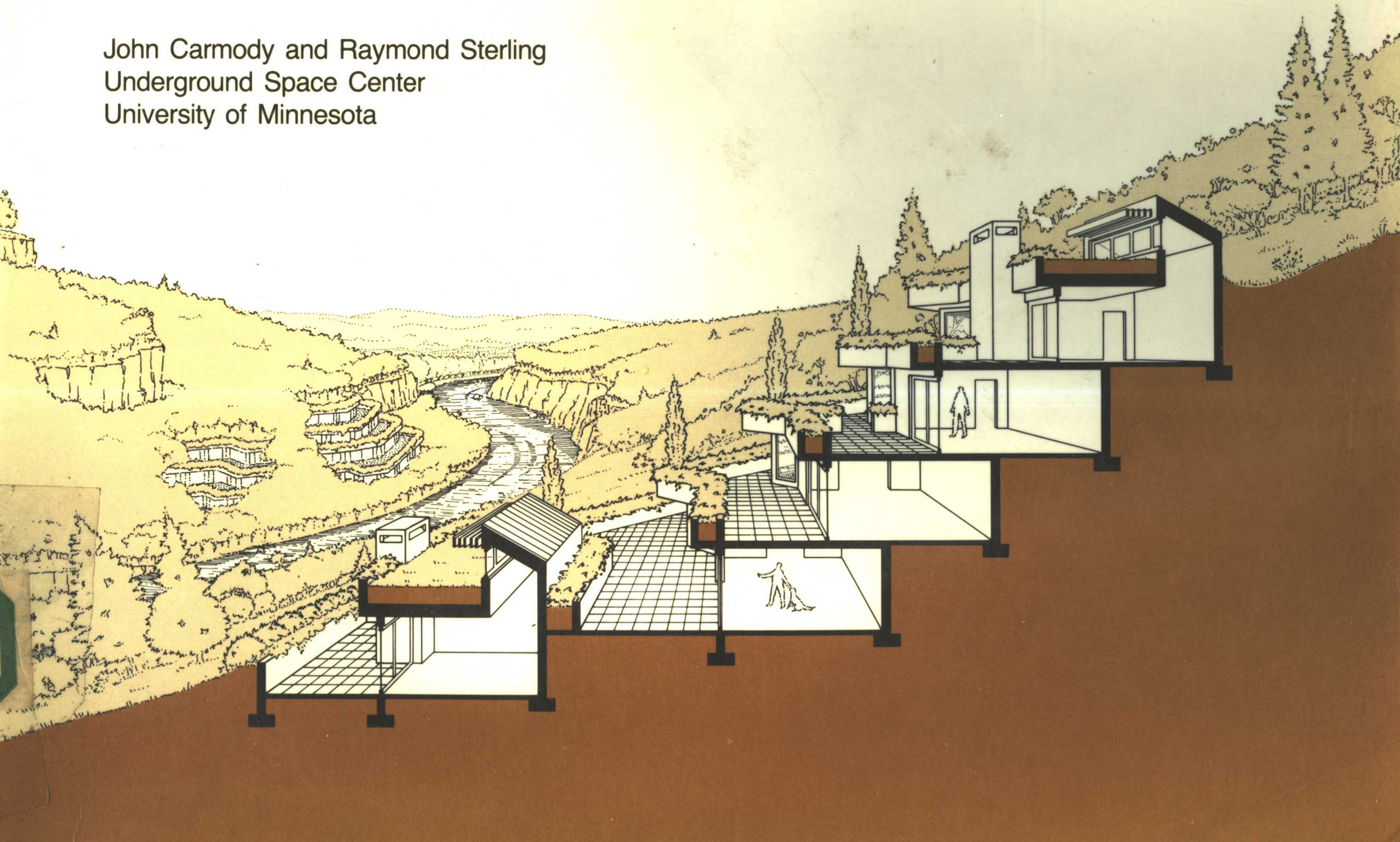
Earth Sheltered Housing Design

Second Edition

John Carmody and Raymond Sterling
Underground Space Center
University of Minnesota



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Preface

Although building into or with the earth is an ancient idea, only in the mid-1970s did earth sheltered housing reemerge as an important alternative design approach for housing in the United States. Reasons for this interest include such benefits as reduced energy consumption, protection from natural and man-made disasters, increased security, noise reduction, and, in some cases, more efficient land use. In addition, earth sheltered housing is viewed as an effective means of building in harmony with nature, thus preserving the environment rather than destroying it while providing intriguing aesthetic potential.

The first edition of this book initially appeared in 1978 as a self-published research report for the Legislative Commission on Minnesota Resources by the then newly created Underground Space Center. Although the book focused on Minnesota applications and cold climate problems, the book served as a catalyst for great public interest in earth sheltered housing, further research work on a national level, and the construction of several thousand earth sheltered houses across the United States. As awareness of the advantages of earth sheltered construction increased, so did the demand for more information. Over the past five years, the staff at the Underground Space Center has produced five additional books that examine in detail certain aspects of earth sheltered or underground building design.

Since the first edition of this book was published, earth sheltered housing has become a more familiar option. During the same period, many other energy-efficient housing options have been developed as well. In 1984, during an indeterminate respite from rapidly rising energy prices, much of the initial impetus in the United States to create new energy-efficient forms of housing has subsided. A period of narrow advocacy for various energy-efficient, whole-house design concepts is giving way to a broader consideration of passive solar design, superinsulation, and earth sheltering as concepts in a palette of design techniques from which to construct energy-efficient buildings appropriate to their climate, site conditions and local market forces.

Interest in earth sheltered housing has increased considerably in many countries around the world where such techniques may, in fact, have a greater relative impact than in the United States. Non-residential applications also continue to grow steadily both in the United States and internationally. The multiple ramifications of earth sheltering and its potential application to building needs around the world will require a sophisticated understanding of the optimum design configurations and details for different types of buildings, different site conditions, and different climates.

The state-of-the-art is still evolving as information on energy performance, construction techniques, and costs continues to increase and improve. This second edition of *Earth Sheltered Housing Design* reflects current trends and provides as much up-to-date information as possible. Like the original edition, it is broad-based and comprehensive, with chapters on the history of earth sheltered design, site and building design, energy use and costs, structural design, waterproofing and insulation, public policy issues, and eighteen case studies.

Acknowledgments

The purpose of this book is to synthesize and present a wide range of information related to earth sheltered housing design. The contributions of many researchers, designers, and builders in this field have made this effort possible. A few people in particular have provided information and assisted in the development of key portions of the book. Dr. George Meixel, Jr., Louis Goldberg, and Lester Shen of the Underground Space Center staff contributed to and reviewed the chapter on energy use. Parametric studies on insulation placement are the work of Dr. Meixel and Lester Shen, while the discussion of monitoring and analyzing energy use in earth sheltered housing is based on work done by Louis Goldberg.

Brent Anderson (Brent Anderson Associates, Minneapolis, Minnesota) served as a consultant on waterproofing systems. His assistance was invaluable in providing technical information and reviewing the waterproofing chapter. Kenneth Labs of Undercurrent Design in New Haven, Connecticut, has provided information and drawings for use in the text. In addition, his research in several areas of earth sheltered design—most notably climate analysis and regional design issues—has provided a valuable basis for portions of this book. The authors also wish to thank numerous architects, builders, and home owners who contributed written material, photographs, and drawings of their projects. Individual credit for these contributions appears where the material is used throughout the book.

This second edition of *Earth Sheltered Housing Design* is an almost entirely new book. Nearly every portion of the first edition has been rewritten and expanded and several new sections have been added. Nevertheless, this book is built on the foundation of the first edition, created several years ago. A few people who made contributions to the first edition deserve mention here. The Legislative Commission on Minnesota Resources played a role in establishing the Underground Space Center in 1977 and has provided funding for a series of research projects related to underground space use and energy conservation, including the first edition of this book. Dr. Charles Fairhurst and Dr. Thomas Bligh acted as principal investigators for the first edition of the book and have been responsible for focusing considerable public attention on the potential benefits of underground space development. The pioneering heat transfer studies in the first edition were the work of Dr. Paul Shipp; additional material on energy use and structural design was provided by Martin Lunde, Terrill Tillman, and Dr. Charles Nelson. Kenneth Labs provided material for the case studies in the first edition, and Tom Ellison made contributions in a number of areas including the chapters on site and building design.

A number of people have contributed their time and talents to the production of this book. John Carmody and Bruce Cornwall collaborated on the design and layout of the book. Most of the illustrations were drawn by Bruce Cornwall under the direction of John Carmody. Keylining, graphic work, and some additional illustrations were done by Katherine Carmody and Mark Heisterkamp. The authors wish to thank Linda Venator of Van Nostrand Reinhold Company for her valuable editorial advice and assistance; Donna Ahrens, who provided additional assistance in editing portions of the text; and Arlene Bennett and Andrea Spartz, who did the extensive typing of the book.

Contents

Facade of a house dug into a cliff in the Loire Valley, France.
Drawing by Bruce Cornwall.

Chapter 1

Introduction to Earth Sheltered Housing

At the most basic level, a house shelters its occupants from the climate. Throughout history, dwellings have also provided protection from enemies and predators as well as some degree of privacy. But the housing of a culture, past or present, reflects more than simply meeting physical needs with available materials and technology. Since the design and construction of houses are based on social as well as physical needs housing also represents the values and attitudes of a society.

In recent decades housing in the United States has reflected the technological capability of our society as well as the attitude that materials, land, water, and energy resources were available in almost unlimited supply. The majority of American housing built since World War II is unquestionably clean, spacious, and of a standard consistently higher than in most other societies, past or present. The true cost and total effect of sprawling urbanization and suburban development, however, have begun to emerge only in the last decade or so.

Energy, water, and land resources are clearly not unlimited. Evidence of stress on natural systems in the form of water and air pollution surrounds us. Much natural vegetation and topsoil has been destroyed as communities have been developed. Likewise, man-made systems that supply fuel and water and remove wastes from cities are also stressed, resulting in high costs to extend and maintain them. Moreover, many find large portions of our urban and suburban environments unpleasant and unattractive places to live. Certainly housing development is not solely responsible for many of these effects; it is, however, a large and integral part of the built environment.

In recent years a number of positive trends have emerged in response to the problems mentioned above. More multiunit development and increased construction activity within existing cities conserve land and utilize existing utility and transportation systems more efficiently. A greater awareness of energy-efficient techniques in housing design has developed and a number of successful approaches have been applied on a relatively small scale. Although these trends are encouraging, the problems are enormous, and much housing construction still ignores them. The plateau reached in energy prices in the early 1980s has made energy conservation a lower priority despite the fact that traditional fossil fuels are not available in unlimited supply, and the possibility that political instability in oil-producing countries could quickly thrust us into another crisis.

Many alternative types of housing have emerged in the last decade that reflect the evolution toward a different set of values in our society and perhaps new forms of residential architecture. Among these is a design approach most commonly referred to as earth sheltered housing. Building with the earth or into the earth has deep roots in many cultures. The reemergence of earth sheltered housing in the United States and in other parts of the modern world has occurred for many diverse and interrelated reasons. It is usually built not simply to achieve one objective—to conserve energy, for example. Instead, earth sheltered housing design addresses a number of resource conservation, aesthetic, and other practical concerns. Because earth sheltered housing applied appropriately has the potential to solve a wide range of problems while intriguing and inspiring designers and home owners, it appears to be a significant option for housing design in the future. In the remainder of this chapter, the reasons for and

1-1: Solaria, an earth-covered house in Vincentown, New Jersey; Malcolm Wells, architect; photograph by Robert Homan.

methods of building earth sheltered buildings throughout history up to the present day are discussed.

Terminology

Before embarking on a discussion of the historical background and rationale for earth sheltered housing, it is worthwhile to review what constitutes earth sheltered construction. As used in this book, earth sheltered construction denotes the use of the earth in a building design to improve the energy, aesthetic, or isolation characteristics of the building. There have been several specific definitions proposed for earth sheltered construction (i.e., buildings with roofs and walls 50 percent covered with earth at least 1 foot thick), but in this book the definition of earth sheltering as a general concept is preferred.

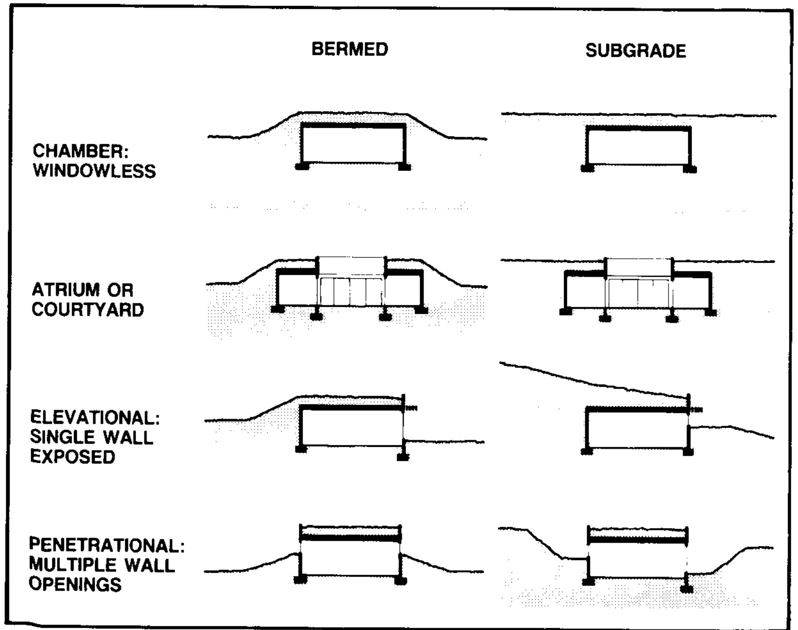
Other general terms that are used to denote earth sheltered buildings or this architectural approach are:

- geotecture
- geomorphic architecture
- underground buildings
- earth-integrated buildings
- earth-protected construction
- earth-contact construction (sometimes used to refer to earth-bermed buildings only—see below)
- earth-coupled buildings (heat transfer aspects primarily)

Terms that are more specific to the type of construction or degree of earth contact are:

- earth-covered buildings—with earth on the roof
- earth-bermed buildings—earth against the building walls only

To aid in the description of different design approaches to underground construction, Kenneth Labs developed a taxonomy of underground space [Labs, 1976]. These classifications, shown in figure 1-2 are based on two important characteristics of underground space—the general type of opening to the surface and the relationship to grade. The windowless underground chamber has no access to the surface and is considered unacceptable for housing. The elevational approach, in which one wall is exposed and the rest are covered with earth, is the most common form of earth sheltered housing.



1-2: Classification of Earth Sheltered Structures

Source: Kenneth Labs, 1976 (see references).

An atrium or courtyard scheme has many historical precedents and is also a viable form of earth sheltered housing today. The penetrational type is most similar to conventional housing in that openings occur in two or more exterior walls. These simplified general forms are useful for classification purposes but actual designs usually employ more complex combinations of forms.

The second aspect that Labs uses in his classification system is the relationship to grade. A completely below-grade structure is referred to as *subgrade*, while a building that extends above existing grade with earth placed around it is *bermed*. These distinctions are usually clear on a flat site, but on sloping sites a building can appear to be subgrade on some sides and bermed on others.

A further classification of earth sheltered houses addresses the issue of whether the roof is covered with a thin layer of earth. Although openings to the outside and relationship to grade may not be significantly affected by the roof treatment, it is an important distinction in terms of appearance, cost, method of construction and energy use. Most often, the terms *earth covered* and *earth bermed* are used to make this distinction.

A final means of categorizing underground or earth sheltered construction is based on the general method of construction. In the vast majority of cases, earth sheltered buildings are placed into soil near the surface that is not self-supporting. The structure of the building must support the weight of the earth pressing against the walls or resting on the roof. This is most commonly referred to as cut-and-cover construction. In contrast, many historical underground structures are carved out of rock or self-supporting soil, requiring no additional structure. Referred to as mined space, this type of construction is typically limited to self-supporting soil or soft rock conditions or to places where it is profitable or necessary to extract harder rock formations. Where mined space is deep below ground and has few openings to the outside, it is more suitable for commercial or industrial uses rather than for housing. An example of this is the extensive development of offices, manufacturing and warehouse space in portions of over 200 million square feet of limestone mines near Kansas City, Missouri. Occasionally, a unique site will lend itself to mined construction for housing, as demonstrated by a recently completed house in the West Indies designed by architect John Barnard (fig. 1-3).

Historical Perspective

To say that earth sheltered construction has existed since the dawn of history is a cliche and yet a valid reflection of the natural protection and enduring applicability provided by the ground in meeting the shelter needs of man. Protection from predators and the climate, together with the lack of building materials, were strong reasons for cavemen to seek shelter in natural openings in the rock. These same advantages coupled with varying priorities and the special concerns or opportunities of a particular time or place are the common thread through the many centuries of recorded troglodyte living.

In 4000 B.C. villagers at the recently unearthed Banpo site in China lived in semiunderground pit dwellings with an A-frame roof supporting a thin layer of soil and vegetation. In later centuries cave dwelling became a widely adopted practice in the arid regions of eastern central China, where a deep loess soil provided ideal conditions for self-supporting excavations in soil (fig. 1-4). Marco Polo, in his

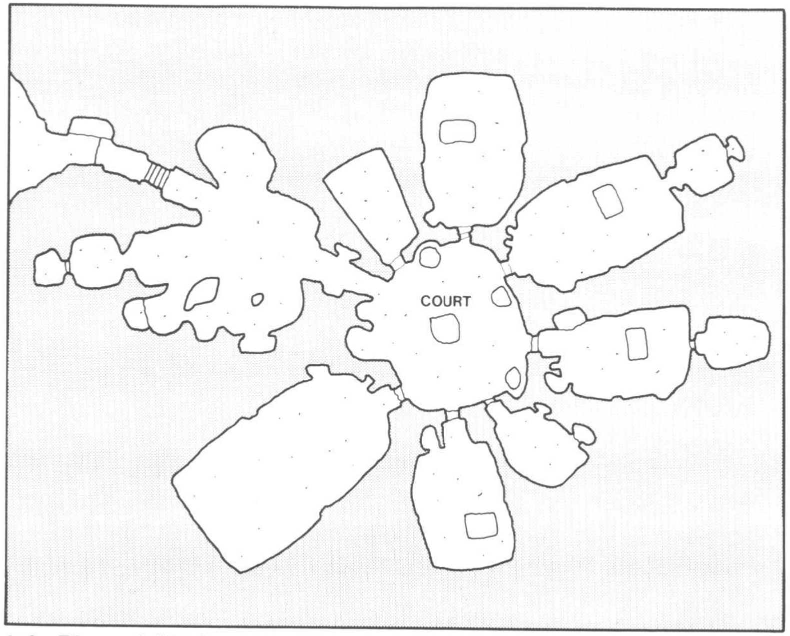
1-3 (above): A recently constructed house in the West Indies carved out of rock; John Barnard, architect.

1-4 (below): Underground courtyard houses in China mined out of the soft loess soil.

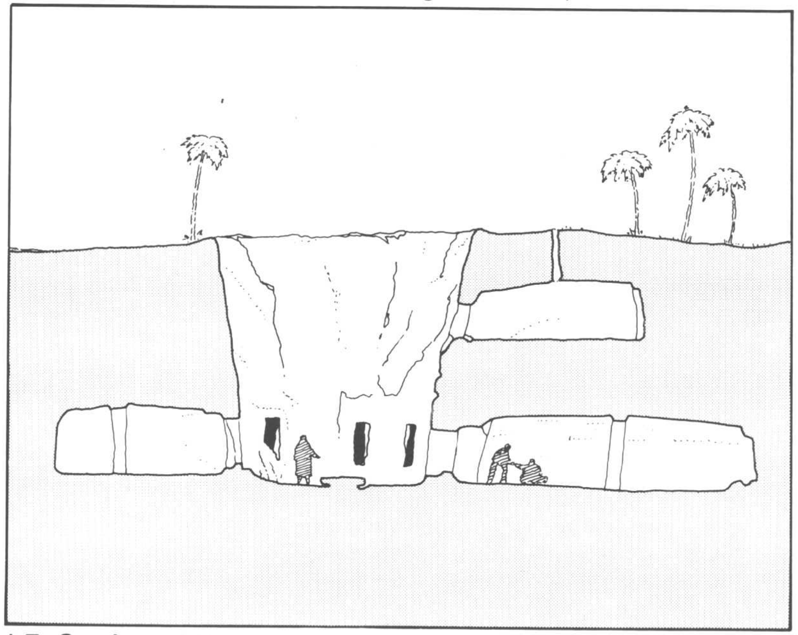
1-5: Underground atrium dwellings built by the Romans at Bulla Regia in northern Tunisia; photograph by Richard Kennedy.

travels to China in the thirteenth century A.D. noted the existence of several tribes who lived in excavated homes. Courtyard houses were used on flat sites, and terraced housing on sloping sites. The thermal advantages of the earth's temperature moderation in a continental climate with cold winters and hot summers, together with the ability to provide shelter with only a pick and shovel, have led to the construction of millions of these cave dwellings through to the present day. In many locations farming continues on the surface above the below grade houses. Most recent estimates from China indicate that approximately 20 million people live in cave dwellings in China today.

Between the second and fifth century A.D. the



1-6: Plan of Underground Dwelling—Matmata, Tunisia

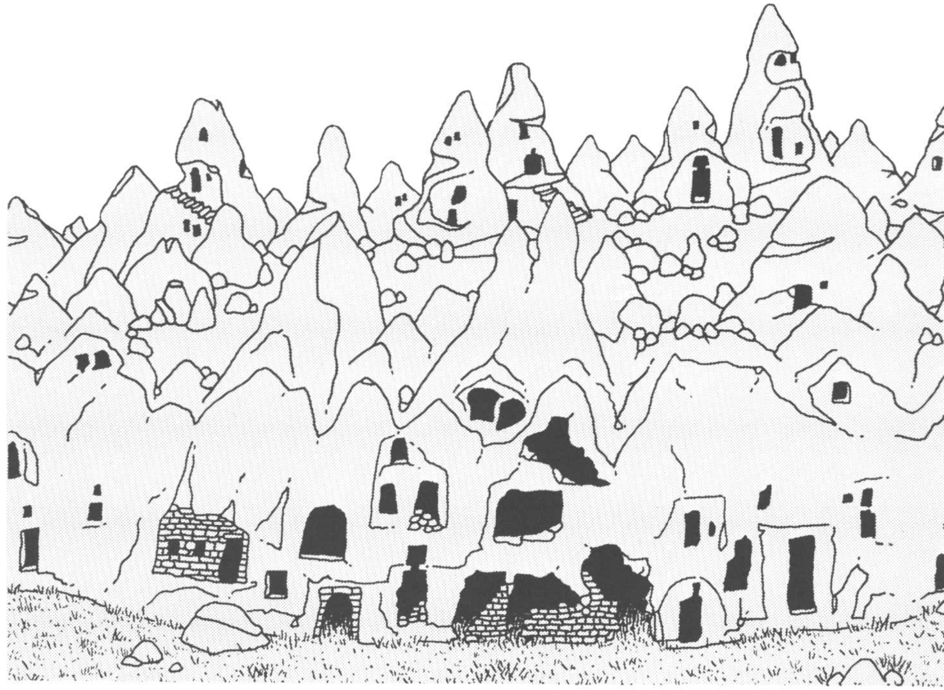


1-7: Section of Underground Dwelling—Matmata, Tunisia

Romans had an active agricultural and economic base in present-day northern Tunisia. Athough they were not accustomed to underground construction of dwellings and apparently did not use this form of construction elsewhere in their empire, they adapted to the extremely hot, arid conditions at Bulla Regia (near present day Jendouba) and constructed below-ground atrium dwellings (fig. 1-5). These were similar to typical Roman atrium dwellings except in their relation to grade. In more recent times in Tunisia, the Berbers have lived in several types of troglodyte settlements—courtyard housing in the flat desert regions (Matmata) and hillside styles in the mountains (Duiret, Ghomrassen). Figures 1-6 and 1-7 show a plan and section view of the deep courtyard housing at Matmata. Courtyards are typically 30 feet deep providing significant isolation from winds and hot temperatures on the surface.

In Turkey, the Cappadocia region and the spectacular Goreme valley are the sites of large cave dwelling settlements. Religious persecution in the ninth century A.D. forced Byzantine Christians to flee to this area where the soft rock and strange wind-eroded formations allowed the construction of elaborate underground communities, churches and homes (fig. 1-8).

Other examples of earth-integrated vernacular architecture in the Mediterranean region exist in the Gaudix region of Spain (fig. 1-9), in Sicily, and on the Isle of Santorini (Thira), Greece. An extensive troglogyte community in the Loire Valley region in central France grew partly as a by-product of of another construction activity—the building of the great French *chateaux*. The soft stone was cut and air-dried to harden into a suitable building stone for



1-8 (above): Underground village carved out of soft rock in the Cappadocia region of Turkey.

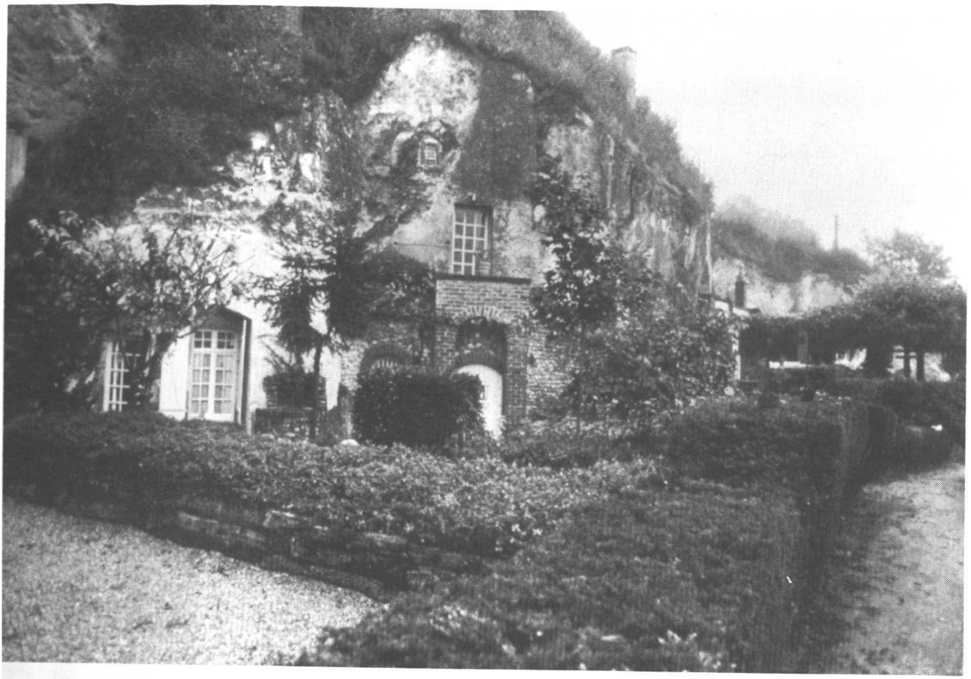
1-9 (below): Underground dwellings in the Gaudix region of Spain; photograph by Richard Kennedy.

the *chateaux*. The caverns left from the excavation were occupied by the stone masons and later by others who perceived their advantages. At its peak in the eighteenth century, there were hundreds of thousands of cave dwellings in France. As shown in figure 1-10, many of these houses are occupied today.

North America has had its own history of earth sheltered construction. The Anasazi Indian culture of the southwest United States has been held up as a model of passive housing design with southern orientations, large thermal mass walls to even diurnal temperatures swings, and small windows to prevent solar overheating. Many of the Indian buildings in this region were also set into the ground or excavated into a cliff site. Mesa Verde, shown in figure 1-11, is a well-preserved example of a cliff site settlement; the ceremonial *kiva* extensively used by Indian communities was also usually excavated below grade.

The sod houses and dugouts of the North American prairie constructed by European settlers were a response to the severe extremes of climate and the lack of building materials. Differing opinions exist as to their comfort and desirability, but they served an important function of shelter in an inhospitable environment.

On the other side of the world, the discovery of opals in the desert regions of central Australia beginning in 1915 led to below-grade living to escape the oppressive heat. White Cliffs, in New South Wales, and Coober Pedy, in South Australia, have sturdy rock formations that allow houses to be mined into the rock (fig. 1-12). Other sites in



1-10 (above): Facade of a house dug into the hillside in the Loire Valley region of central France; photograph by E. Revault.

1-11 (below): Indian cliff dwellings in Mesa Verde National Park, Colorado.

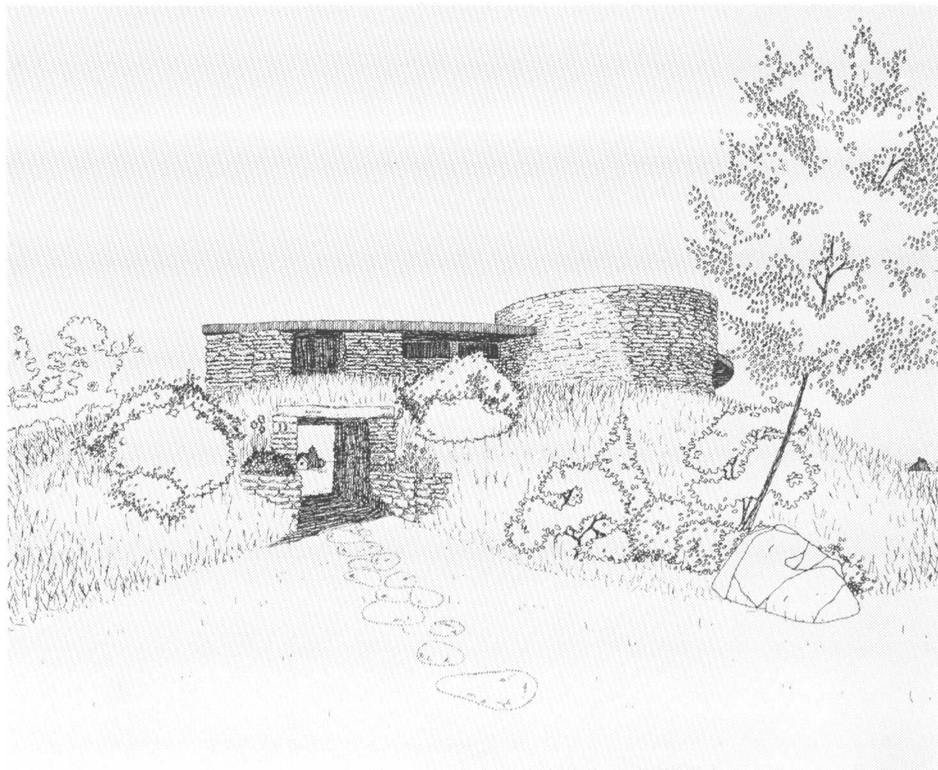
Australia have used makeshift earth-covered dwellings (Andamooka, South Australia) or excavated caves in riverbank soil (Burra, New South Wales) to provide shelter. Some special benefits have accrued to house construction in Coober Pedy, where the discovery of opals during house excavation can pay for the house. Special problems have also occurred as at the copper mining community of Burra, however, where the majority of the riverbank underground homes were washed away during heavy river flooding in 1851.

Recent Construction

Examples of earth-integrated design in the twentieth century can be found in the work of Frank Lloyd Wright in the 1930s and 1940s. In some cases earth berms were utilized as a means of integrating buildings with their sites and creating a low profile image. An earth-bermed, passive solar house shown in figure 1-13 was designed by Wright and built in 1943.

In the United States, several pertinent developments related to earth sheltered housing have occurred since World War II. The first two have provided somewhat negative connotations to subsequent earth sheltered designs: basement houses and nuclear fallout shelters. Basement houses became numerous in the United States as the demand for affordable housing outstripped its production after the war. Many house builders constructed the basement first and occupied it, intending to finish the remainder of the house in a short period of time. Inevitably, many houses were

1-12 (above): Entrance to a dwelling mined in the rock at Coober Pedy, Australia; photograph by Ray Sterling.



1-13 (below): Second Jacobs House in Middleton, Wisconsin built in 1943; Frank Lloyd Wright, architect.

1-14: Interior view of the Geier Residence, Cincinnati, Ohio; Philip Johnson, architect; photograph by Ezra Stoller, ESTO.

not finished quickly and the resulting unsightliness prompted many communities to enact "basement" ordinances to prevent the construction of this type of unfinished structure. A later effect of these ordinances has been an institutional impediment to the construction of well-designed, complete earth sheltered homes (see chapter 6).

The most common nuclear fallout shelters for residences were backyard shelters constructed specifically for this purpose during the height of the "cold war" in the late 1950s and early 1960s. A number of whole house designs, however, were based around this concept. The most notable of these was the house Jay Swayze built for the 1960 World's Fair in Seattle. Over one million people toured the house, which was in fact a wood-frame house built freestanding within an underground concrete bunker. Programmed lighting and painted scenes on the walls outside the house windows exemplified the attempt to provide a completely artificial environment below ground. This basic design was replicated in several areas of the United States but in the middle to late 1960s, the environmental movement and the anti-war sentiments in the United States created a public backlash against nuclear shelter programs.

Ecological and environmental concern did have a very positive impact on other types of earth sheltered construction, however. In 1965 Philip Johnson, most noted for his glass house and his gleaming steel and glass skyscrapers, designed an earth-covered house on the edge of a man-made lake in Ohio (fig. 1-14) and subsequently a small earth-covered museum on his own property.

Malcolm Wells in 1971 proposed several wilderness principles for building construction and expressed a philosophy of "building without destroying the earth." Wells noted that untouched wilderness land has several beneficial effects on the environment and in fact is essential to man's survival on the planet. These effects include creating pure air and water, storing rainwater, creating rich soil, producing its own food, using and storing solar energy, consuming its own wastes, providing human and wildlife habitat, moderating the climate, and creating a beautiful environment. According to Wells, modern architectural practices of destroying these natural systems in exchange for lifeless, synthetic, hard surface environments are unacceptable; he thus advocates earth sheltered architecture. In his book, *Gentle Architecture* [Wells, 1981], Wells states:

> *Green plants turn sunlight into food and fuel. They take inedible earth minerals and water and carbon dioxide, and, holding them up to the sun, give us food and fuel and oxygen in return.*