drainage systems were constructed of sun-dried bricks and cut stones [28] (p. 3938). Another example of a well-constructed drainage system was found in Scotland, in the village of **Skara Brae (ca between 3200 and 2200 BC)**. Archaeological excavations found a complex drainage system that served as an early form of toilet facilities [28] (p. 3939). The utilization of the underground continues with the Greeks and the Romans, with the development of urban underground passageways and underground sewer systems. The most significant hydraulic system of ancient Greece was **the aqueduct of ancient Samos** [24] (p. 19). The aqueduct was built mainly for defense purposes, since in case of an enemy attack, the city would lack the required water supply. The Romans continued to use aqueducts to transport water, but from longer distances. One of the important large-scale underground tunnels from this period is **the Cloaca Maxima in Rome,** a drainage system that is still preserved, and this was used by the Roman citizens [24] (p. 15). The Cloaca Maxima served in wastewater removal, rainwater removal, and swamp drainage [28] (p. 3951). In addition to the Cloaca Maxima, the Romans further constructed vaulted underground passageways with small windows, known as the *cryptoporticus tunnels* [24] (p. 15).

During the 19th century, the underground was widely utilized for tunnel construction. In this period, New York designed the city's first aqueduct, known as **the Croton Aqueduct** [24] (p. 24). The rapid population growth and contamination of available water sources, such as wells and cisterns, led to the 1832 cholera outbreak in New York and urged the need for a direct water source. The construction of the Croton Aqueduct lasted from 1837 until 1842. The aqueduct carried 45 million gallons (170,343.53 m^3) of water daily from a reservoir in Croton and brought the first water supply to New York city [29] (p. 2). In urban history, the outbreaks highlighted urban vulnerability and were considered an opportunity to understand the city and reshape it [30] (p. 9).

Subsequently, the development of urban underground infrastructure led to the construction of transportation subways, such as the Atlantic Avenue Tunnel in Brooklyn, New York. The tunnel was constructed in 1844 to address the vehicular and pedestrian conflicts derived from the growing urbanization and associated land demands [24] (p. 31). Another city that used underground tunnels for security and transport was London. The idea of constructing an underground railway tunnel was first mentioned in 1851, during the Great Exhibition (international exhibition of the industry of all nations) in London. The underground railway network would connect the end stations of the Great Western Railway line and the Great Northern Railway line. The first six-kilometer-long section of **the London Underground**, between Paddington and Farringdon Street, was opened on 10 January 1863 [31] (p. 2). The early underground lines were constructed by cutting a shallow trench flowing the road and laying railway tracks in the trench [32] (p. 30). They operated using steam engines until 1905, but due to limited ventilation capacity, the grade lines of tunnels had small depths, from 4 to 8 m [31] (p. 2). Ventilation shafts and openings were positioned in multiple locations to allow natural light in the underground network but

also to enable the release of smoke and steam in the atmosphere [32] (p. 30). During the First World War and the Second World War, the London underground railway was used as a shelter [8] (p. 9). After the construction of the London Underground Network, many other cities in the world decided to build subways, which increased the awareness of the usage of underground space.

2.3.2. Underground Built Settlements—Ancient Underground Cities

There are many historical examples of underground built settlements, also known as underground cities. The conception of underground cities in the literature refers to underground defense structure in the form of large interconnected systems and in the form of small underground shelters [33] (p. 71) or to the classification as underground shelters, with defense characteristics and underground built settlements, as places without obvious defense characteristics [34] (p. 6). For the purpose of the research, three different examples of underground built settlements are mentioned: the Derinkuyu underground city, located in Cappadocia, Turkey, the Wieliczka Salt Mine underground complex in Poland, and the Underground Building Complexes of Project Riese in Poland. One of the regions where the underground defense structures are mostly spread is the Capaddocia region in Turkey. More than 40 multi-floor underground built settlements were identified in the Capadoccia region [35] (p. 65). These underground cities consisted of a complex network of passages and tunnels, built to withstand attack and provide shelter for people. For these purposes, they contained ventilation shafts, water tanks, niches for oil lamps, stables, and moving stone doors to block corridors in the case of an attack [35] (p. 66). One of these cities is **the Derinkuyu underground city**, built in 1300 BC [35] (p. 66). The Derinkuyu underground network contained 18 floors, with the deepest floor reaching the depth of 85 m [35] (p. 66); [36] (p. 2253) with different spaces, such as schools, places for religious purposes, living and social gathering, and storage for food and weapons. The underground city could be accessed by one entrance only, which was protected by a large circular stone. Floors did not have an exact placement or boundaries, and the vertical distances between the floors were not equal [37] (p. 398). All sectors within the settlements were defended at various levels, consisting of a series of millstone doors [34] (p. 6). The city had more than 50 ventilation shafts to allow air to circulate by itself [36] p. (2254).

Another example of an underground city is **the Wieliczka Salt Mine underground complex**, located in the Malopolska province, Poland. The Malopolska province is one of the oldest saltwork areas in Poland, from the middle Neolethic period (3500 BC). Salt exploitation began in the 13th century and finished in 1996 [38] (p. 6). The underground complex contains the following: 26 mining shafts, out of which 6 are still active, and 180 inter-level shafts, reaching a depth of 327 m; 2391 chambers; and 245 km of galleries [38] (p. 6). The Wieliczka Salt Mine Museum was established in 1951. In 1976 the museum was listed in the register of national monuments and since 1978 inscribed in the UNSECO World Heritage, together with the Bochnia Salt Mine as Royal Salt Mines [38] (p. 7). The salt mine is currently used for touristic and healing purposes. The Teodor Wessal Chamber is used as a treatment room for rehabilitation, by using the unique microclimate of the mine for treating respiratory diseases [38] (p. 7). Reaching a depth of 135 m, some of the chambers have religious functions, and due to excellent acoustic quality, they are also used for organizing ceremonial activities and concerts [38] (p. 7).

Furthermore, there are many examples of underground built settlements used for defense purposes and seeking shelter, but in relation to the contemporary context of this research, it is also important to mention the military–historical aspect of its utilization. Among these examples are **the Underground Building Complexes of Project Riese, located in the Owl Mountains** in Poland. Project Riese (German word for "giant") was one of the largest underground building projects from World War II. It was implemented from 1943 to 1945 to support the military activities from the Third Reich [39] (p. 37) The main aim of the project was to localize armaments factories and the main headquarters, due to the counterattack of the Red Army and the setbacks of the German troops in the East in

1943 [40] (p. 2). The project development included massive construction works in terms of road networks, underground tunnels, and chambers as well as ground infrastructure. It was the most expensive construction of military headquarters in Germany during this period with high engineering standards [40] (p. 2). The construction work was performed by forced labor and prisoners from the Gross-Rosen concentration camp (present-day Rogoznica), where many people lost their lives due to malnutrition and work overload [41] (p. 77); [40] (p. 3). The construction works were not completed, and with the arrival of the Red Army, many of the underground structures were destroyed. Due to the high level of secrecy involved in the project development and lack of documentation, it was difficult to identify and localize all facilities that belonged to the Riese complex [40] (p. 3). Out of the large-scale project, six underground systems of tunnels were found: Rzeczka (560 m), Wlodariz (300 m), Osowka (1700 m), Jagowice (500 m), Soban (740), and Sokolec (800 m), [39] (p. 36), [41] (p. 77). Only the underground tunnels of Rzeczka, Wlodariz, and Osowka are open to the public and can be visited as tourist routes and museum exhibitions [39] (p. 38).

2.3.3. Underground Urban Development—Contemporary Underground Cities

The concept of underground urban development was first introduced in 1932, by the architect Edouard Utudijan, under the term "urbanisme souterrain" or underground urbanism, with the main aim of promoting better use of underground space in cities [42,43]. This concept raised many discussions among urban planners of that time, such as Ebenezer Howard and Eugene Henard, and was firmly rejected by architects, such as Le Corbusier and Frank Lloyd Wright, who considered the vehicle network an important part of their plans [43]. One of the important planners in the development of underground urbanism was Vincent Ponte. Ponte envisioned the city as a "multi-level interconnected city, which would facilitate core functions, interrelated above and below ground" [43] (p. 50). The first strategic resource that was used to shape underground urbanism was the relocation of space functions underground, in order to decrease the density above the surface and release surface land [44] (p. 2). This was achieved with the renovation and reorganization of the Louvre Museum. In 1981, the French President, Francois Mitterrand started the construction of *the Grand Projects* in Paris with the aim of redesigning cultural institutions in France. The projects involved the design of individual buildings but also the urban design of significant parts of Paris. Most of *the Grand Projects* were welcomed with national and international protests [45]. One of the most debated projects was **the Grande Pyramide du Louvre**, designed by the Chinese American architect Ieoh Ming Pei. Since most of *the Grand Projects* incorporated designs with glass, the design of the glass steel pyramid in the center of the 17th century courtyard of the Louvre complex was not positively received [45]. Being the focal point of the urban complex, the pyramid connects the main sections of the museum with the underground spaces (amphitheaters, research laboratories, restaurants, and shops) and forms an integral part of the urban environment. In addition to the main Louvre Pyramid, three smaller pyramids were incorporated in the urban design and landscape of the complex. In 1985, an inverted pyramid was added on the opposite side of the main pyramid [46]. With the main to ease the flow and concentration of visitors, the complex did not include public roadways, only direct access to the metro station Louvre [42] (p. 5). Furthermore, extreme environmental changes and rapid urban growth increased the use of underground space as a solution to meet the technological and resource demands and create resilient cities that can withstand unpredictable changes. Subsequently, underground urban development progressed further using alternative energy sources [13] by preserving groundwater, geothermal energy, and geomaterial resources, named *the Deep City Method* [44] (p. 2). This sustainable model of urban underground development can be found in the examples of **the underground city of Helsinki in Finland, the Montreal underground city in Canada, and the underground city of Singapore.** For these cities, one of the main drivers of underground space development is climate conditions. The extremely cold winters in Helsinki and Montreal and the tropical climate with heavy rainfall and humid conditions in Singapore have led to the development of under-

ground pedestrian networks, to provide a comfortable gateway for the the citizens [13,47]. These underground pedestrian networks consist of public corridors linked between the buildings and the streets below [43]. The historical overview of the underground utilization is summarized in Table 2 and presented through the transformation in the use of underground space and its heritage and resilience aspect.

Table 2. Historical overview of the underground utilization in cities—transformation in the underground space use based on a literature review. Table overview by authors.

Historical Overview Example, Historical Period	Heritage Aspect	Resilience Aspect	Transformation in Underground Space Use
Underground Urban Infrastructure			
Underground Mesopotamia (4000–2500 BCE)	Archeological excavations	Stormwater control Collection of rainwater for household and irrigation use	Underground storm drainage systems and sanitary sewer systems
Skara Brae, Scotland (ca between 3200 and 2200 BC)	Included in the UNESCO World Heritage List since 1992	Planned settlement with hygienic quality	Underground drainage system as an early form of toilet facilities
Ancient Greece, 6th Century BC	Included in the UNESCO World Heritage List since 1999	Defense purposes	Urban underground passageways and underground sewer systems Hydraulic systems—Aqueduct of Ancient Samos
Ancient Rome, 6th Century BC	Archeological excavations	To carry away surface water for sanitation and hygiene purposes	Underground Sewage system—Cloaca Maxima for wastewater removal, rainwater removal, and swamp drainage
New York, from 1837 until 1842	Not formally recognized as heritage, but as a landmark site. Linear public park-Old Croton Aqueduct Walk	Water distribution for addressing disease outbreaks, due to the lack of clean water and contaminated sources—first direct water supply to New York city	Water distribution system—Croton Aqueduct
New York, 1844	Not formally recognized as heritage	Transport benefits—decrease in vehicular and pedestrian traffic conflicts and delays	Underground railway tunnel—the Atlantic Avenue Tunnel in Brooklyn
London, 1863	Former Metropolitan Railway tracks and stations are used today	Reduce street congestion	Underground railway network—London
Underground Built Settlements—Ancient Underground Cities			
Cappadocia, Turkey, 8th Century BC	Included in the UNESCO World Heritage List since 1985	Shelter and storage of goods Complex ventilation system and protected well for natural airflow and water supply	Derinkuyu underground city
Wieliczka Salt Mine underground complex	Included in the UNESCO World Heritage List since 1978	Underground complex for touristic and healing purposes—re-use of heritage	Salt Mine and underground city

Table 2. *Cont.*

Historical Overview Example, Historical Period	Heritage Aspect	Resilience Aspect	Transformation in Underground Space Use
Underground Building Complexes of Project Riese	Not formally recognized as heritage	Large-scale project, six underground systems of tunnels were found—re-use of heritage	Underground building projects from 1943 to 1945 to support the military activities of the Third Reich Out of six tunnels found, three are open to the public for tourist purposes—Underground Museum
Underground Urban Development—Contemporary Underground Cities			
Underground city of Helsinki in Finland (1980—ongoing)	Not formally recognized as heritage	Climate resilience Disaster resilience—transformation of underground shelters into underground public spaces for every-day use (church, museum, swimming hall, etc.)	Contemporary Underground City of Helsinki use (underground network of bunkers with public spaces for every-day use)
Montreal underground city in Canada (1967—ongoing)	Not formally recognized as heritage	Climate resilience	Contemporary Underground City of Montreal (pedestrian network linking hotels, shopping centers, residential, and commercial complexes, etc.)
Underground city of Singapore (2019—ongoing)	Not formally recognized as heritage	Climate resilience	Contemporary Underground City of Singapore (Underground Master Plan for building a resilient city)

Driven by the increasing population growth and lack of land resources, underground cities have expanded the usage of underground space to meet future urban needs. As such, they consist of many layers with transport infrastructure, commercial spaces, restaurants, libraries, and sport facilities [13] (p. 1755). Despite the negative aspects of the underground perception, the contemporary usage of underground spaces can provide significant benefits—by enabling safety in the case of natural and man-made disasters, reducing the occupation of surface land, reducing the need for heating and cooling capacity, transportation demands, travel time, decreasing the environmental impact on cities through the preservation of natural vegetation, reducing noise pollution, and ultimately, improving the quality of life on the surface [13] (p. 1754), [48] (p. 54).

In terms of disaster mitigation and prevention [23], the sustainable use of underground space can be found in the example of the underground parking garage in Katwijk, a coastal town in South Holland. The design of the underground garage was based on its integration within the existing coastal landscape but also contributing to the possible flood defense and protection of the coastline [49]. Another contemporary example of building resilience by using underground space is the Stormwater Management and Road Tunnel (SMART) in Kuala Lumpur. The tunnel is used for vehicle transportation and as a channel for stormwater diversion [50] (p. 465). Similar disaster-resilient design strategies can be found in Tokyo's flood defence infrastructure project, also known as the Metropolitan Area Outer Underground Discharge Channel [51]. The tunnel system is used to drain flood water into underground cylindrical shafts and to discharge it further into rivers to mitigate and sustain flood impact.

Although the contemporary use of underground space provides significant benefits in resilience planning, it is still limited in terms of its functionality and reasoning, which is mainly related to infrastructure utilization. This is based on a long-standing practice where civil engineers were considered experts in the underground space construction, while architects and planners were in charge of the planning on the surface. It lacks an interdisciplinary approach, which would extend the limits of its beneficial use [14,52]. This research seeks to show that it is important to improve the quality of life in both layers and furthermore to consider ground and underground as integrated into one specific layer for possible multiple public domain functions.

3. Contemporary Case Study Results

This section examines the results of the conducted research, based on the comparison of the findings, in terms of the following: the transformative role of underground space use and resilience planning (a) and the limited and extensive use of underground space (b), to reveal in what other way underground space can and should be observed in order to achieve urban resilience.

In terms of **the transformative role of underground space use and resilience planning (a)**, the heritage value of the underground space and its long history of utilization is already recognized through the transformation in the use as urban infrastructure, underground built settlements, and underground urban development. The historical utilization (Table 2) shows that the underground space should not be perceived as a service layer of the city but understood as a heritage layer, for which active use is crucial for sustainable development. Despite technological restrictions, the underground space use was functional in terms of both living and infrastructure development. Today, technological achievements enable the multi-purpose use of underground space, which is evident through the contemporary utilization in terms of disaster and climate resilience planning. The underground master plan of Helsinki was initially developed for shelter purposes with multi-functional public spaces that could quickly transform into shelters if the need arises. The underground city of Montreal was built as a climate-resilience strategy, while the underground master plan of Singapore is focused on enhancing urban resilience planning, through the systematic utilization of underground space for future needs.

Based on the **limited vs. extensive use of underground space (b)**, the research highlights the possibility of multifunctional underground utilization. There are public spaces that are useful to people and require no natural light but are mostly avoided in underground planning development. This raises questions, such as what are those spaces that do not require natural light in terms of their functionality and why those places are mostly not considered in underground urban development. Those spaces include theatres, cinemas, movie sets and audio recording studios, libraries, shopping centers, museums—exhibitions and aquariums, planetariums, saunas, hospital operating rooms, therapy centers, research centers with laboratories, and others. Exceptions and examples of these typologies can be found in underground space design, which confirms that the underground level is more than just infrastructure—it can function as a public domain and should be an integral part of groundscape design and planning. This is evident in great numbers of contemporary architecture projects that emphasize the value and utilization of underground space. Out of these, 20 contemporary examples (Table 3) are selected based on the way the underground architecture is integrated with the public spaces on the surface and how this contributes to urban resilience. The examples are further divided into five categories: infrastructure design projects; cultural design projects; sport facilities and underground offices, according to the set definition of underground space in the first chapter of the paper. The selected examples are analyzed based on the presence of integration with the ground layer and resilience strategies and their role in achieving urban resilience.

Table 3. Contemporary examples of the underground space use—redesign of public spaces on the surface layer. Table comparison developed by authors (with references and photo copyrights in the article Appendix A).

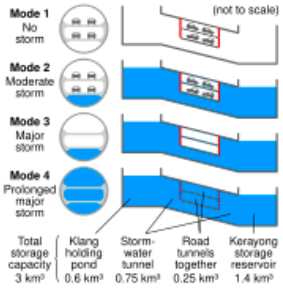
Case No.	Location, City, Country	Project Title, Author(s), Year Built	Project Photo *	Underground Utilization	Integration with the Ground Layer	Resilience Strategies	Role in Achieving Urban Resilience
UNDERGROUND TUNNELS AND PARKING (Infrastructure Design Projects)							
1.	Coastline of Katwijk, The Netherlands	Underground Parking Katwijk an Zee, Royal Haskoning DHV, 2016		Underground parking garage	Integration with the natural coastal environment	Defensive coastal protection Functional parking requirements	Protection of the coastline for the future Reducing occupation of surface land for parking
2.	City Centre of Kuala Lumpur, Malaysia	Stormwater Management and Road Tunnel (SMART), the government and the private sector corporation, 2007		Dual purpose underground tunnel	Infrastructure without urban integration on the surface	Flood water Management Reduce traffic congestion	Reduce flash flooding Reducing demand on transportation on surface land
3.	Saitama Perfecture, Tokyo, Japan	Metropolitan Area Outer Underground Discharge Channel (G-can project), Japan Institute of Wastewater Engineering Technology, 2006		Underground flood tunnel	Infrastructure without urban integration on the surface	Flood water management The underground space is accessible to the public through paid tours and virtual experience	Mitigating and preventing climate change Element of tourism for raising disaster awareness
4.	Cascais, Portugal	D. Diogo de Menezes Square/Miguel Arruda Arquitectos Associados, 2009		Underground parking	Integration with the surface layer—square through the roof structure platform	Preservation of heritage—harmonious integration with the medieval stonewalls of Cascais fortress	Redesign of public space—use of underground parking rooftops as public square
UNDERGROUND MUSEUMS, LIBRARIES, GALLERIES, AND PAVILIONS (Cultural Design Projects)							
5.	Paris, France	Grande Pyramide du Louvre Complex, Ieoh Ming Pei, 1989		Underground museum	Integration with the surface layer—square through the roof structure pyramid	Preservation of heritage—renovation and reorganization of the Louvre Museum Underground utilization to reduce the use of the public layer on the surface	Redefining the urban square and landscape—new urban identity
6.	Ahmedabad, India	Amdavad ni Gufa, MF Hussain and BV Doshi, 1994		Underground Gallery	Domes with shafts overground provide entrance and allow natural light to enter the building	Climate-responsive by maintaining temperature inside to withstand severe summer heat	Sustain climate impact

Table 3. *Cont.*

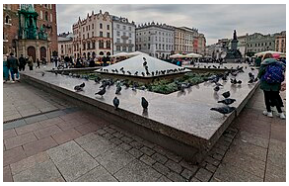
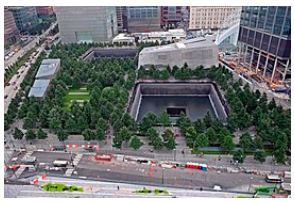
Case No.	Location, City, Country	Project Title, Author(s), Year Built	Project Photo *	Underground Utilization	Integration with the Ground Layer	Resilience Strategies	Role in Achieving Urban Resilience
7.	Krakow, Poland	Rynek Underground Museum, Andrzej Kadłuczk and, Dominik Przygodzki, 2010		Market Square Underground Museum	Integration with the public market square—a fountain that provides skylight through a 4-sided pyramid	Preservation of the archeological findings below the main market square	Re-use of existing heritage
8.	London, United Kingdom	Serpentine Gallery 2012 London, Herzog & de Meuron and Ai Weiwei, 2012		Pavilion	Sunken pavilion raising 1.5 m above ground level with floating platform roof	The design celebrates the legacy and hidden history of its previous pavilions	Urban acupuncture—regenerating public spaces
9.	City Park, Budapest, Hungary	House of Music, Sou Fujimoto, 2014		Museum	Integration with the existing trees through the holes on the roof structure, allowing natural light to enter	Increase green spaces and trees to decrease air pollution	Rehabilitation of the city park
10.	Sand dune, Blåvand, Denmark	Tirpitz Bunker, BIG, 2017		Museum	Integration of the galleries with the natural sand dune environment	Creating a new cultural place as contrast to the war history of the site Memorialization	Reuse of existing heritage The concept of memorials in post-disaster rehabilitation as a method of urban regeneration
11.	Plaza, Helsinki, Finland	Amos Rex Museum, JKMM Architects, 2018		Museum	Shapes in the ceiling provide strategically framed views to the streetscape	Sense of connection to the city, whilst being underground and presence in urban context Reuse of a formerly used bus station underground	New urban identity
12.	Datong, Shanxi Province, People's Republic of China	Datong Art Museum, Foster + Partners, 2021		Museum	Integration with the city's surface through the pyramidal roofscape The building's sculptural form becomes the city's landscape	Reducing the scale of the building Orientation of the windows minimizes solar gain	Redefining city's cultural plaza—new urban identity
13.	New York, United States	National September 11 Memorial Museum, Davis Brody Bond, 2014		Memorial Museum	Integration with the Memorial Plaza on the surface through a pavilion	Preserving the history and memory of the September 11 terrorist attack	The concept of memorials in post-disaster rehabilitation as a method of urban regeneration

Table 3. *Cont.*

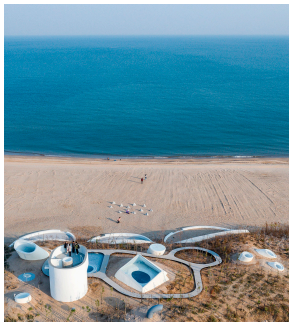
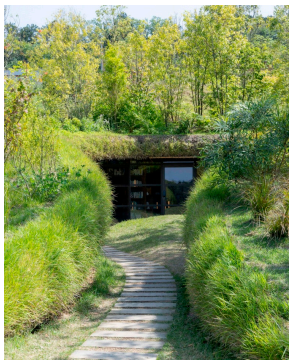
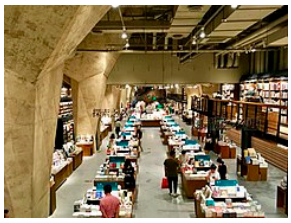
Case No.	Location, City, Country	Project Title, Author(s), Year Built	Project Photo *	Underground Utilization	Integration with the Ground Layer	Resilience Strategies	Role in Achieving Urban Resilience
14.	Coastal landscape, Qinhuangdao, China	UCCA Dune Art Museum, OPEN Architecture, 2018		Museum	Integration with the dune—museum is carved into the sand	The concept of shelter, resembling caves, was used as a narrative for the museum design Preservation of the natural landscape	Protection of the vulnerable dune ecosystem
15.	Kurkku Fields, Kisarazu, Japan	Library in the Earth, Hiroshi Nakamura & NAP, 2022		Library	Integration with the natural environment on the ground layer—the library is seamlessly concealed underneath	The interior design provides experience of the place without encountering architectural elements, such as columns and beams	New form of harmonious integration of nature and human activity—nature preservation
16.	Chengdu, China	Fangsuo Book Store, Chu Chih-Kang, 2015		Library, Store	Entrance tunnel—escalator enclosed in a sculpted meteorite-like structure Intentional design concept of separation	Preserving the history and memory through temple-like space design, inspired by the Buddhist temples and the scripture libraries	Reinventing cultural traditions and values- the ancient concept of scripture libraries
			UNDERGOUND RELIGIOUS PLACES (Cultural Design Projects)				
17.	Töölö neigh-bourhood Finland, Helsinki	Temppeliaukio Church, Timo and Tuomo Suomalainen, 1961–1969		Underground church	Integration with the ground layer—Temppeliaukio square	Preservation of the granite rock of the square Water from the bedrock is collected in small channels in the floor	Design is well integrated with the unique geological characteristics of the square—preservation of nature and urban identity
			UNDERGOUND SPORT FACILITIES				
18.	Atacama Desert, ALMA Observatory, Chile	ALMA Sports Hall, Benjamín Murúa Arquitectos, 2023		Sport Centre	Entrance lies adjacent to the domed roof at ground level, but currently (during research 2023) the design lacks urban integration	Design adaptation to harsh environmental conditions Taking advantage of the geothermal energy of the place and reducing the need for mechanical cooling and heating	Adapting to environmental impact

Table 3. *Cont.*

Case No.	Location, City, Country	Project Title, Author(s), Year Built	Project Photo *	Underground Utilization	Integration with the Ground Layer	Resilience Strategies	Role in Achieving Urban Resilience
19.	Gymnasium Courtyard, Hellerup, Denmark	Gammel Hellerup Sports Hall, BIG, 2013		Sports Hall	Integration with the ground layer—courtyard through the roof of the sports hall, which serves as an interior and exterior skin	Low environmental impact and good indoor climate	Transforming the gymnasium courtyard into a new social focal point—new urban identity
			UNDERGOUND OFFICES				
20.	Vita Berg Park, Stockholm, Sweden	Pionen—White Mountain, Albert France-Lanord Architects, 2008		Underground office	Intentional lack of integration Entrance is carved into the hard rock of Vita Bergen—The White Mountains	Transformation of an old-World War II bunker into server hall and offices of the Swedish internet service provider, 30 m underneath the granite rocks of Vita Berg Park	Reuse of heritage

* Project photos details can be found in Appendix A.

The outlined contemporary examples (Table 3) encompass underground space utilization in the form of underground tunnels and parking, underground museums, libraries, pavilions and galleries, underground religious spaces, underground sport facilities, and underground office spaces. In terms of the presence of **integration**, with the ground layer, the research shows how the integration with the surface layer lacks mostly in contemporary infrastructure projects, referring to the use of underground tunnels for flood mitigation, as the underground road and flood tunnel in Kuala Lumpur and the underground discharge channel in Tokyo. In terms of the design for underground parking spaces, the examples of the underground parking in Katwijk and in Cascais enable integration with the surface layer, by integrating the design with the public space on the surface. Despite the need for an integrated underground urban development, there are examples that intentionally avoid the integration with the surface layer, due to the nature of reusing existing underground spaces, such as the former World War II bunker in Stockholm and its transformation into the Pionen underground office or due to the conceived design concept, based on separation from the outside, such as the Fangsuo Book Store in China.

To deepen the importance of the integration of the underground space with the public space on the surface, the outlined examples from Table 3 are further presented in Table 4 in the form of a general matrix of their section schemes for the purpose of recognizing the presence of groundscape integration. As outlined in chapter 1 of this paper, to achieve urban resilience, public spaces need to be designed to ensure accessibility and use. Therefore, the contemporary examples are analyzed based on the set spatial context of groundscape integration (outlined in Table 1) in terms of the following: physical aspects through visual connectivity and accessibility; typological aspects through vertical connectivity and roof surface walkability; and functional aspects through their multi-functional role.

Table 4. Matrix of schemes—Exploring the spatial context of contemporary underground integration. Table comparison and schematic drawings developed by authors.

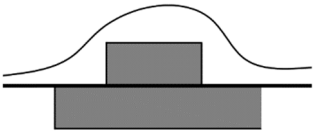
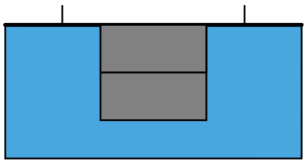
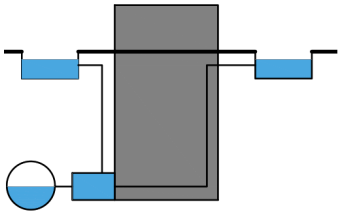
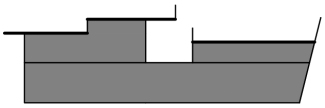
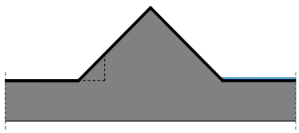
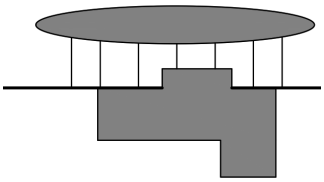
Case No.	Project Title, Author(s), Year Built	Project Section Schematic Presentation	Groundscape Integration				
			Functional Aspect	Physical Aspect		Typological Aspect	
		Ground Layer Object Functional Space Water Present Missing	Multi—Functional Role	Visual Connectivity	Accessibility	Vertical Connectivity	Roof Surface Walkability
UNDERGROUND TUNNELS AND PARKING (Infrastructure Design Projects)							
1.	Underground Parking Katwijk an Zee, Royal HaskoningDHV, 2016		Coastal reinforcement with recreation area and underground parking space	+	+	+	+
2.	Stormwater Management and Road Tunnel (SMART), the government and the private sector corporation, 2007		Underground flood and road tunnel	-	-	-	-
3.	Metropolitan Area Outer Underground Discharge Channel (G-can project), Japan Institute of Wastewater Engineering Technology, 2006		Underground flood diversion facility and touristic site	-	-	-	-
4.	D. Diogo de Menezes Square/Miguel Arruda Arquitectos Associados, 2009		Underground parking and public square	+	+	+	+
UNDERGROUND MUSEUMS, LIBRARIES, GALLERIES, AND PAVILIONS (Cultural Design Projects)							
5.	Amdavad ni Gufa, MF Hussain and BV Doshi, 1994		Underground gallery and park	+	+	+	+
6.	Grande Pyramide du Louvre Complex, Ieoh Ming Pei, 1989		Underground museum and public square	+	+	+	-
7.	Serpentine Gallery 2012 London, Herzog & de Meuron and Ai Weiwei, 2012		Sunken pavilion and park	+	+	+	-
8.	Rynek Underground Museum, Andrzej Kadłuczka and, Dominik Przygodzki, 2010		Underground museum with market square	+	-	+	-
9.	House of Music, Sou Fujimoto, 2014		Museum and park	+	+	+	+

Table 4. *Cont.*

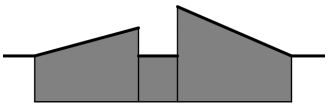
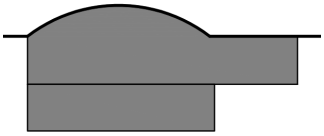
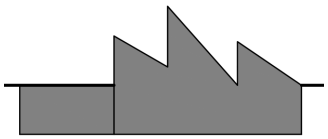
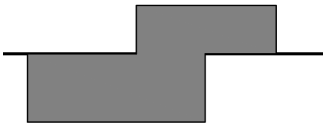
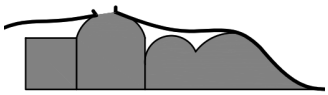
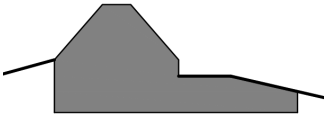
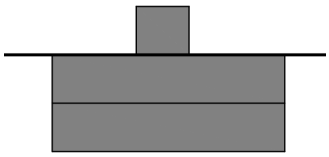
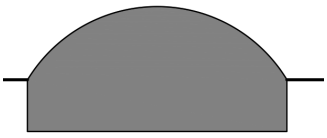
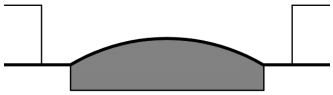
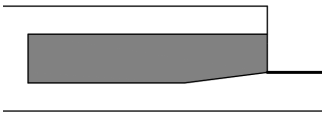
Case No.	Project Title, Author(s), Year Built	Project Section Schematic Presentation	Groundscape Integration				
			Functional Aspect	Physical Aspect		Typological Aspect	
		Ground Layer Object Functional Space Water Present Missing	Multi—Functional Role	Visual Connectivity	Accessibility	Vertical Connectivity	Roof Surface Walkability
10.	Tirpitz Bunker, BIG, 2017		Museum and memorial	+	+	+	+
11.	Amos Rex Museum, JKMM Architects		Museum and public square	+	+	+	+
12.	Datong Art Museum, Foster + Partners, 2021		Museum and public square with park	+	+	+	-
13.	National September 11 Memorial Museum, Davis Brody Bond, 2014		Memorial museum and memorial public square	-	+	+	+
14.	UCCA Dune Art Museum, OPEN Architecture, 2018		Museum embedded in coastal landscape	+	+	+	+
15.	Library in the Earth, Hiroshi Nakamura & NAP, 2022		Museum embedded in natural landscape	+	+	+	+
16.	Fangsuo Book Store, Chu Chih-Kang, 2015		Museum and bookstore	-	+	+	+
	UNDERGOUND RELIGIOUS PLACES (Cultural Design Projects)						
17.	Temppeliaukio Church, Timo and Tuomo Suomalainen, 1961–1969		Place for worship and concert venue with public square /temple Square	+	+	+	-
	UNDERGOUND SPORT FACILITIES						
18.	ALMA Sports Hall, Benjamín Murúa Arquitectos, 2023		Sport complex	-	+	+	-
19.	Gammel Hellerup Sports Hall, BIG, 2013		Sport hall and school courtyard	+	+	+	+
	UNDERGOUND OFFICES						

Table 4. *Cont.*

Case No.	Project Title, Author(s), Year Built	Project Section Schematic Presentation	Groundscape Integration				
			Functional Aspect	Physical Aspect		Typological Aspect	
		Ground Layer Object Functional Space Water Present Missing	Multi—Functional Role	Visual Connectivity	Accessibility	Vertical Connectivity	Roof Surface Walkability
20.	Pionen—White Mountain, Albert France-Lanord Architects, 2008		Office space in cave	-	+	-	-

4. Discussion

From the outlined examples (Table 4), the research recognizes how the contemporary underground projects are mostly designed with a multi-functional purpose, which contributes to the functional aspect of underground urban integration. However, it is important to emphasize that this multi-functional utilization is still in the domain of multidisciplinary design (where more than one discipline deals with the same problem independently), without an interdisciplinary approach (where multiple disciplines work together on solving the problem integrally). The design of the underground infrastructure projects related to flood mitigation shows the lack of underground integration, although the underground parking projects show the importance for an integrated design with the surface layer. Other contemporary examples show the presence of accessibility and vertical connectivity in their design. Only a few examples lack visual connectivity, as recognized in the design of Pionen—White Mountain office in Sweden, the ALMA Sports Hall in Chile, the Fangsuo bookstore in China, and the National September 11 Memorial Museum in New York. The underground urban integration is also reinforced through the walkability on the roof surface, which is not recognized in the design of the Pionen—White Mountain office in Sweden, the Photocatalytic Cave in Mexico, the Temppeliaukio Church in Finland, the Serpentine Gallery in the UK, the Datong Museum in China, the complex of the Grande Pyramide du Louvre in France, the Rynek Underground Museum in Poland, and in the ALMA Sports Hall in Chile. It is important to emphasize that the examples of the complex of the Grande Pyramide du Louvre and the Rynek Underground Museum are designed with opposite aims. The design of the Grande Pyramide du Louvre focuses on integration as a key aspect. The Rynek Underground Museum with its market square is discreetly positioned. The design of the fountain does not look like an integration, and although the underground museum below the market has a certain form of visual connectivity, the underground museum below the market cannot be initially recognized.

Furthermore, the research shows how the underground space utilization in all presented contemporary design projects plays a significant role in **achieving urban resilience**. Underground parking projects contribute to disaster risk mitigation and the redesign of open public spaces on the ground, by reducing the occupation of surface land and designing public squares and parks, while preserving landscape settings. Cultural design projects with underground space use contribute to the regeneration, rehabilitation, and redefinition of public spaces, by creating new urban identity as recognized in the design of the complex of the Grande Pyramide du Louvre in France, Amos Rex Museum and the Temppeliaukio Church in Finland, the Datong Museum in China, and the Gammel Hellerup Sports Hall in Denmark, but also through the concept of memorialization [53], which can be seen in the example of the National September 11 Memorial Museum in New York. It is also evident how the underground cultural design projects are the ones that stand out the most, indicating how architects have recognized the potential of underground space use for this function. In terms of **heritage**, the research shows that un-

derground space utilization contributes to urban resilience through the re-use of heritage, which is evident in the design of the Underground Museum in Poland, the Pionen—White Mountain underground office in Sweden, and the Tirpitz Bunker underground museum in Denmark, but also in terms of reinventing cultural value by preserving history and memory, evident through the design of the Fangsuo bookstore in China.

Based on the comparative findings, the research identifies three main criteria important for the planning and design of underground space in the city. These criteria refer to the following: **percieving underground space as integrated urban layer**; **enabling unlimited use of underground space**, through multi-functional underground utilization; and **using underground space as an opportunity for a achieving urban resilience** but not only through infrastructure use and development. The coherence of these criteria will allow for an interdsciplinary approach in the research and design of urban underground development, which can contribute to developing the groundscape resilience concept.

From the outlined examples it is evident that all underground design projects contribute to resilience planning through their design, but their integration with the ground layer on the surface contributes to the quality of use of the public spaces and their fexibility in terms of adaptation. This reinforces their capability to cope in a changeble context and contributes to the achievement of urban resilience of the city. The schematic model of the groundscape resilience concept is shown in Figure 3. It incorporates the relation of the public space on the ground layer and the underground layer identified as groundscape integration and its relation towards the required criteria for developing groundscape resilience. The integrated groundscape approach includes the following: unlimited utilization of underground space ensured by the functional aspect of spatial integration—through the multifunctional role of undergound projects; spatial integration through the typologial aspects—by enabling vertical connectivity and roof surface walkability; spatial integration thrrough physical aspects by enabling visual connectivity and accessibility; diverse resilience strategies that contribute to resilience planning; and the contribution to urban resilience through the quality of use of public spaces—by reinforcing groundscape integration.

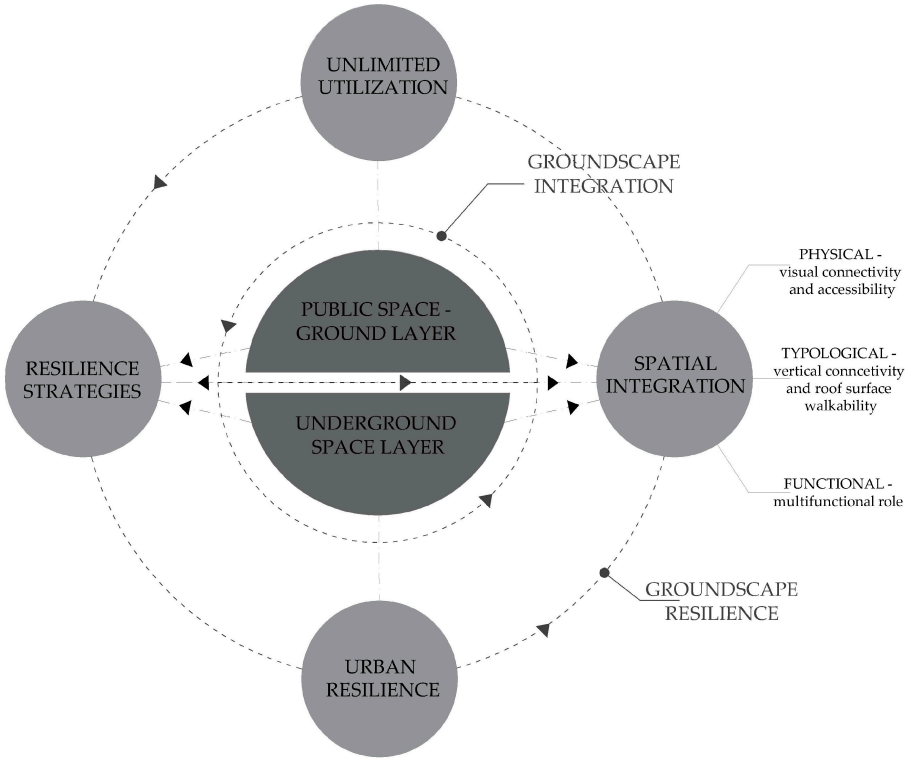


Figure 3. Schematic model of the Groundscape Resilience Concept. Figure diagram by authors.

One of the objectives of this research and paper was to show how the concept of underground space can be diversely used and explored from various aspects. The results from the literature review confirm the complexity of the presented problematics with historical reinterpretations and multiple approaches towards the underground research. Considering the difficulty in addressing the interdiciplinarity issues and complexity of planning the integration of underground space into a groundscape resilience complex, this research was limited in the contemporary case study scope from several viewpoints: 1. spatial limitation focusing only on case studies within the urban setting; 2. the limited number of analysed examples consisting of 20 representative case studies selected based on the research aim—to link urban resilience and underground utilization; 3. categorization limitation where housing examples were excluded because they are specific and covered through the historical overview typology. Furthermore, this paper shows that the enhancement of the resilience concept needs to be explored in future studies by focusing on the distinct architectural category and its underground contribution to urban resilience.

The groundscape resilience concept, as defined by this paper, is the first step towards changing the understanding of the relation between the ground layer of the city and the underground layer into an integrated groundscape, which can become an integral part of city planning and redefine the form of urban living.

5. Conclusions

The main field of study within this research was related to the usage of underground space from an urban and social perspective, which has not been studied enough in underground research. The research shows that underground space was initially connected with negative associations, such as fear and death, derived from religious beliefs and social prejudice. Despite this perception, people eventually realized its potential in terms of infrastructure utilization, but also as a place for living, by seeking shelter and escape from harsh climate conditions. Subsequently, underground built settlements evolved into underground urban development and contemporary underground cites.

The overall work contributes to the understanding that underground space is more than just infrastructure utilization. The contemporary examples outlined in Table 3 show that infrastructure utilization is just one form of utilization. Other recognized forms of underground utilization refer to underground cultural design projects, such as museums, libraries, pavilions, and galleries, underground sport facilities, and underground office space. The presented contemporary underground examples confirm the need for an interdisciplinary approach in the underground space utilization and with the diverse recognized forms reveal that this is possible.

An additional contribution of the this research is reflected by the methodology of developing the criteria for the groundscape resilience concept in terms of perceiving underground space as an integral part of the main public city layer; its unlimited utilization through its multifunctional role, and in terms of contributing to resilience planning and in achieving urban resilience through groundscape integration.

Future planning strategies should address the set criteria for underground use and development and combine the knowledge from the past with the use of advanced technology. The application and extension of the set criteria will lead to an interdisciplinary approach in the research and design of underground development and broaden the concept of groundscape resilience.

Author Contributions: Conceptualization, N.O. and B.B.O.Š.; methodology, N.O., B.B.O.Š. and T.Z.; validation, N.O., B.B.O.Š. and T.Z.; formal analysis, N.O. and T.Z.; investigation, N.O., B.B.O.Š. and T.Z.; resources, N.O., B.B.O.Š. and T.Z.; data curation, N.O., B.B.O.Š. and T.Z.; writing—original draft preparation, N.O.; writing—review and editing, N.O., B.B.O.Š. and T.Z.; visualization, N.O. and T.Z.; supervision, B.B.O.Š.; project administration, B.B.O.Š.; funding acquisition, B.B.O.Š. and T.Z. All authors have read and agreed to the published version of the manuscript.

Funding: Institutional research: 'Urbanscape Emanation', University of Zagreb, Faculty of Architecture (IP-2023, led by prof.dr.sc. Bojana Bojanić Obad Šćitaroci and dr.sc. Tamara Zaninović).

Data Availability Statement: Directly contact authors for any questions.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Case No.	Project Title, Author(s), Year Built, Location, City, Country	Photo Source/Reference	Authorship
1.	Underground Parking Katwijk an Zee, Royal Haskoning DHV, 2016, Coastline of Katwijk, The Netherlands	https://nl.m.wikipedia.org/wiki/Bestand:Kustwerk_Katwijk_aan_zee-17.jpg Last Accessed on 18 July 2024	Published on 14 October 2017 Author: Marianne Cornelissen-Kuyt
2.	Stormwater Management and Road Tunnel (SMART), the government and the private sector corporation, 2007, City Centre of Kuala Lumpur, Malaysia	https://commons.wikimedia.org/wiki/File:SMART_Tunnel_modes.svg Last Accessed on 18 July 2024	Published on 13 March 2021 Author: Cmglee
3.	Metropolitan Area Outer Underground Discharge Channel (G-can project), Japan Institute of Wastewater Engineering Technology, 2006, Saitama Perfecture, Tokyo, Japan	https://en.wikipedia.org/wiki/File:Kasukabe2006_06_07.JPG Last Accessed on 18 July 2024	Published on 7 June 2007 Author: Dddeco at Japanese Wikipedia
4.	D. Diogo de Menezes Square/Miguel Arruda Arquitectos Associados, 2009, **Cascais, Portugal**	Gallery of D. Diogo de Menezes Square / Miguel Arruda Arquitectos Associados - 26 (archdaily.com) Last Accessed on 18 July 2024	Published on 7 June 2015 Photopgrapher: © Fernando Guerra | FG+SG, with courtesy of: Miguel Arruda Arquitectos Associados
5.	Grande Pyramide du Louvre Complex, Ieoh Ming Pei, 1989, Paris, France	https://commons.wikimedia.org/wiki/File:Cour_Napol%C3%A9on_du_Louvre_(228021559).jpg Last Accessed on 18 July 2024	Published on 8 August 2018 Photographer: Alessio Mercuri
6.	Amdavad ni Gufa, MF Hussain and BV Doshi, 1994, Ahmedabad, India	https://en.wikipedia.org/wiki/File:Amdavad_ni_gufa.jpg Last Accessed on 18 July 2024	Published on 4 January 2012 Author: Vaishal Dalal
7.	Rynek Underground Museum, Andrzej Kadłuczk and, Dominik Przygodzki, 2010, Krakow, Poland	https://commons.wikimedia.org/wiki/File:Rynek_Fountain.jpg Last Accessed on 18 July 2024	Published on 21 October 2022 Author: Ivan Ruggiero
8.	Serpentine Gallery 2012 London, Herzog & de Meuron and Ai Weiwei, 2012, London, United Kingdom	https://commons.wikimedia.org/wiki/File:Serpentine_Gallery_Pavilion_2012_-_geograph.org.uk_-_2974055.jpg Last Accessed on 18 July 2024	Published on 1 June 2012 Author: David Hawgood
9.	House of Music, Sou Fujimoto, 2014, City Park, Budapest, Hungary	https://commons.wikimedia.org/wiki/File:House_of_Hungarian_Music.jpg Last Accessed on 18 July 2024	Published on 30 January 2022 Author: Elekes Andor
10.	Tirpitz Bunker, BIG, 2017, Sand dune, Blåvand, Denmark	https://commons.wikimedia.org/wiki/File:Tirpitz-Stellung_(10583800164).jpg Last Accessed on 18 July 2024	Published on 30 October 2013 Author: Dirk Vorderstraße
11.	Amos Rex Museum, JKMM Architects, 2018, Plaza, Helsinki, Finland	https://commons.wikimedia.org/wiki/File:Lasipalatsi_-_Amos_Rex_20180821_152632.jpg Last Accessed on 18 July 2024	Published on 21 August 2018 Author: Sino Yu
12.	Datong Art Museum, Foster + Partners, 2021, Datong, Shanxi Province, People's Republic of China	https://www.fosterandpartners.com/projects/datong-art-museum Last Accessed on 18 July 2024	Created on 5 June 2022 Owner: Katy Harris/Foster + Partners
13.	National September 11 Memorial Museum, Davis Brody Bond, 2014, **New York, United States**	https://commons.wikimedia.org/wiki/File:9-11_Memorial_and_Museum_(28815276064).jpg Last Accessed on 18 July 2024	Published on 19 August 2016 Author: Paul Sableman
14.	UCCA Dune Art Museum, OPEN Architecture, 2018, **Coastal landscape, Qinhuangdao, China**	https://www.openarch.com/en/task/334 Last Accessed on 18 July 2024	Published on unknown date Photographer: ©Wu Qingshan with courtesy of: UCCA Dune Art Museum, OPEN Architecture
15.	Library in the Earth, Hiroshi Nakamura & NAP, 2022, **Kurkku Fields, Kisarazu, Japan**	https://mymodernmet.com/underground-library-kurkku-fields/ Last Accessed on 18 July 2024	Published on 30 December 2023) Photographer: © Kohei Omachi
16.	Fangsuo Book Store, Chu Chih-Kang, 2015, Chengdu, China	方所成都店阁楼架空步道望向一楼.jpg Last Accessed on 18 July 2024	Published on 6 June 2018 Author: 来斤小仓鼠吧

Case No.	Project Title, Author(s), Year Built, Location, City, Country	Photo Source/Reference	Authorship
17.	Temppeliaukio Church, Timo and Tuomo Suomalainen, 1961–1969, Töölö neighbourhood Finland, Helsinki	https://commons.wikimedia.org/wiki/File:Temppeliaukio_Church_Helsinki_05.jpg Last Accessed on 18 July 2024	Published on 31 July 2014 Author: GualdimG
18.	ALMA Sports Hall, Benjamín Murúa Arquitectos, 2023, Atacama Desert, ALMA Observatory, Chile	https://nrao.cl/fundacion-nacional-de-ciencia-inaugura-multicancha-en-el-osf/ Last Accessed on 18 July 2024	Published on 14 March 2023 Photographer: © C. Padilla / AUI NRAO Chile with courtesy of: AUI/NRAO Todos los Derechos Reservados
19.	Gammel Hellerup Sports Hall, BIG, 2013, **Gymnasium Courtyard, Hellerup, Denmark**	https://commons.wikimedia.org/wiki/File:Gammel_Hellerup_Gymnasium_1.JPG Last Accessed on 18 July 2024	Published on 9 September 2015 Author: Ramblersen
20.	Pionen—White Mountain, Albert France-Lanord Architects, 2008, **Vita Berg Park, Stockholm, Sweden**	https://commons.wikimedia.org/wiki/File:5_Pionen_Data_Centre.tif Last Accessed on 18 July 2024	Published on unknown date Author: Simon Klose

References

1. Pace, G. An Introduction to Underground4value. In *Underground Built Heritage Valorisation*; Pace, G., Salvarani, R., Eds.; CNR Edizioni: Rome, Italy, 2021; pp. 1–18.
2. Conti, L.; Easton, M.; Saldais, M.; Smith, R.; Dumovic, V. *Oxford Big Ideas Humanities and Social Sciences 8*; Oxford University Press: Victoria, Australia, 2016; pp. 41–55.
3. Varriale, R. Underground Built Heritage: A Theoretical Approach for the Definition of an International Class. *Heritage* **2021**, *4*, 1092–1118. [CrossRef]
4. UNESCO. Records of the General Conference, 31st Session, Paris, 15 October to 3 November 2001, v. 1: Resolutions. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000124687.page=56 (accessed on 28 July 2023).
5. Toikilik, T.E. Underwater Cultural Heritage Act. Master's Thesis, International Maritime Law Institute, Msida, Malta, 2019. Available online: https://imli.org/wp-content/uploads/2021/04/TINMETT-ELIZABETH-TOIKILIK-.pdf (accessed on 23 November 2023).
6. Usama, N.; Talib, S.; Alim, S.A.; Shezad, S.M. Comparative Analysis of Underground & Underwater Tunnel. *Int. J. Eng. Res. Technol.* **2020**, *9*, 325–333. [CrossRef]
7. Jasinska, K. Underground as an integral part of the contemporary city: Functional, spatial and visual aspects. *Technical. Issues* **2016**, *1*, 37–43.
8. Admiraal, H.; Narang Suri, S. *Think Deep: Planning, Development and Use of Underground Space in Cities*; International Society of City and Regional Planners and International Tunnelling and Underground Space Association, (ISOCARP): The Hague, The Netherlands, 2015.
9. Wheeler, J. Gislebertus d'Autun and the Narrative of Scripture. *Aletheia* **2018**, *3*, 3–8. [CrossRef]
10. Lee, E.H.; Christopoulos, G.I.; Kwok, K.N.; Roberts, A.C.; Soh, C.K. A Psychosocial Approach to Understanding Underground Spaces. *Front. Psychol.* **2017**, *8*, 452. [CrossRef]
11. Fira de Barcelona. The City Designed by Leonardo da Vinci that Was Centuries ahead of Its Time. Available online: https://tomorrow.city/a/the-city-designed-by-leonardo-da-vinci-that-was-centuries-ahead-of-its-time (accessed on 25 July 2023).
12. The Hundertwasser Non-Profit Foundation. The Green Motorway—The Invisible—The Inaudible. Available online: https://hundertwasser.com/en/architecture/arch25v_die_gruene_autobahn_die_unsichtbare_die_unhoerbare_1065 (accessed on 25 July 2023).
13. Kollarath, M.R.; Raina, S.; Madapur, B. Underground Cities: Sustainable Urbanism of the Future. *Int. J. Recent Technol. Eng.* **2019**, *8*, 1754–1758. [CrossRef]
14. Perrault, D. Groundscapes—Other Topographies. In *Dominique Perrault*; Editions HYX: Orléans, France, 2016.
15. Dominique Perrault Architecture. Open Online Course about the Groundscape Architecture. Available online: https://www.perraultarchitecture.com/en/media/training/3585-open_online_course_about_the_groundscape_architecture.html (accessed on 25 May 2024).
16. McMillen, H.; Campbell, L.K.; Svendsen, E.S.; Reynolds, R. Recognizing Stewardship Practices as Indicators of Social Resilience: In Living Memorials and in a Community Garden. *Sustainability* **2016**, *8*, 775. [CrossRef]
17. Jha, A.K.; Miner, T.W.; Stanton-Geddes, Z. *Building Urban Resilience: Principles, Tools, and Practice*; World Bank Publications: Washington, DC, USA, 2013. [CrossRef]
18. Elewa, A.K.A. Flexible Public Spaces through Spatial Urban Interventions, Towards Resilient Cities. *Eur. J. Sustain. Dev.* **2019**, *8*, 152–168. [CrossRef]
19. Leroy, J.; Amdal, J.; Vuillet, M.; Cariolet, J.M.; Diab, Y.; Becue, Y. Vulnerability and social resilience: Comparison of two neighborhoods in New Orleans after Hurricane Katrina. *E3S Web Conf.* **2016**, *7*, 08002. [CrossRef]
20. Pimm, S.L. The complexity and stability of ecosystems. *Nature* **1984**, *307*, 321–326. [CrossRef]
21. UNISDR. 2009 UNISDR Terminology on Disaster Risk Reduction. 2009. Available online: https://www.undrr.org/publications (accessed on 28 July 2023).

22. UNDRR. Heritage and Resilience. Issues and Opportunities for Reducing Disaster Risks. 2013. Available online: https://whc.unesco.org/en/events/1048/ (accessed on 28 July 2023).
23. Omićević, N.; Bojanić, O.; Šćitaroci, B. *The Urban Rehabilitation of Post-Disaster Scapes*; Springer Nature: Singapore, 2023. [CrossRef]
24. Diamond, R.S.; Kassel, B.G. A History of the Urban Underground Tunnel (4000 B.C.E.–1900 C.E.). *J. Transp. Technol.* **2018**, *8*, 11–43. [CrossRef]
25. Volchko, Y.; Norrman, J.; Ericsson, L.O.; Nilsson, K.L.; Markstedt, A.; Öberg, M.; Mossmark, F.; Bobylev, N.; Tengborg, P. Subsurface planning: Towards a common understanding of the subsurface as a multifunctional resource. *Land Use Policy* **2020**, *90*, 1–18. [CrossRef]
26. Sterling, R.; Neslon, P. City Resiliency and Underground Space Use. In *Advances in Underground Space Development*; Zhou, Y., Cai, J., Sterling, R., Eds.; Research Publishing: Singapore, 2013; pp. 43–55. [CrossRef]
27. Ruby, A.; Ruby, I. *Groundscapes: The Re-Discovery of the Ground in Contemporary Architecture*; Land&Scape Series; Gustavo Gili: Barcelona, Spain, 2006.
28. De Feo, G.; Antoniou, G.; Fardin, H.T.; El-Gohary, F.; Zheng, X.Y.; Reklaityte, I.; Butler, D.; Yannopoulos, S.; Angelakis, A.N. The Historical Development of Sewers Worldwide. *Sustainability* **2014**, *6*, 3936–3974. [CrossRef]
29. New York City Landmarks Preservation Commission. Old Croton Aqueduct Walk. Available online: https://www.nyc.gov/assets/lpc/downloads/pdf/proposed_landmarks/Old_Croton_Aqueduct_Walk_proposed.pdf (accessed on 27 May 2024).
30. Vaeceslav, M. Post-Pandemic City: Historical Context for New Urban Design. *Transylv. Rev. Adm. Sci. Spec. Issue* **2020**, *16*, 94–108. [CrossRef]
31. Bartak, J. The Oldest Underground Railways in the World and their Anniversaries. *Acta Polytech. CTU Proc.* **2020**, *29*, 1–5. [CrossRef]
32. Dennis, R. Lighting the Underground: London, 1863–1914. *Hist. Urbaine* **2017**, *50*, 29–48. [CrossRef]
33. Yamac, A. Some Interesting Underground Cities and Peculiar Underground Structures of Kayseri (Turkey). In *Jerusalem Journal of Archaeology*; Shivtiel, Y., Ed.; The Institute of Archaeology, Hebrew University of Jerusalem: Jerusalem, Israel, 2022; Volume 3, pp. 70–107. [CrossRef]
34. Bixio, R.; Yamac, A. Underground Shelter in Cappadocia (Turkey). In Proceedings of the Hypogea 2023, the VI International Congres of Speology in Artificial Cavities, Genoa, Italy, 29 September–1 October 2023; pp. 153–160.
35. Yildiz, P. Analysis of the 'Cappadocian cave house' in Turkey as the historical aspect of the usage of nature as a basis of design. *WIT Trans. Ecol. Environ.* **2006**, *87*, 61–70. [CrossRef]
36. Nyvelt, V.; Musilek, J.; Čejka, J.; Stopka, O. The Study of Derinkuyu Underground City in Cappadocia Located in Pyroclastic Rock Materials. *Procedia Eng.* **2016**, *161*, 2253–2258. [CrossRef]
37. Saher, K.; Mihci, G. Auditory Exploration of Derinkuyu Underground City Cappadocia Turkey. In Proceedings of the Second Edition of the Invisible Places International Symposium, Sound, Urbanism and Sense of Place, Sao Miguel Island, Azores, Portugal, 7–9 April 2017; pp. 396–403.
38. Kimic, K.; Costa, C.S.; Negulesa, M. Creating Tourism Destinations of Underground Built Heritage—The Cases of Salt Mines in Poland, Portugal, and Romania. *Sustainability* **2021**, *13*, 9676. [CrossRef]
39. Stach, E.; Pawlowska, A.; Matoga, L. The Development of Tourism at Military-Historical Structures and Sites—A Case Study of the Building Complexes of Project Riese in the Owl Mountains. *Pol. J. Sport Tour.* **2014**, *21*, 36–41. [CrossRef]
40. Pasierb, B.; Nawrocki, W. Not only the 'Gold Train' –the 'Underground Town' of Riese (Poland)—the ambiguity of interpretation ERT and GPR methods. *Archaeol. Prospect.* **2020**, *27*, 361–375. [CrossRef]
41. Jablonski, M.; Lipecki, T.; Jaskowski, W.; Ochalek, A. Virtual Underground City Osówka. *Geol. Geophys. Environ.* **2016**, *42*, 77–78. [CrossRef]
42. Duffaut, P. Underground City-Planning: A French Born Concept for Sustainable Cities of Tomorrow. In Proceedings of the International Symposium on: Utilization of Underground Space in Urban Areas, Sharm El-Sheikh, Egypt, 6–7 November 2006; Available online: https://tunnel.ita-aites.org/media/k2/attachments/public/underground_city_planning.pdf (accessed on 18 July 2024).
43. Besner, J. Cities Think Underground—Underground Space (also) for people. *Procedia Eng.* **2017**, *209*, 49–55. [CrossRef]
44. Qing, L.H.; Aurele, P.; Philippe, T.; Zhao, L.X. An Integrated Planning Concept for the Emerging Underground Urbanism: Deep City Method Part 1 Concept, process and application. *Tunelling Undergr. Space Technol.* **2013**, *38*, 559–568. [CrossRef]
45. Enright, T. *The Making of Grand Paris: Metropolitan Urbanism in the Twenty-First Century (Urban and Industrial Environments)*; MIT Press: Cambridge, MA, USA, 2016.
46. Rethinking the Future, 2022. Louvre Pyramid by I.M, Pei: The Glass Pyramid. Available online: https://www.re-thinkingthefuture.com/case-studies/a2527-louvre-pyramid-by-i-m-pei-the-glass-pyramid/#google_vignette (accessed on 27 May 2024).
47. Urban Redevelopment Authority. Underground Developments a Benchmarking Study to Explore International Best Practices in Underground Space Management. Available online: https://www.ura.gov.sg/-/media/Corporate/Get-Involved/Plan-Our-Future-SG/Underground-Works/Benchmarking_Study.pdf (accessed on 28 July 2023).
48. Montazerolhodjah, M.; Pourjafar, M.; Taghvaee, A. Urban underground development; an overview of historical underground cities in Iran. *Int. J. Archit. Eng. Urban Plan.* **2015**, *25*, 53–60.

49. Dezeen. Dune-Shaped Car Park by Royal HaskoningDHV Doubles as a Flood Defence. Available online: https://www.dezeen.com/2016/07/05/underground-car-park-royal-haskoningdhv-parking-amersfoort-south-holland/ (accessed on 28 July 2023).
50. Isah, N.; Ali, M.B. A relationship between Flood Occurrences and the Maintenance Works of SMART Tunnel, Kuala Lumpur, Malaysia. *Int. J. Res. Rev.* **2015**, *2*, 434–449.
51. Bloomberg, L.P. Climate Change Will Test Tokyo's World-Class Flood Defenses. Available online: https://www.bloomberg.com/news/features/2023-11-13/ambitious-tokyo-flood-tunnels-tested-by-worsening-natural-disasters (accessed on 28 November 2023).
52. Besner, J. Underground space needs an interdisciplinary approach. *Tunn. Undergr. Space Technol.* **2016**, *55*, 224–228. [CrossRef]
53. Zaninović, T.; Omićević, N.; Bojanić Obad Šćitaroci, B. (De)Linking with the Past through Memorials. *Architecture* **2023**, *3*, 627–657. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.