The Architectural Use of Underground Space: Issues & Applications

Kenneth B. Labs

Master's Thesis
Washington University
1975

Reprinted 2008

2008

Doylestown, PA

Production Notes

My brother, Ken, passed away in 1992. He wrote this paper over the course of several years, finishing it in 1975 for his Masters in Architecture at Washington University, St. Louis, MO. After completion, he self-published this document and sent it around the world to those who requested it; I remember copies going to Australia, India, Europe and Canada. His fee barely covered the cost of reproducing, binding and shipping, so in essence it was a labor of love. His love of architecture was exuberant and his desire to share this knowledge knew no bounds. Knowing how strongly he felt about the need to come up with environmentally responsible designs, I have no doubt that he would use current technology to keep this document living on in the hopes of inspiring architects today.

Ken's dedication to the field of architecture and alternate energy, especially solar, is obvious in the research effort he put into this project, which was considered a landmark by his professors and peers. Except for climatic data (which of course, has not been updated in the re-release of this paper) and information regarding the value of energy (especially oil and its derivatives), the basic physics and math are still solid. Today, however, modern architecture and construction benefit from many new energy-efficient materials and technologies such as smart building controls, 95% efficient motors, new compressor technologies, boiler heat reclamation systems, solar heating and electrical generation, geothermal systems and energy-saving illumination products—to mention just a few.

Over the last few years I have tried to reproduce Ken's thesis with the tools I have at my disposal. Since I had only a 1975 vintage photocopy, some of the art needed retouching and some was left as is, although digitally enhanced. Tables, where possible, have been recreated. He originally wrote the entire piece on a manual typewriter and did "page layout" as he went along. I have tried to maintain the original page layout and page numbering system as much as possible throughout, hence the format of this document is "landscape" and meant to be spiral bound at the top.

The thesis was reset in Centaur and Frutiger. Both low resolution and high-resolution PDFs are available to print. The low resolution will download faster, but graphics quality may suffer. The outside cover is new, but Ken's original thesis cover follows this document.

It is my hope that the architectural community will find this not only an interesting glimpse into the past, but relevant today and an inspiration for future projects.

—Wayne Labs, June, 2008.

The Architectural Use of Underground Space: Issues & Applications

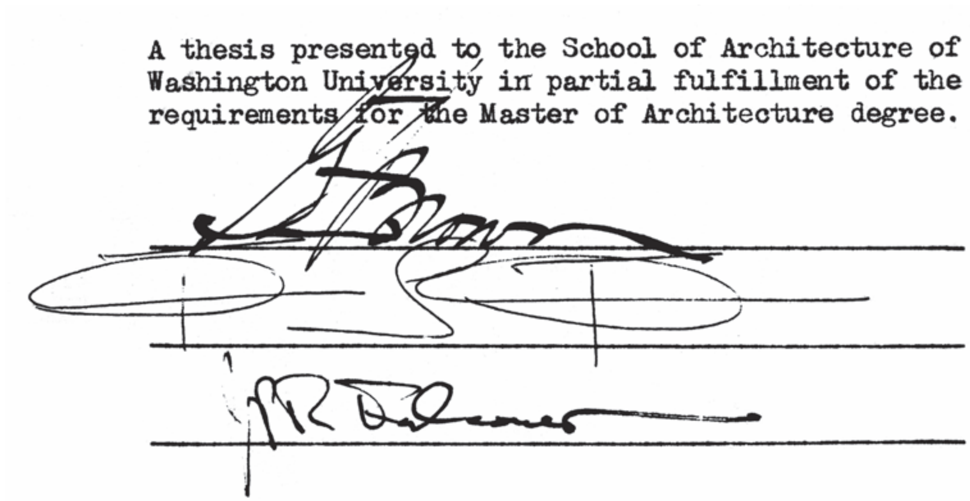
Kenneth B. Labs

The Architectural Use of Underground Space: Issues & Applications

Saint Louis, Missouri

May, 1975

Reprinted September, 2008.


A thesis presented to the School of Architecture of Washington University in partial fulfillment of the requirements for the Master of Architecture degree.

Foreword

My brother, Ken, and I grew up on a family farm in Mechanicsville, PA—located in the center of once-idyllic Bucks County, where 50 years ago most of the land was agricultural. Today, thanks to uncontrolled sprawl and the lack of interest in planned communities, there are a handful or two of working farms remaining in the entire county. Bucks is now home to commuters, many of whom in this Internet age still commute by car from their expensive, oversize single-family homes to jobs in Princeton, New York, and Philadelphia. Excess traffic chokes old farm-to-market roads, which funnel SUVs onto already over-crowded state and U. S. highways.

Ken and I shared many overlapping interests. We grew up with, of course, rock & roll, but our interests also turned to jazz and the classics. Hobbies were important. While I was an avid electronics enthusiast, my brother enjoyed building models of all kinds—redesigning and rebuilding them. He drew and sketched our farm buildings, model cars, airplanes, and model railroad accessories including factories, houses, and stations.

Ken received a guitar for Christmas in his early teens and taught himself to play, read music, and understand music theory. He was proud of the chord book he created from scratch—depicting just about every chord known to any musician. He formed a band, and I recorded and mixed his group during practice sessions in the basement of our family's revolutionary-war era farmhouse.

Many of our days and years were spent in the basement; it was our recording studio, our radio studio, lounge, model-building shop, electronics shop, photographic dark room, reading room, listening room—you name it. It was always comfortable there. It was a cool respite from the dog days of August. In the winter, it was relatively warm and free of drafts.

When Ken attended Washington University and was home over Christmas, he announced that he had to do a thesis for his masters degree in architecture, but couldn't quite settle on a topic. Our dad, half-jokingly, asked him why not consider researching basements since we spent the better part of our young lives in one. Along with his brother, our dad had constructed several farm buildings on the property—including a new barn with a basement (complete with underground drain) for egg candling and storage. So dad was quite familiar with building construction, drainage, and basements.

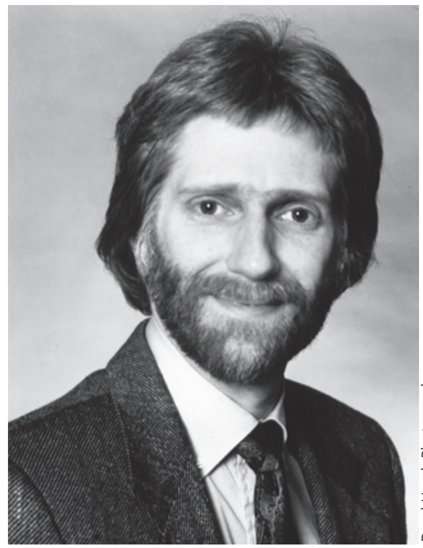
Needless to say, my brother was challenged with the idea, and the result is his thesis, which he completed in 1975 for Washington University in St. Louis. I believe—from what I had heard from his peers at the time—that this was a seminal work on the subject. Therefore, I have recreated it to the best of my ability (I don't have the original art) for the architectural community to use as it sees fit. I believe that this work should continue to exist, and I think that my brother would have felt that this is his gift to the community.

—Wayne Labs, 2004

Kenneth Labs 1950-1992

From *Progressive Architecture* 11-92

Kenneth Labs, who as a senior editor of P/A remade the magazine's Technics department, died on September 19 of mesothelian cancer in a Branford, Connecticut, hospice.



Daryl Hawk Photography

Ken came to P/A in 1989 with a broad range of experience. After getting his Master of Architecture degree from Washington University in St. Louis, he worked in private architectural practice in Connecticut and Texas, in town planning in Pennsylvania, and in research. As a visiting lecturer, he taught environmental technology at the Yale School of Architecture, and he wrote a number of published documents on planning, underground construction, and energy-efficient design, including the 1983 book *Climatic Design: Energy-Efficient Building Principles and Practices,* which he coauthored with Donald Watson.

So by the time he arrived at P/A in 1989 for what would turn out to be—by his own accounting—his longest stretch in one job, Ken had some clear ideas about what an architecture magazine's technical coverage should be. Unlike previous Technics editors, he did relatively little writing himself, preferring to edit papers by experts in various fields. He began commissioning articles from researchers, practitioners, and consultants, giving them a venue for publishing new research.

Such a strategy was new to P/A; in the past, we had most often applied a kind of journalistic filter to Technics coverage. Ken's method earned us new attention and respect both from readers and from the research community.

The method also brought controversy, since the authors of our Technics articles tended to advance particular points of view. An article on brick veneer and steel studs (Feb. 1992, p. 113), for example, spawned five responses from other experts, which Ken published—along with the author's response to each (June 1992, p. 47).

Ken often said that, in order to be taken seriously, the architecture profession needed a refereed journal like those of the medical profession, where papers are submitted to peer review before publication. Establishing such a journal was one of his long-term goals; in the meantime, he did his best to push our Technics department in that direction.

But his influence on P/A extended beyond Technics. He was a vocal participant in our weekly editorial meetings, often playing devil's advocate on design issues. He had a scientist's impatience with the way some architects package vague ideas as "theory," insisting that a theory is a set of prescriptions, not an ethereal set of influences. From his frequent calls for more empirical criticism to his dogged defense of the suburb, Ken challenged our opinions and kept us on our toes.

But Ken's criticism was easy to take, because of his genial, country-bred manner. He was born on March 21, 1950, in Doylestown, Pennsylvania, and grew up in nearby Mechanicsville, where his parents, George and Violet Labs, had a chicken farm. In some ways, Mechanicsville never left him: he kept the do-it-yourself mentality that one learns on a farm. At work, that meant devising his own detailed style manual for Technics writers and sketching his own layouts before meeting with the art department. At home, it meant lavishing attention on his 1950s builder ranch in Mt. Carmel, Connecticut, putting in new halogen lighting, an elaborate sound system, and storage units with scrupulously matched moldings. He kept us updated on these projects, along with the running battle he waged with chipmunks over his strawberries.

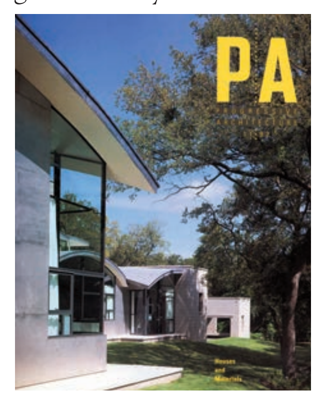
Another of his passions was for music; he liked to say he had a guitar for every day of the week, and he sometimes played jazz guitar in New Haven nightspots. At least once, this interest cropped up in P/A: he illustrated an article on acoustics (April 1991, p. 45) with a Robert Johnson album cover that depicted the blues guitarist singing and playing while facing the corner of a hotel room. Ken, remembering the cover, had his assistant rooting through second-hand record stores to track it down for his story.

Not all of us were aware of his other interests until his death; among them were nature photography, bird watching, and writing poetry. We learned from one editor that he was crazy about rhubarb and had collected dozens of rhubarb recipes for a possible book. It sounded like Ken; he approached every pursuit as a scholar, categorizing and cataloguing and learning all he could.

As Ken's cancer advanced, he became less able to make the commute from his home to our office in Stamford. Armed with a fax machine and a modem, though, he continued his work eagerly, giving it up only when his physical symptoms prohibited it. In his later faxes, his zeal for questioning the magazine's status quo only increased; "You can say anything you want when you have cancer," he explained.

Less than a month before his death, Ken was married to Joanne Improta, formerly P/A's Circulation Marketing Manager. We were all heartened to know that Ken was spending his last days with Joanne, whom we knew to be warm, caring, and—clearly—courageous.

Besides his wife and parents, Ken is survived by a brother and sister-in-law, Wayne and Nancy Labs, of Doylestown, and their son, Jonathan. To all of them we extend our warmest sympathies. Ken was an irreplaceable colleague, and a good friend.



Progressive Architecture, November, 1992

The Architectural Use of Underground Space: Issues & Applications

Preface by Frank L. Moreland

Very occasionally does one find a master's thesis like the one presented here by Kenneth Labs. Rarely do students pursue subjects out of love and certainty that the subject is important when there is rampant disinterest exhibited by researchers, educators, professional societies and society at large. Indeed, students are usually well advised not to pursue such subjects. Nevertheless, this thesis could scarcely be better timed or more perfectly designed to be the first major document on a subject just now coming into its own.

New fields of endeavor usually begin with a blurred history and scattered experiments, projects, and papers. However, it is only when one document brings together the important strains of past effort within a logical framework that the field is identified and significant work begins.

As Mr. Labs' thesis notes, mankind has been involved with the use of underground space throughout its history. For a variety of reasons the use of habitable underground space in the United States has declined from very little to negligible in the past 100 years. Some of these reasons were sound, i.e. technological constraints, health and safety factors, and economic logic. Some were far less reasonable, i.e. aesthetic propaganda, laws discouraging their use, and short sighted economics. Only in the past few years has the energy conserving characteristic of most underground space attracted compelling attention. I feel that the coincidence of these events spells a remarkable increase in the use of underground space and the creation of professionals, researchers, and journals specialized in underground space.

The National Science Foundation and the Energy Research and Development Administration this year have funded their first major efforts on underground and earth covered buildings. Both organizations plan to increase their support for research and demonstration projects in these areas. Moreover, the incidence of use of underground buildings in this country, Sweden, France, and Japan has increased markedly in the past five years. The United States now has excellent examples of underground buildings in most major building categories, e.g. housing, research labs, offices, museums, commercial, manufacturing, public facilities, schools, etc. While the number of examples is exceedingly small, their rate of incidence is increasing.

One should note that the users of these facilities report a high level of satisfaction. Indeed, some underground schools have been the subject of psychological surveys. The results of those surveys indicate that the use of underground space may promote achievement while reducing anxiety. Thus, the fact may be that emotional arguments opposing underground space are counter to reality.

Mr. Labs' thesis comes at a pivotal time: the resolution of the major constraints regarding underground space and the beginning of demand for underground space. Mr. Labs has told the story of underground space and the opportunity it holds. This work should become the first major primer in the field.

Acknowledgments

Due to the lack of published documentation on the subject of underground space, I have had to rely heavily on the cooperation of numerous interested individuals and agencies in the design and engineering professions. Without their assistance and reference to other persons and articles, this work would very likely have been terminated in its early stages. Although they are too many to mention here, I express my sincere appreciation, and happily note that many of these individuals appear throughout the paper by various references.

For review of the preliminary draft I am grateful to my immediate advisors Prof. George Z. Brown and Prof. Rudd Falconer, in whose studio several years ago I first realized my own interest in earth covered structures. My sincere thanks also is given to Prof. Irving Engel for reviewing Part III, and to Dr. Alan Covich of the Biology Dept. for his comments and suggestions regarding Part I.

I am especially grateful to those individuals among the practicing profession for their encouragement, and to Prof. Patrick Horsbrugh of the University of Notre Dame and the Environic Foundation International for his continuing interest.

A special thanks is gratefully extended to Prof. Frank L. Moreland, Director of the Center for Energy Policy Studies, University of Texas at Arlington, for his enthusiasm and generous introduction to the thesis.

It might also be noted here that through the efforts of Mr. Moreland, the sponsorship of the Center for Energy Policy Studies, and the support of the National Science Foundation, the first major conference to be held specifically on earth covered buildings will occur this July in Fort Worth, Texas. Certainly it is a welcome and timely event for those concerned with the design and use of underground space, and hopefully one which will be sincerely acknowledged by the profession as a whole.

Some portions of Part III of this paper, pertaining to underground thermal environment and energy conservation, were undertaken as an independent study project in Spring of 1974. This was conducted under the sponsorship of Prof. David Lord, currently in the Department of Architecture of the Harvard Graduate School of Design.

In appreciation of many hours of thought-provoking conversations about the relationships between man, survival, and architecture, this study is dedicated to Prof. Francis J. Quirk, former chairman of the Department of Fine Arts, Lehigh University, Bethlehem, PA.

Author's Introduction

Because this paper is addressed primarily to those concerned with the activity of design, it has been organized in a manner that roughly parallels the sequence of the design/decision-making process. Part I deals with the overall environmental context, and specifically with those issues that come to bear on architectural design; it is intended to provide a background and a presentation of those concerns which make the underground alternative a legitimate and competitive solution which ought to be considered at the earliest stages of analysis and conceptualization. It discusses the "why" of earth-building as related to the increasingly urgent issues of environmental impact and ecologically-simplified land use.

Part II discusses the range of applications, building types, and some contemporary examples, and the different approaches to underground development which are currently being considered or solicited by practicing professionals and professional agencies. It is intended to present the subject of underground space at the program and design level, and as such is analogous to the design-development stage of architectural activity.

Part III is primarily oriented toward the final resolution of physical problems: it discusses the nature of the earthen environmental envelope, and introduces the types of subsurface demands that differ from conventional surface construction. An examination of interfacing issues—earth cover, plant material, slopes, thrust, and structure, for example—is provided along with an investigation of climatic and thermal concerns.

I trust that this sequence and format is best able to introduce a way of thinking about earth-integrated building as a practical alternative as well as an environmentally-salubrious mode of building which possesses its own exciting spatial and formal (or non-formal) potentialities. In closing, the appendices provide an availability to some pertinent information which can be of use for preliminary design data. It is presented here with the hope that future work will continue to assemble references and related information, so that designers attracted to dealing in the "architectural underground" need not work in the dark.

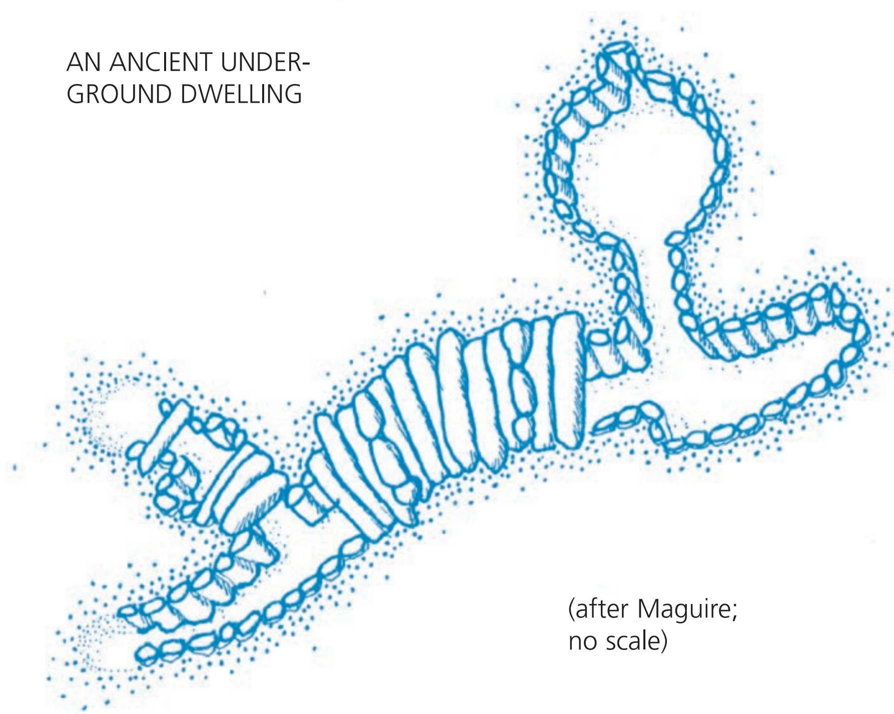
Part I—Contextual Issues

The Underground Heritage

The seeking of shelter within the earth is no new idea; man and animal alike have exploited the protective and insulative properties of the soil long before recorded history, developing sophisticated, yet simple, means of dealing with harsh climates and hostile environments.[1] Ranging from arid deserts to polar cold regions, subterranean dwellings offer refuge from exposure to sun, wind, storm, and extreme variations in atmospheric temperatures, as well as providing thermal compensation for seasonal temperature changes. Beyond producing immediate and "natural" shelter, the practice of underground architecture possesses a tremendous heritage that, although poorly if ever documented in architectural history texts, is rich in spatial variety, in response to the overall environmental milieu, and in diversity of design solutions to such issues as access, ventilation, lighting, and cultural values.

Troglodytic communities have existed in areas all over the world, including Turkey, Egypt, Ethiopia, Israel, China, North Africa, and the American Southwest, to name a few. A brief look at historical and contemporary "indigenous" architecture reveals ingenious building schemes and a wisdom in the use of resources which we would be wise to observe in our own efforts to minimize our technological enslavery and its associated energy consumption. The following pages, then, describe a few such examples of subterranean building in different regions and climates of the world. For a more comprehensive survey of troglodytic settlements, see Royce LaNier's book, *Geotecture*, pp. 3-17 (Department of Architecture, University of Notre Dame).

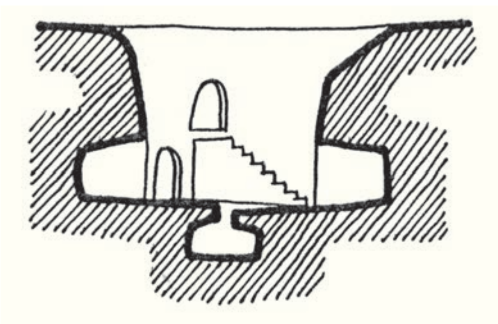
AN ANCIENT UNDERGROUND DWELLING

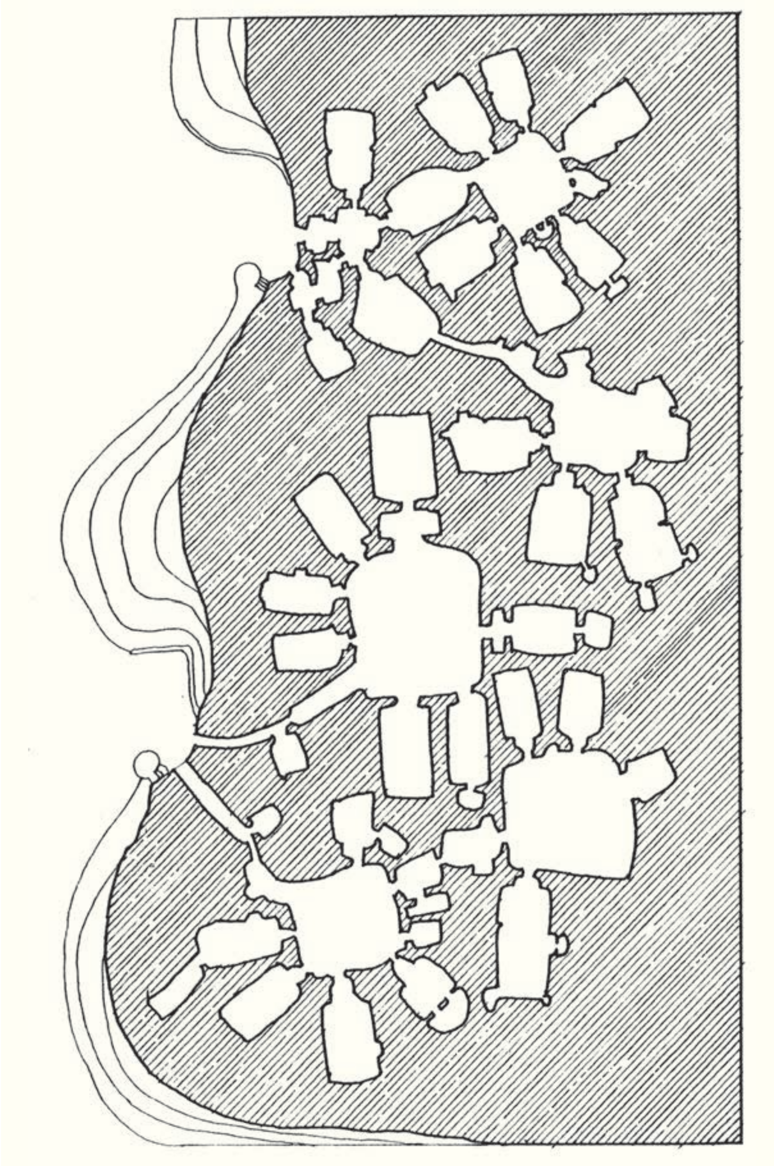


(after Maguire; no scale)

MATMATA is a subterranean village located in the arid lowlands of southern Tunisia. A population of several thousand live in artificial caves tunneled into the walls of excavated crater-like courtyards that range in size from 20 to 30 ft deep, and from 40 to 200 ft in diameter. Access to individual units is by means of these courtyards (see plan at right), which provide a community function as well as defensive isolation of units from the surface: "...each neighborhood square services up to one hundred inhabitants and becomes a natural front yard, rear yard, and storage and community space."[2]

Court areas are connected to the surface by sloping tunnels, off which are located chambers for storage and animal quarters. Dwellings are reported to lie beneath at least 50 ft of earth, the primary purpose of which is to escape the extreme heat and severe local windstorms. The soil type is a soft sandstone.





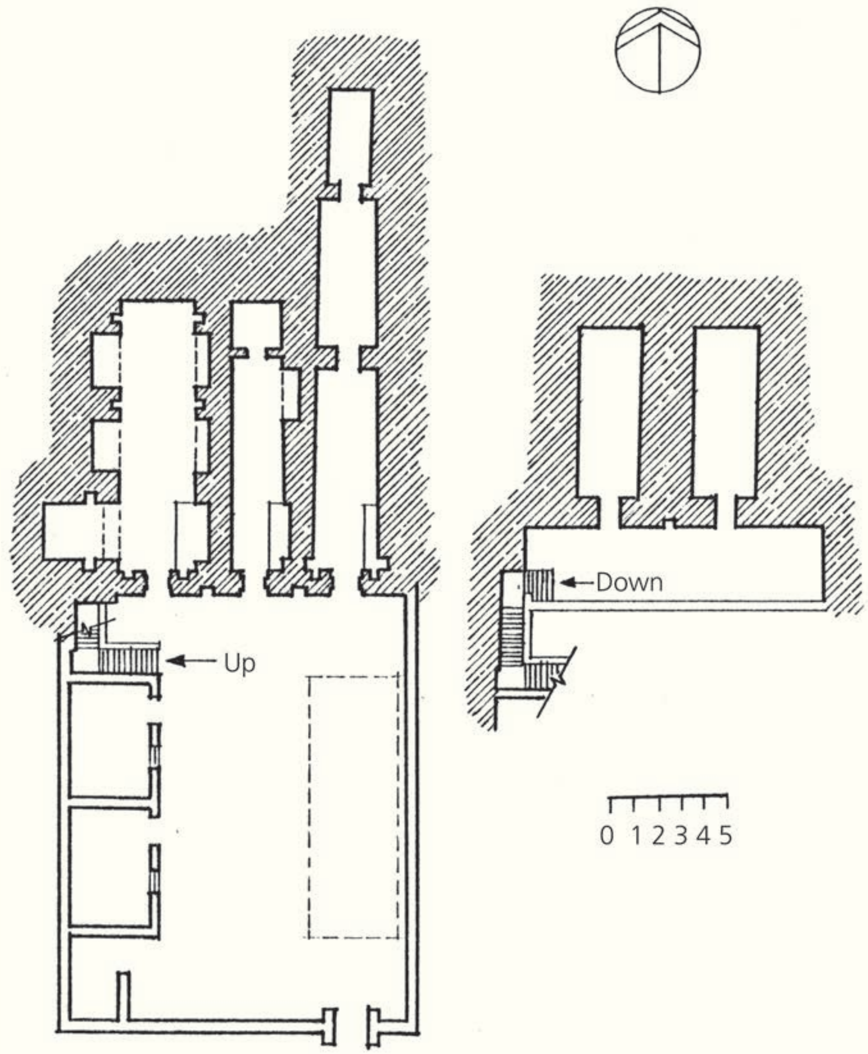
left: after Schoenauer

right: after Goldfinger

WESTERN AND NORTHERN CHINA'S loess belt is reported to house some ten-million inhabitants in underground dwellings carved out of the soil throughout the provinces of Honan, Shansi, Shensi, and Kansu.[3] House-courtyard relationships are integral to the functioning of the plans, but specific sizes and arrangements vary from 30 - 40 ft square, single-level sunken courtyards, to stacked multiple-unit courtyards 25 - 30 ft deep, and covering one-eighth acre in area.

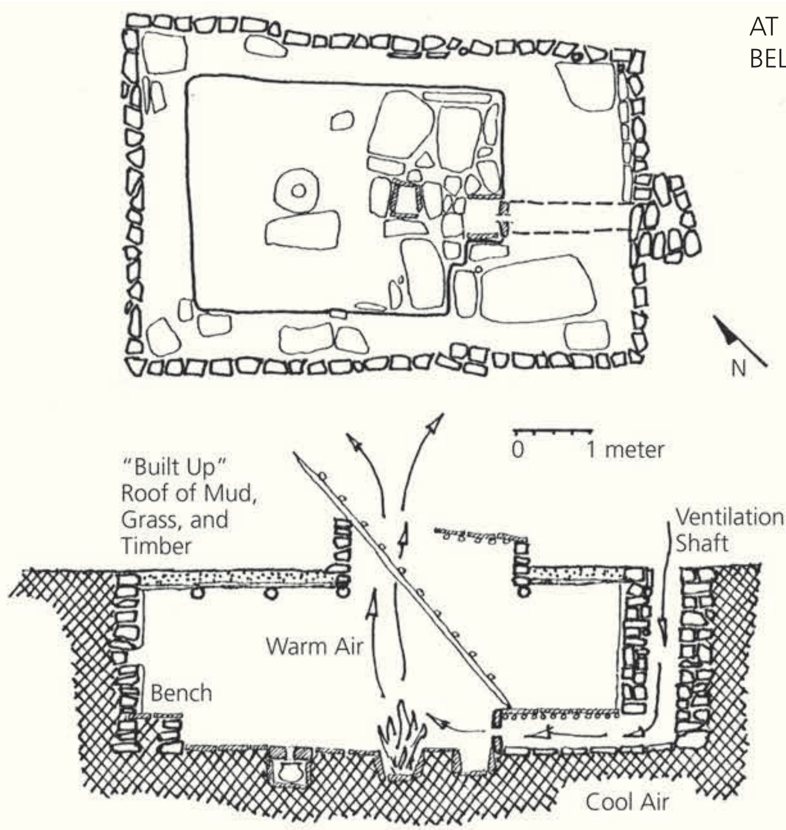
Courtyards are "shaped, sized, and oriented to permit penetration of the low winter sun," and are generally independent of the common L-shaped stair that provides access to the dwelling unit.[4] The easily-carved loess has been exploited for its relatively high subsurface temperatures in the bitter cold climate, and for its protective shielding from the very high winds present in the area.

Rudofsky reports, "Not only habitations, but factories, schools, hotels, and government offices are built underground," these also seeking refuge from a harsh environment within the earth. The plan at right demonstrates a variation on the village units described by Fitch, Schoenauer, and Rudofsky, in that it makes use of a surface-constructed courtyard and two underground levels tunneled into the side of a loess deposit at Kung-hsien, Honan. (after Boyd)

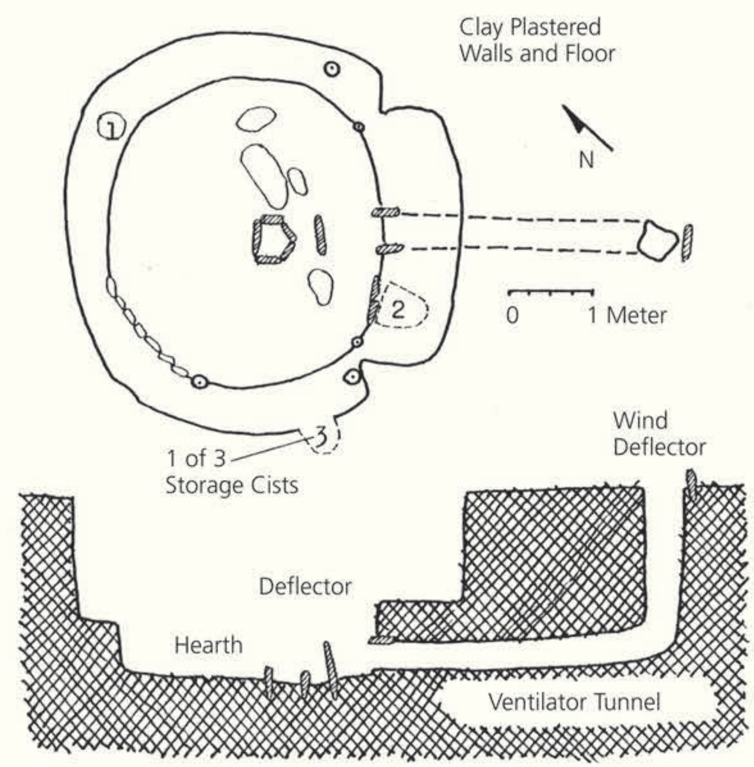


GROUND AND UPPER FLOOR PLANS OF CAVE DWELLING; PRIVY AND GUEST ROOMS AT WEST WALL OF COURTYARD

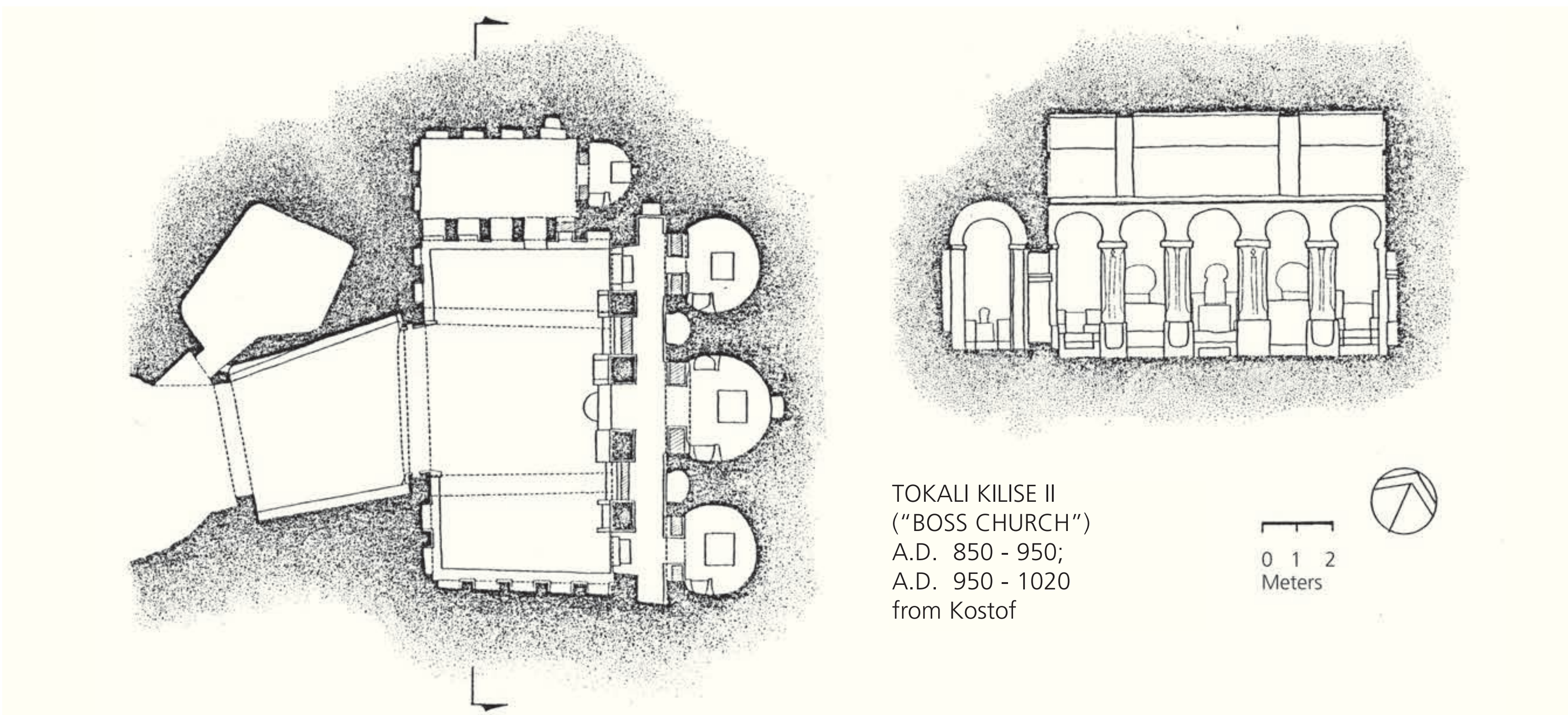
KIVAS are subterranean rooms that were used by various Indian tribes throughout the American Southwest for ceremonial purposes. Although now largely abandoned and researched by means of archaeological excavations, many kivas remain in use, some being adapted for dwellings. While kivas vary greatly in many respects, including size, shape, depth, and construction particulars, the most interesting aspect related to this study is the widespread use of external ventilator shafts and a natural convective cool air circulation system. Shown below are two different Kiva types reported by Smith and Gumerman in northeast Arizona, (reconstruction by KBL) [5]



AT LEFT: KIVA AT ANTELOPE MESA (AFTER SMITH)
BELOW: EXCAVATED RUINS AT BLACK MESA (GUMERMAN)



ROCK CUT CHURCHES abound in the province of Cappadocia, Turkey. Carving dwellings, monastic centers, and subterranean churches out of the soft rock tuff, early Christians sought refuge from severe winters, hazardous snows, and antagonistic Turkish raiding parties. Decorated underground churches alone in Cappadocia number over seventy, and an estimated "scores" of other less ornate examples are known to exist. "In 1965, three entirely rock cut towns were discovered in Cappadocia, one of which, penetrated through a single entrance extended over an area of six kilometers."[6] Kostof estimates that a single man could carve out a large room of 2000 - 5000 cubic feet in one month, adding that since loads and thrusts are negligible, the carver-architect could easily be uninhibited. Shown below is a plan and section of the Church of TOKALI, "one of the largest and most imposing structures in all of troglodytic Cappadocia."



TOKALI KILISE II
("BOSS CHURCH")
A.D. 850 - 950;
A.D. 950 - 1020
from Kostof

THE SIGNIFICANCE OF CONTEXT

The intent of this thesis is to examine the benefits of the architectural use of underground space. With the growing awareness of man's mismanagement of the environment, a number of concerned architects and engineers have proposed alternative building practices which strive to work in harmony with natural processes.[1,2] These proposals accept an essential, dynamic relationship between building activity and its environmental context, and they deal directly with the modifications brought about within that context by man's constructions. Since this is a subject seldom discussed in either the professional literature or in the schools, the kinds of benefits that are claimed for such "contextual" practices are difficult to evaluate. For underground construction they typically are presented as: energy conservation, minimal disruption of wildlife habitat, minimal interference with natural cycles, soil and water conservation, less overhead and maintenance, lower insurance rates, more efficient use of space, preservation of open space, and a more "natural" aesthetic.

Part of the problem of evaluation may be understood as a derivative of the historical Western regard for man's "dominion over nature;" in this repeat, the architect assumes a prevailing attitude which precludes or makes unnecessary the consideration of nature as a process or function of itself.[3] A second aspect may be the failure of architecture to observe a systemic view in ascertaining broader environmental issues and priorities. In short, architects have traditionally been preoccupied with a piecemeal approach to the built world, ignoring the larger, collective ramifications of their activities. This may be interpreted as a result of the individual-lot pattern of ownership and construction which has been such an important determinant of urban and suburban form. Planning as a practice, too, has enjoyed little support in coordinating these individual activities; similarly, there has existed no incentive in America to aspire to more transcendent goals for land use, that is, to advocate policy which unifies the thrust of individual activities and at once deals with their effects. To a large degree, this may have been viewed rightly as unnecessary—with the tremendous wealth of land constituting this nation and the limited scale of urbanization prior to the twentieth century. [4] The "ecological crisis," however, is largely due to the failure of all to acknowledge the role of the individual within the context of a larger system; [5] the sum of individual actions now creates a major collective impact on the system as a whole. There is, therefore, a need to re-think our handling of the parcel-practice of land use, if it is to be continued.

One approach is to preserve or improve on the existing natural context of a given lot or site. This solution requires no change in the manner of land ownership, although it does necessitate universal acceptance either in principle or policy to have system-wide effectiveness. A major argument for the use of underground space adopts this "manifesto" of site improvement with regard to the functioning of ecological systems. In order to evaluate both the basis and the efficacy of earth-integrated building in achieving this objective, it is necessary to review some of the fundamental principles and processes of the natural world, and how they are affected by man's conventional building practices.

MAN AND THE ECOSYSTEM

Man's life and activities occur within and are inseparable from a set of contexts known as *ecosystems*. An ecosystem may be defined as "a self-sustaining community of organisms — plants as well as animals—taken together with its inorganic environment." [6] The study of ecology deals with these two components, the biotic, living community (termed the "biocoenosis"), plus the abiotic, nonliving environment, and the interactions between them. These interactions may be described as material (inorganic compounds and nutrients) and energy flows. Dansereau outlines four major characteristics of an ecosystem as (a) the *productivity* of its resources, (b) *the interlocking pathways* of cycling elements, (c) the *peculiar requirements* of the agents by which such cycling occurs, and (d) the quality and quantity of the resulting *reinvestment*.[7] The following discussion will demonstrate how man's activities in attempting to maximize humanly-useful productivity of environmental resources (a), frequently conflicts with both the quality and quantity of the "reinvestment," (d). Such conflict necessarily has significant implications for the use of resources, building materials for example, in addition to the design of buildings, which have considerable effect on natural cycles and processes, (b) and (c). Although a building is not a living organism in a biological sense, in many ways its processes and daily life-cycle function in a similar manner. This analogy provides a useful construct for determining a building's role in the ecosystem; consequently, the analogy will be employed whenever useful for illustration.

COMMUNITY COMPONENT

A cardinal rule of an organism's existence is that it modifies in some way its environment. Thus, while an isolated coral polyp exerts little influence on its surroundings, a community of coral constitutes a reef which provides habitat for thousands of other animal and plant species. Similarly, while a single detached house may appear to be at worst a benign presence in a natural setting, a subdivision creates its own ecologic community identifiable by its characteristic association of plant and animal types. To carry the illustration further, an urban metropolitan area affects its physical surroundings so profoundly as to create its own meteorological envelope; internally, meanwhile, the urban infrastructure has destroyed most natural habitats and supplanted them with a new physical milieu and resource pool of dubious value. [8] An alteration of this magnitude must eventually raise the question of the desirability of these phenomena, and subsequently, their implications for the planning and design professions .

The primary and essential difference between the functioning of the natural and the built environment lies in their respective purposes in development. Eugene P. Odum describes the "strategy of ecosystem development" as striving for "increased control of, or homeostasis with, the physical environment in the sense of achieving maximum protection from its perturbations." [9] Ecosystem or community development follows a process generally known as ecological succession; it is so named because a series of increasingly "mature" communities replace, or succeed, their predecessors in stages over time. [10] Robert H.

Whittaker provides the following example: [11]

> When in an area of forests a farm field is abandoned, a series of plant communities grow up and replace one another—first annual weeds and grasses, then shrubs and trees—until a forest ends the development.

This terminal community stage is referred to as a *climax*, for it represents the most advanced community achievable given the existing parameters of the physical environment (such as the amount of sunlight, rainfall, length of growing season, and available nutrients, e.g.). The climax can be interpreted as the *goal* of natural development, for it offers the most stable and protective system which may be created from the resources at hand.

The climax is known as a steady-state, or dynamic equilibrium, which is self-maintaining. It derives its stability and defense against disruptions primarily from its complexity of organization; as the number of internal relationships and linkages increase, the system's buffering against disruption and collapse is theoretically reinforced. [12] Hence, an oak-hickory climax, with its greater wealth of different species, is regarded to be much more resistant to disruption than the frail Arctic tundra, which exhibits relatively few plant and animal species. Diversity of content is frequently employed as a measure of complexity, or of the "richness" of a system; consequently, *species diversity* (pertaining to the number of different species) is usually related directly to the stability and maturity of an ecosystem. [13]

PLANNING IMPLICATIONS

One is led to speculate on the usefulness of the concept of diversity as a planning strategy:

> If it can be shown that biotic diversity does indeed enhance physical stability, then we would have an important guide for conservation practice. Preservation of hedgerows, woodlots, noneconomic species, noneutrophicated waters, and other biotic variety in man's landscape could then be justified on scientific as well as aesthetic grounds..." [14]

If in fact complexity is a "good" to be maximized, then it follows that any artificial simplification, or land use proposal that negates some aspect of that complexity, is potentially disruptive and a threat to the natural mechanisms of stability. A reasonable corollary would state that natural communities should be preserved, and that development proposals must respect or enrich their respective contextual processes. [15]

To better appreciate this as a planning consideration, let us return for a moment to the example of the suburban ecological community, and to one of man's most highly-prized possessions of "nature," namely a well-manicured lawn. The American lawn typifies what is regarded as a *juvenile* community system; it is dominated by a single plant species, provides relatively little significant wildlife habitat, and like all monocultures, is vulnerable to different degrees of competition (crabgrass, for instance), disease, parasitism, and predation. To preserve the lawn in its cherished juvenile state (contrary to its "aspiration" toward maturity, greater species diversity, increasing complexity, and a resultant visual irregularity), it requires continual maintenance in the form of time, work, and energy (gasoline, and often electricity as well). Moreover, since most mechanisms of biological control (the appropriate predatory bird and animal species) have been eliminated, the exacerbated problem of unwelcome invading plants and insects demands the frequent application of chemical pesticides and herbicides. Removal of grass clippings results in a gradual loss of organic content in the soil, which encourages the application of chemical fertilizers, which in turn, have been found to further contribute to soil degradation and the loss of soil porosity. Decreased porosity means less percolation and increased water runoff, themselves being urban problems of considerable significance that will be discussed in the next section. It is a revealing contradiction that the ground mole, one of the few mammalian species able to exploit the lawn as a habitat, provides beneficial pest control while it is simultaneously exterminated with the notion that it is itself a "pest." [16]

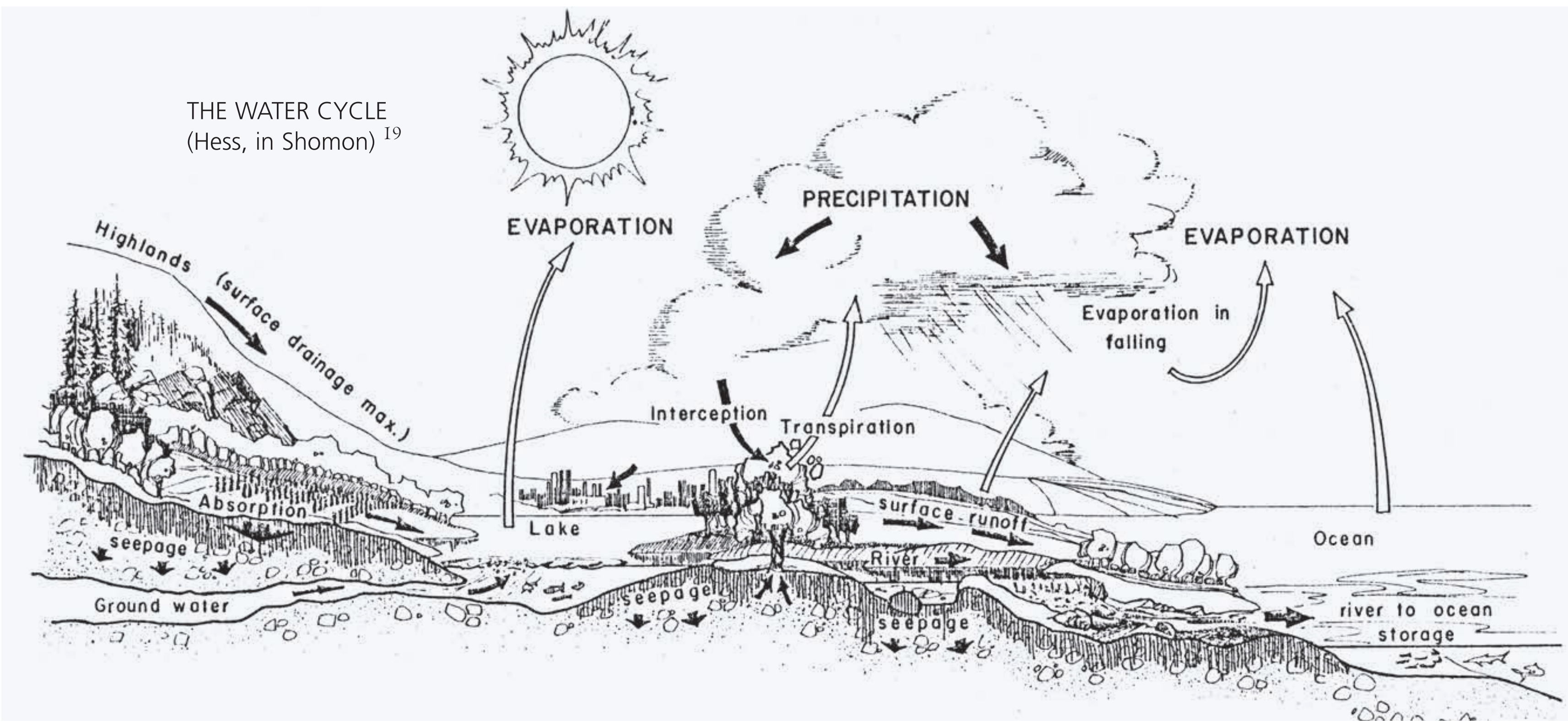
While it may be difficult to prove that increased diversity will ensure a more stable, self-maintaining system, there is little question that the monoculture is costly to maintain, inherently unstable, and an environmental liability. [17] If the implications of the complexity-diversity concept are somewhat unsure, then the lesson of the monoculture is more direct: the simplification of biotic relationships and processes within a community jeopardizes the integrity and stability of that community system, resulting in increased maintenance costs, and ultimately, in the sacrifice of some degree of environmental quality. This principle will be shown to constitute part of the "ecological argument" for the use of subsurface space. The two other related concepts deal with the cycling processes of nature and the energy-conserving benefits of underground space. Again, the natural processes are first briefly described in order to construct a framework for evaluation.

THE ABIOTIC COMPONENT

The physical and material interactions which link the biotic community with the physical environment are of no less importance than the biological processes themselves. The overall pattern of these physical flows is usually referred to as *natural cycles*, and may be regarded as "perfect," a relatively-closed recycling system, or "imperfect," which designates an open-ended, one-way flow. The hydrological cycle (see illustration, next page) is perfect in this sense; despite the enormous scale of its distribution, there is no net gain or loss of water available to the global ecosystem. Man's building activities do, however, severely affect the availability of water at the local and regional levels by lowering water tables and contributing to the depletion of aquifers. Water does, moreover, act as a unidirectional transport medium; due to this function, soil, and both organic and inorganic nutrients conveyed by water runoff and erosion from the land are considered permanently "lost" to the sediment of the seas. Many imperfect cycles, such as the necessary nutrient, phosphorous, are closely related to the effects of runoff, erosion, and leaching (conveyance by groundwater).

The study of the energy transactions and transformations, which occur as a result of all these processes, is known as *ecological energetics*. [18] It is concerned with the energy budgets of communities, and the dynamics and efficiencies of energy flows within and through ecosystems.

It should be pointed out that all energy sources utilized by man are derived from natural processes, and that the expending of these energies, be they hydrocarbons or nuclear, have significant direct impacts on the ecosphere at many levels. Solar energy may be considered an exceptional case, in that the sun is the source that propels biological systems. Our more commonly used energy reserves are, instead, stored forms of solar energy, bound in organic compounds over geologic time. One must realize that the burning of fossil fuels, or the operation of an atomic reactor, creates several major forms of pollution—chemo-atmospheric, radioactive, thermal, and dust, to name just a few. Since the acquisition, transport, and waste disposal problems associated with these fuels likewise constitute major environmental threats, energy conservation is to be regarded an issue related to global environmental quality, as well as an economic end in itself.



THE WATER CYCLE
(Hess, in Shomon) [19]

PLANNING IMPLICATIONS

Barry Commoner has proposed looking at ecological processes with the understanding that "everything must go somewhere."[20] This attitude provides some keen insights into man's impact on natural cycles, and may help divert the kinds of tragedies that can occur from some of these things turning up in unsuspected places. For our purposes here, tracing the would-be flows of normal cycles through the built environment reveals some rather serious disconnects, and frequent acceleration of "downhill" (as conveyed by streams and rivers) losses to nutrient sinks in the oceans. The observation that man's activities significantly alter inorganic natural processes as well as community development functions has resulted in at least two newly-emergent fields of research directly related to the architecture and planning professions. They include the methods and techniques of environmental impact analysis,[21] and the study of the energetics of the built environment.[22] It is a logical speculation that as these fields reveal more and more about the architectural issues of environmental impact, then different types of performance standards are likely to be implemented at both federal and local levels.[23] The necessary upshot of such policy determinations will, of course, result in an expanded search for both nature- and energy-conserving architectural form and hardware. Many advocates of underground construction contend that the conscientious development of underground space is an appropriate solution (for a variety of applications) to both these criteria:[24]

> Some relaxation of environmental quality standards may be necessary in the race to meet short term energy demands, but it is important to recognize that energy sufficiency and environmental quality are not always conflicting aims. Increased use of underground space is one example where the two goals can be met simultaneously.

The following section will examine the purported benefits of underground construction with relation to the natural processes that have been described, and will attempt to probe its scale of effectiveness as an architectural alternative to conventional surface building.

THE "ECOLOGICAL" ARGUMENT

The essence of the ecological argument for underground space is that its use can minimize a building's impact on the local biotic community and natural processes. By building beneath the surface, or by utilizing soil and plant cover as an integral part of a building's insulation and structure, one provides the opportunity to re-establish a plant community and its associated wildlife habitats. These, then, provide for the retention of beneficial biological controls, greater species diversity, and reinforcement of the pre-existing integrity of the local ecosystem. The earth-building practice also allows nature to process rainwater in its normal, unhurried way, in addition allowing man to capitalize on a host of useful functions provided by plants, for example, shading, evaporative cooling, and dust filtration. [25] Let us summarize some important effects of the built environment on ecological processes, and use this to ascertain the precise environmental benefits derived from use of underground space.

"Environmental impacts" are conventionally regarded with respect to their short-term and long-range effects. These parameters can be further interpreted as either local or systemic in scope. The combined effect of many "local impacts" may be seen, as in the case of suburbanization, to contribute to larger effects of a systemic nature. The display of these factors in a simple matrix makes both the scale and scope of some selected environmental aspects of the built world easily readable, and more comprehensible in terms of their interlocking relationships.

The charts on the following page plot the abbreviated impacts of two significant aspects of our conventional building practices: 1) the clearing of a site of its natural biotic community, and the replacement with (if any) a less mature association, and 2) the substitution of an appreciable amount of impervious surface on the site, resulting in an increase in both volume and velocity of stormwater runoff, [26, 27] as well as the automatic preclusion of the re-establishment of any biological community on that surface. [28] While his own contribution to the problem of water" [29] may seem either obscure or

(Text continued on p. 16.)

	BUILT PERTURBATION		LOCAL EFFECTS	SYSTEMIC EFFECTS
ABIOTIC	IMPERVIOUS SURFACE Roofs Roadway Parking Lots (Especially with storm drainage)	SHORT TERM	• Increased water runoff	• Flooding • Erosion • "Downhill" accumulation of nutrients and organic debris
		LONG RANGE	• Loss of topsoil, degradation of soil quality • Decreased percolation	• Need for flood control • Sedimentation of waterways • Acceleration of mineral cycles • Loss of water quality

	BUILT PERTURBATION		LOCAL EFFECTS	SYSTEMIC EFFECTS
BIOTIC	SITE CLEARING "Defoliation" Replacement of local biotic community with (usually exotic) high-maintenance monoculture	SHORT TERM	• Loss of wildlife habitat • Elimination of indigenous plant community • Microclimatic modification (heat, dust)	• "Simplification" of ecosystem structure • Deterioration of biological controls • Creation of modified subclimate ("dome")
		LONG RANGE	• Decrease in local no. and diversity, species • Increased need of continual maintenance • Use of pesticides, herbicides, fertilizer	• Threats to stability of ecosystem • Increased energy need • Introduction of chemical pollutants • Increased "pest" problems

(Text continued from p. 14.)

trivial to the architect, one must consider the ratio of impervious to natural, permeable surfaces in any urbanized area. One source, for example, credits "developed, urbanized areas" with washing away seven times the eroded sediment as "wooded" areas. [30] Surprisingly enough, the subject of water runoff and retention has only recently received much attention in the design fields, although it has long been an important aspect of conservation engineering in rural areas. [31] Indeed, it serves well to bear in mind that topsoil is a precious resource in itself, and is a product of innumerable generations of successional stages; not only does normal building practice waste tremendous amounts of soil through accelerated erosion on-site and elsewhere, but moreover, the aesthetic that demands good topsoil to support a lawn also negates the potential, more "protective" usage to support a mature, more diversified biotic community. Land, too, is a resource that is not easily "recycled." Although one building may easily follow another on the same site, the quality of the soil and its related biological community usually depreciates with such recycling. Similarly, the establishment of a relatively mature plant and animal community requires a considerable amount of time; an understanding of the essential components of a desired stage of complexity may, however, be exercised in escalating the process according to a planned program of development. [32]

This, then, is the essence of the role of underground development in providing an "ecological" architecture: by returning the skin of the earth to nature, rather than using it as a footing for buildings, one is able to minimize potential disruption to the biotic and abiotic functions described earlier in this paper. More properly, this is earth-integrated construction as "conservation architecture," a term suggested by Wells. Given the local and contextual nature of this conservation approach, one is obliged to ponder its potential significance and scale of effectiveness, and of course, its limitations.

We have dealt thus far with the conflict between the goals of man and nature, and it has been suggested that subsurface construction is one architectural means of resolving this dilemma. It should first be made clear that underground space is not the only means to this end, nor can it in all cases provide all the attributes claimed for it. As stated much earlier in this paper, earth-integrated design is, above all, a contextual practice, and the relative benefits to be gained from it are closely associated with the specific qualities of that context, among them being the type of natural community (flora and fauna), climate, proposed density of development, and geographic region.

It may seem implicit from the preceding discussions that the underground alternative applies mostly to low-density solutions. This need not be the case, however, as may be seen from many of the historical cases. Perhaps it is unfortunate that most conservation-oriented underground proposals to date consist typically of single units in somewhat isolated environments. In reality, one can make a fairly substantial case that the more remote a single building, the greater the capacity of its surroundings to "absorb" its presence and perturbative effects—hence, the less need to deal with them. Consequently, underground design alternatives can only have a truly significant positive value if they are widely applied to the building patterns and building types that are most destructive of natural processes and habitats. One good example to begin with would be suburban sprawl, or that which urbanizes the most land in the shortest amount of time. While only a few genuine underground suburban prototypes have been proposed, one can quickly imagine the potential for developing entire subdivisions of earth-integrated units. [33]

Coupled with an effort to preserve or restore indigenous animal and plant species, suburbs might come to be known as augmentive, instead of destructive, of community ecosystems. John Barnard's success with the reception of his promotional "Ecology House" (see ill.) has prompted him to investigate the feasibility of marketing underground dwellings built on a franchise basis. [34] Indeed, if the benefits that Barnard has realized in his single unit are universally characteristic of such construction, then underground housing may possess many readily-demonstrable advantages over conventional suburban units. Lloyd Harrison, Jr. posits, "since privacy can be maintained with a limited separation between [underground] houses, dwelling separation could be reduced." Commenting further on the planning implications for subterranean subdivisions, he suggests that the increase in usable lot surface gained from burying the house would offset the smaller lot sizes, as well as providing collective economic savings from shorter utility runs and street services. [35]

At the site-specific level, it is easily shown that the more salubrious interfacing with the natural environment provided by underground space is superior to many of our conventional design practices. Until such notions are accepted as important and practiced by architects, there is little hope that such benefits will be realized.

ENERGY CONSERVATION

A more hopeful side of the environmental argument is the energy-conserving potential of underground space. Energy expenditures, as well as environmental impacts, may be viewed as either short-term or long-range. Since underground buildings often involve somewhat higher exists of construction, the relationship between initial and operating costs need to be examined very closely. Actual operating costs for heating and cooling have been reported to be as little as 10% of comparable surface structures for deep-underground cold storage facilities,[36] and as little as 30% for near-surface atrium-houses. [37] Proponents of an experimental under-ground house proposal in New York State calculate that with a simple, ducted heat-retrieval system, mechanical heating demands beyond a preliminary "warm up" period would be virtually eliminated. [38] Savings of this magnitude can quickly compensate for greater initial costs of construction, and certainly indicate that much more study is warranted regarding the nature of heat loss to subsurface surroundings.

The application and economic analysis of Yeang's energetics model for the built environment, [39] would, no doubt, provide some useful insights into the expenditure and returns of both the investor's dollar as well as the overall demand on the energy resources of the earth. An argument in favor of longer-term use, and more permanent building types, would, moreover contribute significantly to the stimulus for increased development of underground space.

SUMMARY: THE ROLE OF THE ARCHITECT

One may conclude that the direct benefits of underground construction are most perceptible at the individual-building level, where the interface between the built and natural environment is most evident. The more significant ecological advantages of subsurface space are, however, to be derived at a large (community) scale of application, where the collective, individual benefits contribute to a greater, synergetic whole. Accordingly, occasional single unit application of underground development is totally incapable of solving any environmental problems at a systemic level, regardless of how sensitively it responds to its immediate context. Underground building may then be seen as a passive, or "protective" (in the sense that it is used by Odum; see p. 18) approach; it can not correct ecological ills inflicted already by reckless urbanization, nor can it restabilize existing disruptions of natural processes. It can, however, provide a means for consolidating man's efforts at built-development with the "strategy" of natural development, i.e., to achieve and maintain a state of maximum complexity and maximum diversity. As such, the increased utilization of underground space offers an environmentally salubrious mode of building at both individual and collective scales of application.

The abstractness and global scale of ecological systematics has a tendency to obscure both the urgency and responsibility of dealing with environmental impact at the level of usual architectural practice—yet it is exactly this lot-by-lot, piecemeal approach that has helped bring about the current ecological crisis. One often hears the comment within the profession that architects design only a very small percentage of the built environment. While this may be true, it is also true that architects as a profession occupy a pivotal position in prescribing solutions for emergent problems, in providing models for growth, and for advocating policy for sound land use practices.

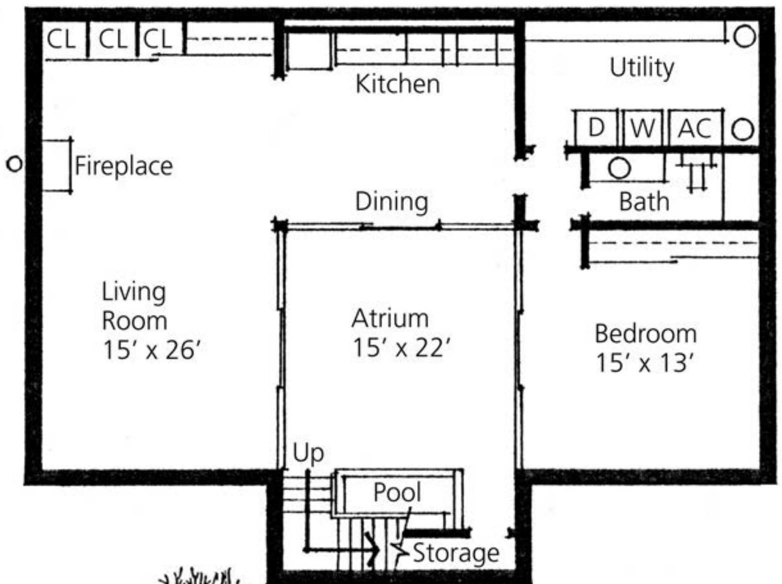
It is curious that, with the exception of a few isolated individuals, the architectural profession has invested very little effort in examining the potential of underground space as a response to either environmental impact or energy conservation. Many of the engineering professions, on the other hand, have taken an exemplary position for investigating the applications of subsurface apace, as evidenced by the recent publications, *The Use of Underground Space to Achieve National Goals* (American Society of Civil Engineers, 1972), and *Legal, Economic, and Energy Considerations in the Use of Underground Space* (Engineering Foundation & National Research Council, 1974 by the N.A.S.). These reports are policy-oriented, and demonstrate considerable gains to be derived from exploiting our reserve of underground space.

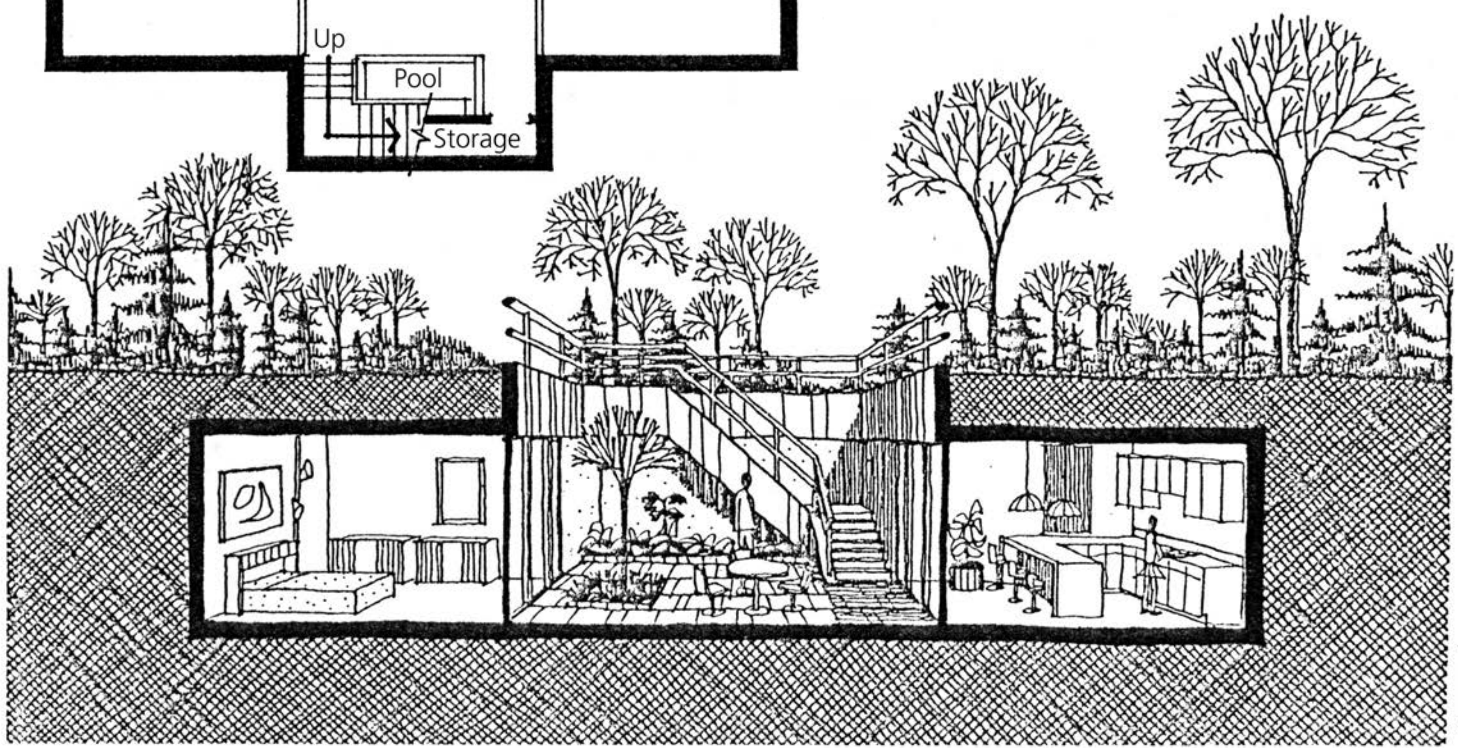
If "external" demand for underground space does increase in the future, then there will certainly be a need for designers to acquaint themselves with the peculiar qualities associated with underground environments. These may include user attitudes and response, issues of natural versus artificial light, heating and ventilation requirements, and physical construction and interfacing with both the underground and the surface.

Aside from the ecological considerations, there are many other less abstruse reasons to go underground with a building. Examples include exploitation of the "thermal-leveling" properties of the soil as a climate response, elimination of exterior maintenance, aesthetic and formal (or lack thereof) desires, preservation of open space in congested or ceremonial areas, and maximization of use-intensity in urban situations. These, as well as the preceding underground "environmental qualities," are fundamental design issues, and will be discussed in the remainder of this paper.

The illustrations on the following pages depict design schemes that are primarily derived from a concern for respecting natural processes; although of similar scale, they suggest the range of possibilities yet to be explored in near-surface underground design.

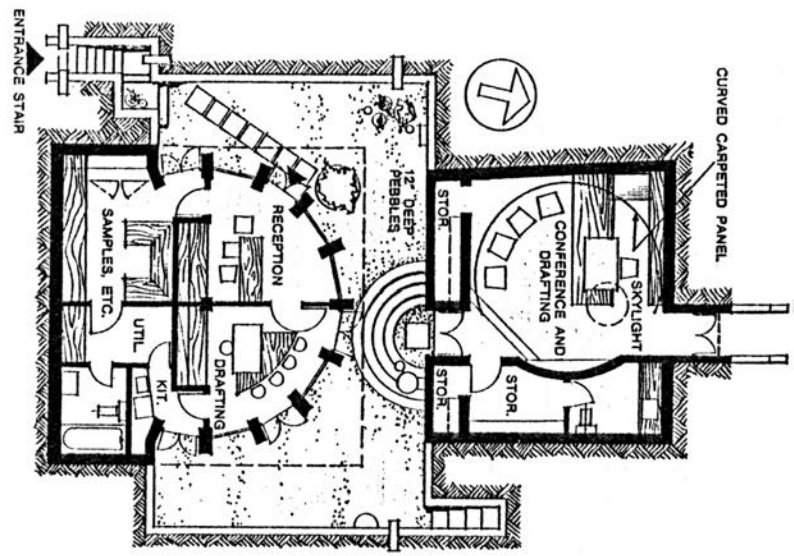
ECOLOGY HOUSE, Marston Mills, Mass., is in a sense a "demonstration model" to promote an idea that has been with architect John E. Barnard, Jr. for a long time. Entrance to the poured concrete structure is gained through a 300 sq. ft. atrium which provides daylight to all important areas of the house. Barnard estimates an energy savings of 60% for heating and a 25% decrease in construction costs. Visitor response is reported to be very good. [40]

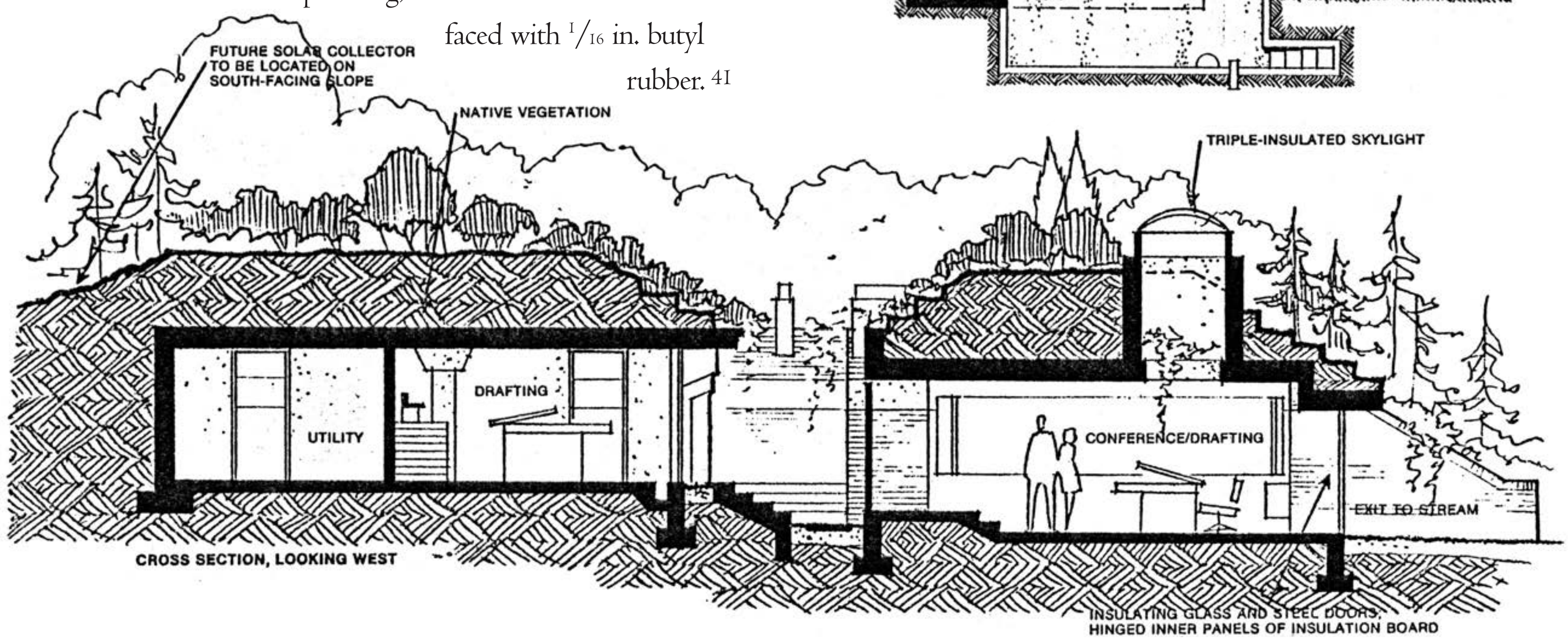




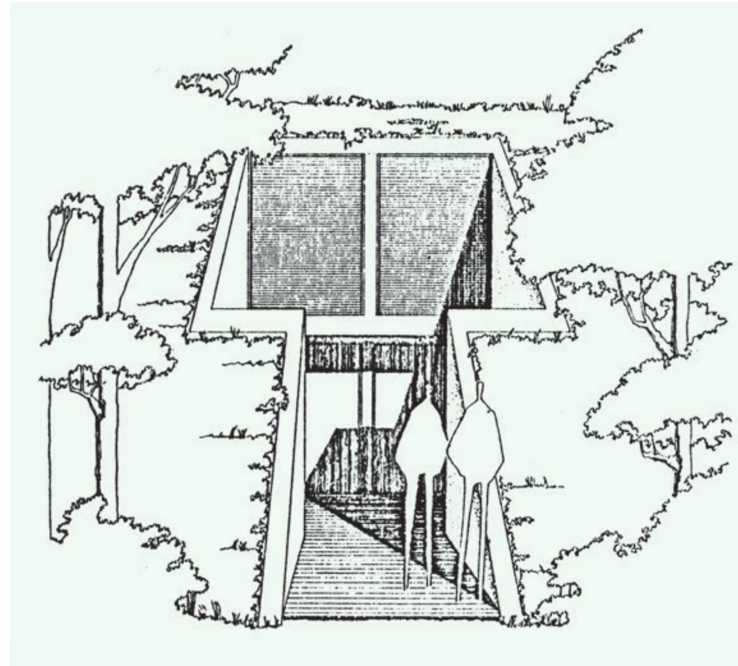
Cormody

MALCOLM WELLS' OFFICE in Cherry Hill, N.J., is a fine example of underground construction providing a multiplicity of benefits. Embracing his concept of "conservation architecture," the two halves of the building are buried beneath three feet of earth cover intended to support bushes and trees alike. Entry is provided by a recessed, permeable pebble courtyard of white limestone to maximize reflected light. Although immediately adjacent to Highway 70, Wells reports at most a faint sound. The roof slab is designed for 500 psf loading, and to ensure complete waterproofing, the concrete structure is surfaced with 1/16 in. butyl rubber. [41]





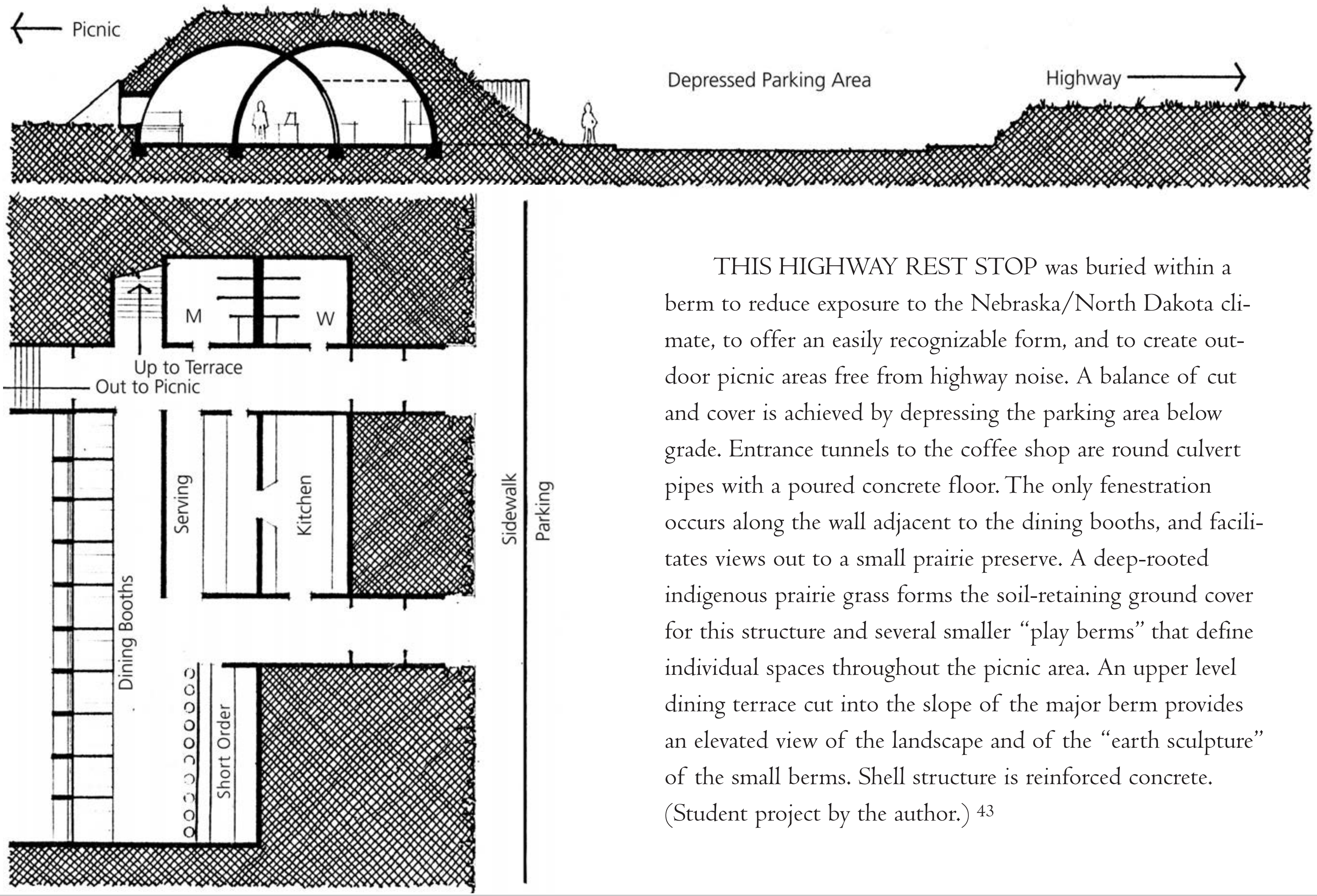
THESE DUNE HOUSES for Amelia Island, Florida, are not accidentally underground. What architect William Morgan, a man much experienced in earth-integrated building, proposes here is a means for protecting the fragile coastal ecologic community both physically and visually. The two- and three-storey berm type houses are conceived to tunnel through the width of the existing system of secondary dunes, which range up to 35 ft high, thereby providing access at grade level and upper storey views into the forest. The duplex condominiums are entered through a small courtyard at duneside, and are to be constructed of reinforced block walls and concrete slabs, with wooden partitions and decks. Morgan feels this combination to be competitive with conventional above-grade construction. Overall density is seven units per acre. [42]



ABOVE: ELEVATION

FROM AIA JOURNAL, FEBRUARY, 1974

BELOW: SITE SECTION



THIS HIGHWAY REST STOP was buried within a berm to reduce exposure to the Nebraska/North Dakota climate, to offer an easily recognizable form, and to create outdoor picnic areas free from highway noise. A balance of cut and cover is achieved by depressing the parking area below grade. Entrance tunnels to the coffee shop are round culvert pipes with a poured concrete floor. The only fenestration occurs along the wall adjacent to the dining booths, and facilitates views out to a small prairie preserve. A deep-rooted indigenous prairie grass forms the soil-retaining ground cover for this structure and several smaller "play berms" that define individual spaces throughout the picnic area. An upper level dining terrace cut into the slope of the major berm provides an elevated view of the landscape and of the "earth sculpture" of the small berms. Shell structure is reinforced concrete. (Student project by the author.) [43]

Part II—Design Issues

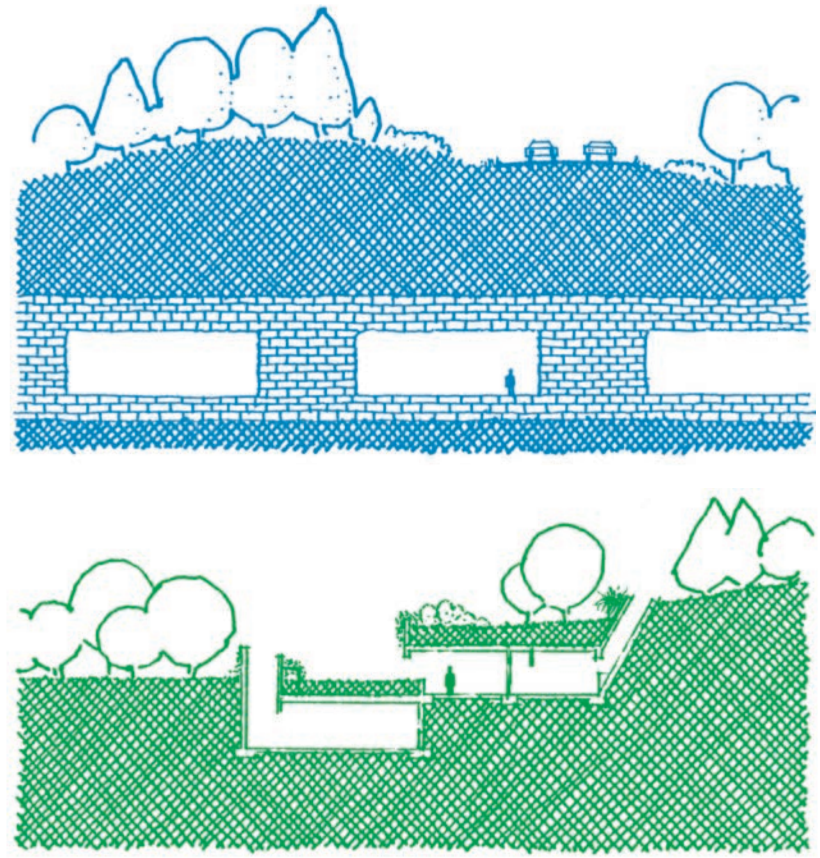
THE NATURE OF UNDERGROUND DESIGN

Many benefits and liabilities have been associated with the architectural use of underground space. Only at the design or project level of application can most of these claims be identified and justly evaluated. Specific programs, sites, and user requirements demand a rigorous understanding of the context within which a given proposal is offered; as in the case of conventional solutions, the appropriateness of the underground alternative will always be closely related to these issues of physical, social, and economic context. Part II will deal with the taxonomic and physical options for subsurface development, and with the range of building types and functions that have been argued to be best suited for underground location and development.

Some of the specific claims in the literature for and against underground development are summarized in Appendix IIA. Briefly, these may be perceived as dealing with a) issues of architectural and environmental control, b) immediate and broadly-based planning concerns, c) amount of economic investment versus rate of returns, and d) perceptual or aesthetic issues. The way in which these issues apply to a given project is dependent on a host of factors, including the mix of environmental constraints,[1] the requirements of the building program, intended short and long term uses, and the importance of image, meaning, and user satisfaction. The successfulness of subsurface alternatives will vary with physical conditions as well as the ability to provide the suitable behavioral settings[2] for a specific task. For instance, while a windowless dwelling doubtlessly holds little appeal for most people, the effectiveness of a cold storage facility or movie theater is greatly enhanced by the elimination of fenestration. Similarly, structures in the tropics can benefit from isolation above grade to capture prevailing breezes (and for other reasons, including protection from vermin and soil moisture) while subsurface buildings in northern and arid climates can gain significantly from the "thermal leveling" effect of the earth.[3] Perhaps most essential to the discussion of contextual response is an understanding of the characteristics and the range of physical options that are considered to be "underground." Also of use will be some agreement as to the terminology which has been applied to underground space. This will be reviewed in the accompanying Appendix IIB.

MORPHOLOGY OF UNDERGROUND SPACE

From the designer's viewpoint, there exist two major types of underground space having architectural relevance. The first of these is near-surface or shallow space, possessing a relatively thin layer of earth cover, or facilitating some other conventional surficial use upon its roof structure. The second area is deep space, which is virtually independent (remote) from the surface; it can be characterized by the umbilical-like tubes, tunnels, and/or elevators which provide access and interchange with the surface. The architectural distinction between these is not primarily one of depth, but lies in the degree of functional relationship between the underground and the surface. As described by Dr. Truman Stauffer, deep space may accommodate radically different surficial and underground uses, while near-surface development requires some compatibility between these uses. [4] This distinction will be examined more closely in the sections that follow.



(TOP): TWO TIER DEVELOPMENT OF DEEP LITHOSPACE; MUTUAL INDEPENDENCE OF SURFACE AND U.G. USE. (NO SCALE)

(BOTTOM): NEAR-SURFACE, TERRASPACE; CONSONANCE OF SURFACE AND U.G. USE. (NO SCALE) REDRAWN AFTER STAUFFER.

THE ARCHITECTURE OF THE NEAR-SURFACE

Shallow space offers a wide range of design opportunities as a result of its proximity to the surface. These involve the handling of entry, natural lighting, visible form, outward views, and physical interfacing with natural surroundings. With penetrations through the surface, terratectural design can provide most of the same amenities associated with surface construction, while simultaneously capturing the major benefits of underground use. Many practicing architects have acknowledged this, and have responded with a rich variety of intriguing and innovative proposals.

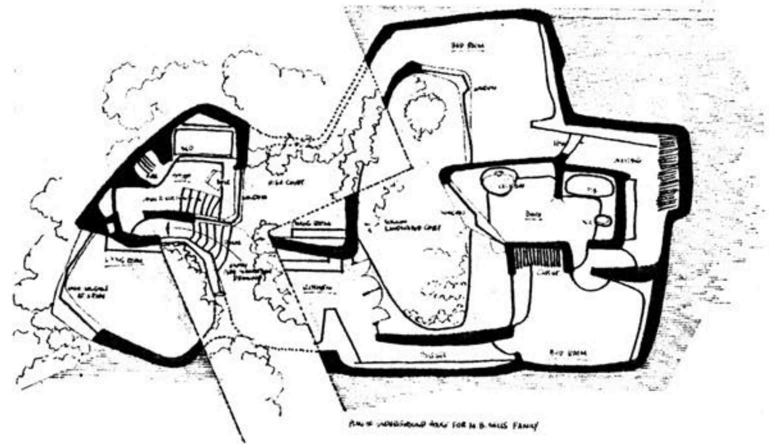
Two very different attitudes about the use and treatment of shallow underground space emerged during the early and mid-1960's. One of these is the nuclear shelter interest in the subsurface, with its adaptation for long-term habitation. The second might be described as an "organic" theme on man's relationship to nature. While these two positions may not necessarily exclude one another, they have nonetheless resulted in radically different aesthetic expressions. The proposals of Malcolm Wells, for example, embrace his ethic of "conservation architecture"—of unifying the effects of man-made environment with the overall processes of nature. [5] The physical form of his early projects (illustration overleaf) manifest this intention—and even romanticize the not-far-distant associations with cave-dwelling through a sculpturesque irregularity of surface.

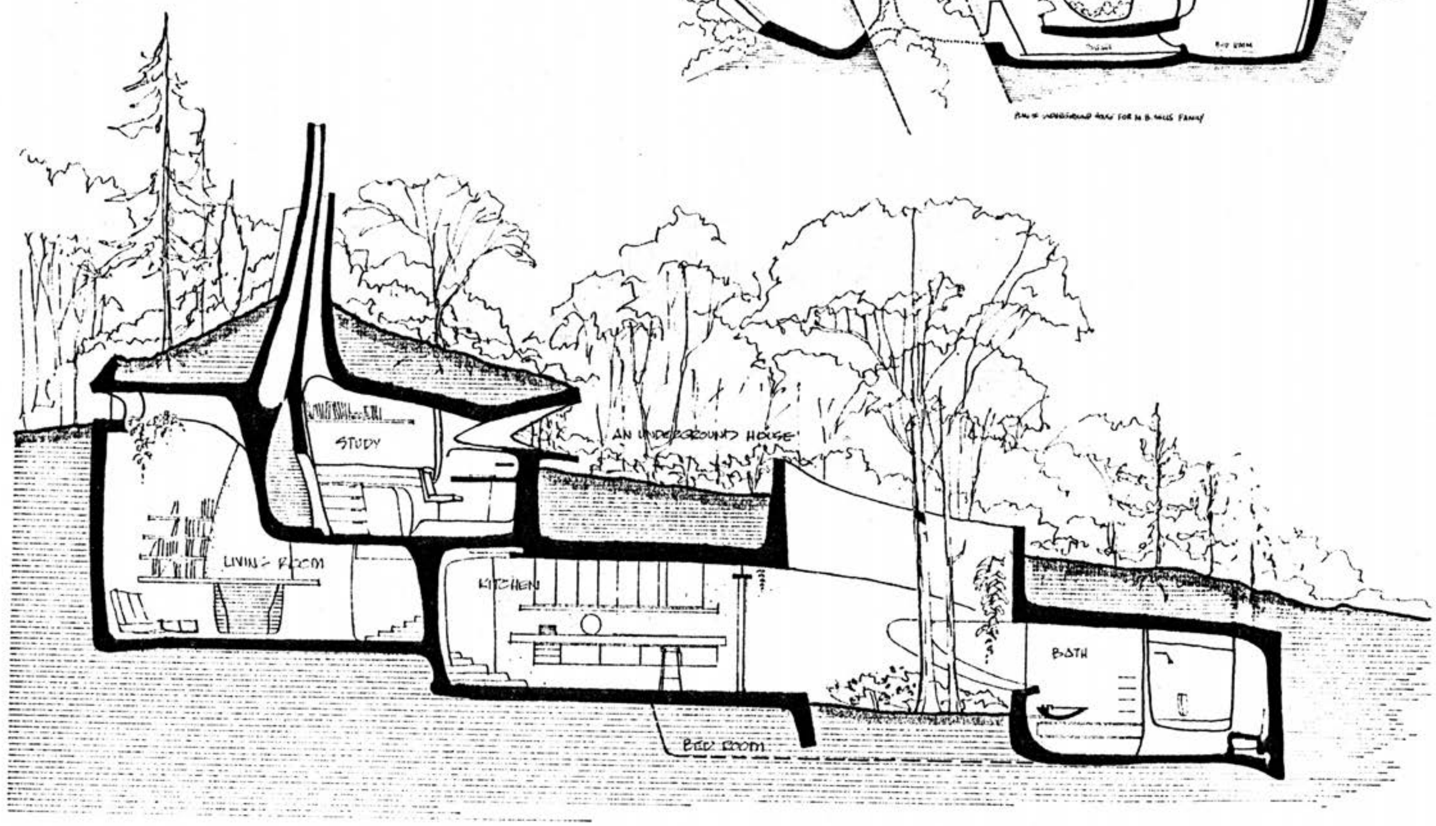
The same organic aesthetic is superficially promoted with the cave-like units suggested in the "Ecological City" envisioned by Mort and Eleanor Karp. The aim here is explained,

> ...so that the hills and valleys, forests, fields and waterways, instead of being destroyed are adapted to human uses, retaining for each place its own natural character, giving us a variety of city form that changes as the world does and affirming that our place on earth is as a conserver rather than a destroyer. [6,7] (see illus.)

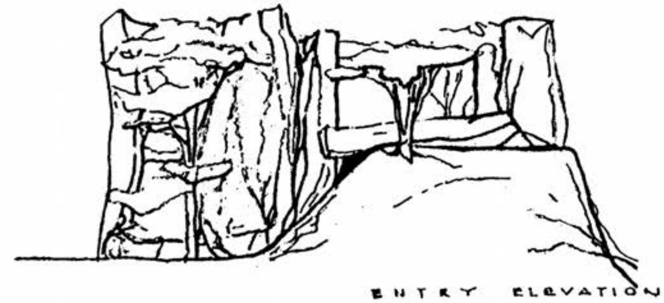
This represents an essentially formal concern, and it is derived from a purpose and philosophy about ecology quite apart from that of Wells. It does, nevertheless, find a similar organic expression roughly simulating, or sympathetic to, the forms of nature.

WELLS HOUSE PROPOSAL BY ARCHITECT MALCOLM WELLS. (SEE ALSO PAGE I23.) WELLS' USE OF UNDERGROUND SPACE STEMS FROM A DESIRE TO CONSERVE THE INTEGRITY OF THE NATURAL PROCESSES DISCUSSED IN PART I. COMPARE THIS TO THE ROW HOUSE ON THE FOLLOWING PAGE FROM THE KARPS' PLAN TO CONSERVE LANDSCAPE IMAGE THROUGH SIMULATION OF NATURAL FORMS. (DWG. BY THE ARCHT., P/A '65; NO SCALE)

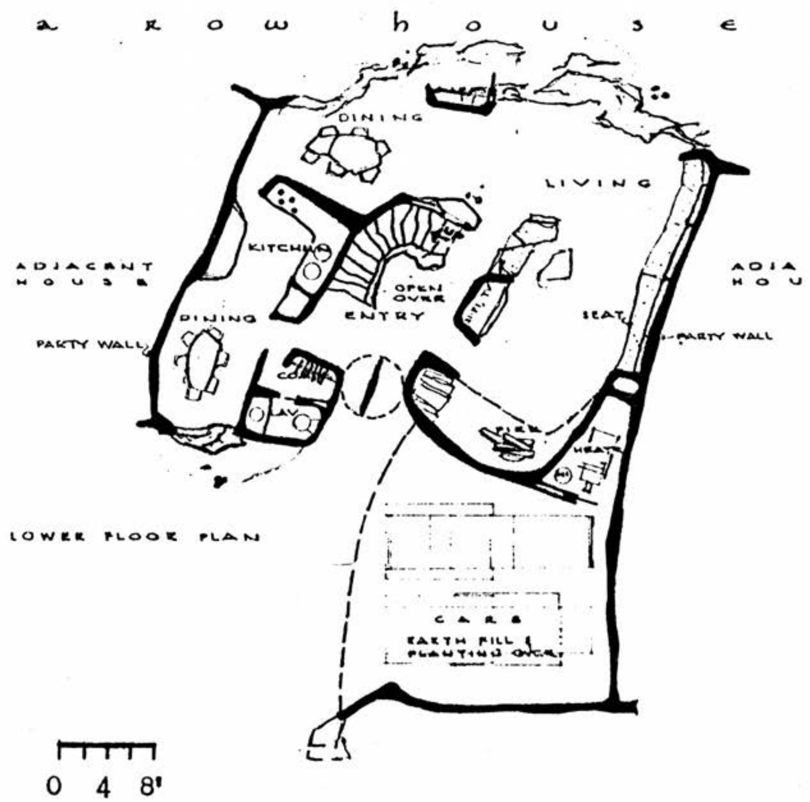


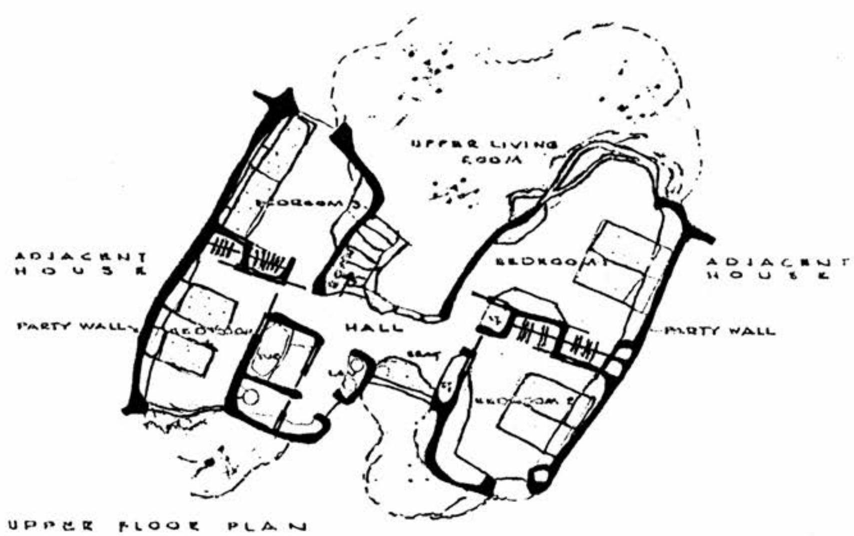


Another early '60's organic approach to the underground is evident in the work of Paolo Soleri, (not illustrated) whose earth- formed concrete shells are covered with an insulative layer of soil that serves as a substrate for planting. In the arid Arizona region of his practice, this technique conforms to the visual character of the landscape as well as to the demands of its severe climate.[8]



"A ROW HOUSE IN THE ECOLOGICAL CITY. THE BLOCKS AND WALLS, THE TREE FORMS, ARE REINFORCED CON-CRETE (sic). THE FOLIAGE IS TRANSLUCENT FIBERGLASS. HEATING IS FROM RADIANT FLOOR PANELS." (DWG. BY THE ARCHTS., LANDSCAPE '65; NO SCALE)



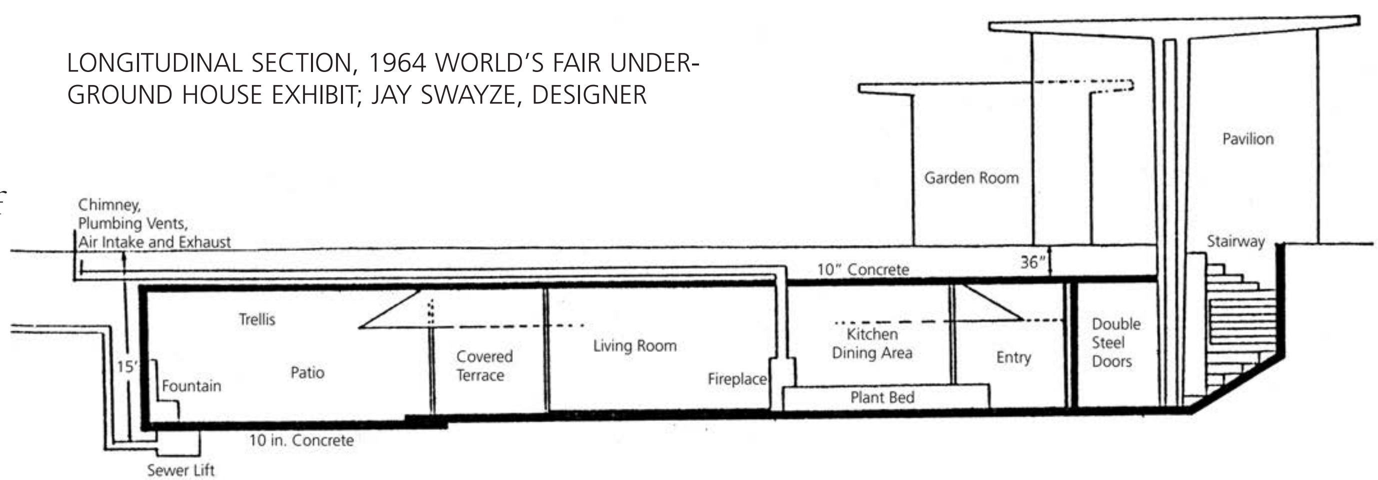


The civil defense interest in the subsurface was the result of the cold war consciousness of the 1950's and early 1960's. From this arose a desire to create underground protective structures which could provide the normally-expected amenities for continuous peacetime habitation. This presents a difficult aesthetic challenge, in that the defensive function necessarily precludes such vulnerable elements as windows.

Perhaps the most notable solution to this dilemma was proffered by builder Jay Swayze, who in the early 1960's constructed his own home under several feet of Texas soil in Plainview.[9]

Swayze's approach to underground construction, also demonstrated in the Underground House exhibit at the 1964 New York World's Fair (right), is essentially simulation of the surface. This is achieved by encapsulating an otherwise conventional suburban house (with windows) within a large concrete shell. The mechanical system circulates air between the two walls, making the house's operable sash functional for admitting air currents. These windows provide "views" outward to surrounding murals with color-modulated artificial lighting to simulate different times of the day.[10] Swayze has developed these techniques to greater sophistication in more recent houses, in which underground "backyard" patios and even swimming pools have been added. An important aspect of Swayze's double-shell system is flexibility: the external concrete

LONGITUDINAL SECTION, 1964 WORLD'S FAIR UNDERGROUND HOUSE EXHIBIT; JAY SWAYZE, DESIGNER

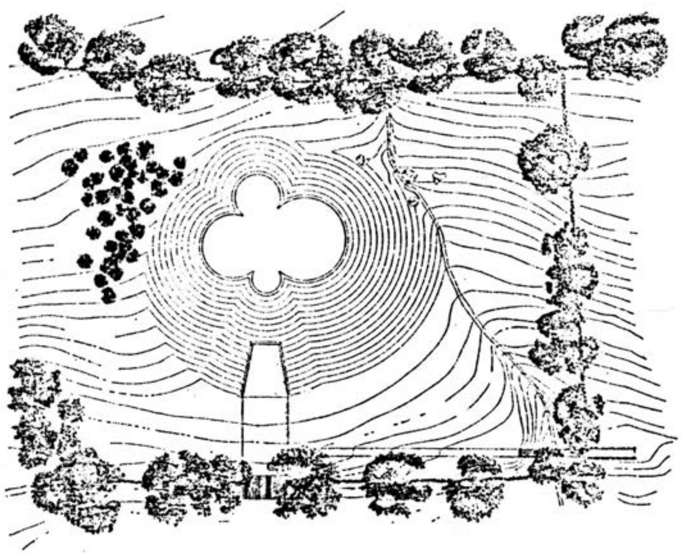


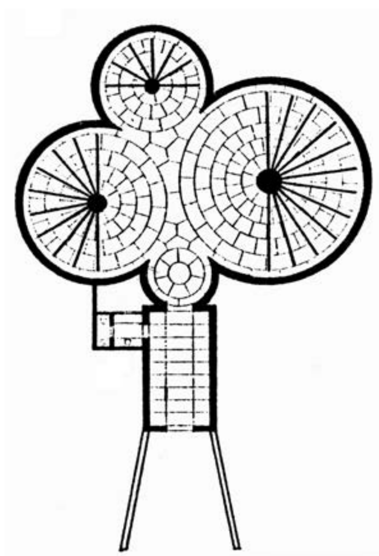
FROM *ELECTRONICS WORLD*
(NO SCALE)

box provides an open plan within which a host of later (successive) functions can occur. Mr. Swayze's philosophy does not rest on the need for bomb shelter protection; indeed, he maintains his advocacy of underground space for reasons of environmental conservation and long term utilization of the invested natural resources. [11]

In spite of their apparent aesthetic incompatibility, the external objectives of Swayze and Wells can be seen to be essentially the same. On the other hand, despite the superficial organic resemblance of the Karps' proposal to that of Wells, they are in fact far more estranged philosophically. This points out factors to be considered in the subsequent examples, that is, the relationships between use of underground design as an aesthetic or experiential end in itself, the use of subsurface space to satisfy external needs, and the formal and architectural means of resolution of either and both of these.

(Editor's Note: This text is continued on p 8. The next six pages (a-f) show examples.)





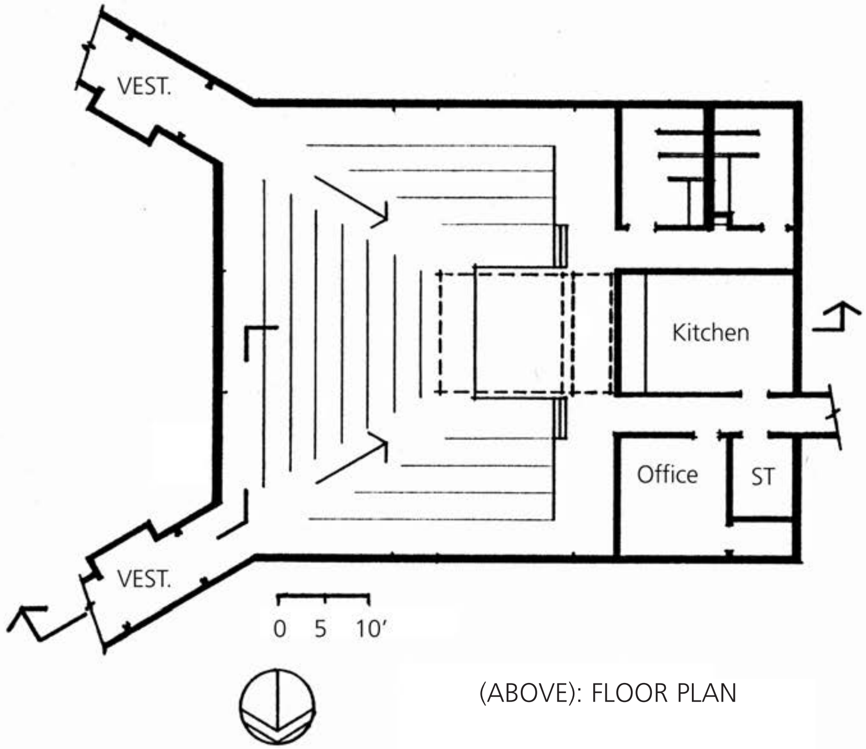
(ABOVE): JOHNSON GALLERY, NEW CANAAN, CONN. SITE PLAN

(RIGHT): FLOOR PLAN

(BOTH NO SCALE

PHILIP JOHNSON'S art gallery on the site of his New Canaan, Connecticut estate, exploits several aspects of the berm-building approach to the underground. The insulative properties of the earth insure a year round 50% humidity and 70° temperature, while the simplicity of shape offers a strong, yet natural, visible form. Johnson enjoys the mystery of the unexpected and the romantic paradox of an elegant cave, commenting, "I didn't want a building in my back yard."

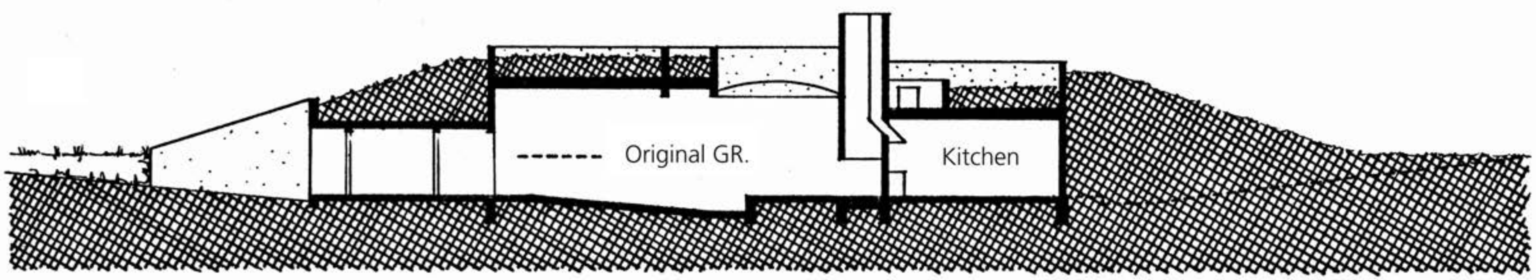
The quatrefoil plan of the "Kunst Bunker" consists of four circular bays ranging from 12 to 40 ft in diameter. A central spine in the larger three of these supports the revolving carpeted display/storage panels. The cloverleaf-like perimeter is expressed on the surface by means of a projected concrete curb. This defines the edge of the lawn from the structure's roof, which is covered with sand. Johnson is careful to point out that his gallery is not truly "underground" (but encircled by berms), and that one approaches it by walking up a slight incline to the entrance. (Site plan and floor plan at left from *Architectural Forum*, May 1966)

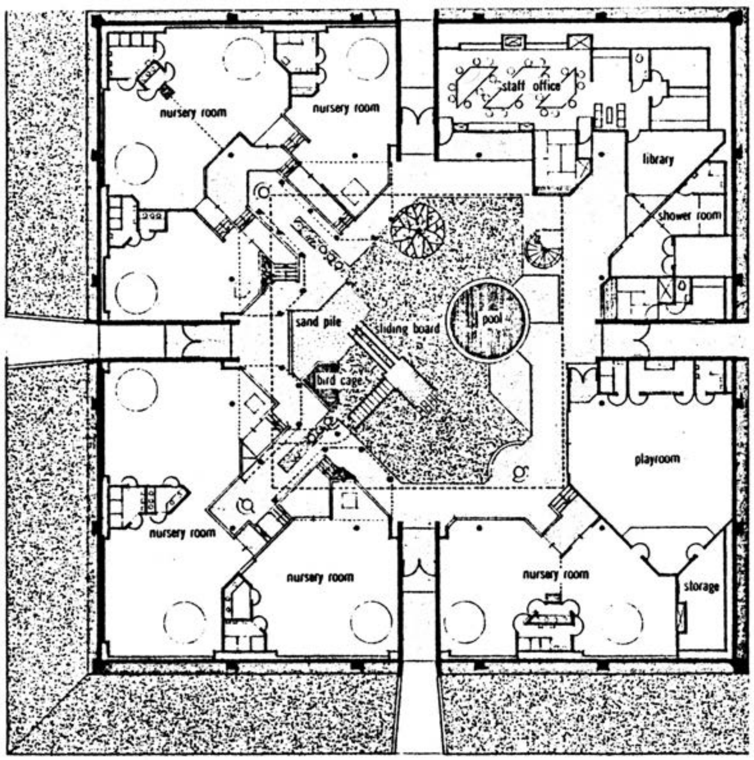


(ABOVE): FLOOR PLAN

(BELOW): SECTION

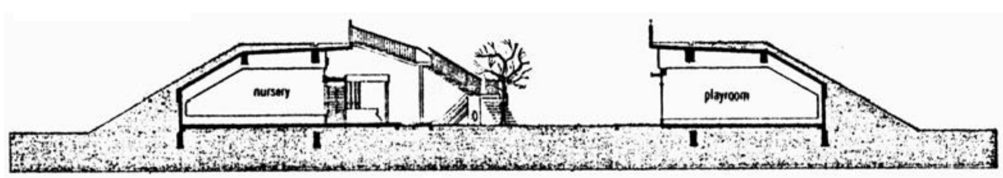
THIS SMALL AUDITORIUM seats 150 and provides additional kitchen and conference space. The clients, a group of Pueblo Indians, supplied the program for a council chamber and a site in northern New Mexico. The earth-covered building form finds its cultural roots in the ceremonial kiva (see p 14), which serves as an ideal response to the severe climate of the region. A central skylight and hearth, perimeter bench, and depressed seating area make up the major components of the traditional meeting room, and they are recreated here. Two main approaches enter diagonally and converge on the platform, with an intermediate coat rack in the vestibule. The entrance ramps are an extension of the auditorium floor; roof-mounted mechanical equipment is shielded by a vestigial parapet. (A sketch proposal by the author, Brooks + Orendain, Architects; 1974)





PLAN ABOVE SHOWS EXTENT OF BERM OF WEST AND SOUTH SIDES ONLY. (SCALE: 1/500)

(BELOW): EAST/WEST SECTION; SCALE: 1/500

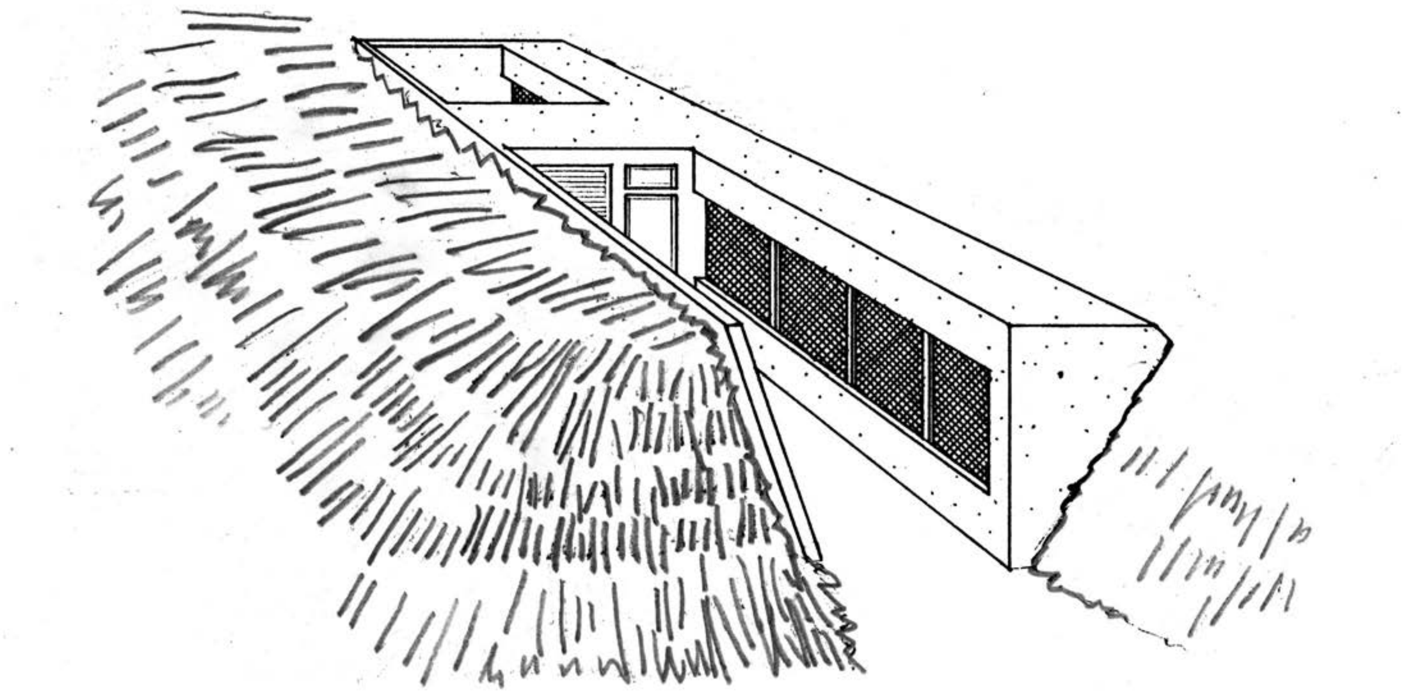


THE PL INSTITUTE KINDERGARTEN (in Japan) exemplifies a large berm building with a central courtyard. Architect Takefuma Aida wanted the structure itself to serve as a play element that might enrich the spatial experience of the young children. A 27° slope was selected after experiments conducted involving children's play activities, and the slopes are planted with grass to cushion the surface. Takefuma expressed the desire to deliberately eliminate the architectural conspicuousness of the building:

> My desire, however, is for the kindergarten to disappear within a rural setting in the middle of a weathered city. I am trying to return architecture to the natural landscape... Then we decided to make the architecture disappear and to devote everything to play space.

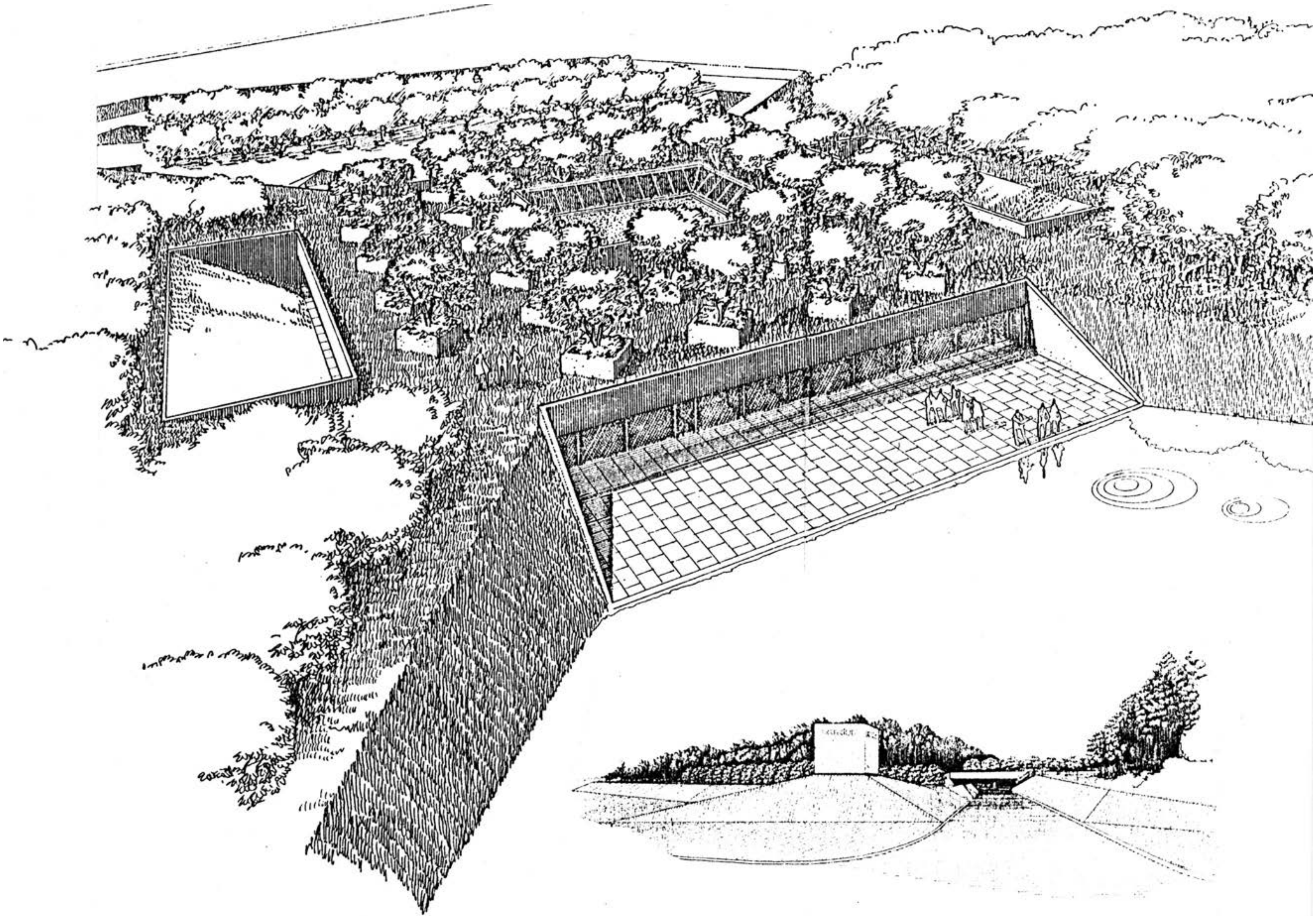
The construction is reinforced concrete, with a building area of 1240 m^2; the floor area is 935m^2 (9683 ft^2). Earth cover is about 3.5 feet.

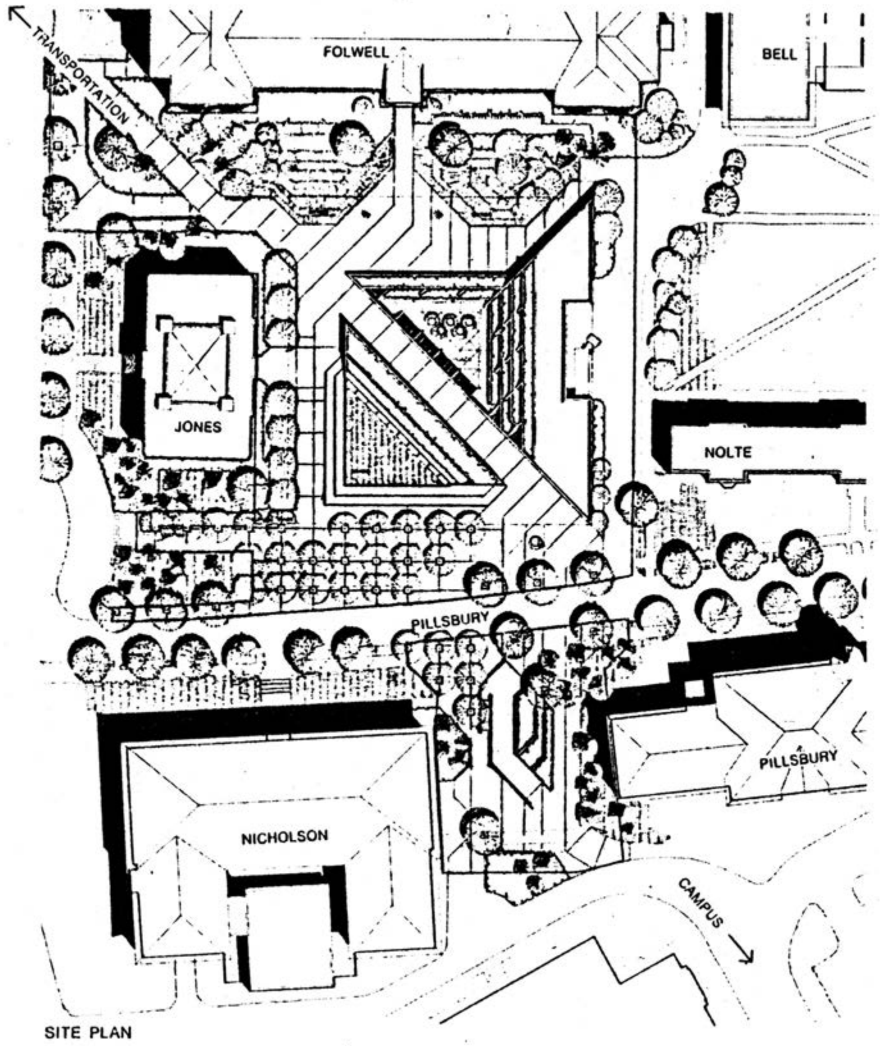
(From *Japan Architect*, April 1974)



THE STOVEPIPE WELLS REVERSE OSMOSIS PLANT (shown above) provides drinking water to visitors at the Death Valley National Monument in California. National Park Service architects recessed it to lessen its "presence" and to exploit the earth's insulative effects: when ground surface temperature is 180° F, temperature 6-7 ft below the surface is a mild 75° F.(From *Progressive Architecture*. October 1973)

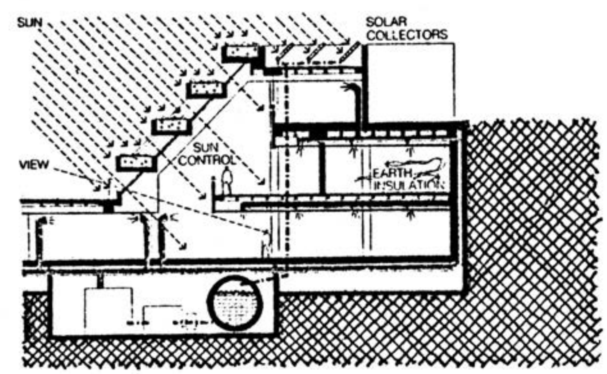
THE PERDUE OFFICE BUILDING, Salisbury, Md., (over to page "e") is another earth-integrated scheme from the office of William Morgan. The 25,000 sq ft facility bridges a shallow valley and accommodates a reforestation effort that will more than double the existing forest. East/west expansion can double the floor area, and conversion of the sidelight slots into courtyards will insure natural lighting. (From *AIA Journal*, February, 1974)





SITE PLAN SHOWING DIAGONAL CIRCULATION PATTERN AND SUNKEN COURTYARDS. NO SCALE

THE NEW BOOKSTORE/ADMISSIONS OFFICE building at the University of Minnesota (Minneapolis) is sited beneath a court-like area created by surrounding buildings. Of the 83,000 sq. ft. of space, 95% is below grade on two levels. The subsurface solution was chosen to de-emphasize the structure's presence, and as a means towards energy conservation; thermal and energy performance is to be monitored and studied. Windows onto a sunken courtyard provide abundant natural lighting, and linear planters are used as integral sun shading devices. The diagonal pedestrian "bridge" retains a circulation link between a nearby bus station and the main campus. Surface decks are exposed aggregate concrete, and the building structure is board-formed concrete. Architects are Myers and Bennet; *Progressive Architecture* awards winner, January 1975



CONCEPTUAL SECTION (FROM *PROGRESSIVE ARCHITECTURE*)

THE ARCHITECTURE OF DEEP SPACE

Deep underground space has rarely been exploited in this country as a purely architectural resource. Nevertheless, the realization that the underground constitutes a unique spatial resource—in that it preserves the surface for other activities that surficial development denies—has stimulated increasing interest in its use in recent years. It is not surprising that deep space has been given more attention by urban planners and engineers involved with regional services than by architects, for the greatest social and economic rewards seem to be more closely related to horizontal than vertical distribution of facilities and functions beneath the surface. This is reasonable, for in expanding subsurficial circulation and transportation systems, one also increases exposure and access to a given piece of real estate in the vertical dimension. The benefits of multi-level—especially weather-protected pedestrian—access is of importance to the designer at both individual and collective building scales of application. The discussion of deep space here will concentrate on urban design and its utilization within urban contexts; first, however, it will be useful to point out a few essential characteristics of the types of development of deep space.

CONSTRUCTION PROCEDURES AND IMPLICATIONS

Unlike terratectural practice, deep space may be created through tunneling or mining procedures, through cut-and-cover techniques, or through the provision of "basements" by conventional construction. The effective coordination between private developers constitutes a major planning task if mutual and maximum benefits are to be realized (see p III 7). For this reason, most large scale underground developments have been created as a result of major redevelopment projects in which such coordination is assured.

To be sure, all three construction techniques have been in common usage, although for quite different spatial purposes. A few examples of each will clarify both the current applications of deep space, and the role of the architect and planner regarding its development.

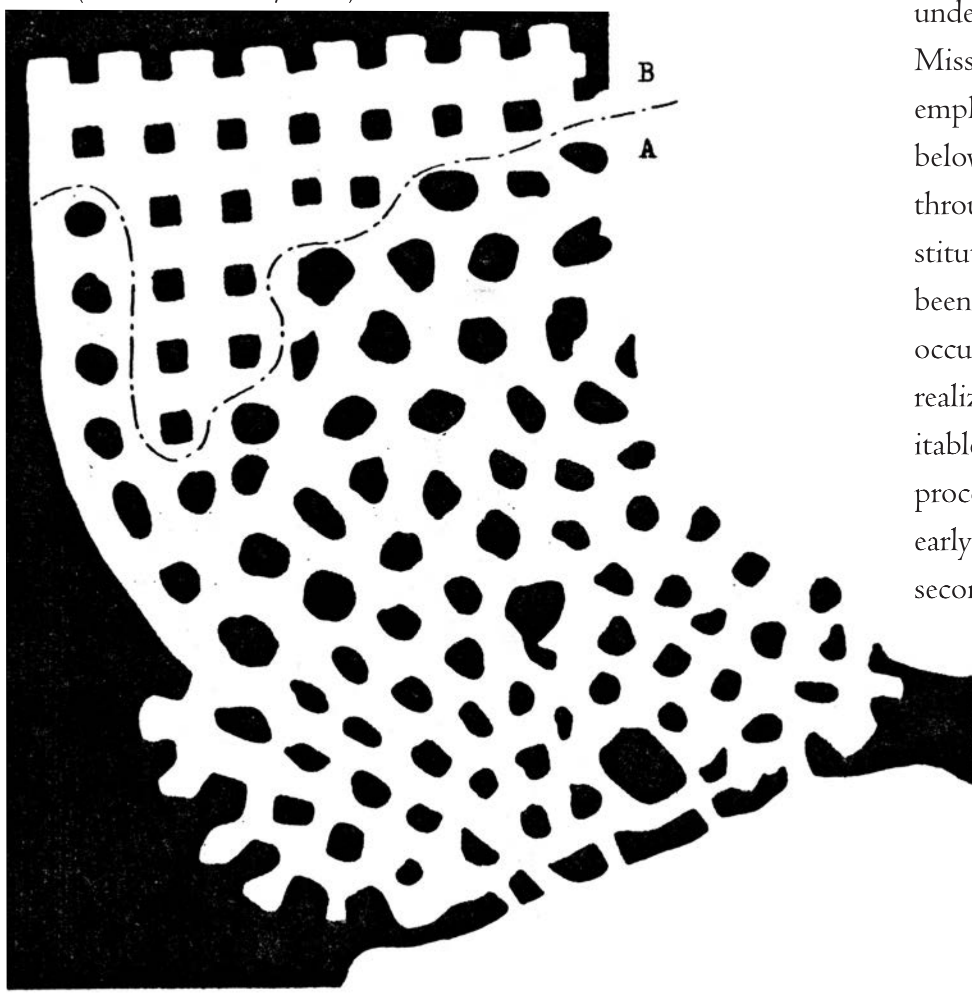
Cut and cover techniques create surface disruption that is neither desirable nor often feasible, particularly in densely urbanized areas. Except for single parcel development, cut and cover construction will usually be limited to areas in which underground development can be completed before the development of surficial uses, or where surficial right of way already exists or can be acquired. Even so, a number of multi-level projects have been built by these procedures, suggesting the potential of larger developments yet to come.

Mining and tunneling, although seldom considered within the architect's repertoire, have been exploited for the accommodation of a variety of very different functions. Transit systems are among the most immediate examples, and possess underground design opportunities far beyond themselves (in terms of ready accessibility to other underground spaces).

Tunnel driving is independent from—and thus non-disruptive of—surface activity. Due to the intrinsically-linear nature and diametric limitations of tunneling, however, it is doubtful that such construction will find much application for exclusively architectural purposes. A few rather surprising uses of tunneled space do suggest, nonetheless, a generally unsuspected potential for this technique. At Lidingo, Sweden, an entire sewage treatment plant has been located underground in a series of parallel tunnels totaling 37.5 miles in length. This facility currently serves 540,000 persons, and can be expanded for service for up to one million. Although the cost of tunneling in granite is great, the Kappala Union (the regional authority) was granted permission by the Court of Water Law to tunnel under private property, thus averting the expense of surface rights acquisition. The reason for locating the plant underground is related to environmental requirements and land space shortage. [12]

Linearly oriented functions such as assembly lines and parking facilities may also be accommodated within tunneled space, and some unusual examples of these are documented in the literature, particularly with respect to war time munitions factories and dual purpose public shelters for civil defense. [13]

APPROXIMATELY 20% TO 25% OF THE GROSS FLOOR AREA IS LEFT IN SUPPORTING PILLARS OF LIMESTONE, WITH A TYPICAL CEILING HEIGHT OF 12 TO 14 FT; PILLARS ARE COMMONLY 20 FT SQUARE, AND MAY BE SPACED FROM 40 TO 65 FT O.C., RESULTING IN A PERPENDICULAR LATTICE OF AISLES RANGING IN WIDTH FROM 30 TO 45 FT (FROM STAUFFER, 1973)



THE KANSAS CITY UNDERGROUND

Perhaps the most impressive commercial use of deep space in the United States is to be found among the many underground installations located throughout Kansas City, Missouri. Dr. Truman Stauffer has reported that some 2,000 employees work in the underground environments (30 to 200 ft below the surface) created from limestone mining operations throughout the greater metropolitan area. Technically, this constitutes "secondary use," the quarrying of the limestone having been the primary intention. Since the original major secondary occupations of mined-out space in the early 1950's, it has been realized that the leasing of underground space is a more profitable venture than the mining itself;[14] accordingly, mining procedures have been adapted from the prevalent irregularity of early excavations to a grid which permits greater efficiency of secondary use.

LEGEND

PILLARS AND REMAINING LIMESTONE

FRONTIER OF PLANNING EFFECT

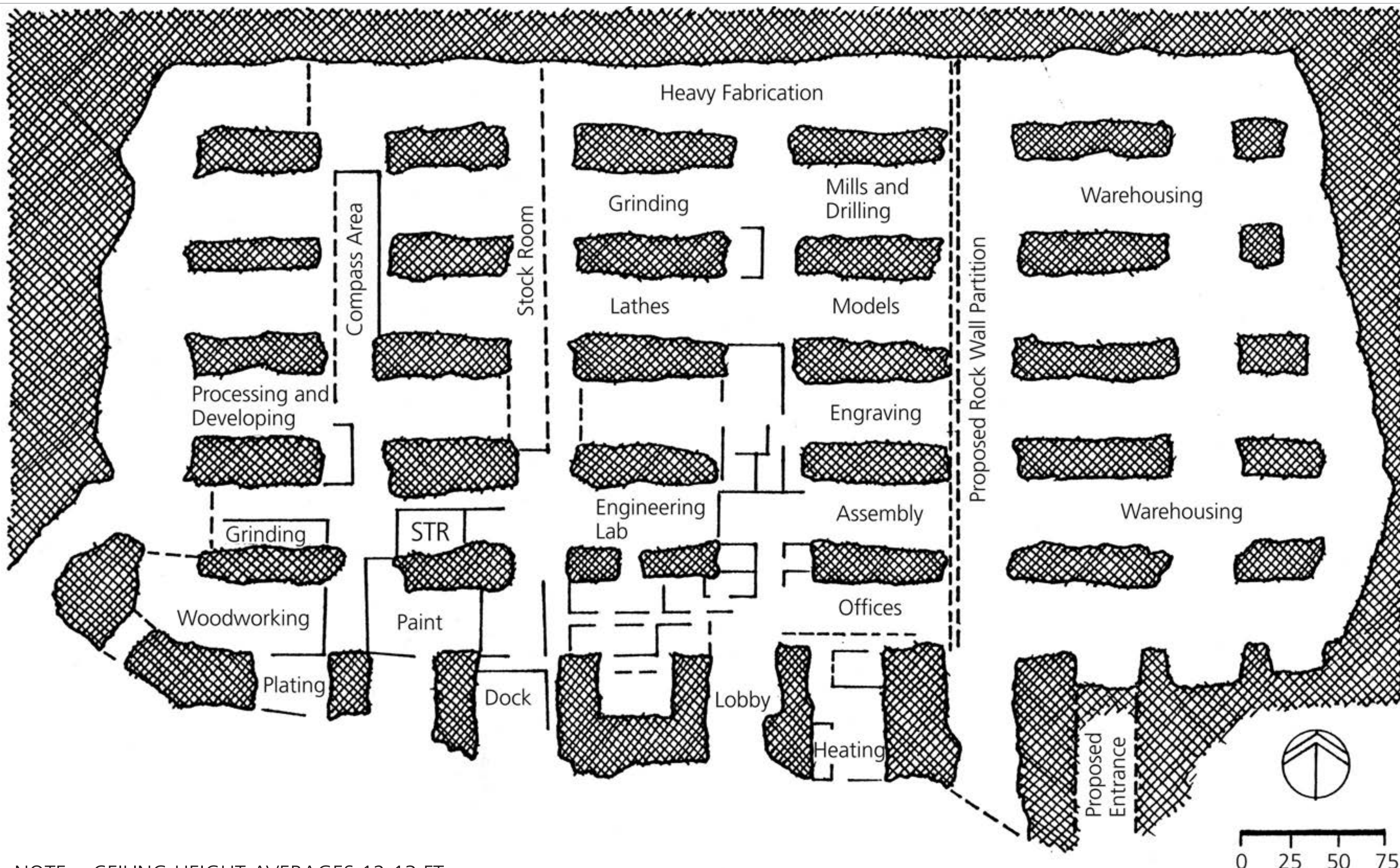
A IRREGULAR PILLAR SPACING

B REGULAR PILLAR SPACING

A total of 140,000,000 square feet (5 sq mi) of underground space is reported from 13 major sites throughout the metropolitan area; an estimated 5,000,000 square feet is being added each year, all with the anticipation of future space rental. [15] Of the existing underground space, about 15,000,000 square feet is in secondary use, and another 27-30,000,000 is reported "suitable and available for use." [16] In order to promote some appreciation of the ramifications of this scale of development, Dr. Stauffer points out that the area created by the Downtown Industrial Park alone has "added" 28 acres to Jackson County, (see p II32) Prof. Richard Gentile reports that about 25 acres of new space is being added each year from current mining activities at the larger sites which are in operation. [17]

As Dr. Stauffer has suggested, Kansas City may indeed be regarded as a "laboratory" for the study of underground space. Although the city is endowed with what has been described as a geological resource of limited availability, [18] much of the experience with the use of underground space is translatable elsewhere. For this reason, some further examination of the development of Kansas City underground space is warranted.

As early as 1928, a plan was envisaged by Willard E. Winner which would have created an extensive subterranean street and parking system throughout 50% of the downtown area. [19] This never materialized due to lack of political support, but the underground concept persisted. During the years 1926-44, some secondary use occurred at nearby Atchinson, Kansas, and with publication of the Defense Department's book Underground Plants for Industry in 1956, the use of the underground began to be given more serious consideration. [20] Mr. Amber Brunson, owner of the Brunson Instrument Company, is credited with being the first in the area to quarry rock with spatial intent as the primary motive. Brunson began investigation of underground sites for location of his manufacturing business in 1948; after finding the available abandoned mines unsuitable for his purposes, he selected a virgin site and began mining in 1954. Mining was completed six years later, and the relocation to the new site was accomplished in 1961. [21]



NOTE: CEILING HEIGHT AVERAGES 12-13 FT.
FLOOR PLAN OF THE BRUNSON INSTRUMENT COMPANY, 77 FEET BELOW THE SURFACE. TOTAL FLOOR AREA IS NOW AN ESTIMATED 250,000 SQUARE FEET, 75,000 BEING USED FOR FACTORY AND OFFICE, AND THE REMAINDER FOR WAREHOUSING. NOTE THE DIFFERENCE IN PILLAR ARRANGEMENT FOR TEES CUSTOM INSTALLATION. FROM GENTILE [22]

Because the Brunson plant represents a deliberate creation of deep underground space for a use conventionally located on the surface, it is an important landmark of geotectural application. Reasons cited for Brunson's decision are primarily related to the need for a vibration-free and atmospherically-stable environment. [23] The realized benefits of operation, however, greatly exceed this main intention. These are reported by Bligh and Hamburger as: [24]

1. savings in maintenance from lack of wind, moisture, heat, and freezing effects,
2. decreased insurance rates due to fireproof construction rating and protection from wind damage,
3. utility savings: lines are hung from ceiling or concealed in floor slab with no danger of freezing,
4. savings due to elimination of foundations, especially for machinery support (loading on the floor is possible to 200 tons/sq. ft.),
5. elimination of need to isolate machinery and instruments from vibration, and
6. operating savings derived from fewer machinery realignments (due to environmental stability). The table below compares the performance of the Brunson plant with a typical surface facility accommodating a comparable function.

Cost And Energy Comparisons For A Precision Manufacturing Plant Above And Below Ground [a]

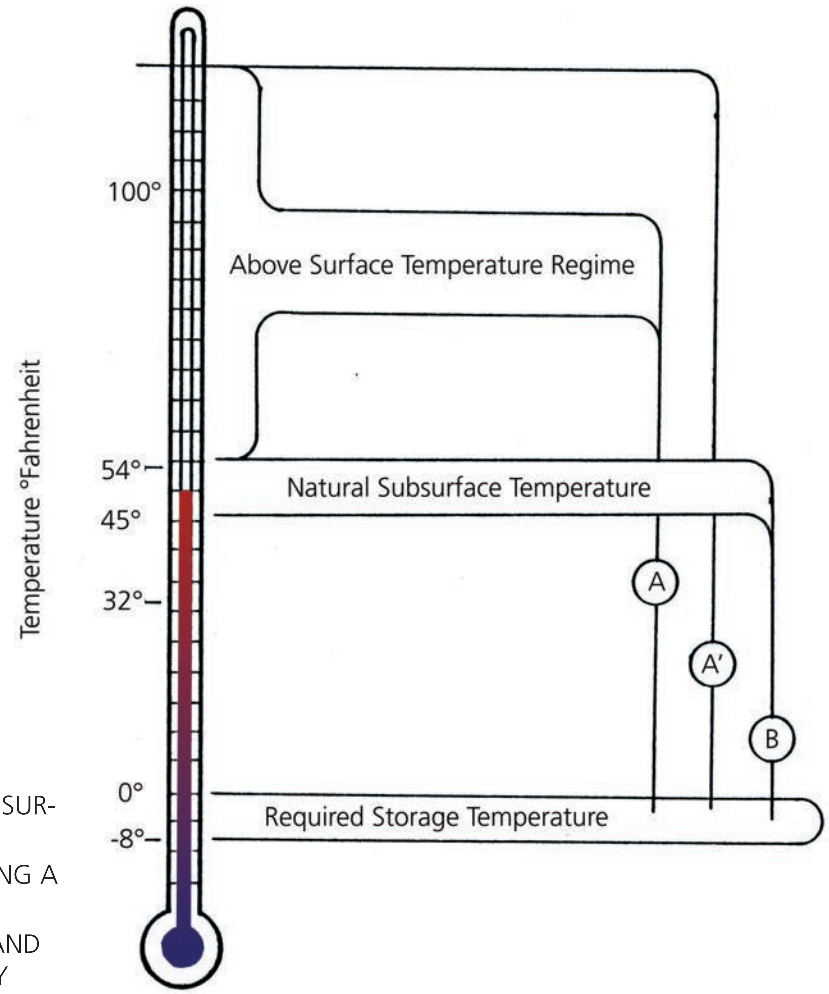
Item Compared	Above Ground (Estimate) [b]	Underground (Brunson Co.)
Heating units (BTUH)	2,000,000	750,000
Refrigeration (tons) for dehumidification	500-700	57
Operating cost ($/year)	50,000 - 70,000	3,200 [c]
Fire insurance ($/$1000)	2.85	0.10

[a] BRUNSON INSTRUMENT CO., CONDITIONS: 140,000 SQ. FT.; 125 EMPLOYEES; 77 FT. BELOW THE SURFACE; 54°F INITIAL ROCK TEMPERATURE.
[b] FROM FABER (SEE BLIGH & HAMBURGER'S ARTICLE)
[c] THIS FIGURE IS PARTICULARLY LOW SINCE THE AIR CONDITIONING PLANT IS OPERATED ONLY AT NIGHT TO BRING THE TEMPERATURE AND HUMIDITY BELOW THAT REQUIRED. BECAUSE OF THE HEAT CAPACITY OF THE ROCK, TEMPERATURE AND RELATIVE HUMIDITY OF THE AIR THEN RISE SLOWLY DURING THE DAY. THIS TECHNIQUE REDUCES THE ELECTRICAL DEMAND FACTOR.
(FROM BLIGH AND HAMBURGER) [25]

The major reason for Kansas City's movement underground is economic—rental costs average 40% below surface costs (U.G. costs typically range from $.75- $2.00 per sq. ft. per year), and maintenance, utilities, and insurance are said to run as low as 15 - 20% of comparable surface uses. [26] These factors, plus the proximity to major truck and rail routes, make the Kansas City underground especially attractive to warehousing and storage industries, where the relative costs between spatial overhead (rent, insurance) and environmental control (energy costs, equipment maintenance) are critical elements in a facility's efficiency. [27]

It is no wonder, then, that 89% of Kansas City's underground secondary use is devoted to warehousing, and 7% to manufacturing; the remaining 4% consists mostly of office space. Of particular note are the savings afforded by the thermo-insulative properties of the limestone with regard to refrigerator and freezer storage. The cold of a freezer room at -8° F is recorded as penetrating 16-20 ft into the surrounding rock.

A COMPARISON OF SUBSURFACE TEMPERATURE REDUCTION WITH SURFACE TEMPERATURE REDUCTION TO MEET REFRIGERATED STORAGE NEEDS (AFTER STAUFFER, 1975) [28]



A — TEMP REDUCTION REQ'D USING A SURFACE SITE FOR REFRIG STORAGE

A' — EQUIPMENT RANGE CAPACITY USING A SURFACE SITE (REFRIG)

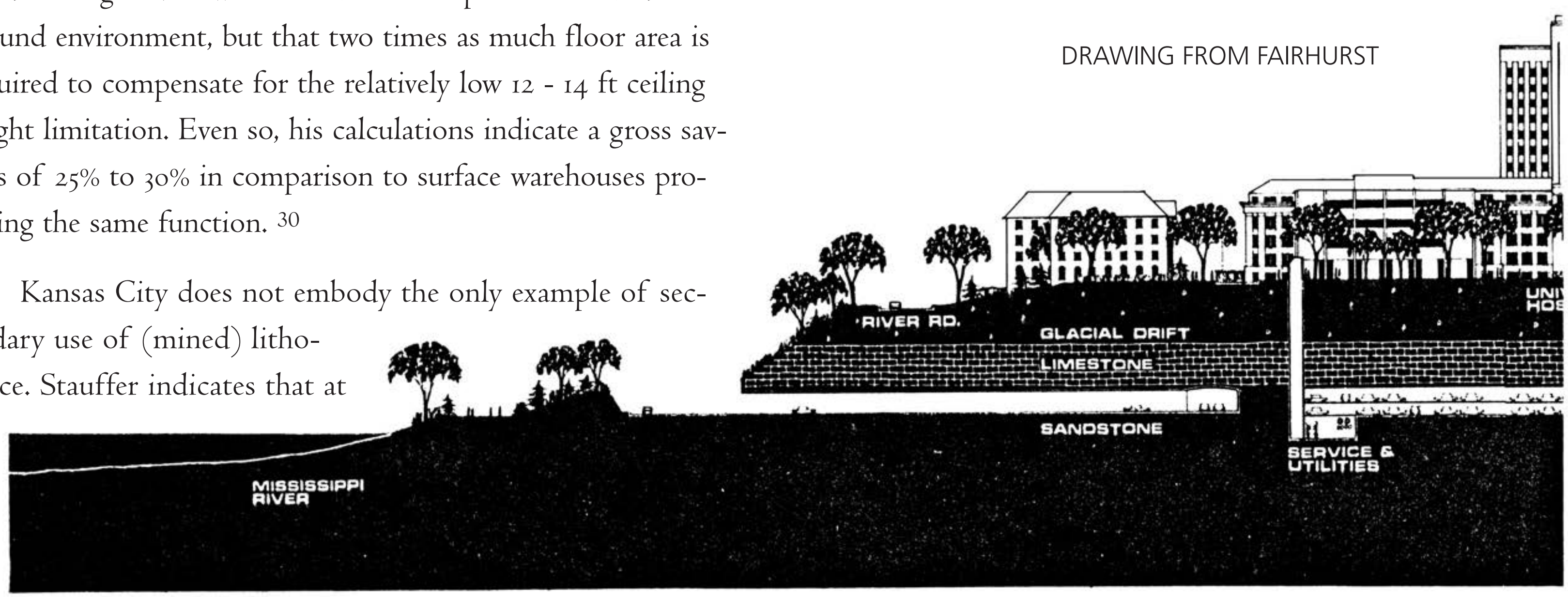
B — ECONOMY OF TEMP REDUCTION AND LWR EQUIPMENT RANGE CAPACITY USING A SUBSURFACE LOCATION

In the event of equipment failure, this depth of "cold reserve" will provide, [29]

> months...for the temperature to reach 0° F providing, of course, the doors are kept sealed. The cost of operating [underground] refrigerated space is approximately a third less than it would be in a conventional warehouse.

A more conservative estimate is given by refrigerating engineer John G. Muller, who points out that one ton of air conditioning serves twice as much floor space in the underground environment, but that two times as much floor area is required to compensate for the relatively low 12 - 14 ft ceiling height limitation. Even so, his calculations indicate a gross savings of 25% to 30% in comparison to surface warehouses providing the same function. [30]

Kansas City does not embody the only example of secondary use of (mined) lithospace. Stauffer indicates that at least nine states possess incidences of secondary occupancy in limestone mines, and reports five more states with varying numbers of underground mines. [31] Such sites are of limited availability (particularly with respect to urban areas), and are not necessarily suited geologically to extensive secondary use. Other opportunities for primary-use creation of mined underground space do exist, and are being exploited at different levels of intensity. Most notable of these is research being conducted in the Twin Cities of Minneapolis-St. Paul

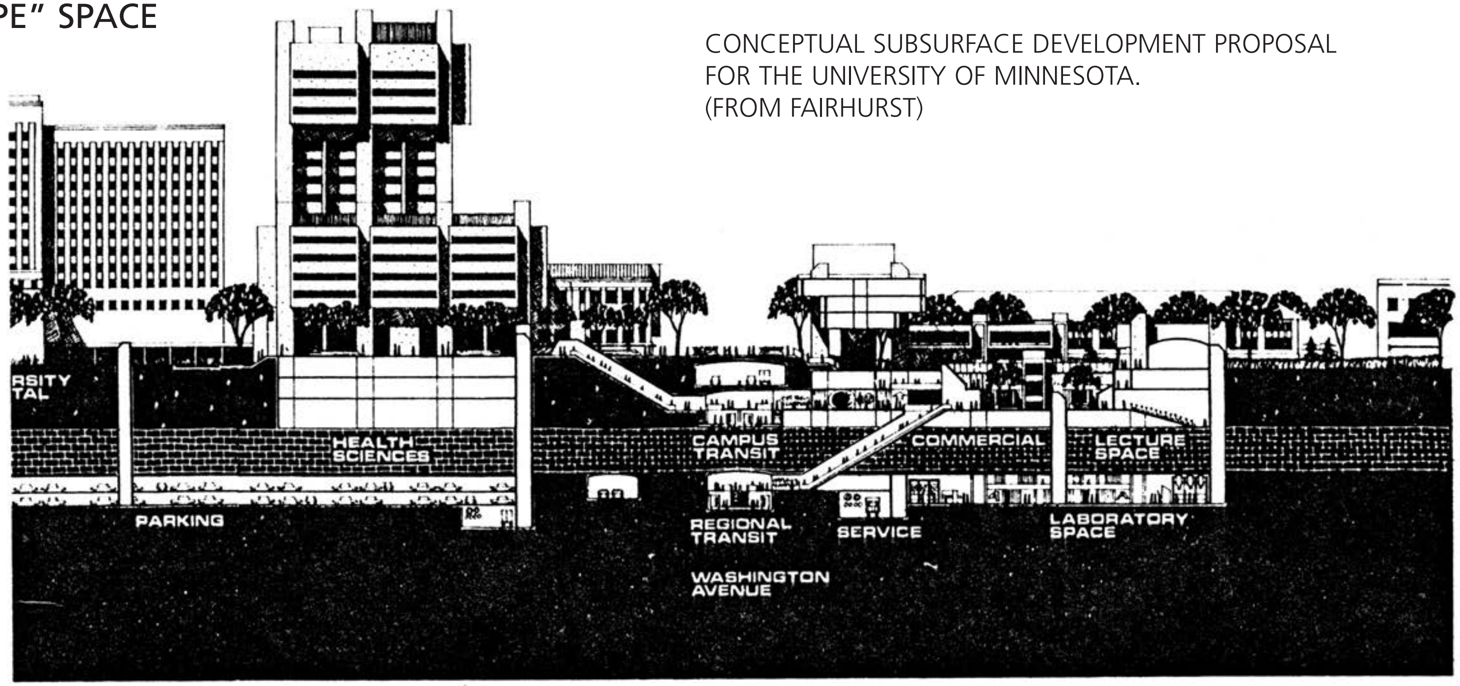


DRAWING FROM FAIRHURST

to study the feasibility of developing urban space beneath the existing city. A conceptual scheme of such a development appears below and on the preceding page, depicting the types of services projected for the campus of the University of Minnesota. At present, an underground test room of 50 x 100 x 15 ft is being built (approximately below the word "commercial" on this page) to explore engineering and construction practices preliminary to larger scale planning for expansion of both campus and urban systems. [32]

"BASEMENT-TYPE" SPACE

The form of underground development most familiar to architects is that referred to by Stauffer as "basement space." In addition to its usual assignment of mechanical and service areas, many other major examples are well known—the six stories of offices and vaults below grade of the Chase Manhattan Bank, and the vast complex of space beneath the Federal Reserve Bank in Minneapolis, for example. Of far greater magnitude and urban consequence are the extensive mall and concourse developments at Place Ville-Marie and Place Bonaventure in Montréal, and at Les Halles in Paris. Place Ville-Marie, for example, contains 50 stores beneath the high rise and plaza



CONCEPTUAL SUBSURFACE DEVELOPMENT PROPOSAL
FOR THE UNIVERSITY OF MINNESOTA.
(FROM FAIRHURST)

area, and is exposed to the passage of an estimated 80,000 persons daily. So successful is its use that pedestrian traffic at major intersections on the surface is said to have fallen off by 70%. Place Ville-Marie represents the first phase of an underground system that is projected to eventually serve 100 acres. Since these projects are well published, [33] they will not be dealt with at great length here.

The economic premium placed on centrality of location demands the maximum return from investment in a plot of land; [34] nowhere is this more evident than in Japan, where 25 subterranean shopping precincts ("chikagai") had been reported by 1967. [35] The Japanese shopping towns are quite similar in concept to the Canadian and French examples discussed above; they differ in size and managerial structure, for each is self-contained with its own real estate administration and municipal services, including police and security patrols. Japanese construction ministry authorities have generally insisted on locations where a minimum of 500,000 potential customers are available from the immediate vicinity. The development of the chikagai have been encouraged largely by department stores and railway companies, which form an integral element of the towns' accessibility. A typical example of the subterranean town is found under the city of Kobe (near Osaka) at the Sannomiya station. Here 225 shops and restaurants (see p II27) are located amidst a "green belt" of potted ferns and flowers, and 640 yards of subsurface streets. Laundries and medical centers are also available to the daily excess of 800 thousand visitors. [36]

The extensive private development of the chikagai has created some problems of its own. In May 1974, a decision was made by the Police and Fire Departments, Ministries of Transportation and Construction, and the National Railways not to permit (at least in principle) any new underground streets. Health and safety hazards and excessive traffic were given as reasons; the underground constructions were said to pose obstacles to further development of urban areas, and any new underground streets must, therefore, conform to district plans. [37] The Japanese experience surely demonstrates the absolute need for an accepted plan of underground development.

THE FUTURE OF THE URBAN UNDERGROUND

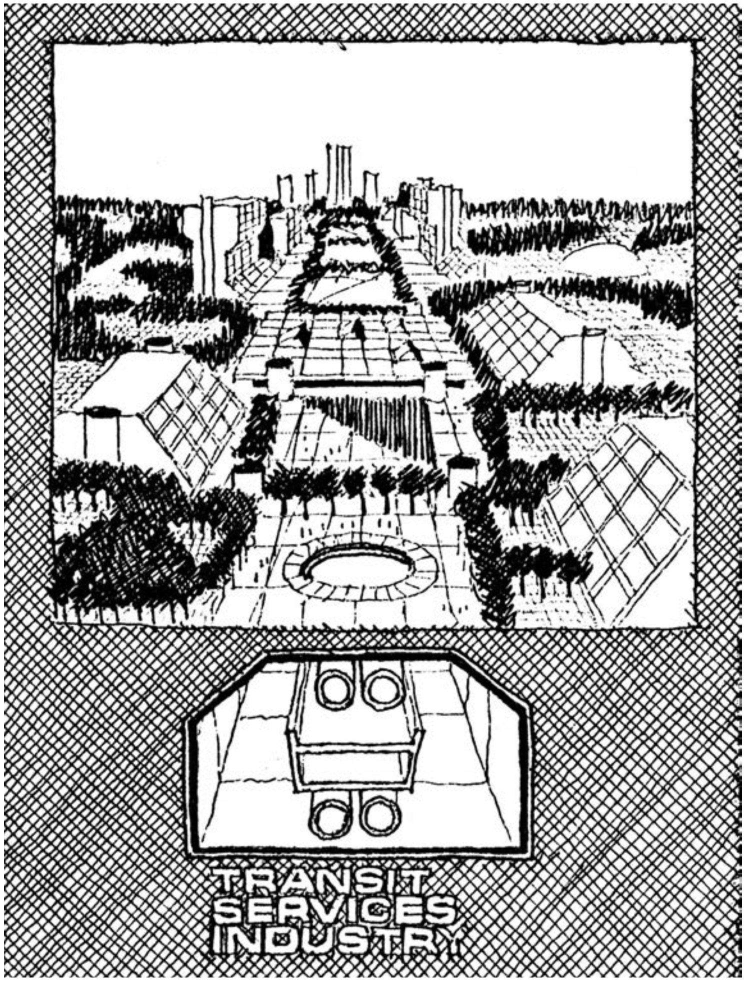
The role of underground development in urban areas has been studied by researchers both within and outside the design professions. Irving Hoch, a research associate on urban and regional economics, Resources for the Future, Inc., writes:

> It is somewhat disquieting that in 100 Russian cities, 35% or more of investment in structures is underground. (Do they know something we do not?) Sweden has an extensive underground development program for civil defense purposes. About two billion dollars has been spent so far [1966] for underground installations, of which half are military, half are civilian,. Virtually all new buildings are constructed with underground shelters; present mass shelters are used for underground parking, convention rooms, and civic centers. [38]

Hoch perceives the economic demand for underground space in urban areas as directly related to land values, which may be modeled as a function of distance from the central business district. This assumes a generally higher cost of underground development with respect to surface structures, and may in the future be modified by environmental and "antipollution activity," which "is likely to increase the demand for underground space use." [39]

That environmental benefits can be derived from the urban use of underground space has been recognized by the architecture and planning professions, and forms the basis of architect Gunnar Birkert's proposal for a system of subterranean "conduits." These 1000 ft wide, 200 ft deep covered troughs are conceived as providing a linear core of transit, goods, and utility distribution lines, and an associated permanent structural framework for housing factories, recycling and waste treatment facilities, central heating and cooling plants, and other necessary urban support systems. Birkert's intention is to simultaneously maximize the efficiency of servicing urban inter-relationships (in terms of time, energy, and land use), and to liberate the surface for the functions which it can optimally and uniquely accommodate (parks, housing, and schools, for example). [40]

A similar underground corridor concept (illustrated on the following page) is promoted as contributing to the conservation of energy, pollution control, a relieving of traffic con-



THE DRAWING ABOVE DEPICTS AN UNDERGROUND CORRIDOR CONCEPT, WHICH SERVES SURFACE FACILITIES AS WELL AS ADJOINING UNDERGROUND USES. (FROM THE NOTES FOR THE CONFERENCE "UNDERGROUND SPACE AS AN URBAN RESOURCE.")

gestion, greater efficiency of urban systems and services, an increase in open space, and preservation of land resources. These amenities are thus seen to provide for "an ecological renewal of the city." [41]

The efficacy of using the underground as a means toward alleviating surficial problems is only as real as the vision of those who prescribe its application. While it is possible that such systems can contribute to the relaxing of auto use, for example, the implementation and use of these corridor systems (or conduits) is likely to suffer from many of the existing problems of fixed rail transit and lack of popular public use. True, the linear associations of factories and services provide greater incentive to use these facilities (for a certain class?), but to what extent this may return in real gains is difficult to say. [42] The arguments here are of much the same nature as those presented in Part I, and must likewise be evaluated in their respective contexts. While Birkerts' accumulation of energy and recycling facilities within the distribution conduits is sensible from an efficiency point of view, the likelihood of relocating regional power plants, waste treatment facilities and transportation corridors, and effecting cooperation between these private utilities and public agencies may be at best, remote. Certainly every effort should be made toward capturing the environmental gains claimed by proponents of these approaches; ultimately, however, the justification of these claims will lie in the hands of the planners, architects, and engineers who are able to make them a physical possibility, and an attractive economic venture.

Perhaps it would be appropriate here to conclude this discussion with a scenario of the future offered by planner Constantinos A. Doxiadis; in his own way Doxiadis expresses the essence of the ideas of many who foresee a “return to the earth” as an advancement in civilization: [43]

> Entopia expresses realistically the Utopia of dreams, for which there is no place; and it is the opposite of the many Dystopias in which we now live. This Entopia will someday be built. Our children will begin to see it within their time, our grandchildren will see much more of it and our great grandchildren will enjoy it to the full.
>
> Entopia is organized as a complex of many communities, each with its own special character; all integrated into a harmonious whole with each other and with nature.
>
> We cannot see any means of transportation or communication in Entopia, because the land surface of the city has once again been given back to the people. Here the children play and communicate with one another and the elderly and disabled can walk and take their pleasure. Everyone enjoys these roads, where they can walk without fear or danger. The cars exist and connect all points to one another (each house with every other one), but they are all underground, they are fully automated and they travel at great speed.
>
> We see no factories, because these also are automated and below the surface. The few technicians who operate these underground factories work in the buildings to be seen on the green open spaces. The factories themselves are sited either under public installations, or below sports grounds or green open spaces, like those near the river, which used to be the worst part of the city.

ISSUES: PUBLIC ACCEPTANCE

One of the greatest perceived—or assumed—obstacles to the greater utilization of underground space is regarded to be the problem of public acceptance. [44] The roots of the assumed reluctance toward underground working and/or living environments may be attributed to a number of causes; these in turn suggest different approaches for dealing with the issue of "palatability" from a design standpoint as well as from a promotional one.

First of all, there is a group of problems related to the imagery of underground environments; these may be described as dealing with popular conceptions (or misconceptions) of the underground, of cultural symbolism, and of experiential associations. Western civilization's disdain for the subsurface is typified by the horrors of Dante's Inferno, by the underworld (Hades) of classical mythology, by the rude and barbaric connotations of troglodism, and even by the commonly perceived repulsiveness of dirt, and its association with death and decomposition. These represent cultural attitudes about the underground, and although somewhat removed from immediate experience, they are nonetheless real in their implications for architectural meaning. Architect Alfred Browning Parker, FAIA, refers to a design proposal of a berm-enclosed sanctuary for the University Christian Church in South Miami, Florida. His idea was to create "a community presence of repose and harmony with the earth... The not-being of the outside was intended to increase the significance of the space within." Although reportedly satisfying the budget, simplifying maintenance, and solving the noise problem of a busy intersection site, unfavorable congregational response defeated the proposed design. "It looks like a tomb," was the comment of some church members. [45]

More personal than the symbolic aspects are the images and associations compiled through one's own experiences. These may be purely experiential or indirectly observed, and may or may not take on social or psychological meanings. Consider, for example, the few occupational images generally available—coal mining, sewer maintenance, subway engineer; consider, too, the frequent connotations of subgrade space as inferior, utilitarian, or secondary in quality; personal experience with dank, dark, and unfurnished house cellars, apartment basements, and subways may soon accumulate and can confirm beliefs regarding an inferiority of the underground. It is likely, too, that subways, being a vehicle of mobility for the lower classes, possess social overtones that are reinforced by the ubiquitous graffiti and associated bargain basements and back doors of concourse department stores in many of our older cities. Seemingly, our social order has contrived to keep the lower classes and the less mobile underground, and quite literally out of sight. [46] Professor Donald Hagman's commentary on the offensiveness of underground dwellings summarizes both the disagreeableness of present imagery and poses a question worth consideration:

> Because national defense no longer seems to require it, at the moment below-surface living seems contrary to natural law and is a fit subject only for science fiction. If the construction of underground habitats became very inexpensive, one might have to worry about who would occupy the space. Would underground space become the new place for low-income housing, the new ghetto, the new place to hide social problems that remain because of slow income redistribution policies? Something would have to change dramatically before the elite would chose underground habitation. [47]

Hagman's remarks are in many ways spurious and lack qualification; one is led to question or suspect what constitutes his own (unstated) image of "underground habitation." His comments do describe, however, the need for an improved conceptual and visual image of underground development, and a better understanding of its purpose and potential. The problem of dealing with an already-unsavory popular image of an almost non-existent practice is fundamental to a greater acceptance of underground architectural alternatives, and has been met with a variety of responses from designers and writers alike. One way of contending with negative apperceptions is to supplant them with superior alternatives, either real or imaginary. This can be accomplished through publication of projects and by other promotional means. Another method of dealing with the problem of acceptance is through research. Richard D. Lonsdale suggests that the apprehensiveness of business managers and employees alike is due to a "perceptual barrier" to the very idea of working underground. If this reluctance is rooted in ignorance, he proposes that its validity can be tested through surveys of existing underground employee-attitudes and satisfaction with their working environments. Lonsdale's sense of a perceptual barrier leads him to recognize a promotional barrier as well; advertising and advocacy are as scant as is research, and therefore provide little incentive for considering the subsurface approach.

Other means are also available for legitimizing the case for underground use; they of course include the primary issues of energy conservation, environmental quality, and the various social benefits that follow from them. Certainly a better understanding of the benefits and perceptual issues alone can go a long way towards dispelling the devised notions regarding "natural law" expressed by Hagman. In a different manner, the application and use of terminology such as "geotecture," "terratecture," etc., may be perceived as lending a greater respectability to the subject that goes beyond their immediate purpose. These unfamiliar but readily-grasped terms possess the added virtue of being image-free, and without previous associations. Unless their usage becomes more universal and less restricted to small academic communities, however, they run the risk of becoming little more than pretentious euphemisms.

In the final analysis, palatability will be determined by the quality of subsurface environments. In the words of planner Ed Roberts, "public acceptance...is a matter of effective design."

UNDERGROUND ENVIRONMENTS AND USER RESPONSE: IMPLICATIONS FOR DESIGN

Generally speaking, there are few intrinsic spatial qualities of underground buildings. The terratectural examples and taxonomy demonstrate that subsurface architecture need not be windowless, "introspective," or cramped. Deep underground structures, while necessarily windowless in the surficial sense, may recoup much of the actual window function through the use of more imaginative spatial planning, through the use of internal vision panels (that may serve the same "visual linkage" as. provided by windows), and through the use of window surrogates. [48] Although the use of the window generates much architectural discussion, the "need" for windows remains a subject of much debate. (This subject will be discussed in greater depth in Appendix IIB.) Nonetheless, the quality of windowlessness is frequently correlated with the undesirability of the taxonomic types to which it applies.

The general lack of data regarding user response to underground facilities makes most arguments for or against the subsurface inconclusive. A sampling of the literature and research on the subject does provide some suggestion towards the inevitable architectural consequences. [49]

Psychologist Robert Sommer describes the complaints of employees of underground offices as concerning the "stuffiness and stale air, the lack of change and stimulation, and the unnaturalness of being underground all day." [50] He cites the frequency of employee's substitute windows—landscape scenes, travel posters, animal pictures, and the like—and states that "employees went upstairs at every opportunity except for a few who seemed totally turned off to their surroundings." A frequent response of interviewees in an underground data processing firm [51] was that they lost their sense of time, that things seemed dull or moved slowly. Such comments are difficult to evaluate; although indisputably related to both perceptible and perceptual underground conditions, the number, variety, and relative importance of the factors which shape "environmental satisfaction" are great, and often not to be taken at face value. An employee's attitude toward his or her particular task, relationship with fellow employees, ability to effect changes within the environment, contentment with salary and opportunity for advancement may all color one's attitudes and therefore expressions of satisfaction with a physical environment. [52] For instance, in this particular case, little information is given regarding the architectural quality of the spaces involved. It is specified, however, that the underground location carries an unequivocal social connotation: "the firm's executives were to have offices on the top floors of the building—it was the lower echelon clerks who would be underground." Sommer concedes by his own findings "that we also found underground offices where people were less vehement about their frustrations," adding however, that "no one was enthusiastic about being underground." [53]

In contrast, Truman Stauffer's experience with workers in Kansas City's lithospatial businesses also indicates a faulty perception of time—but in this case, to the effect that days seem to pass more quickly in the absence of external cues. Stauffer has also found employee response in Kansas City to be very favorable; this is partly due to the time factor, and partly due to the constancy of thermal comfort (which can be an important factor where work activity involves manual or industrial labor). [54]

The discrepancies between these findings can be attributed to differences in observation techniques, the nature of the tasks being performed, differences in the quality of the spaces, and to a host of social and psychological influences. A worker's past experiences and present expectations, the congruence of one's self-image with the status connotations of the working environment, the opportunities for stimuli to counter occupational boredom, the physical (thermal, aural, etc.) comfort of the environment—all are important and mutually-interacting (dynamic) factors in the determination of one's environmental satisfaction. These again are issues of context, and their roles and implications will vary as a function of task, status, and environmental quality. The truth of the adage that one sees what one looks for (i.e., one's attitude, or "environmental disposition") has been verified by sociological and psychological research; it must be recognized not only in discussing the perception of and satisfaction with underground environments, but in the design of subsurface interiors and behavioral settings.

Many of the architectural responses to user preconceptions about the underground are obviously related to compensation. Maximization of internal volumes, high ceilings, minimization of non-transparent partitions, optimal air circulation, variable illumination levels, "warm" or brightly-colored wall surfaces, programmed lighting, and abundant interior planting are all devices which have been employed in subsurface designs to counter preconceived notions of the characteristics of the underground. The variety of options and opportunities is unlimited, but demands great sensitivity to the basic principles of design. Although instances of surficial simulation have been said to be successful, the nature of geotectural design differs—particularly regarding human values and perceptions—from the surface, making literal transpositions of stereotypical decisions and relationships a dubious, if not disastrous, practice.

WINDOW SURROGATES

A prime function of the window has been argued as providing external stimulation that is (at least partially) capable of alleviating boredom with a work situation. This same function may be accommodated by internal atriums, which can provide both expansiveness of space and a view. Other mechanisms can serve the same purpose: Sommer mentions the use of fish tanks as an example of an activity-centered substitute window. Electronic devices, such as Panasonic's "Advision" color mosaic display system, could provide an entire wall of continuously evolving color patterns that might easily be programmed to provide higher and lower stimulation levels at their respectively-required times of the day. [55] The developing field of holography offers the potential for constructing three-dimensional projections, optical sculptures, and a variety of other visual and spatial effects. With the illusional quality of the holographic process, its potential could crassly be exploited to replicate picturesque window scenes, exemplifying simulation at its most blatant level of sophistication.

SIMULATION

Simulation itself may be utilized for many purposes, the most common of which is to provide a more familiar and (by assumption) more comfortable environment. This may be seen by its advocates as promoting public acceptance, but may elicit more sour responses and confusion than goodwill. [56] One source relates that some benefit was derived from installing draperies "wind blown" by electric fans in windowless buildings during World War II. Simulated window effects of this kind may indeed provide a sense of psychological comfort, but whether its success lies within the physical suggestion (deception) of a window, or through the sensory stimulus of the air movement itself can only be conjectural without testing. The "need" for simulation may indicate an inappropriate application of underground use, but may arise from purely cultural origins, or express other architectural or spatial deficiencies.

Simulation may be used to evoke certain feelings as complements to specific activities. Unquestionably one of the most ambitious (or grossest) simulations has been created by the Japanese in the Kocho Restaurant. Located on the second of four basement levels in the 14-storey Hew Yuraku Office Building in Tokyo, the restaurant consists of a two storey high traditional garden space with its association of teahouse, shoin, farmhouse, and party room.

> The mood, completely divorced from niggling budgets, is all luxury, ease, and wonderful waste. A parking lot and elevator hall are adjacent. Nonetheless, the minute one leaves the parking lot or the elevator, he enters a different world where shackles of time and place are forgotten.
>
> Everything here is artificial. The entire restaurant is so cut off from surrounding walls, and even from the grey concrete ceiling two stories above the garden floor, that the illusion of having stepped out of a large city into a rural retreat of the past is completely successful. Lighting, air conditioning, even the recorded sounds of the insects and of flowing water, dramatically heighten the effect. [57]

Much of the success of the restaurant's effect can no doubt be attributed to its incongruity of contexts--that is, its sheer inconsistency with one's expectations. It is this aspect of underground space--the element of isolation from the outside and the absence of experiential cues--that offers one of the great potentials of underground design for the architect. Philip Johnson expresses this device with respect to his gallery (see p II 7a): [58]

> Oh, yes, everyone likes caves...People get a positive pleasure going into my gallery. Going into a building that isn't there, they get that feeling of, "Where are we going?" Since every room is about 10 times bigger than they expect, there's a positive element of surprise and romance. Caves are probably an atavism of some kind; people enjoy being enclosed.

As designers learn to exploit the unique possibilities of underground alternatives, one would think that the issue of simulation will eventually become solely an aesthetic decision, not a mechanism for accelerating psychic adjustment.

PSYCHOLOGICAL AND PHYSIOLOGICAL ISSUES

If there are any serious psychological consequences of part-time underground use beyond those discussed thus far (attitudinal and perceptual), they are not well understood, and even more poorly documented. Sommer points out that claustrophobia (fear of confinement or enclosure) and other clinical maladies are much less common than they used to be, and that socially-related disturbances (alienation and schizoid detachment, e.g.) are more prevalent today. His implication seems to be that "environmental damage" may find expression through sociopathic responses rather than physical or object-related ones.

A number of studies, in both individual and group situations, have been conducted regarding shelter confinement and sensory deprivation, but their relevance to normal working or living environments is tenuous. For instance, researcher Michael Siffre has observed a change in biorhythm after 205 days underground, leading him to believe that in the absence of daylight "individuals would fall into [a] 48-hour cycle with 24-hour day/night cues." [59] What meaning if any this may have for diurnal underground dwelling or working conditions is unclear. LaNier cites a sensory deprivation study in which subjects consistently underestimated the length of passage of long periods of time, and in which, "...the isolated condition of sensory deprivation allowed an increased capacity for clear and creative thought broken by brief periods of sleep." [60] The usefulness of this information likewise is not readily apparent, particularly where an optimization of internal visual and/or spatial stimuli is achieved for reasons previously discussed.

Empirical research conducted by the U.S. Army indicates that "an artificial diurnal cycle approximating temperate zone cycle appears beneficial to [temperate-zone] inhabitants of northern regions." [61] Faber Birren, a leading authority on the subject of light and color, has written extensively on the necessary qualities of artificial light, and notes the future role of "psychic lighting:" [62]

> In an office, factory, or school, daylight sources plus some ultraviolet may be utilized for a good

> part of the day. For psychological and emotional reasons other light in other intensities and tints may be programmed: warm light in the morning, increased intensity and whiteness as the day progresses, "complexion" lighting at coffee breaks or during the lunch hour, pink or orange at dusk.

Psychic lighting may be used to enhance the passage of time, but to state a requirement for literal daylight programming would be a moot assertion: Jay Swayze anticipated a need for time clock controlled day/night simulated lighting in his underground house in Plainview (see p II6). The actual environmental desires of his family, however, encouraged him to override the timing device so that individuals could dial in whatever "time of day" they wished for their respective rooms.

The findings of studies conducted at the Abo Elementary School, a "true" underground near-surface structure in Artesia, New Mexico, are encouraging. The Abo School was built with the secondary purpose of serving as a survival shelter, and has twice been researched regarding its performance, psychological effects, and public acceptance. Bligh and Hamburger quote the researchers' summary: [63]

> It seems that after ten years of experience with children attending an underground and windowless elementary school, the professionals concerned with the health care of children in Artesia, New Mexico, the location of the Abo School, are generally convinced that not only is the school not detrimental to the physical and mental health of their patients, but it is actually a benefit to some.

> Although not as supportive of the school/ fallout shelter facility as the parents of the children who attended, the sample of the public clearly favored the school. Nine out of ten recommended that other schools be built like Abo, if such schools cost no more to build than other schools.

Results of a rigorous study on windowless classrooms conducted by the University of Michigan's Architectural Research Laboratory indicate that the removal of school building fenestration had little if any perceptible effect on children's learning achievements or their behavior. Teachers, on the other hand, were initially resistant to the idea of windowless classrooms, but by the conclusion of the experiment were among the most enthusiastic supporters, expressing a preference for the windowless environment. [64] As may be expected, preference for windowlessness is rare, although as yet unproven as harmful. (see App. IIB)

ECONOMIC ISSUES

The initial costs of underground construction are likely to be as variable as the number and permutations of types suggested in the accompanying taxonomy. The cost of development of mined-out areas may be almost negligible, whereas the expense of deep-cut and cover operations may be prohibitive. Few comparative studies have been conducted, and these generally have little direct architectural value. The following discussions are intended only to introduce some of the concerns which may be pertinent to different types of projects.

Perhaps counterintuitively, lithospace may constitute the least expensive of underground types, provided that the waste rock is a usable product, and that a local market exists. Experience in Kansas City provides the model for this, particularly in the case of Amber Brunson's instrument plant, where the sale of excavated limestone reduced the total cost of construction to one-third that of a surface facility.[65] Mining within rock, assuming the appropriate geological conditions exist, eliminates the need for costly foundations and external building shell, but can be a lengthy process. The availability of the necessary machinery will certainly be a major factor, as will the potential for future expansion. Nevertheless, the fact that the larger Kansas City installations are able to expand at the rate of 25 acres each year makes it an attractive alternative. Other developmental costs include the installation of mechanical equipment, plumbing and electrical systems, and interior partitioning and furnishings. Stauffer reports that the approximate cost of creating Kansas City lithospace (with about a 14 ft ceiling height) is $1.25/sq ft, plus utilities,[66] or roughly, the annual leasing rate for many of the facilities located there.

Cut and cover construction from the surface is usually considered "economically feasible" to 20 ft depths,[67] although much greater ones are possible. Soil and/or rock conditions will determine whether or not side supports (an additional cost) are necessary, or whether sloped sides will suffice. Some projects have been constructed with much of the shell cast directly against the earth, and in other cases, with earth mounds serving as formwork for vaults. Building items such as waterproofing and increased structural capacity to support the specified overburden of earth, plants, water (saturated soil), etc., constitute definite increases in the cost of the shell, which may (in part) be recovered from the elimination of surface finishes, insulation, and savings in mechanical equipment demands. Some costs, such as that of the roof slab, may increase as a function of depth, making the amount and nature of overburden a significant design issue. While Barnard reports a 25% decrease in building cost over a conventional surface structure, [68] this economy is closely related to the shallowness (12 -18 inches) of earth cover.

Operating, maintenance, and overhead expenses have generally been reported as lower for the underground, and has been discussed earlier. Hoch provides another (Swedish) example: [69]

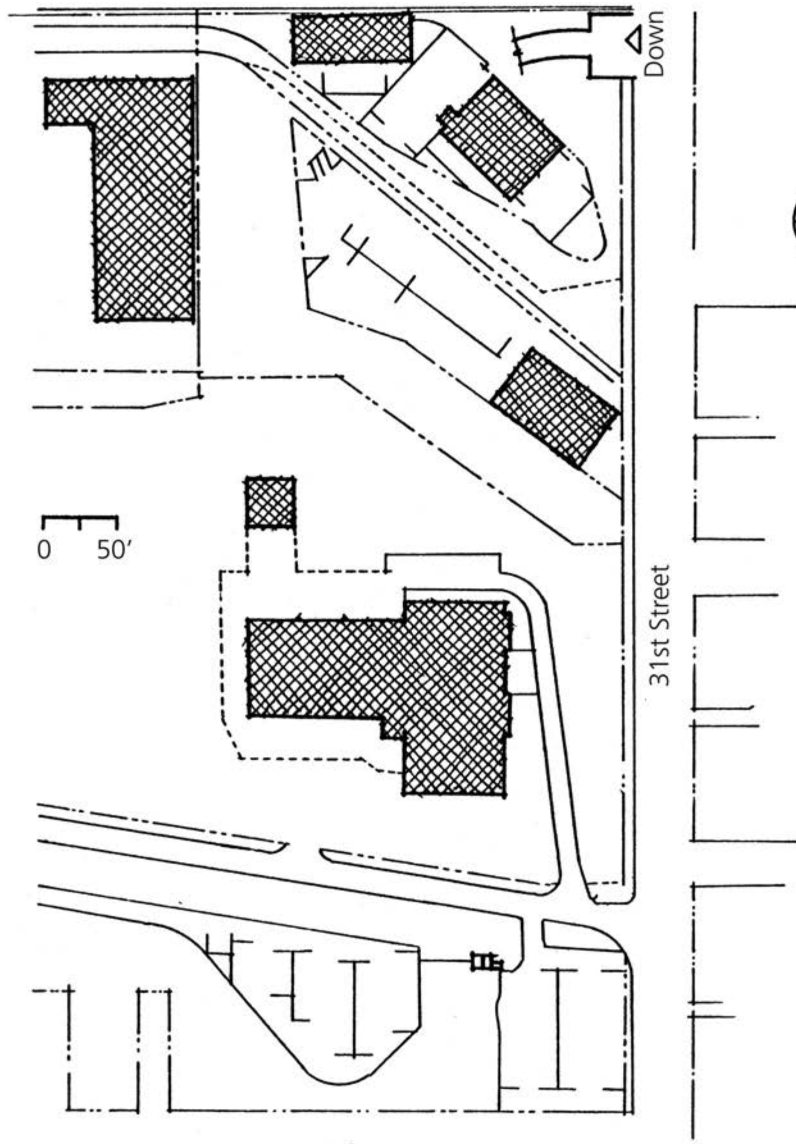
> ...the capital cost of putting a plant underground was 10% to 15% greater than that of the conventional plant. However, operating and maintenance costs were so much lower that the underground plant was the better investment. (There were no exteriors to paint or repair and little heat was needed.)

Perhaps the greatest economic benefit is the increase in usable space afforded by the underground. This properly is a planning consideration as well, and will be discussed in the following section} its economic value is of course related to the prospective uses to which the surface and subsurface are to be put. There can be little doubt that the economies of underground space use will inevitably be the measure of its increase or neglect; until it is studied more carefully, it is unlikely that many investors will regard it seriously as an alternative.

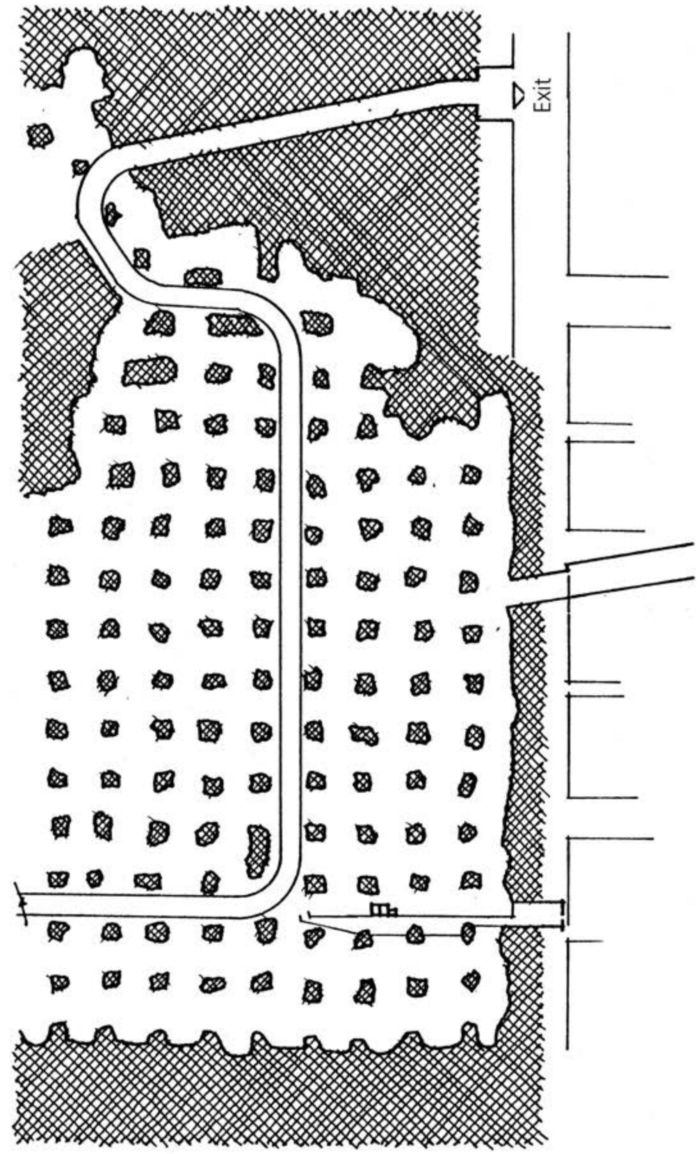
PLANNING ISSUES

The conservation and urban planning potential of underground space have been discussed in Part I and elsewhere, and need not be re-examined for confirmation here. Two other aspects related to more intensive use should be mentioned; these include the opportunities for what Stauffer calls "two tier" development, and the irrelevance of most existing zoning regulations. The site plans on the following page sufficiently demonstrate the two tier concept: the two plans overlay each other in the vertical dimension,

(Continued on p 33.)



TWO-TIER DEVELOPMENT AT DOWNTOWN INDUSTRIAL PARK, KANSAS CITY, MO (AFTER STAUFFER



(Continued from p II31.)

creating two totally-independent levels of profitable real estate, well within the municipal limits of the city. Many other sites in the Kansas City area are overlain with natural landscape and farms; one enterprise plans eventually to develop housing above their facility, while another has been negotiating with a local community to construct an 18-hole golf course above its ten million square feet of warehouse.

Land use of this nature has resulted in the concept of a split title fee and of dual zoning designations to permit different uses on the same parcel of land. Most zoning codes, based on conformity of aesthetic standards, have little governance over subgrade development; [70] this usually means that underground construction may occupy full lot limits at the subsurface level, irrespective of setbacks and building bulk controls. Local building codes may regulate other particular aspects of subsurface construction, and these should be investigated in all design situations. The independence of underground and surface uses, be it two-tier, transit tunnels, or inter-connected basement complexes, offers fairly obvious benefits in terms of sorting out potentially conflicting uses, A good example is the multi-level concept of urban development, which separates auto and commercial service circulation from pedestrian malls and human services. This offers benefits related to public safety and weather protection, as well as providing additional horizontal linkage to the vertical fragmentation of the city.

Still another significant planning aspect of underground use is in facilitating a greater continuity of surficial use. Hoch and Harrison [71] both point out the disruptive effects of high ways, industrial and strip developments, and the dangers and difficulties they provoke. These could be placed underground—even under residential districts, as suggested by Young, Birkerts, and Doxiadis [72]—thus providing additional land and fuel efficiencies.

OPEN SPACE PRESERVATION AND BUILDING FORM

The examples and preceding discussions point out how the subsurface can be developed in congested areas, retaining the open space that existed previously. Subgrade development is also a frequent and appropriate response to many building addition programs, where the uncontested image of a pre-existing building is desired. The underground approach may then be exploited for its "non-building" qualities, and its lack of presence. But this may also raise objections where form is desired, and this too can have its expression. The use of earth forms as a design element is a practice doubtlessly as old as architecture itself, and is regarded by many as a formal device that is powerful in its romance and simplicity. A review of the terratectural illustrations is evidence enough that the earth-integrated practice is not lacking in expression, although this may not be interpreted as what one commonly conceives a building to be.

AESTHETIC ISSUES

Another argument for the subsurface is aesthetic, particularly as it is related to the perception of urban form. Gunnar Birkerts, in the introduction to his proposal, *Subterranean Urban Systems*, makes the following statement about the physical presence of buildings:

> There are too many individual buildings today. Not every physical or functional need deserves the right to become a visual object on our landscape. Nor (does it have the right to occupy a piece of land, exerting its visual effects. Most likely, its presence is not needed for the formation of our urban fabric. We have to impose a "birth control" upon certain buildings and other structures in order to check the ugliness of urban sprawl. Achieving this de-escalation is one of the main and most difficult tasks confronting the society and the Architect today.

Birkerts' own proposal presents one solution to this situation. Arthur Drexler, as Director of the Museum of Modern Art's Department of Architecture, concurs: [73]

> An awful lot of things that have to be built don't require or merit architectural treatment, in the sense of being thrust forward into your consciousness as statements about material or space or anything else; they have no particular intrinsic interest. Architecture is still thought to be a matter of buildings, when it ought to be something else. Today all of our buildings are designed as large, useful objects. Each year we put up thousands of warehouses and factories, for example, which have no business existing as objects at all. They are services, means to an end. Why are they not concealed? Services belong in the ground. We should insist that whatever services are required be invisible, not beautiful.

George Nelson, an architect and professor at the Harvard Graduate School of Design, has taken this concept of "invisibility," and argued for its use as a cure for much of the visual pollution of our cities. He sees two possibilities: [74]

> One is familiar to us: build underground... The other, not familiar, is to build above ground, using structures like low profile Aztec or Mayan pyramids, covering them with topsoil and planting nasturtiums, poison ivy, or whatever comes to mind. Such structures would of course be visible, *but not as architecture*, which I see as their great virtue.

Nelson sees the required fact of windowlessness for many building types to provide the opportunity for realization of this concept. The common shopping center serves as an example:

> A typical shopping center is never thought of as waste by developers, but most of the land involved is covered with asphalt for parking. A civilized society might consider this as something of a waste, too, since the land under the asphalt is permanently destroyed as far as life support is concerned.
>
> Given the shopping center of today, there are few people who would want to live next to one, and as a result the adjoining properties are generally given over to parasitic marginal uses. But if one were to sweep the prevailing mess under one or more earth covered mounds, the entire aspect and meaning of the area would change, presumably for the better.

Of course the aesthetic benefits, or the elimination of unnecessary visual and nervous information, is difficult to quantify, and probably even more difficult to promote to finance-conscious clients. Yet, the ecology of benefits and returns integrally a part of the earth-building practice presents issues which the concerned designer must confront: they deal first hand with man's impression on the physical environment, and simultaneously demand the most rigorous grasp of the very essence of architecture

There unquestionably has been a renewed perception of the architect's role with respect to the form and content of the built environment. The past decade has witnessed attempts to probe the necessity of the architectural monument, the importance of city image, the hidden dimension of socio-cultural and psychological factors in design, and man's need to design according to the principles of nature. The concept of designing for survival, certainly the oldest architectural pursuit, seems only recently to have been rediscovered. Yet, never in history has man's basic relationship to the earth been more altered or diminished—or so threatened. Until it is more widely recognized that architecture is but man's detailing off the landscape," [75] then the collective mind of the profession will continue in its efforts to rationalize and justify the meaning of our current work.

SUMMARY: BUILDING TYPES

It is generally assumed by moat advocates of underground space that a prime, if not the major, motivation for expanding underground use is to make the surface both more available and more suitable for natural processes and human livability. No one recommends burying everything beneath the surface; it is neither feasible nor desirable. Nevertheless, a host of functions exist that are, by necessity, already well suited for and able to benefit from underground locations. [76] As suggested elsewhere, these include functions that are windowless, and functions that demand a critical degree of environmental control, or have no intrinsic relationship to the surface. A survey of the literature and of existing underground facilities indicates the suitability of the following building types:

INDUSTRIAL/CIVIL WORKS	COMMERCIAL/INSTIT'L
Waste treatment facilities	Department stores
Transportation systems	Supermarkets
Telephone exchanges	Shopping malls
Power substations	Restaurants
Light industry	Night clubs
Assembly plants	Theaters, cinemas
Warehousing, bulk storage	Concert halls
Refrigerated, cold storage	Museums, galleries
Parking lots, garages	Convention ctrs.
ALSO SUGGESTED	**AND**
Bus terminals	Libraries
Repair stations	Laboratories
Transport depots	Schools
Hotels, motels	Research centers.
Recording studios	Housing, offices

The American Society of Civil Engineers has attempted to assess the relative values and economic payoffs for different building types via a cost/benefit study in their report, *The Utilization of Underground Space to Achieve National Goals* (1972). Factors of economic, social, political, and technical feasibility were used to calculate the value of locating the following life support systems underground: 1) shelter structures, 2) transportation, 3) water resources, 4) liquid waste disposal, 5) solid waste management, 6) communications, 7) energy distribution. The generally perceived benefits of undergrounding these facilities is discussed in the following excerpt:

> At least three or four opportunities provide high potential for improvement when the underground frontier is examined closely. First, it will release *resources* or their surrogate (indicator) *money*, to apply elsewhere than where money is now applied in our systems. Most of the applications are presently constrained to the surface. Second, the new [underground] frontier can free *space* which grows dearer as the urban areas expand and become congested. Third, underground development offers increased *flexibility* and expands the numbers of options, in efforts to strike new balances in the urbanization process. Fourth, strategic development and use of underground space afford savings in one of the dearest commodities man possesses, namely, *time*. These factors (resources, space, flexibility, and time) present both an opportunity and a challenge to man's creativity.

The cost/benefit and cost effectiveness analyses led to the following conclusion:

> An analysis of the results leads to the identification of those functions that have the most promise of providing social and economic benefits. These are, in order of magnitude: shelter; commercial, industrial, and production structures; transportation; solid waste management; and electrical energy distribution. Of the alternative approaches for modifying the functions, the one that is likely to generate the desired benefits is the locationing of the facilities in subsurface space. But when overall feasibility is examined under the foregoing approach, the function for which underground location is the most feasible and the one that would generate maximum benefits is *transportation*. Secondarily, location of *electrical energy distribution* in subsurface space would achieve the next highest benefit.

Although found as providing the greatest overall benefits if implemented at a broad scale of application ($27.7 billion/year), shelter functions (residential, industrial, commercial) were interpreted as least likely to be applied at a significant scale of development. This is a result of assumed objections to windowlessness and lack of market appeal. In that public response will be related to quality of design, shelter feasibility may be greater than that assumed by the study. A summary display of the study's perceived benefits appears in App. IIB.

GENERAL APPLICATION

Like windowlessness, there exists no commonly held social, architectural, or aesthetic theories which can readily discriminate between building characteristics that are sub-surface exclusive and those which are ideally sub-surface suited. Some attempts to qualify the needs of the diverse behavioral settings required for human activity may be construed to provide some clues, however. For example, Mayer Spivak describes a three-part theory of "Archetypal Place," [77] consisting of concepts of setting deprivation, archetypal places, and life cycle requirements, and the idea of critical confluence. Spivak defines thirteen primary archetypal place types, and contends that the absence (deprivation) or availability of these at the times necessary to satisfy basic drives (critical confluence) constitute behavioral mechanisms which are fundamental to life itself. Some of these parameters, such as shelter, sleeping, mating, and grooming, require settings (e.g., bedrooms and bathrooms) that assure privacy and the opportunity for withdrawal; [78] these criteria are space-specific, and have definite architectural consequences. [79]

In that underground structures offer great advantages in acoustical isolation and visual control, an argument in its behalf for residential application may be made from these observations; or may suggest the practice of zoning certain functions to the subsurface (music rooms in particular), especially in areas where units are in close proximity.

In general, the idea of fully-underground, windowless houses is not likely to hold much public appeal, and would imply that some surface/subsurface compromise be considered. [80] Terratectural alternatives (commercial as well as residential) offer the opportunity for integrating the benefits of surficial and underground space, at the same time being within the easiest "reach" of most professional expertise. Since nearly any low-rise structure can be accommodated in the near surface without sacrificing windows, skylights, and surficial access, the shallow option offers the greatest flexibility and practical potential. In view of this, Part III will emphasize the physical issues of near-surface construction, and the problems of interfacing with the natural environment.

Part III—Building Issues

BUILDING ISSUES

Earth and atmosphere differ greatly in the irrespective interactions with a building shell. From these differences arise the benefits—and some peculiar problems—to be experienced with underground construction. The intention of Part III is to promote some familiarity with the properties of the earthen physical environment, with some modes and methods of interfacing with the subsurface, and with design considerations regarding heat loss, energy conservation, and mechanical equipment.

To simplify the structure of discussion, these environmental properties and their respective building responses will be divided into two headings, the first being a review of physical (material) parameters, and the second being a discussion of thermal (energy) characteristics. As stated in Part II, this section will deal exclusively with those issues pertaining to near-surface (terratectural) construction, and will not discuss the structure of deep space, as it relates to the methods and expertise of engineering geology.

PART IIIA: THE PHYSICAL ENVIRONMENT OF SOILS

Soil is a general expression that applies to the unconsolidated layers of the rock and organically-derived mix of particles that overlies bedrock. The nature and composition of soil varies from site to site, as it is a product of weathering and other environmental processes (erosion, leaching, plant and animal activity, organic decomposition) upon the local geology. The stages of soil development are evident in the soil profile, the vertical cross-section of earth taken at some given place. Examination of a typical profile reveals several strata called horizons, each of which is distinguishable as a separate interval in the geological act of rock becoming soil. The drawing on the next page depicts a sample profile, and describes some of the usual characteristics of each horizon.

Individual soils are generally classified according to origin (parent material, geological history) and by grain size, or the relative composition of the four principle constituents of sand, gravel, silt, and clay. They are defined as follows:

Gravel Greater than 2mm in diameter

Sand Between 0.05 and 2mm; grains visible, gritty to the touch

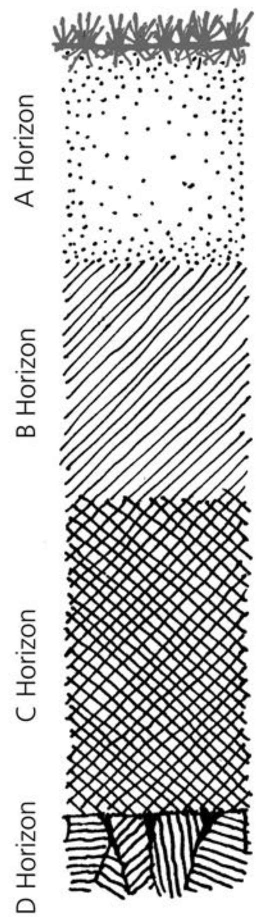
Silt Between 0.002 and 0.05mm; grains invisible, but can be felt (smooth and fine, deposited by rivers)

Clay Less than 0.002 mm; very smooth and flourly; in stiff lumps when dry, sticky when wet; slippery and unstable

Soils are sometimes found in these pure states, but the vast majority of known soils are a combination of two or more; these mixes are described by their components, for example, a "sandy clay," or a "clayey sand." A three part combination of sand, silt, and clay in nearly equal amounts is known as *loam*, a friable (easily crumbled or pulverized) soil which usually contains some organic (vegetal) matter. Other designations for commonly encountered or problematic soils include *gumbo*, a fine-particled, sandless clay which is dark, plastic, [1] and very sticky. It is known to expand and contract greatly with variations in moisture content, and is said to be one of the most difficult soils to handle in excavation.

THE SOIL PROFILE: A VERTICAL CROSS SECTION

THE SOIL PROFILE IS TYPICALLY COMPOSED OF THREE OR FOUR PRINCIPLE STRATA (A,B,C, & D), EACH OF WHICH MAY BE DESCRIBED IN TERMS OF INTERNAL SUBSTRATA (A_1, A_2, etc.). (AFTER ODUM, SEELYE)



SURFACE

A HORIZON: TOPSOIL
(Zone of humification process)
A_0 leaf litter, organic debris
A_1 humus soil
A_2 leached material

B HORIZON: SUBSOIL
(Zone of mineralization)
little biotic activity, fewer roots than topsoil; frequently considered as upper (B_1) and lower (B_2) subsoil

C HORIZON: PARENT MATERIAL
(Level of weathering activity)
no biotic activity, few roots; soil source material in varying degrees of modification by inorganic agents

D HORIZON: UNDERLYING MATERIAL
such as consolidated bed-rock, hardpan, etc.

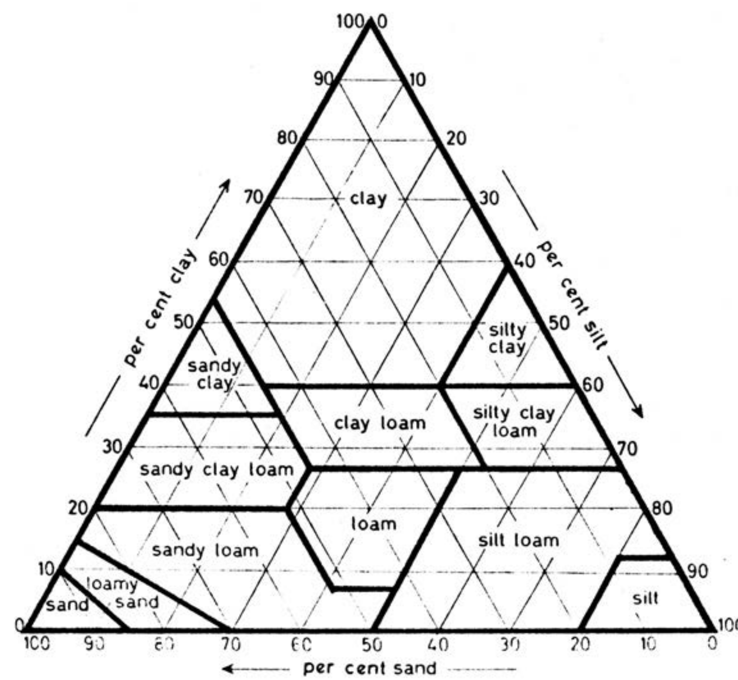
(Not to Scale)

Humus denotes a dark brown amorphous earth of the topsoil, consisting of partly decomposed vegetal matter; it will decay, hold water, and shrink as it loses moisture content, making it unsuitable for foundations. *Hardpan* is a densely-cemented, cohesive, and hard (rock-like) soil that will not soften when wet. It is both difficult to excavate and offers great resistance to penetration by boring tools. *Loess* refers to a uniform, cohesive, and porous—but coherent—(windblown) deposit of very fine particles. Their size ranges between 0.01 mm and 0.05 mm, corresponding to silt or a silty clay fraction. Cut slopes in loess are able to stand nearly vertically. *Mud* describes a mixture of silt or clay with water. The consistency of mud is that of an almost fluid mass. [2]

The composition of soils is frequently displayed on a triangular coordinate such as the one at right (sometimes known as a "Feret triangle"); its partitioning here demarcates the qualifications for a number of common soil types.

Since the structural behavior, bearing strengths, and engineering mechanics of soils are well documented in a number of foundations and engineering texts, the discussion here will emphasize those characteristics most directly related to architectural design. Some other terms that will be useful in describing these properties include *cohesiveness*. A cohesive soil is one in which soil particles tend to form a united mass; this is attributed in part to intermolecular attraction between particles, and partly to the capillary action of soil moisture, the

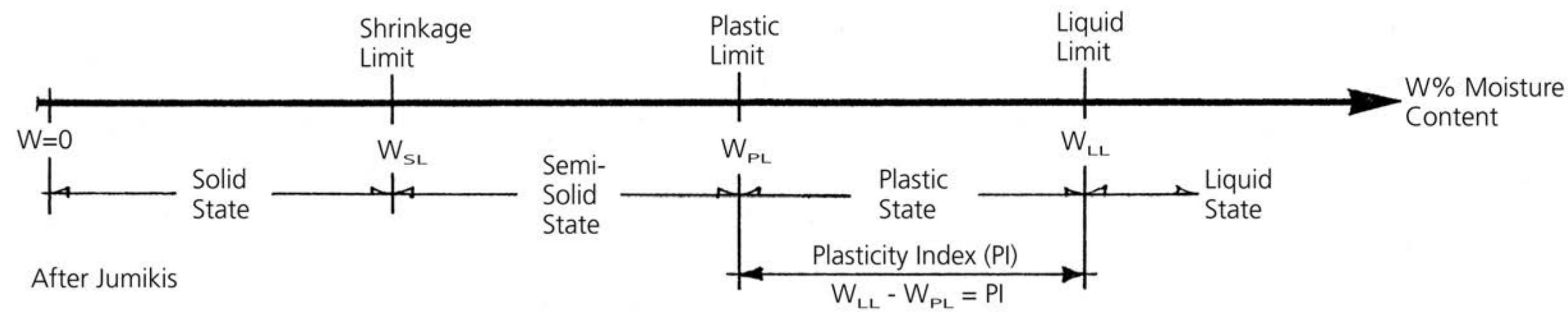
SOIL CLASSIFICATION SYSTEM USED BY THE UNITED STATES DEPARTMENT OF AGRICULTURE (SEE LYNCH)



latter being referred to as *apparent cohesion*. When submerged, the capillary attraction is negated by the fluid presence of water, and the apparent cohesion is destroyed. Cohesive soils typically swell when wet, and shrink as they undergo a loss of moisture, *Non-cohesive* soils are composed of finely weathered rock particles (e.g., sand); non-cohesive soils do not possess plasticity. *Plasticity* refers to the ability of a soil to be molded, or to flow without rupture, disturbance of coherence, or major changes in volume. Soils are regarded to possess relative—or *degrees of*—plasticity, which is directly related to their moisture content. *Plasticity Index* is utilized to describe the stages of consistency (shown below), and is defined as the difference between a soil's *liquid limit* and its *plastic limit*. All cohesive soils exhibit liquid, plastic, and solid states of consistency as a function of soil moisture. Liquid limit and plastic limit refer to the amount of moisture contained in a soil during its transition from one state to another. These relationships are diagrammed on the following page. ("W" denotes moisture content) The capacity of a soil to change state is an important determinant of its stability, and of its internal friction. These in turn, are of great interest to the designer, for they present both restrictions and opportunities toward design solutions. [3]

Soil Classification by Plasticity Index (After Jumikis)

Type of Soil	Cohesiveness	Degree of Plasticity	Plasticity Index	Liquid Limit	Plastic Limit
Sand	Non-cohesive	Non-plastic	0	20	20
Silt	Partly cohesive	Low Plastic	<7	25	20
Silty clay	Cohesive	Medium Plastic	>7	40	25
Clayey silt	Cohesive	Medium Plastic	<17	40	25
Clay	Cohesive	High Plastic	>17	70	40



The internal friction of a soil governs its *angle of repose*, i.e., the maximum slope which it may assume and remain stable, or be content to rest. Bern slopes may not exceed this angle without danger of slippage, but, as may be seen in the accompanying chart, will vary from place to place as a result of local soil and weather conditions.

Typical Angles of Repose (See Appendix III)			
Soil Type	**Characteristics**	**Degrees**	**AS Ratio**[4]
Clay	firm (10-20% H_2O) wet	20-30° 7°	2:1 8:1
Sand	dry saturated	33° 15°	1.5:1 3.7:1
Earth	firm, in situ loose, or humus	45° 30°	1:1 1.7:1

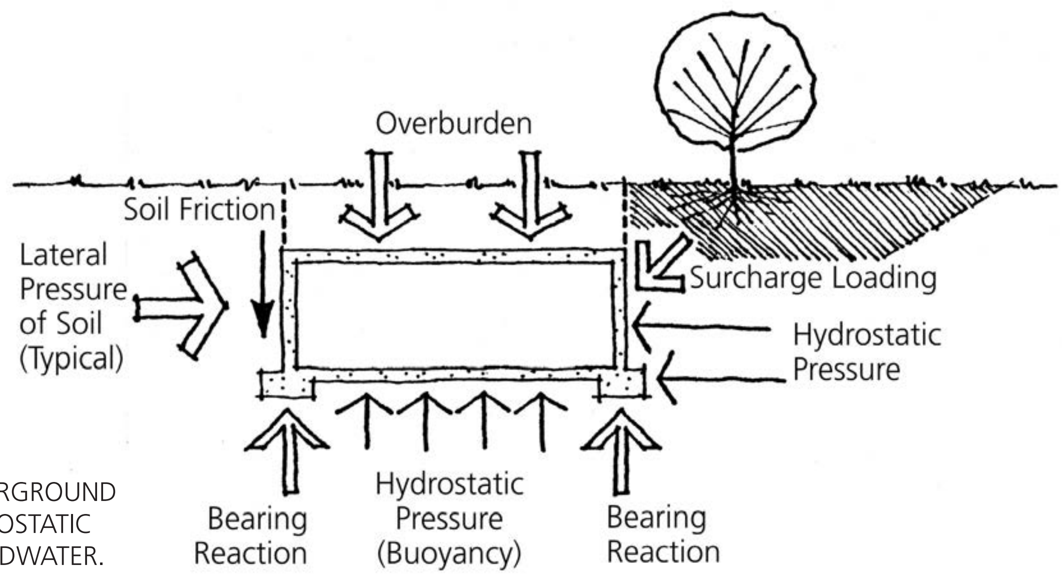
An angle of repose of 33° (a 1.5:1 slope) is perfunctorily taken as a design value for common soils, although a number of other factors, including rainfall, drainage, moisture content, subsurface geology, and plant cover may modify this a great deal. In general it may be said that damp earths will withstand the steepest slopes, and that constantly wet or dry clays, silts, and loams will be limited to shallower angles.[5] Since slippage resistance will vary as a function of weather (moisture) and loading (plant, snow cover, etc.) conditions, these must be taken into account when slope angles are planned. (An expanded listing of angles of repose and a discussion of "safe slopes" appears in Appendix III) Several means of mechanical and chemical stabilization (see p. III18) are frequently employed to maintain steep and newly-graded slopes; the use of ground cover vegetation serves also to unify the soil surface, and provides other benefits as well (see Part I).

Another physical characteristic of soils having direct bearing on terratectural design are their unit weights and water holding capacity. Both contribute loadings required for the sizing of structural members. Some common soil weights are provided here for illustration, and a more comprehensive list appears in the appendices.

Some Unit Weights of Soil (See Appendix III)		
Soil Type	Condition	Lbs/Cu Ft
(Water (Ref.)	**4° F**	**62.4)**
Earth	dry, loose moist, packed	76 96
Sand	dry wet	100 120
Clay	organic very dense	88 125
Loam		100

SOIL PRESSURE AND BUILDING STRUCTURE

Consider a simple rectangular box located beneath several feet of earth cover. The principle forces acting on the shell will consist of those shown in the diagram below. The most simple of these, the weight of the overburden, will be a direct result of design decisions as to the nature and thickness of the cover, as

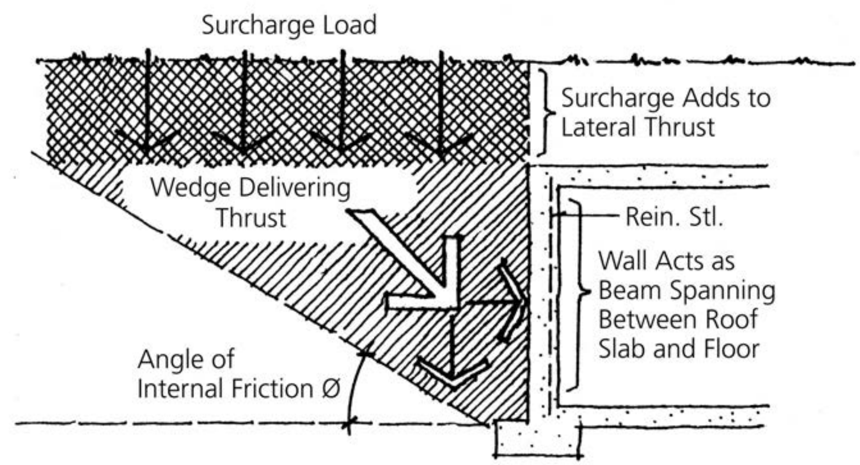


TYPICAL LOADING PRESSURES ON AN UNDERGROUND STRUCTURE IN A SOIL ENVIRONMENT. HYDROSTATIC PRESSURES OCCUR IN PRESENCE OF GROUNDWATER.

well as additional anticipated live loading, be it people, automobiles, deck furniture, oak trees, or whatever else may be desired. Overburden loading may generally act as a uniformly distributed load, unless organized otherwise (as in the case of a sloped overburden surface). Surface point loading will be distributed somewhat by the soil, and this distribution is assumed here to be calculated after the manner of surcharge loads, described later. Data for soil and moisture loading is provided in the appendix, but it should be pointed out that if the surface is to be planted, the accumulation of biomass from such plants may also contribute loading of great importance. Robert Zion recommends, for example, that the weight of a tree can be computed at the weight of 75-100 pounds per inch of caliber. [6] Information of this type is scarce, and necessitates a careful study of the anticipated loading conditions (and generous safety factors to accommodate future loads!).

In spite of the apparent stasis of underground structures, a great number of physical forces less perceptible than that of direct overburden are in action upon them. Rankine's Formula supposes that a mass of earth when released of its opposing horizontal forces (as in the case of a vertical excavation) will attempt to dislodge and slip downward along the plane described by the soil's angle of internal friction. [7] The earth is regarded as a wedge which delivers a diagonal thrust downward against the structure. This force is resolved into a lateral thrust against the wall, and a vertical pressure acting on the footing and lower soil masses. Some nominal downward friction is conveyed to the wall by soil in contact with its surface, and thus may contribute to the load on the footing; it is usually neglected in calculations regarding the

DIAGRAM OF RANKINE'S "SLIDING WEDGE" CONCEPT



wall itself, however. Because the mass accumulates in a downward direction, the lateral pressure against the wall increases with depth, resulting in a trapezoidal loading (see illustration). Rankine's theory calculates the thrust as:

$$T = \frac{w(1-\sin\theta)}{1+\sin\theta}\frac{H^2}{2}$$

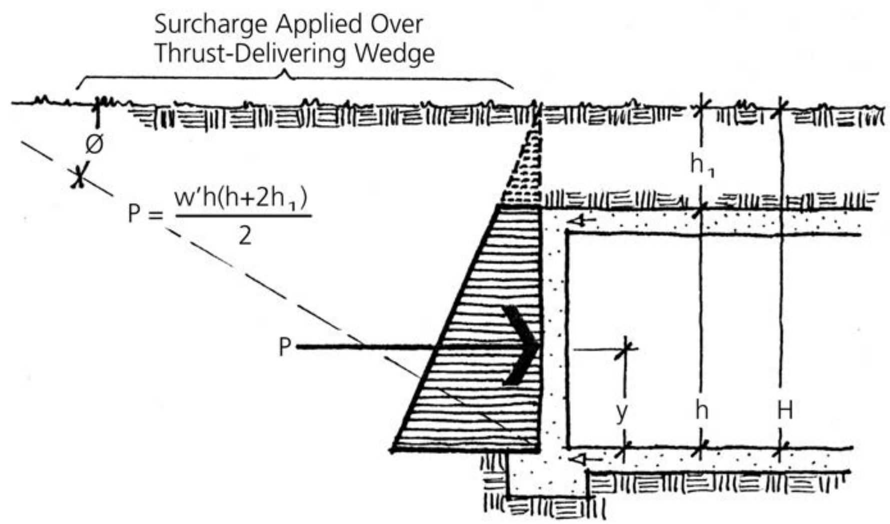
where:
w = unit weight of soil
θ = angle of repose
H = height of wall + depth of surcharge

The term $\frac{w(1-\sin\theta)}{1+\sin\theta}$ expresses what is called the *fluid loading*[8] of the wall. When the value of 100 pcf. is entered for *w*, and an angle of repose of 35° for 0 (both typical for loam), the expression simplifies to a loading pressure of 29.5 psf.; this figure is frequently rounded off to 30 psf., and is known as the *equivalent fluid pressure* (*w′*) for "ordinary" conditions. In lieu of computing the equivalent pressure for different conditions using the entire Rankine expression, a table of such equivalents is often employed to simplify calculation. The following table is a compilation of these for different conditions.[9]

EQUIVALENT FLUID PRESSURES (PSF. AT I'-0" DEPTH)

SOIL CONDITIONS	w'	w
• well-drained gravel	.20	
• very permeable coarse-grained backfill (w/o fine soil admix)	.27	.110
• average earth	.30	.100
• low permeable coarse-grained backfill (w/ silt-size admix)	.35	.115
• soil w/ stones, loamy sand, backfill w/ conspicuous clay	.45	.115
• wet sand	.50	
• water-bearing soil	.62.5	
• saturated earth	.75	.100
• fluid mud	.80-100	
• soft clay	.100	.100
• plastic clay	.120	.120

(w values in pcf.; provided for comparison)



Utilizing the equivalent fluid pressure w' from the table, the Rankine equation simplifies to resultant pressure $P = (w'H_2)/2$. The wall itself is conceived as a beam spanning from the roof slab to the floor with this pressure acting against it.

The center of the resultant P's action is located by the expression:

$$y = \frac{h(h+3h_1)}{3(h+2h_1)}$$

where: y = distance from base of wall to centroid of pressure,
h = height of wall in feet
h_l = depth of surcharge

H is given to equal $(h + h_l)$, thus the resultant P_2 on H is $P_2 = (w'H_2)/2$.

The resultant P_l on h_l is $P_l = w'(h_l^2)/2$.

The resultant on the wall h, therefore, is

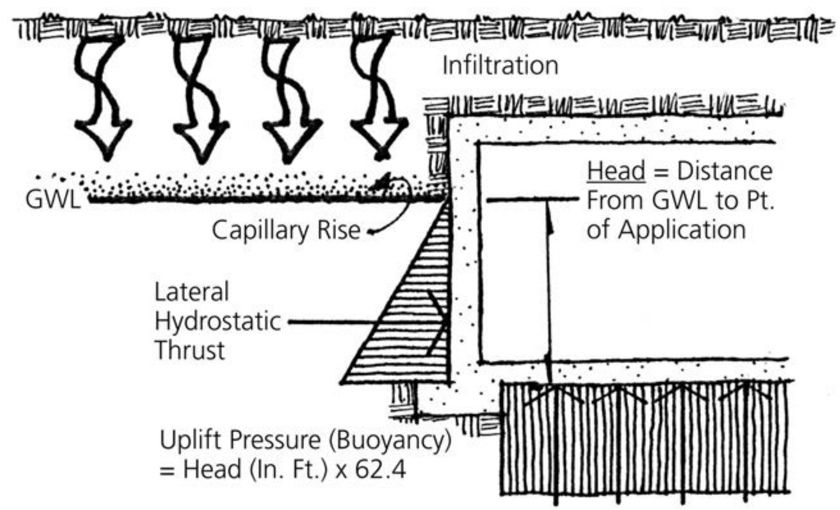
$(P_2 - P_l) = 1/2\, w'(H^2 - h_l^2)$, so the pressure exerted on the wall is given by:

$P = 1/2\, w'h\,(h + 2h_l)$

From this, the moment may be determined, and the wall section sized. Additional surcharges are easily calculated in the same operation as above: "...the applied [surcharge] loads are calculated in terms of weight of soil, thus giving additional height to the triangle of pressure."[10] For instance, if a patio were to be constructed of four-inch brick laid on edge (35 psf.) set in a two-inch deep bed of packed sand (about 15 psf.), this would constitute an additional surcharge loading of 50 psf., or the equivalent of six-inch greater depth (at 100 pcf.) of the existing surcharge overburden; *h*, and *H* would simply be increased by one-half foot in the original computation to compensate for the additional patio load. This principle may be applied for any extra loading which may be translated into equivalent terms of the soil's own weight.[11]

GROUNDWATER AND HYDROSTATIC LOADING

Soil water content is of interest for at least three reasons in addition to its contribution to overburden weight: it may impose hydrostatic loading of great pressure on the structure, it necessitates moisture and waterproofing measures to insure a dry interior, and soil moisture itself constitutes a major factor in the thermal conductivity of soils, and hence, the rate of heat loss to earthen surroundings. Soil moisture may be attributed to one or both of two sources: precipitation is absorbed by the surficial horizons, and then infiltrates into lower regions by the gravity-induced process of *percolation*. As the percolating water trickles downward, some of it is taken up by the soil medium it passes through, thereby increasing its moisture content. The remaining snow or rainwater finally reaches and recharges the *water table*, the levels of soil saturated with *ground water*. The ground water level (GWL) assumes no fixed height, but fluctuates seasonally and annually as a function of rainfall and other climatic phenomena. Groundwater flows, and behaves in much the same manner as surface water. It tends, therefore, to conform roughly to surficial topography, as modified by subsurface geological conditions. The soil strata immediately above the saturated GWL is humidified by capillary attraction, the drawing up of water by the physical forces of cohesion and surface tension. Soil water due to infiltration, capillary action, and the liquid presence of ground water pose somewhat different problems of design, and may be dealt with in different ways. First, it should be noted that groundwater, like its surficial counterpart, produces what is known as a *hydrostatic head*, or a hydraulic pressure which at any given point is equal to the difference (in feet) between that point and the water level surface multiplied by the unit weight of water, 62.4 pcf. This hydrostatic pressure acts equally in all directions, producing a lateral thrust on submerged walls, and a vertical *uplift* on the underside of structures below ground water level (see below). Uplift pressures can



be of great magnitude, and must be considered in the structural design. [12] A head of 8 ft will produce a uniform uplift of 500 psf (8 x 62.4), hardly a trivial amount for a floor slab which may itself normally weigh less than 100 psf. Conditions of this nature demand that

1) the floor slab be designed to resist the upward pressure, and 2) that the uplift force itself is distributed to the overall structure so as to prevent buoying up of the slab independent of the rest of the building.

R. W. Sexton suggests that structures built for these conditions might be likened to (and possess the structural integrity of) a storage tank, "except that they are built to resist pressure from without rather than within."[13]

With respect to lateral pressure, it may be seen that where an equivalent fluid pressure for a normal, well-drained soil has been assumed, that hydrostatic loading will be in principle additive to the wedge-thrust pressure. Water has a buoyant (lightening) effect on soil which is saturated, thereby diminishing its apparent weight (w), and relieving some of its load pressure on the wall. Pressures computed using the dry soil w' values and hydrostatic pressures are not, therefore, directly additive, but are modified by this buoyancy. [14] Hydrostatic force is incorporated in the Rankine calculation where a saturated or liquid soil condition is assumed, and where the appropriate w' is utilized.

The presence of groundwater near the surface does not rule out underground proposals as design solutions, but usually will be reflected somewhat in the cost of construction. One writer in reference to basements has stated, "...the question is not whether it is possible to cope with water conditions, but how to go about it economically." [15] In areas with known high water tables where a near-surface structure is desirable, it would no doubt be wise to consider derivations of the berm alternative. Since infiltration and occasional seasonally-high ground water levels are commonly dealt with quite satisfactorily, a few of these conventional techniques will be reviewed here.

WATERPROOFING

There are two basic and compatible approaches to the handling of soil water with respect to buildings. One is to accept its presence and design for those conditions, and the other is to manipulate the conditions themselves in the attempt to reduce the amount of water present. The first of these is waterproofing of the structure, and will involve one or more of three common techniques. Integral waterproofing relies on the water withholding ability of the structural shell itself to repel soil moisture. With the possible exception of steel plate, probably only reinforced concrete is suitable among common materials for this technique. It is said that a properly-designed [16] concrete wall may offer the best of integral waterproofing. Since the high degree of control necessary to achieve the desired quality is difficult to obtain in the field, a number of product admixes are available to insure the water-resistant integrity of the concrete. These generally consist of chemical additives that increase the workability of the concrete mix, helping to eliminate undesired porosity, or of inert materials (very fine sand, clay, etc.) that fill the interstitial voids which transmit moisture. [17] Integral waterproofing is susceptible to failure if the concrete should crack, heave, or contract at the joints, and is, therefore, often supplemented with membrane or surface coating techniques.

The membrane waterproofing method employs a relatively thin elastic and cohesive moisture barrier, which is ideally applied to the outside of the structure. External water pressure then forces it against the wall, which offers it support; this location, however, makes it vulnerable to frost, root attack, soil acid, and rupture by backfilling operations. Consequently, a protective wall layer is frequently built up against the outside face of the membrane (creating a sandwich-like structure) to isolate it from direct contact with the soil. [18]

The membrane itself has conventionally consisted of a hot-mopped bituminous substance (coal tar, asphalt, pitch) with alternating plies of a fabric reinforcer (felt, burlap, fiberglass, canvas). Thickness is determined by the anticipated head of water (see chart on following page). More recently, membranes of butyl rubber (typically $^{1}/_{16}$ in.), vinyl, and other synthetics in sheets have been utilized with overlapped and

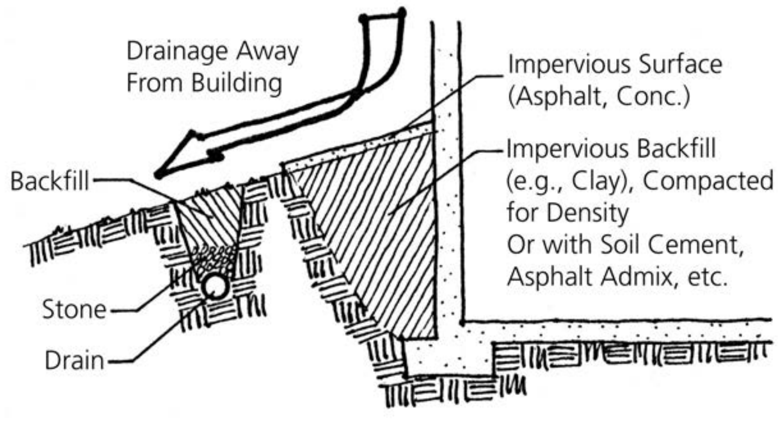
Number of Plies of Waterproofing by Head of Water		
Head (in ft)	Coal Tar/Felt	Asphalt/Felt
0	2	2
1-3	3	3
4-10	4	4
11-25	5	5
(FROM TIME-SAVER STANDARDS)		

cemented joints. Some other forms of external waterproofing applications are available (for example, a product made of bentonite, an ultra-fine clay which swells when wet, and acts as a sealant); for more information, see manufacturers' product data.

Surface coatings serve the same function as the membrane, but are generally of a rich cement base (and are sometimes referred to as "hydrolithic"), and are applied directly to the outside (preferred) or to the inside of the structure. Their impenetrability is dependent on how effectively they seal the pores of the surface, although being non-elastic, are also subject to shrinkage and cracking and a subsequent loss of waterproofing integrity. Interior surface coatings possess the virtue of being able to be applied after the wall is completed; cracks are easily visible and accessible for simple, economical repair, and may not present a problem. Cement surface coatings are hard-wearing and typically total (in two layers) 3/4 inch in thickness for walls, and one inch for floors. Surface coatings are reported to have resisted hydrostatic heads of 190 feet.

DRAINAGE

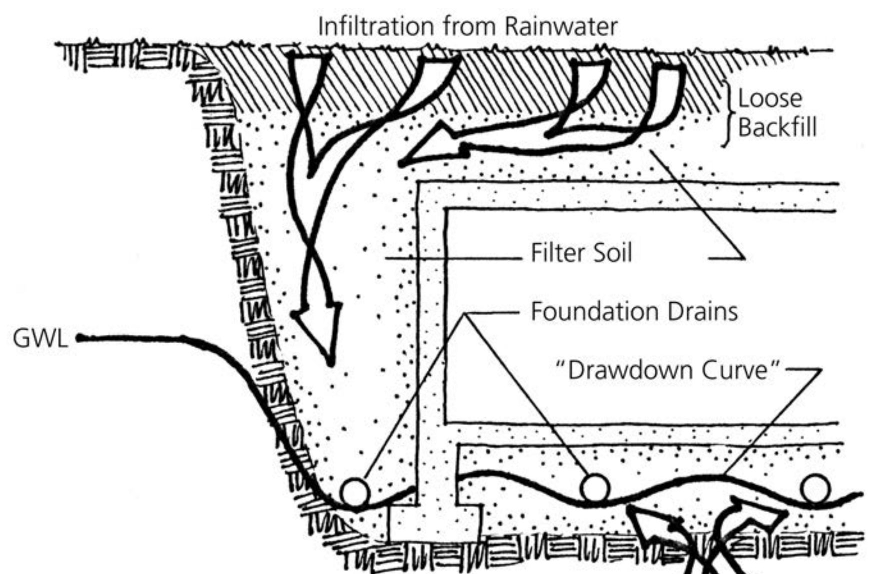
The second basic approach to dealing with soil water is to drain it away from the building, as soon and as fast as possible. This may be done at both surface and subsurface levels. In areas of low water table where ground water is no problem, infiltration may be minimized by routine practices of surface drainage. The standard procedure in surface buildings is to pitch the ground surface away from the structure, so as to prevent seepage downward along the wall. Many references recommend sealing the surface around the perimeter of the building with an impervious layer of asphalt or concrete (a walk, e.g.), in order to deflect water away from the



CONVENTIONAL SURFACE-SEALING PRACTICE WITH INTERCEPTED DRAIN (AFTER JUMIKIS, PARKER)

subgrade wall. While this may offer a possibility for underground application as well (for instance, a surface patio extending beyond building wall lines), it may also be undesirable. [19] Some sort of subsurface deflector analogous to the impervious surface surrounding a building might provide some benefit, particularly if used in conjunction with gravel or tile intercepting drains; their usefulness will of course be determined by specific site conditions.

In areas where a seasonally-high water table is known to exist, a somewhat different attitude is taken. "If there is a large head of 3 ft or 4 ft, it is almost always more economical to put in a drain and filter soil system." [20] The purpose of subgrade drainage is to depress or draw down the ground water level by accelerating its conveyance to some lower point—an outfall on a lower part of the site, for example. The relative groundwater heights over a given site must be known to make successful design of a gravity system possible; if there is insufficient difference in head over the site, the water may be drained into a sump, and pumped to a discharge location elsewhere. [21] Since the purpose of a foundation drainage system is to remove water from the wall area, a fast-draining,



(Adapted after DeSalvo, B.R.)

highly-permeable soil is usually preferred for the backfill instead of a dense, compacted one. This will serve to reduce earth pressures on the wall (especially those exerted by compacting), and to minimize the retention of infiltration and capillary moisture. Where the water table is higher than the floor slab, under-floor drains may also be required, and should be spaced so as to draw down the water level beneath the underside of the slab. The depression curvature of the GWL is shown in the preceding drawing; its shape is related to the permeability of the soil. Note also the use of a filter soil (often sand or gravel) beneath the slab—this too aids in reducing capillary rise to the floor slab. [22]

OTHER BUILDING CONSIDERATIONS: SITE & SOLUTION

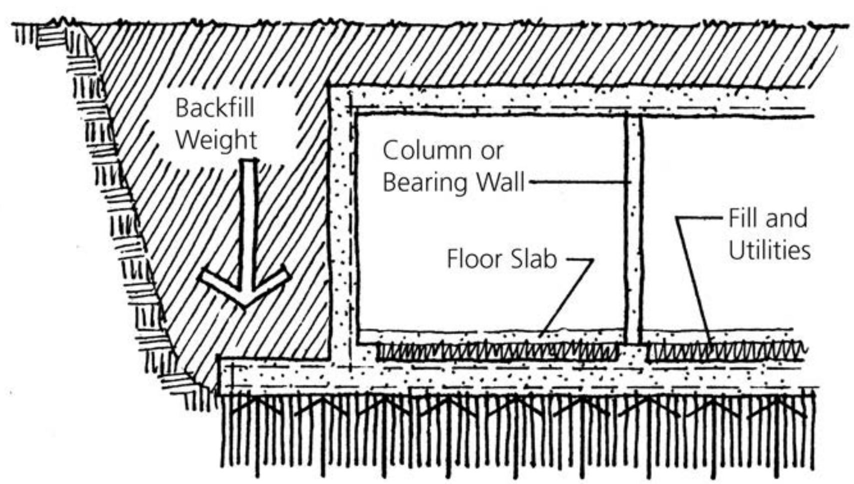
Even a cursory examination of the issues discussed this far should relate how the many variables defined by a specific site will tend toward simplifying the selection of suitable (taxonomic) solutions. The costs of handling groundwater and waterproofing, the nearness to the surface of (and expense of excavating) bedrock or hardpan, local topography, slope exposure to sun and winds—all these are considerations in determining the relative benefits and degrees of "undergroundness" which may be appropriate to a given problem. Certain structural and taxonomic combinations possess their own strengths and weaknesses and must be evaluated in the context of site and program. From a general standpoint, however, it can be seen that surficial or recessed berm types provide a useful mix of physical characteristics, including a minimal amount of deep excavation, a balance of cut and backfill (or cover), the elimination of groundwater problems, and an external geometry that sheds precipitation and therefore reduces moisture infiltration.

From a structural standpoint, it is obvious that the flat slab is poorly suited to the conditions imposed by (heavy) earth loading. Structural vaults, on the other hand, resolve the combined vertical and lateral loads neatly, and themselves shed water by their geometry. Semicircular vaults may be formed relatively easily by conventional construction procedures, and also increase volume/surface ratio over slab construction.

The interior design of such vaults may present some difficulties (esp. acoustically), but certainly offer dramatic spatial opportunities as well. Laterally-compressive earth loads may be responded to in a similar manner, making (carefully analyzed) curvilinear walls suitable as well; the quatrefoil plan of Philip Johnson's gallery (see illustrations, Pt. II) is primarily an expression of his radial display/storage system, but also makes sound structural sense. Other considerations to be kept in mind regarding different taxonomic types involve the overall resolution of loading and choice of foundations. Clearly, an elevationally-exposed underground design tucked into a hillside will have completely different loading conditions on opposite outer walls. In stable earths, such a situation should provide no major difficulties, but in highly plastic soils, the problem needs to be considered carefully. Likewise, a vaulted cross section should be loaded equally on both sides, while several-storey-deep structures will require considerable reinforcing of side walls. Since foundations are designed as underground structure as a matter of course, little needs to be said about them here. One particular type may be of special interest, however, and is discussed briefly below.

In the likelihood of continual subgrade water presence, with respect to both hydrostatic loading and moisture penetration, the choice of foundation types becomes increasingly critical. Where a tank-like enclosure is desirable (see p. III11), the use of a *mat foundation* can provide significant benefit. A mat foundation consists of a single, heavy reinforced slab which supports the entire structure above it (hence is sometimes called a *raft,* or *floating,* founda-

MAT FOUNDATION AS A RESPONSE TO UPLIFT



tion, depending on its detailing). Mat foundations act as integrated structural units, eliminate water-vulnerable joints, and more evenly distribute the building's weight over the subsoil. It is, therefore, particularly desirable for weak, unstable, and/or wet soils which may shift or swell with changes in moisture content.[23] Mats basically are designed much like a roof slab, but inverted, with the soil or hydrostatic pressure providing an external distribution of load, and the column bases delivering point loads. In the case of severe hydrostatic uplift (to counter building buoyancy), the slab may be thickened to resist internal bending moments and to provide additional dead weight.[24] Slab ends can also be cantilevered (as depicted in the accompanying illustration) to capture the dead weight of the backfill in providing anchorage against the lift.

In summary, waterproofing, walls and foundations will differ little from normal basement construction, although some structural systems may be better suited for underground constructions as self-contained entities. In either case, site surveys and analysis must be undertaken to determine the exact design conditions and the appropriate responses. Other major physical considerations regard the stability and usage of the earth cover, particularly with respect to planting and "roof" drainage.

DECK DRAINAGE AND PLANT COVER

The desired earth and plant covers should be programmed from the beginning. Larger plant types usually require deeper soils, and this will have an impact on building structure. M. Paul Friedberg provides the following rule of-thumb guides to soil cover:[25]

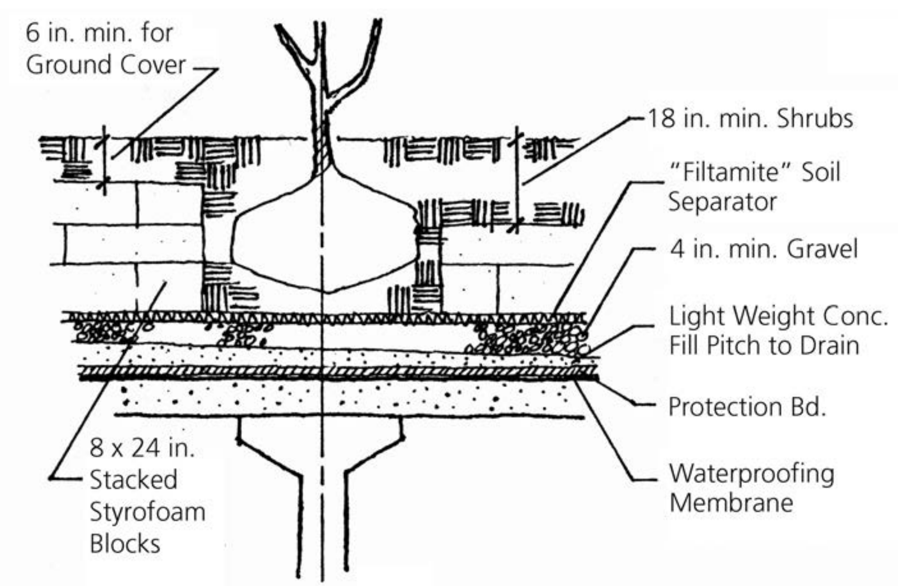
6 - 12 in.	Sufficient only for grass
12 in.	Grass, some ground cover, some shrubs
18 - 24 in.	Adequate for most shrubbery
24 - 36 in.	Minor trees (dep. on potential size)
36 - 60 in.	Major trees

Unquestionably, sufficient soil depth for substantial shrub and tree cover will result in large loading pressures—up to 375 - 625 psf for major trees, not including the tree weight.[26]

One immediate response is to substitute a lighter soil mix in place of, or combined with, the local topsoil. Coke, vermiculite, Styrofoam®, and Dorovon* may all be used to

*Ed note: The original spelling, **Dorovon**, can not be located anywhere on the Internet. **Dorovan** does refer to a series that consists of very poorly drained, moderately permeable soils on densely forested flood plains, hardwood swamps, and depressions in the Atlantic Coast Flatwoods, Eastern Gulf Coast Flatwoods, and Southern Coastal Plain Major Land Resource Areas. —National Cooperative Soil Survey.

this end, although their water holding capacities must be taken into account (see Appendix III). The least expensive solution is usually perlite ("Perloam"), which weighs 8 pcf. Its compressive strength is fairly low, however, and is said to make the soil feel spongy underfoot when used as more than 1/3 of the total mix. A typical rooftop or planter mix will usually include approximately equal amounts of such a lightening agent, topsoil, and coarse sand, to aid in drainage. Since few plants can tolerate standing water, "roof" drainage is an important factor in promoting growth in shallow earth cover. Friedberg recommends



the following section (below, left) for a minimal earth cover: [27]

Extensive roof areas may require roof drains. With or without drains, the structural slab should be pitched (0.5 - 1% minimum), or a graded concrete topping can be applied (which can also serve as a protective cover for waterproofing membranes). Mounding techniques may be employed to provide depth where needed, and to reduce earth loads where it is not required. In the Kaiser Plaza installation, trees were left in the 50 in. high wooden planter boxes in which they were delivered from the nursery, and mounds were built around them. [28] The wooden boxes provide initial support and stability, and decompose as the tree roots seek their own bracing.

In bermed or sloped schemes, soil slippage may become a problem. Steep surfaces can be stabilized by driving in 2 x 4 "deadmen" normal to the slope angle. Another solution is to create sub surface terraces, or to utilize (undersurface) retaining step-curbs across the plane of the slope. Other possibilities include jute mesh and rope mats staked into the topsoil. Chemical additives—soil cements and asphaltic compounds—securely stabilize soil masses, but at the expense of soil quality as a planting medium. Probably the best stabilizer is a deep-rooted ground cover which can penetrate several soil layers. [29] Backfill profiles must be selected with caution; soil layers of different densities and plasticity indexes will not unite well and may promote slippage along their interface. Clay, for example, is very slippery when wet, and may easily cause water-laden upper soil layers to slough off after rainstorms.

Again, a knowledge of specific site conditions (and related plant material) is imperative to insure a successful execution of design. Finally, it might be noted that some experience with roof top planting over an underground [30] structure indicates that plant growth might be accelerated, or growing season modified, by drainage conditions and/or the building's thermal effects. This area is poorly studied, but suggests that both imagination and caution be exercised in the design and detailing of subsurface buildings. Consultation with a landscape architect is recommended for providing both design inputs and feasibility evaluations for particular schemes and circumstances.

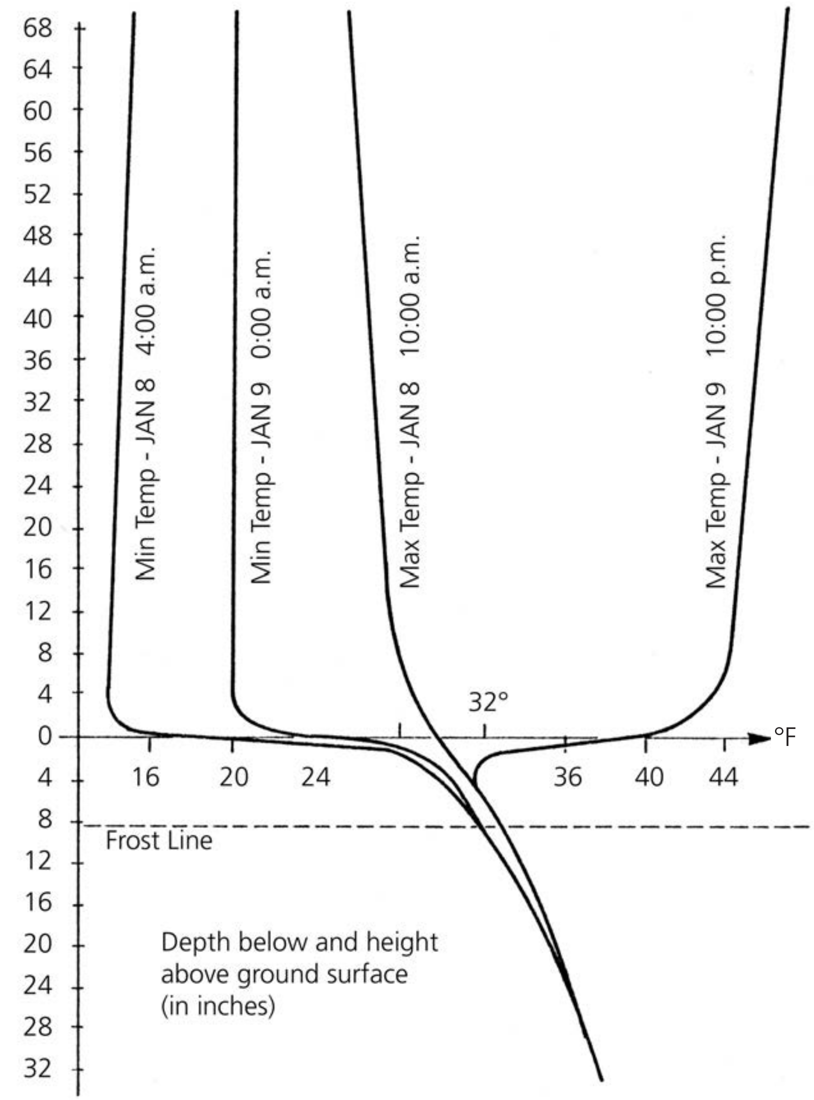
PART IIIB: THE THERMAL ENVIRONMENT OF SOILS

Illustrations such as the one on page 1114 are sometimes used to describe the thermal advantages of locating within an earthen rather than atmospheric environment. The temperature differential alone, however, relates only part of the total phenomena. While seasonal earth temperatures are much more moderate than that of the surface (atmosphere), the thermal properties of the soil itself—in terms of heat transfer, holding capacity, diffusivity, etc.—differ radically from that of the atmosphere.

Thermal soil mechanics is a complicated study, and one that has not given much attention to architectural applications. Heat transfer in solids can be described with sufficient accuracy for equipment selection; heat transfer in soils is governed by a number of variables which are in constant fluctuation (moisture content, e.g.). Unlike air, soil composition varies from place to place. Soils do not, however, respond to climatic change as rapidly as does the atmosphere, and herein reside the architectural thermal benefits of earthen environments.

TEMPERATURE OF THE SOIL PROFILE

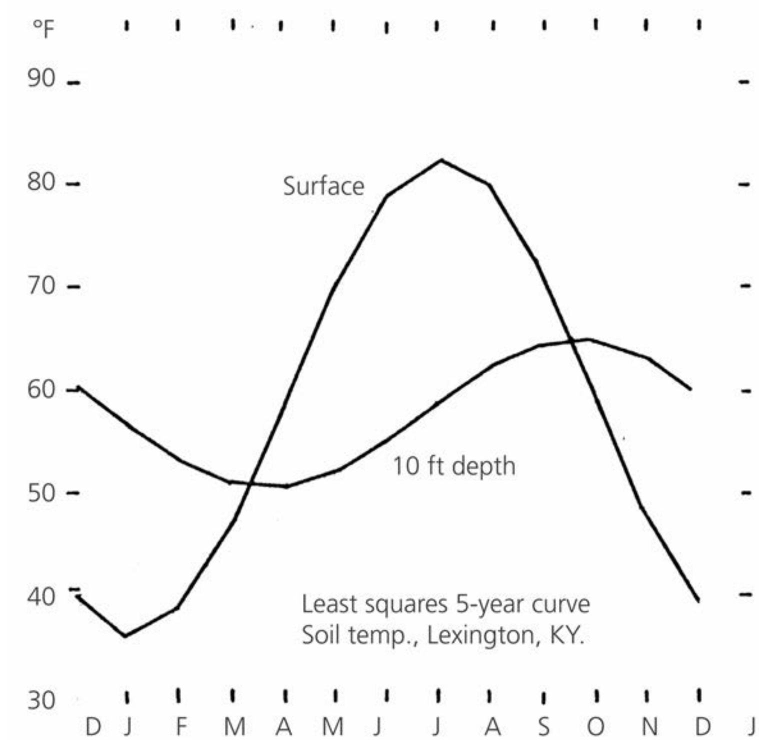
In order to appreciate the full significance of underground construction as a means to energy conservation, an examination of the thermal properties of the soil profile is warranted. Ground temperatures are governed by a number of factors, most important of which are 1) geographic, including latitude, altitude, and weather conditions; 2) site characteristics, including surface conditions and surface temperature, landscaping, microclimate, and water table; and 3) earth characteristics, the thermal and physical properties of the soil, including moisture content and packing density, [31] Independent of these, and most immediate, is the change in temperature with respect to depth. This relationship is commonly displayed as a "tautochrone," a curve plotting the vertical distribution of temperature in the ground at a given moment in time, (see tautochrone, right) This last factor, of time, also is of prime importance in determining soil temperature at a given depth, particularly in areas where seasonal variations are great. Diurnal fluctuations appear "largely in the surface horizons,



MAXIMUM AND MINIMUM TAUTOCHRONE, JANUARY 8-9, NEW YORK METROPOLITAN AREA (1956). AFTER JUMIKIS and rapidly fade out with depth, so that "below 6 in. - 20 in. the soil temperature does not reflect daily changes at the surface." [32] This is demonstrated clearly in the tautochrone on the preceding page, which also illustrates the relationship between earth and atmospheric temperatures.[33]

At greater depths, soil temperatures respond only to seasonal changes, and then after a considerable time delay. Geiger reports, for example, in studies carried on in Potsdam, Germany, that the warmest time of the year at a depth of 12 meters was exactly the same as that when the winter cold had penetrated to a depth of 1 meter (see table, right). [34] Research in Kentucky shows an approximate three month retard in soil temperature extremes at a depth of ten feet, in contrast to seasonal maximum and minimum at the surface (see graph at right). [35] These studies point out another factor regarding soil temperature, that the annual fluctuation may extend as deep as 30 ft to 40 ft below ground surface. [36]

Kasuda and Achenbach, in dealing with earth temperature related to the design of survival shelters, have introduced an "integrated aver-



SOIL TEMPERATURES AT POTSDAM: 1894 - 1948 (°C)

Depth (cm)	Avg. Annual T Max	Min	An'l Fluc'n Avg	Abs	Time of Year Max	Min
100	20.7	1.0	19.6	25.4	7/30	2/11
200	17.2	3.6	13.6	17.2	8/15	3/4
400	13.7	6.3	7.3	9.7	9/22	4/3
600	11.9	7.8	4.2	5.9	10/30	5/4
1200	10.0	9.3	0.7	2.0	2/10	8/10

age" of temperatures over the gradient from surface to ten feet below ground surface. This average is of particular relevance to near-surface underground construction, which remains exposed to a range of temperature fluctuation during the course of the year. So-called "steady-state" ground temperatures may be assumed to occur below 6 ft - 10 ft beneath ground surface, [37] and consequently apply directly only to "deep" structures significantly below ground level. An examination of steady-state distribution, however, provides a valuable index to annual ground temperature averages in the upper horizons, and is a key to surveying useful geographic applications of underground building.

TEMPERATURE REALMS IN THE UNITED STATES

The temperature of earth strata sufficiently deep to be considered "stable" has generally been accepted as equivalent to ground water temperatures at a depth of 30 ft- 60 ft, which has, in turn, been demonstrated to be roughly equivalent to annual average air temperature. [38] A map of Collins' well water temperature isotherms is included here, indicating the distribution of steady state earth temperatures throughout the contiguous United States. Included below is a listing of 63 earth and air temperature station averages as reported by Kasuda and Achenbach. These averages compare maximum and minimum values of yearly fluctuations between the atmosphere and soil horizons from surface to 10 ft below, and can be seen to provide suggestions to the relative severity of their respective climates. Appendix IIIB contains calculations of the range of annual variation, or temperature "spread," for each of the 63 stations, and this information will be discussed in the next section in an attempt to establish the most appropriate regions of underground development in the United States.

ANNUAL MAXIMA AND MINIMA OF AIR AND INTEGRATED AVERAGE EARTH TEMPERATURES

ST No.	Earth Temp Station	Air Temp. Station	Maximum		Minimum	
			Air[a]	Earth[b]	Air[a]	Earth[b]
1	Auburn, AL	Montgomery, AL	81	74	49	56
2	Decatur, IL	Huntsville, AL[d]	81	71	43	48
3	Tempe, AZ	Phoenix, AZ	90	81	50	59
4	Tuscon, AZ	Tucson, AZ	86	85	50	65
5	Brawley, CA	Yuma, AZ	95	90	50	59
6	Davis, CA	Sacramento, CA	75	76	44	56
7	Ft. Collins, CO	Denver, CO	72	63	29	37
8	Ft. Collins, CO	Denver, CO	72	63	29	37
9	Ft. Collins, CO	Denver, CO	72	64	29	36
10	Gainesville, FL	Orlando, FL	82	80	62	69
11	Athens, GA	Athens, GA	81	77	45	57
12	Tifton, GA	Albany, GA	83	80	51	62
13	Moscow, ID	Idaho Falls, ID[e]	69	57	16	37
14	Argonne, IL	Chicago, IL	75	64	25	38

Remarks

a: Unless otherwise stated. all the air temperature data are thirty-year norm (1921-1950) airport data published in Technical Paper No. 31, U.S. Weather Bureau Publication, 1956.

b: Earth temperatures shown are integrated average from surface to 10 ft depth calculated by observed earth temperature characteristics, each as average, amplitude and phase angle and earth thermal diffusivity of 0.025 ft2/hr for most of the stations.

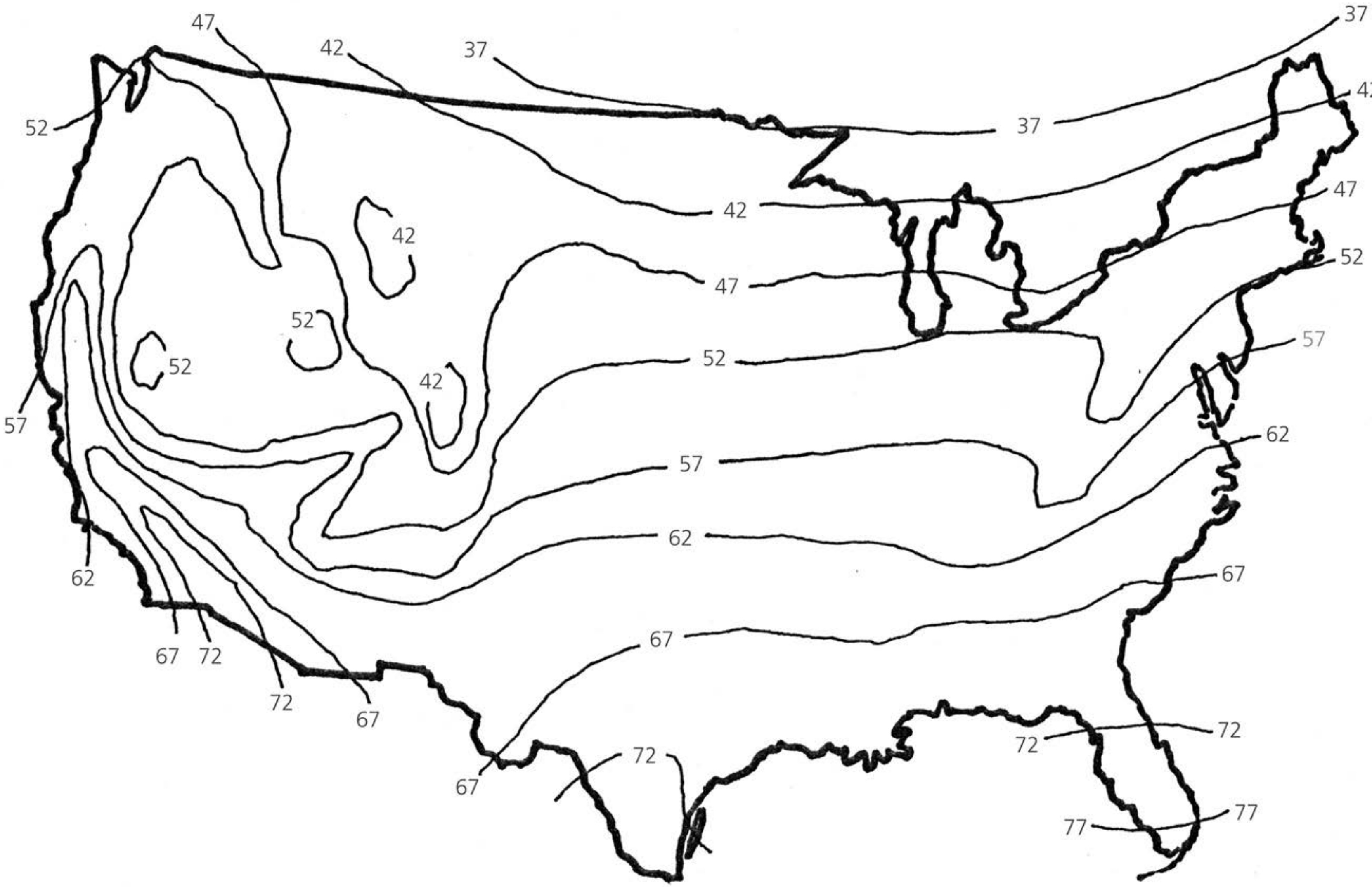
c: City office air temperature data instead of airport data.

d: Climatological Standard normals of 1931-1660 instead of 1921-1950 norm.

e: Exact location of air temperature station unknown.

f: Air temperature data from Penrod [9].

(Table continued on page 24.)



COLLINS' WELL WATER ISOTHERMS: GROUND TEMPERATURE DISTRIBUTION IN THE UNITED STATES

ST No.	Earth Temp Station	Air Temp. Station	Maximum		Minimum	
			Air[a]	Earth[b]	Air[a]	Earth[b]
15	Lemont, IL	Chicago, IL	75	65	25	39
16	Urbana, IL	Springfield, IL	76	67	27	39
17	Urbana, IL	Springfield, IL	76	68	27	42
18	W. Lafayette, IN	South Bend, IN	71	66	25	38
19	Burlington, IA	Burlington, IA [c]	77	71	24	36
20	Manhattan, KS	Concordia, KS	80	69	26	41
21	Lexington, KY	Lexington, KY	76	68	33	42
22	Lexington, KY	Lexington, KY	76	70	33	46
23	Upper Marlboro, MD	Washington, DC	77	70	36	42
24	E. Lansing, MI	E. Lansing, MI [c]	71	63	24	37
25	E. Lansing, MI	E. Lansing, MI [c]	71	64	24	38
26	E. Lansing, MI	E. Lansing, MI [c]	71	63	24	37
27	E. Lansing, MI	E. Lansing, MI [c]	71	63	24	37
28	E. Lansing, MI	E. Lansing, MI [c]	71	63	24	37
29	St. Paul, MN	Minneapolis, MN	74	62	15	34
30	State Univ., MS	Meridian, MS	81	79	48	55
31	Faucet, MO	Springfield, MO	78	65	33	43
32	Kansas City, MO	Kansas City, MO	81	66	30	42
33	Sikeston, MO	Springfield, MO	78	71	33	43
34	Bozeman, MT	Billings, MT	73	56	23	33
35	Bozeman, MT	Billings, MT	73	56	23	32
36	Huntley, MT	Billings, MT	73	64	23	36
37	Lincoln, NE	Lincoln, NE	79	69	24	39
38	Lincoln, NE	Lincoln, NE	79	68	24	38
39	Norfolk, NE	Norfolk, NE	76	66	19	40
40	New Brunswick, NJ	Newark, NJ	75	65	32	42
41	Ithaca, NY	Syracuse, NY	73	59	26	39
42	Ithaca, NY	Syracuse, NY	73	59	26	39
43	Raleigh, NC	Raleigh, NC	79	73	41	52
44	Columbus, OH	Columbus, OH	74	65	30	41
45	Coshocton, OH	Columbus, OH	74	64	30	40
46	Barnsdall, OK	Oklahoma City, OK	82	74	37	54
47	Hominy, OK	Oklahoma City, OK	82	74	37	52
48	Lake Hefner, OK	Oklahoma City, OK	82	77	37	51
49	Pawhuska, Ok	Oklahoma City, OK	82	74	37	50
50	Ottawa, ON	Ottawa, ON [f]	68	59	12	36
51	Corvallis, OR	Eugene, OR	67	66	38	46
52	Pendleton, OR	Pendleton, OR	75	67	31	39
53	Calhoun, SC	Columbia, SC	81	76	47	52
54	Union, SC	Columbia, SC	81	70	47	48
55	Madison, SD	Hurno, SD [c]	75	61	14	33
56	Jackson, TN	Oak Ridge, TN	78	71	38	49
57	Temple, TX	Waco, TX	86	82	47	58
58	Temple, TX	Temple, TX	86	83	47	59
59	Salt Lake City, UT	Salt Lake City, UT	78	63	29	40
60	Burlington, VT	Burlington, VT	70	63	18	35
61	Pullman, WA	Walla Walla, WA [c]	76	60	32	36
62	Pullman, WA	Walla Walla, WA [c]	76	58	32	38
63	Seattle, WA	Seattle, WA	65	61	39	45

Remarks
a: Unless otherwise stated. all the air temperature data are thirty-year norm (1921-1950) airport data published in Technical Paper No. 31, U.S. Weather Bureau Publication, 1956.

b: Earth temperatures shown are integrated average from surface to 10 ft depth calculated by observed earth temperature characteristics, each as average, amplitude and phase angle and earth thermal diffusivity of 0.025 ft2/hr for most of the stations.

c: City office air temperature data instead of airport data.

d: Climatological Standard normals of 1931-1660 instead of 1921-1950 norm.

e: Exact location of air temperature station unknown.

f: Air temperature data from Penrod [9].

REGIONAL APPLICATION

Unfortunately, neither a good data base nor sufficient examples exist to develop a comprehensive study of where subterranean building provides optimal benefits. "Indigenous" architecture in the United States and a survey of the suitability of conventional basements in different areas of the country provide relevant clues and examples, however, and from national climatic data other suggestions can be drawn. In terms of energy conservation related to the use of mechanical equipment, the areas best served by subsurface building are those requiring substantial insulation and artificial heating and cooling. These are climates of extremes: 1) characteristically hot *or* cold, and 2) seasonally hot *and* cold.

In the absence of adequate research and building experience, then, I propose a tentative assessment of realms of regional application based on climatic data and comparative air-ground temperature variations. Areas of best application include those in which seasonal ground temperatures more closely and more consistently approach the "comfort zone" than do air temperatures. These include the arid Southwest (see "Kivas" and proposed Death Valley plant elsewhere in this paper), the northern Great Plains (where early settlers routinely constructed semi-subsurface "sod houses"), and much of the Midwest ranging east to the mid-Atlantic states and north to Canada, where seasonal ground temperatures present a comfortable compromise between the heat of summers and cold of winters. As a means to approach this assessment more systematically, I suggest that the characterization of areas by relative "spread" in earth/air maxima and minima (i.e., [Air_{max} - Air_{min}] - [$Earth_{max}$ - $Earth_{min}$]) provides some index to the severity of seasonal extremes, in which subterranean development offers both a moderating of hot and cold as well as protection of building elements to the exposure of alternating wet and dry and hot and cold. These areas can be listed in a rank order as follows:

Spread: 30°+	Minnesota (St. Paul) South Dakota (Madison) Idaho (Moscow) Nebraska (Norfolk)
Spread: 25° - 39°	Missouri (Kansas City) Montana (Billings) Nebraska (Lincoln) New York (Ithaca) Oklahoma (Barnsdall)
SPREAD: 20° - 24°	Illinois (Chicago; Urbana) Kansas (Manhattan) Michigan (East Lansing) Missouri (Paucett) Iowa (Burlington) New Jersey (New Brunswick) Ohio (Columbus) Oklahoma (Hominy; Pawhuska) (Ottawa, Ontario) Washington (Pullman)

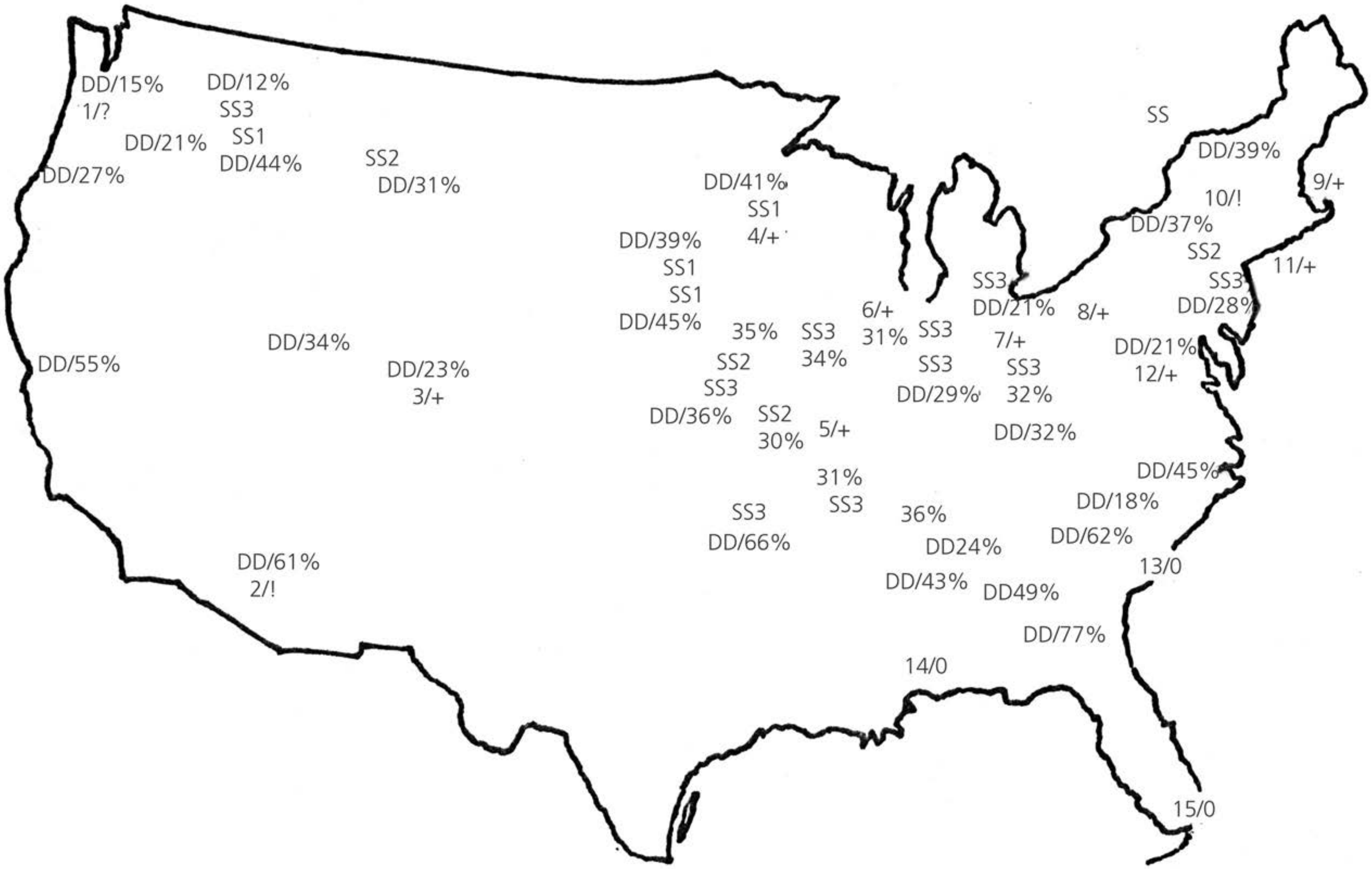
Since this list has been based on the previous 63 earth/air station data, it is limited to the areas from which data is reported, and is, therefor, both incomplete and inconclusive on a national level. It is intended to suggest, nevertheless, areas in which underground building can be interpreted to provide (by the method discussed) "best" benefits, and to indicate the scope or scale of distribution of these areas.

DEGREE DAYS

An examination of regional surface and estimated below-grade "degree days" provides another useful, although somewhat abstracted (because it does not reflect the winter increase in local soil temperature affected by the heating of the structure), comparison of the heat-conserving benefits of the underground.

Consider the following example: the maximum 10 ft "integrated average" earth temperature reported at Lemont, Illinois, reaches a cool high of 65° in the month of August (see station #15 in preceding table), when monthly air temperature averages 75°, and "normal daily maxima" fall in the range of 80° - 85°. [39] The summer underground, then, actually provides a needed source of cooling in which mechanical equipment is usually employed. Winter minimum earth temperature (February average) is recorded as 39° in contrast to a monthly average minimum of 25° air temperature, a difference of 14°. The Climatic Atlas reports the normal daily minimum air temperature for February in the range of 15° - 20° for the Lemont (Chicago) area, and the total monthly degree days as 1044. Since ground temperatures remain relatively constant over the course of a month, we can assume daily degree-days to equal 65° - 39°, or 26; 26 degree-days x 28 days for the month of February = 728 monthly degree-days. Because earth temperatures surrounding the structure would in fact be considerably higher during the period of winter heating, this is a conservative estimate at best, the actual number of degree-days being somewhat lower. Even so, 1044 - 728 = a saving of 316 degree-days, or 30%. This estimate can be seen as even more conservative when one considers that the coldest atmospheric month is January, with a total of 1209 degree-days; supposing that ground temperature prematurely reached its minimum of 39° in January, monthly "underground degree days" would still represent a saving of at least. 25% (65°- 39° = 26; 26 x 31 = 806 DD).

Inasmuch as degree days bear a linear relationship to heating fuel consumption, and hence energy expenditure and cost, [40] this represents a saving of approximately one-third of energy consumption, not including the increased savings due to improved insulation, reradiation, decreased infiltration and wind chill, and other factors involved in heat loss.



SUMMARY OF NEAR-SURFACE (0 FT TO -10 FT) SUBSURFACE SUITABILITY; SEE TEXT FOR EXPLANATION. GROUND TEMPERATURES OVER 65°F NOT REPORTED FOR DEGREE DAY COMPARISON HERE. SEE STATION DATA TABLES.

LITHOSPHERIC LIVING AREAS: A REGIONAL SUMMARY

Due to the absence of sufficiently specific information, this analysis is offered as only a tentative guide to surveying regional issues of application. It is not intended to derive conclusive statements about the viability of subsurface construction in any given area, but instead to suggest the relative benefits, the likely difficulties, and the questions that require further research on a general level of consideration and application.

A relative surface/subsurface heating-degree-day comparison has been calculated for the stations from which data is available (10 ft "integrated average"), according to the method previously discussed. Percentage degree day savings are plotted on the map by the notation "DD/X%" for the coldest winter conditions (i.e., January surface DD vs. February subsurface DD) respective to each area.

The locations previously determined as "seasonally severe" (greatest temperature spreads) likewise are plotted as SS1, SS2, and SS3, corresponding to the three categories discussed earlier in this paper.

The following information has been excerpted from the *House Beautiful* "Climate Control Project's" summary of regional basement conditions, and desirability of "lithosphere" rooms; each of these areas is represented on the map numerically corresponding to the order given below (generally from west to east). Much of the analysis is inconclusive due to lack of information, but nevertheless provides a useful look at regional conditions based largely on experience. [41]

> 1. Portland, Oregon: Basement floor temperatures are reported to range from 46° to 60°, requiring some heating (solar htg. described as "adequate") for comfortable summer use. "Basements on slope exposing wall on sunny side are suitable for living quarters." No specific reference to winter conditions.
>
> 2. Phoenix (Arid Southwest): Atmospheric seasonal "design temperature" range is 16°- 106°, pointing out desirability of ameliorating devices. "In this region basement might prove to be most comfortable living portion of house. Several feet below surface mean annual temperature of 70° is present both day and night in winter and summer. This is an ideal living temperature and by building down into the ground this temperature should prove to be an asset in maintaining constant living conditions"

3. Denver, Colorado: Basement described as "desirable," i.e., cool in summer (no humidity problem) and easily heated in the winter. Optimum condition would include sloping site with southern elevation fully exposed to the sun.

4. Twin Cities, Minnesota: Atmospheric "design temperature" reported to be -12°, compared to minimum basement design temp. of +31°. Southerly-exposed wall is recommended, largely in response to the relatively high humidity of the area. Bligh uses Minneapolis region as example for demonstrating energy-conserving benefits of underground space use.

5. Mid-Mississippi Basin (St. Louis-Kansas City): "Subsurface rooms, with ground temperature constantly at 55°, will conserve considerable fuel in winter because floor slab will always be 20°- 40° warmer than outside air." "Subsurface rooms, if properly dehumidified and ventilated, will be most comfortable part of house during hot months."

6. Chicago, IL: "If properly dehumidified, basement rooms will be attractive retreat during summer months." Severe Chicago cold and wind not discussed, but point out obvious benefits of winter use.

7. Columbus, OH: Minimum basement design temperature given as 30° vs. 8° for outside air, thus providing relative winter warmth. Humidity is indicated as a concern, but "if humidity is controlled, basement will be most comfortable part of house during summer months."

8. Pittsburg, PA: "Basement living quarters would cut fuel requirements for degree days approximately in half in winter, but would require additional vapor sealing and air circulation." "Normal summer temperature in basement too low (!) for comfortable living conditions." Some summer heating required, and a South elevation exposed to sun is suggested, where possible.

9. Boston, MA: Humidity and condensation problems are cited, which may be at least partially alleviated by some sort of solar heating (Southern wall exposure or extension of wall to provide light penetration into window-wells). Ventilation alone inadequate check on dampness; no other notes, although severe winters suggest considerable heat-conserving qualities. (See "Ecology House," elsewhere in this paper.)

10. Albany (Buffalo-Montréal), NY: "Potentially a basement in this area has superior advantages for living facilities, for which it is cooler in summer and warmer in winter, and if these lithosphere rooms were made attractive and spacious, they would probably be preferable to living quarters normally planned for floors

above the ground." Solar heating—by means of light wells and conservatories—is suggested, both for winter warmth and as a means of dealing with occasional high summer humidity.

11. New York Metro area (incl. Phila.): (conditions similar to Columbus area) A basement design temperature of 30° for winter is contrasted to atmospheric design temp, of 12°, and it is stated that "unheated basements will be warmer and drier than the outside atmosphere," 47° and less than 65% RH being present during the winter months.

12. Washington, D.C., Chesapeake Bay area: Basement areas are said to provide maximum summer comfort (if properly dehumidified) and a relative source of heat in the winter. Solar heating methods are recommended, particularly to deal with summer humidity (ventilation may only increase it).

13. Charleston, South Carolina: high humidity and relatively high summer ground temperatures make basement living areas unsuitable for use during the predominant warm seasons; no notes on winter benefits, but the generally moderate climate makes few rigorous demands on the building as a whole. (Stilts suggested)

14. Gulf Coast (Florida to Texas): Basements are generally omitted; "high humidity, combined with high ground temperatures (about 70° in summer) make underground areas unusable for living or storage." Instead, "the higher the living quarters are placed, the more comfortable they are likely to be."

15. Miami, southern Florida: High ground water and ventilation requirements exclude basements from consideration: "a basement would be a liability because of high humidity during most of the year."

A symbolic representation of the preceding regional comments is included on the "suitability" map utilizing the notation below:

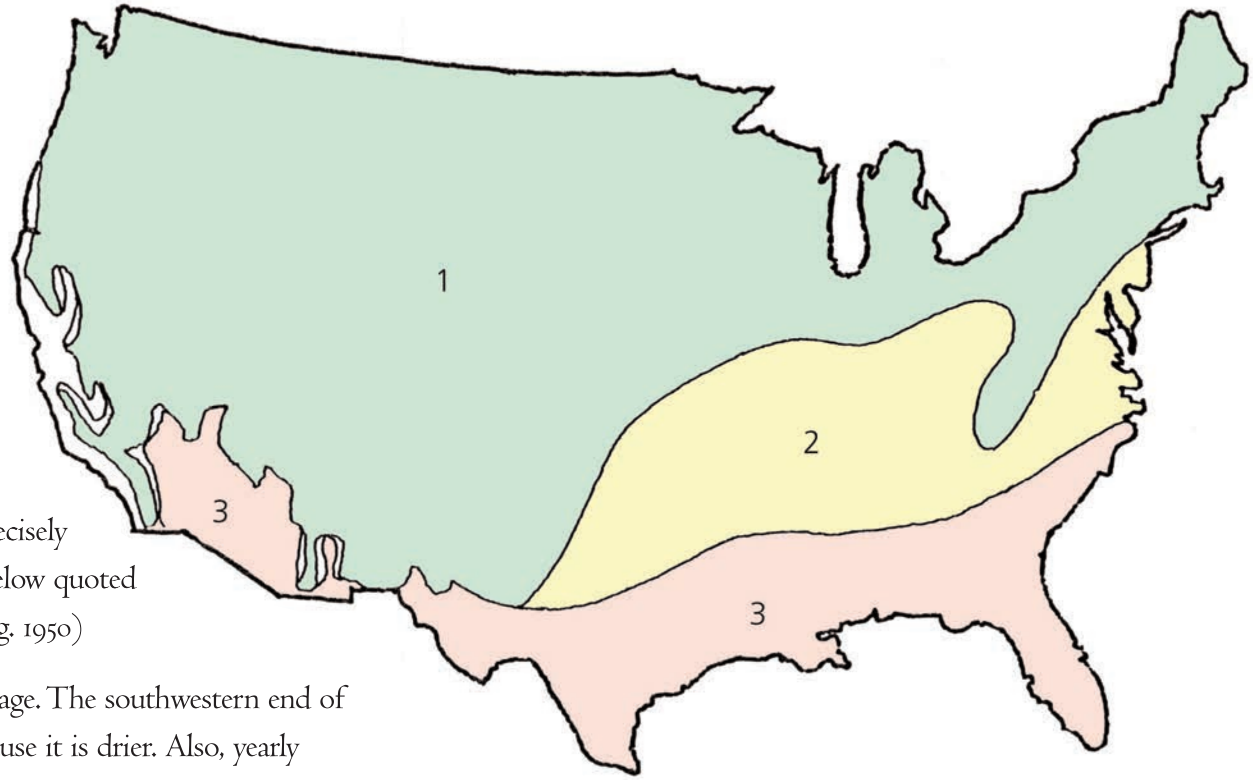
! - Ideally suited: yearly benefits for both heating and cooling, no problems with humidity or condensation.

+ - Considerable benefits, particularly in midsummer and mid-winter, with marginal problems of humidity (e.g.): well suited.

0 - Poorly suited: either benefits are few, limited to a short season, or inherent climatic difficulties (e.g., yearly high humidity)

? - Inconclusive: insufficient information to make judgment regarding overall performance throughout the entire year.

ZONES OF SUITABILITY



This map is reproduced after a study done by Army climatologist, Dr. Paul A. Siple, to determine regional suitability for basement living areas. Siple's analysis is based on ground temperatures and regional humidity, and sums up much of the preceding discussion. Climatic regions change abruptly as a result of local geography, and can only be imprecisely suggested at this scale, (descriptions below quoted from Langewiesche, *House Beautiful*, Aug. 1950)

Zone 1—Area of greatest advantage. The southwestern end of this zone has less summer benefit because it is drier. Also, yearly temperature extremes are not so great. Northern portions of this zone, with cool summers, would need to use sun's heat to take summertime chill off a sunken [underground] living room, but wintertime benefits would be very positive.

Zone 2—This area has both summer and winter advantages. But due to high relative humidities, a sunken room in this zone would require some mechanical air-drying to prevent condensation on walls, floors, etc. It is in this zone that complete, or partial air conditioning would be most economical, and within the range of most people.

Zone 3—Area where underground living offers minor advantages—for the following reasons: because climate above ground is pleasant and without great extremes, or because the underground temperatures are not different enough to correct the above-ground climate, or because of the complications of extreme humidities.

HEAT LOSS: CONSERVATION

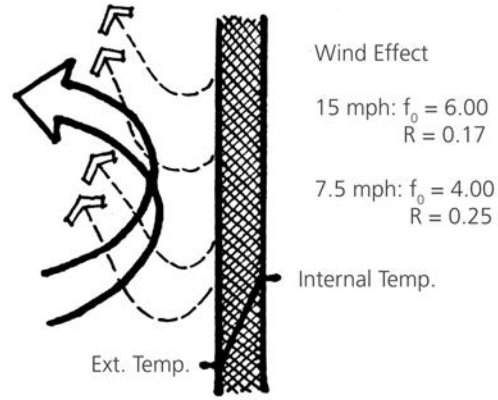
It has already been demonstrated that the use of subsurface space can substantially reduce both winter heating and summer cooling loads in much of the continental United States by the thermal effects of the earth environment alone. Other factors are also involved which further retard heat loss and, therefore, reduce energy consumption. Among these are the absence of wind effect (i.e., surface conductance) [42], reduced or insignificant infiltration, and the increased temperature and heat content of the soil surrounding the structure. The last of these contributes the most significant effect, yet is probably least researched. [43]

McGuinness and Stein acknowledge the absence of an outside surface film (conductance) coefficient, and briefly summarize that "the resistance of the basement enclosing surface in contact with the ground is great." They continue, "Moreover, the earth temperatures rise after an appreciable operating time, further reducing the heat transmitted. For these reasons the loss through basement surfaces below ground is *not* computed by multiplying a U coefficient by the area and a temperature difference." [44] For accurate calculations of heat loss to underground surroundings, values of soil thermal conductivity and thermal diffusivity are required in addition to earth temperature, building material U factors, and the interior design temperature. Since some of these values are often unobtainable and the calculations complicated, different "rule of thumb" methods are frequently employed that bypass the theory involved; they will be discussed later.

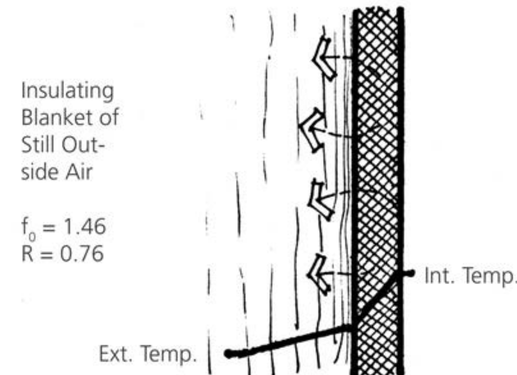
Thermal conductivity of soil varies greatly with variations in its composition and moisture content, which is likely to fluctuate as a function of precipitation and other local weather conditions. It is, however, expressed in conventional terms of conductance, and is easily compared to the resistance of common construction materials, as shown in the chart on the following page. From these values it is apparent that the insulative properties of soil are not unlike those of the building material itself, so that the earth surroundings might be viewed as an "infinite" extension of the structure's own skin. (See next page of illustrations.)

(Text continued on page III34)

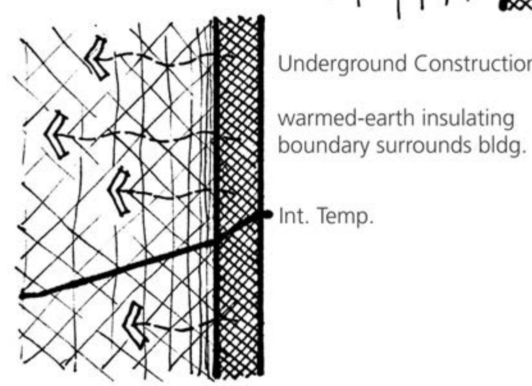
Heat loss calculations are based on the insulative/conductive properties of the wall section, the selected design differential between internal and outside air temperatures, and the surface conductance coefficient, an expression of the “wind chill” rate of removal of heat from the radiating exterior wall surface. As wind velocity and surface exposure increase, so does the efficiency of the atmosphere as a heat sink. ASHRAE Design Coefficients Tables incorporate a standard wind velocity of 15 mph for winter calculations (surface R = 0.17), and 7.5 mph for summer (surface R = 0.25).



Under windless conditions, the removal of heat due to external air movement becomes nearly non-existent, as the surface conductance coefficient f_0 decreases, approaching unity (consequently, R increases). In such a situation, a blanket of warmed air envelops the immediate building mass, creating an insulative boundary layer that retards further loss. Although the phenomenon is operative, it is dependent on the stillness of the surrounding air and is not, therefore, usable as a design determinant. See ASHRAE Fundamentals, pp. 419 & 429



In subsurface situations, however, no “wind chill” exists whatsoever. Instead, a temperature gradient develops across the wall and adjacent section of earth, creating both an effective boundary layer as well as a heat reservoir capable of reradiating heat back into the structure. Heat loss occurs at a much slower rate due to the heat of the surroundings, and must be calculated by a different means, incorporating local temperature and thermal properties of surrounding soils.



THERMAL PROPERTIES OF SOIL, ROCK, & CONCRETE [45]

Material	Conductivity B/hr ft^2°F/ft	Diffusivity ft^2/hr
Light soil, dry	0.20	0.0125
Light soil, damp heavy soil, dry	0.50	0.020
Heavy soil, damp concrete, damp	0.90	0.030
Wet soil average rock	1.40	0.040
Dense rock	2.00	0.050

At the same time, the surrounding soil mass does dissipate some building heat (as does a wall), while slowly increasing its own heat content until some sort of equilibrium is reached. This general phenomenon is poorly documented and demands much further study; it is understood that conductance heat loss from a radiating body is dependent on the heat capacity and thermal diffusivity of the mass of soil in contact with that body. No attempt will be made here to describe the process mathematically, but the fact that the soil temperature adjacent to the building increases is of utmost importance, for it further decreases the degree day demands below those previously calculated for minimum annual earth temperatures; the February low of 39° reported for Lemont, Illinois, for example, would never come into contact with the outside walls of an underground structure there.

This invested heat in the earthen surroundings offers a great opportunity for concentrating on heat-recovery. A system described by Paul M. Sturges for the underground Ecology House project at the State University of New York (College at New Paltz) counterflows intake air against the exhaust from bathrooms and kitchen (and fireplace, when in use); Sturges claims an 80% gain between ambient outside temperatures and room levels. After an eight-month anticipated warm-up period—to bring the 52° walls up to 70°—heat retrieval + internal gains (people, cooking, appliances, and lighting) is expected to offset wall losses, eliminating space heating requirements. [46]

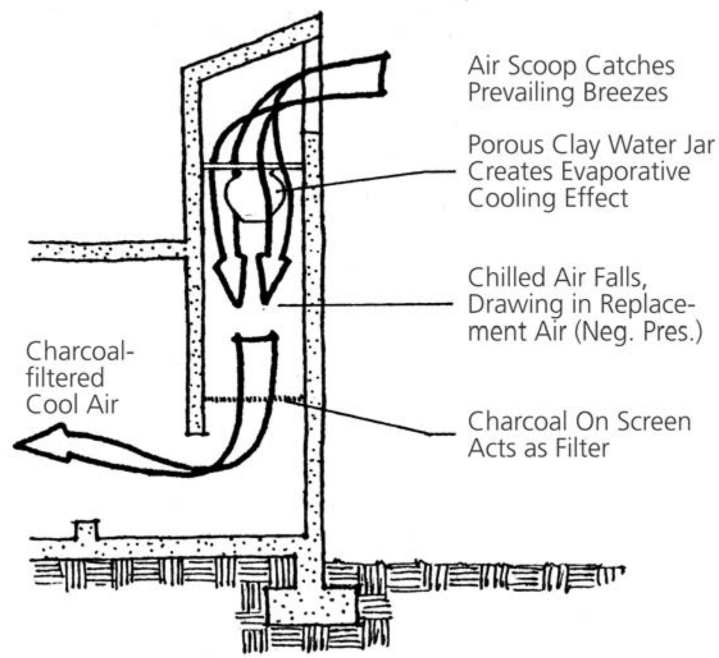
Because the amounts and rate of heat loss to underground environments differ greatly from those to the atmosphere, it is likely that many control systems designed for the surface would be inappropriate for (particularly small scale) subsurface application. Since subgrade wall temperatures (MRT) can be expected to remain very stable, little excess internal heat will be dissipated through the walls. Make-up heat, therefore, must be provided at a much slower rate than normal so as to avoid uncomfortable hot/cold “swings” and overheating. A slower, more constant rate

of heat introduction will involve different economies and efficiencies of operation, and may suggest a greater appropriateness for some systems in less frequent surface use. One of these is the radiant panel method, which may be of particular usefulness with constant circulation of relatively low temperature water. [47]
If wall temperatures can be controlled effectively, the problems of dew-point condensation often associated with basement spaces will be eliminated. Such a system might also mix well water as a refrigerant source where practical. [48]

Many other thermal devices exist and need to be explored. Thermal siphon and chimney effects make use of air density differentials which can be utilized to provide natural convective circulation. Some instances of these have been applied at large and small scales of use, although they are poorly documented. A technique in common practice throughout many mid-eastern countries is shown to the right; compare this induced air circulation system to the convective Kiva ventilating system illustrated in Part I. Contemporary interpretations of these principles are easily imagined; Frank Lloyd Wright discusses an example of such a down-draft ventilator in The Natural House which uses a fireplace-like arrangement with a (mechanically) chilled hearth. An Army manual on underground installations describes how the cooling effect of long shafts or tunnels can be exploited for dehumidification of intake air through condensation on tunnel surfaces. These techniques can be easily adapted for near-surface use, but as yet their effectiveness is untested.

Subsurface fireplaces may serve double duty by providing

TRADITIONAL DUCTED COOL AIR INTAKE SYSTEM USED IN THE MIDDLE EAST. (REDRAWN AFTER DANBY) [49]



space heat in winter and down draft cooling in summer. An added bonus is that the external radiation normally lost by fireplaces on the surface is "invested" in the subsurface environment, and can reradiate this heat or aid in retarding wall heat losses.

CONSERVATION POTENTIAL

The amount of energy that can be conserved in a given situation will depend on the soil conditions discussed previously and on the selection of a heating system with whatever attempts may be made towards heat recovery. With regard to total operating costs, several examples suggest that savings of 60% to 70% may be realized for residential scale structures throughout much of the mid-temperate zone (these estimates are exclusive of heat-recovery systems).

An energy cost study undertaken by Lt. Lloyd Harrison compared a conventional 1500 sq ft (30 ft x 50 ft) single level residence with a hypothetical subsurface structure of the same dimensions. Utilizing climatic data and energy rates for the Denver metropolitan area, Harrison found the underground house to provide a 72% energy savings over the surface dwelling. Sixty percent of this underground consumption is attributed to the heating of intake air for the assumed four occupants, at the rate of 25 CFM/person. [50]

Harrison's results are summarized as follows:

Subject	Surface	Underground
Winter heat loss (BTUH)	39927	12720
Summer heat gain	44650	0
Annual energy demand cost		
Winter: gas (ft3) oil (gal) elec. (KWH)	 93828 $65.80) 710 ($129.90) 23157 ($428.80)	 30777 ($27.60) 233 ($42.60) 7596 ($191.10)
Summer: elec. (KWH)	3962 ($98.40)	0

ANNUAL COST OF ENVIRONMENTAL CONTROL REQUIREMENTS

Using:	Gas	Oil	Electricity
Surface design:	$395	$459	$758
Underground design:	$120	$135	$283
Subsurface costs compared to surface cost	30%	29%	37%

(From Harrison)

John Barnard's Ecology House, discussed briefly in Part I, has demonstrated a savings of approximately 60% over a conventional above-grade dwelling. This figure is based on an annual operating cost of $204 for direct-resistance heating, as determined by the utility rates and climate of the Cape Cod, Massachusetts area. Ecology House is constructed of 8 in. poured concrete with 2 in. of rigid Styrofoam insulation on the exterior; earth cover ranges from 12 in. to 18 inches. Barnard anticipates placing a plastic bubble over the atrium for winter use; the captured solar gain, he calculates, will further reduce heat loss to approximately 80%. [51]

These findings coincide well with the two-thirds estimated savings for heating and cooling reported for Jay Swayze's (electrically-heated) underground house in Plainview, Texas. [52]

Finally, an analysis by Thomas P. Bligh and Richard Hamburger demonstrates that heat transmission reductions by factors of 3 to 8 are obtainable directly through underground location of structures. Part of their study, based on design conditions for the city of Minneapolis, appears below and in the accompanying table. [53]

> Table 4 (next page) gives Q, the heat flow rate per unit area, above and below ground in Minneapolis, for the mean, maximum, and minimum daily temperatures in winter and in summer. This shows, for example, that on a cold winter day the heat flow rate per unit will be 5.5 times greater above ground for a wall with 8 inches of insulation (wall 3), and 8.4 times greater for a wall with 4 inches of insulation (wall 2), compared with an uninsulated wall underground, and Q can be 19 to 22 times greater through a roof than underground.
>
> During summer a large amount of heat that must be removed flows into a building above ground, whereas heat flows out of an underground structure, lowering the cooling load. The ratio Q above/Q below is not given in summer because heat flow underground is out of a building, which is desirable since heat is produced by lights, cooking, machines, and people, whereas heat flow above ground is into a building, which is undesirable as it adds heat to the internal heat load. On a hot summer's day, for example, to maintain an above-ground building (of wall 2 construction) at the same temperature as a similar underground building, (4.0 + 2.5) BTUH/ft^2 of wall area, plus (9.0 + 2.5) BTUH/ft^2 of roof roof area would have to moved by an air-conditioning plant, assuming the heat loss through the floor to be comparable to that in the underground building.
>
> In no way can improved insulation on an above-ground building begin to compete with subsurface structures from the viewpoint of energy conservation.

Table 4: Heat Flow Rate per Unit Area, *Q*, for Buildings above and below Ground[a]

Season/Temperatures	Above Ground				Below Ground[b]
	Roof	Wall 1	Wall 2	Wall 3	(t_2 = 50°F)
Winter (January) mean, [b,c] t_1 = 75°F		t_2 = 10°F (t_1 - t_2) = 65°F			(t_1 - t_2) = 25°F
Q, Btu/h/ft^2	29-35	19-29	13.0	8.5	2.5
Ratio *Q* above/*Q* below	12-14	8-12	5.2	3.4	
Winter (January) minimum, [d] t_1 = 75°F		t_2 = -30°F (t_1 - t_2) = 105°F			(t_1 - t_2) = 25°F
Q, Btu/h/ft^2	47-56	32-47	21.0	13.7	2.5
Ratio *Q* above/*Q* below	19-22	13-19	8.4	5.5	
Summer (July) mean, [e] t_1 = 75°F		t_2 = 80°F (t_1 - t_2) = -10°F			(t_1 - t_2) = 25°F
Q, Btu/h/ft^2	-4.5 to -5.3	-3.0 to -4.5	-2.0	-1.3	2.5
Ratio [f]					
Summer (July) maximum, [e] t_1 = 75°F		t_2 = 95°F (t_1 - t_2) = -20°F			(t_1 - t_2) = 25°F
Q, Btu/h/ft^2	-9.0 to -11.6	-6.0 to -9.0	-4.0	-2.6	2.5
Ratio [f]					

[a] Negative sign indicates heat gained.

[b] An inside temperature of t_1 = 75°F and an underground temperature of t_2 = 50°F were used throughout.

[c] In the winter or heating cycle, the mean temperature for the 24-h period averaged over the month was used since buildings must be heated continuously; here t_2 = 10°F.

[d] A minimum winter temperature of t_2 = -30°F and a maximum summer temperature of t_2 = 95°F were used as an example of the maximum heat flow rate conditions. The heating and cooling plant must be sufficient for thes extremes.

[e] During summer the mean temperature during the day was used since buidlings need cooling only when the outside temperature exceeds 75°F; here t_2 = 85°F.

[f] A ratio of Q above/Q below is not listed for summer since above-ground heat flows into a building, while underground heat flows out of it (see text).

CALCULATION METHOD

ASHRAE's *Handbook of Fundamentals*, in the absence of a more sophisticated method, recommends that below-grade heat loss analyses be based on ground water temperature and the proper floor and wall coefficients for those surfaces in contact with the soil. In general, ASHRAE suggests a U value of 0.1 for walls and floor, and provides the table shown below as "sufficiently precise for general practice." The figures were derived empirically from uninsulated concrete floors on ground, in which a 20°F differential was observed between floor surface and air temperature 6 in. above the floor; wall values were observed at mid-ceiling height to be roughly twice that of floor loss. It would seem that this difference is related to the vertical temperature distribution in the soil profile; the 10 ft "integrated average" may then be found to apply to wall loss calculations, and "steady state" temperatures to floor losses. In summary, the *Fundamentals* states that "since the recommended transmission coefficient for basement walls in contact with the ground is only 0.1, any reasonable, assumed ground temperature will not materially affect the calculated heat loss."

BELOW GRADE HEAT LOSS: BASEMENT WALLS & FLOORS

Ground water temperature °F	Floor loss [a] BTU/sq ft	Wall loss [b] BTU/sq ft
40	3.0	6.0
50	2.0	4.0
60	1.0	2.0

a = Based on basement temperature of 70°F, U = 0.1
b = Assumed twice basement floor loss

A few somewhat more sophisticated techniques for calculating underground (basement) losses have been devised, and these are noted in the accompanying bibliography. Although heat transfer to solid (rock) environments is generally beyond the scope of terratectural practice, a procedure for determining rates of loss and equilibrium levels is presented in the Army manual also listed in the bibliography.

Conclusion

CONCLUSION

After surveying the varied benefits and realizations of underground space discussed in this paper, one can only conclude that we have been severely neglecting a great potential resource. Objections to underground space—particularly cost, image, and psychological—have often been shown in the cases specifically studied to be unfounded. Indeed, much work needs to be done in evaluating actual life-cycle costs and long term energy investments, and in analyzing user responses, but the summation of first studies on creation and use of underground space seems to indicate that much of the fact of underground space lies veiled within a fog of misperception and mystification. To be sure, many dreadful underground spaces presently exist—and perhaps these are the ones with which we are most familiar; it is the intended use, however, and the imagination of those architects who will program and design underground space which will ultimately determine the quality and acceptance of its application.

It is likely that only a few first-rate underground buildings will be sufficient to dismiss most cultural and image-related "taboos" often expressed as making subsurface and earth covered buildings "unacceptable." A judicious relocation of many building types to the subsurface (consider the Kansas City cold storage facilities, e.g.) can provide immense external (environmental, aesthetic) as well as internal (economic, energy) benefit, and with a high degree of satisfaction. Terratectural and shallow earth covered buildings offer most of the same benefits as deep space, yet provide exciting opportunities for innovative interfacing with the surface, and with daylight, natural ventilation, views, etc.; objections to near-surface schemes (such as those illustrated in this paper) should be minimal because of these surficial qualities, and may be promoted from the standpoint of their unique land and energy amenity, the "romantic" landform tradition, and their potential economic benefits (elimination of exterior finishes and relative freedom from maintenance, plus the associated energy savings).

Much work needs to be done in almost all areas of concern—legal, economic, planning, energy, thermal, perceptual, and psychological, to name just a few. As effective and satisfactory applications of underground space will he a result of fairly conventional professional (cost accounting, design, engineering, e.g.) procedures, its increased use may largely he a promotional problem. I think it is safe to say that as more information becomes available regarding the performance, use, and economies of current and proposed earth-covered installations, that this last (promotional) factor will become somewhat self-resolving.

The conclusion to be drawn from this work is that the underground architectural alternative, while no panacea for environmental or land-use problems, is frequently an appropriate—and often a superior—architectural solution; it rightfully ought to be considered so, particularly at the program and site-specific levels of analysis and design. Not all underground alternatives will be the best solution, but in many cases, we may indeed (in the words of Charles Fairhurst) "... have the answer under our feet."

Notes

&

Appendices

[1] British architect David Hancocks, for example, describes in his book *Master Builders of the Animal World* (Harper & Row, 1973), elaborate techniques evolved by different species of ground-dwelling animals for dealing with thermal control of habitations, egg nests, and hibernation dens. Although direct analogies may be misleading, the relative proportion of burrowing or ground-nesting animals in a given climatic region may provide useful suggestions toward the suitability of "lithospheric" architecture in that area. Consider this example, cited by Hancocks (p. 27): "microclimatic studies of burrows only half a meter deep excavated by kangaroo-rats in Arizona have revealed significant differences between internal and external conditions. With a ground temperature of 71°C the temperature at the end of the rat's burrow was reduced to 27°C and the relative humidity was three to four times greater than the outside air."

[2] Myron Goldfinger, *Villages in the Sun*, 1969. Matmata is a seemingly popular architectural curiosity, and is discussed in the following references as well: *CIAM '59 in Otterlo*, Oscar Newman, ed., 1961, Alec Tiranti, Ltd.; "Before the Virgin Met the Dynamo," Janet Bloom in *Arch'l. Forum*, July/August, 1973 ("Energy" issue); Schoenauer and Seeman, *The Court Garden House*, 1962, McGil Pr.

[3] "Going Underground," *Progressive Architecture*, special issue: "The Earth," April, 1967, p. 139.

[4] James Marston Fitch: *American Building: The Environmental Forces that Shape It*, 1972, Houghton Mifflin, p. 262. Other references on China's underground include Bernard Rudofsky, *Architecture without Architects*, Doubleday & Co., 1964 (quoted); Schoenauer and Seeman, op. cit.; *Arch'l. Forum, op. cit.*; and Andrew Boyd, *Chinese Architecture and Town Planning*, 1500 B.C. - A.D. 1911, University of Chicago, 1962.

[5] Kivas are a standard topic of discussion in texts on the archaeology of the southwestern U.S. Generally regarded as the nucleus of community settlements, Kivas ranged in size from 10 - 14 ft for old Kayenta "small" kivas to a maximum of 83 ft diameter for an Anasazi "Great Kiva" in southwest Colorado. See Paul Martin and Fred Plog, *The Archaeology of Arizona*, Doubleday/Natural History Press, 1973. Illustrations adapted from George J. Gumerman, *Black Mesa: Survey and Excavation in Northeast Arizona*, Prescott College Press, 1970, and Watson Smith, *Prehistoric Kivas of Antelope Mesa*, Report of the Awatovi Expedition No. 9, Peabody Museum, Harvard U., 1972. My thanks to an old friend, Richard G. Detwiler (Dept. of Anthropology, SMU) for relating to me his findings on a recent "dig" in New Mexico.

[6] Spiro Kostof, *Caves of God*, MIT Press, 1962; see also *Progressive Architecture*, May, 1964.

[1] Rather than attempt to document these individuals here, many of their various proposals and arguments will instead be presented throughout the paper for illustration.

[2] Although much of this interest is relatively recent and linked to the "environmental awakening" of the 1960's, one should recall Richard Neutra's concept of "Biorealism," which professed that, "the common denominator, the proper gauge of value, lies ultimately in *biological returns, i.e., the aids and harms to the survival of a given community and its organic membership.*" R. Neutra, *Survival Through Design*, 1954, Oxford Univ. Press, chapter 46.

[3] See Lynn White's already-classic essay, "The Historical Roots of Our Ecologic Crisis," for the development of this reasoning; in *The Subversive Science*, Shepard & McKinley, eds., Houghton Mifflin Co., 1969. See also Ian McHarg's interpretation of the impact of this attitude on the design tradition: "On Values," chapter 7, *Design with Nature*, Natural History Press, 1969.

[4] John Brinckerhoff Jackson suggests that the period most significant in changing the. American landscape was the decade following the Civil War. Those years marked the easy massive penetration into western lands provided by the railroads, as well as the early beginnings of the suburban movement prompted by trolley companies. *American Space,* J.B. Jackson, Norton Pub., 1972.

[5] "...the ecosystem cannot be subdivided into manageable parts, for its properties reside in the whole, in the connections between the parts." Barry Commoner, *The Closing Circle*, p. 187 (see chapter 10, "The Social Issues"); A.F. Knopf, Inc., 1971.

[6] LaMont Cole, "The Ecosphere," in *Man and the Ecosphere*, p. 11. Published by Scientific American, 1971.

[7] Pierre Dansereau, "Megalopolis: resources and prospect," p. 8, in *Challenge for Survival*, Dansereau, ed., Col. U. Press, 1970.

[8] Urban ecologist Alan Beck, for example, has described the curious set of "urban" relationships between rats and stray dogs in competing for a common food resource—garbage. Alan M. Beck, *The Ecology of Stray Dogs: A Study of Free Ranging Urban Animals*, York, 1973.

[9] Eugene P. Odum, *Fundamentals of Ecology*, Saunders Co., 1971. (underlining mine)

[10] Succession is, at least in part, due to modifications performed on the environment by preceding populations, which may then be interpreted as having prepared the way for their successors.

[11] Robt. H. Whittaker, *Communities and Ecosystems*, Macmillan Co., 1970, pp. 68-69.

[12] The dynamics and maintenance of systems is a study that per-

vades the physical, social, and life sciences. A discussion of ecosystem dynamics appears in "Relationship of Energy and Complexity in Planning," H.T. Odum and L.L. Peterson, *Architectural Design*, Oct '72, 624-9.

[13] This is not necessarily true in all cases, but is an accepted general characteristic associated with stability; see "species diversity" in.Odum, *op. cit.*, or Whittaker.

[14] Odum, *op. cit.*, p. 256.

[15] This concept forms the basis for a building evaluation system proposed by architect Malcolm Wells, "The absolutely constant incontestably stable architectural value scale," *Progressive Architecture*, March, 1971.

[16] Dr. Frank Egler describes the "home grounds" as "the domain of lawns, lawnmowers, subsoil called topsoil, alien species that are susceptible to every known form of pest, disease, and inherent weakness. The whole is kept alive by an inordinate amount of expensive care and attention, comparable to our practices in homes for the aged and incurable. In my opinion, the Home Landscape is largely a sick environment, kept alive by sprays, sprays, and more sprays. It is a very interesting sociological problem aided and abetted by all the short-term, profit-making industries, as well as by the staffs of our agricultural experiment stations who can be remarkably illiterate when it comes to Total Ecology." From "Ecology and Management of Rural and Suburban Landscape," in Dansereau, *op. cit.*, pp. 87-08. See also J. B. Jackson's article, "Ghosts at the Door," for a cultural history of the American tradition of the lawn, and the likelihood of the emergence of a new suburban landscape; in Shepard & McKinley, *op. cit.*, pp. 158-168.

[17] For a discussion of the kinds of costs and issues involved in the disruption and simplification of biotic systems, see pp. 95-108, "Environment of Urban Industrial Culture," in *Governing Nature*, Earl Finbar Murphy, Quadrangle Books, 1970.

[18] For a definitive elaboration of the study of ecological energetics, see John Phillipson' s book of the same title, Edward Arnold Publishers, Ltd., 1966.

[19] Drawing by Paul Hess, in *Open Land for Urban America*, J.J. Shomon, Johns Hopkins, 1971.

[20] This is excerpted from Commoner's "Four Laws of Ecology," chapter 2, *The Closing Circle*. Alfred A. Knopf Co., 1972.

[21] Also known as "environmental analysis," "sensitivity analysis," and several other terms, this is in contradistinction to the federally-required "environmental impact statement" (EIS) required by

NEPA. See the *Journal of the AIP*, Nov., 1974, *Progressive Architecture*, June, 1974, for models of current practice.

[22] Ken Yeang's article, "The Energetics of the Built Environment," breaks down energy investments into three categories: initial cost of the built environment, cost of utilization, and cost of renewal. In *Architectural Design*, July, 1974, pp. 446-451.

[23] This is already coming into being as many municipalities consider alternative methods of growth and development controls. See, for example, the techniques of "impact zoning," in *House and Home*, Aug., 1972. Another similar approach being encouraged in Bucks County, Pa., is "performance zoning," a concept which is founded on performance standards for impervious surface ratio, open space ratio, density, etc. (*Performance Zoning*, a model ordinance, Bucks County Planning Commission, 1973).

[24] Charles Fairhurst, Vice Chairman, Underground Construction Research Council, American Society of Civil Engineers, in "Going Under to Stay on Top," *Underground Services*, v. 2, no. 3, 1974 (England).

[25] Plants provide a wealth of functions rarely considered by architects. For an excellent survey of these, see *Plants, People, and Environmental Quality*, Gary O. Robinette, Govt. Printing Off., 1972.

[26] In calculating stormwater runoff, roofs and paved surfaces are generally considered to shed water on an order of 9 to 90 times faster than a forested area, and 4 to 5 times faster than lawn; this only tells part of the story, however, because it does not deal with where the runoff goes, and how quickly it finds its way into streams and rivers. See footnote #27, following.

[27] "If you'd like to see a bit of instant geology sometime, come with me when it rains to the little valley beyond the new shopping center. Even before we get there you'll hear the roar made by tons of wild storm water charging down the pipe from the parking lots. It's truly a terrifying experience. The 26 acres of buildings and blacktop that make up that shopping center pour 600,000 gallons into the pipe every-time an inch of rain falls." "In the valley of the shadow of the supermarkets you need not wait a million years between shows. You can see it all in minutes, see sand bars appear, disappear, and reappear, echoing geologic actions that used to take generations, sometimes even millennia, in the days when nature had more of an even chance." Malcolm Wells, guest editorial in *Progressive Architecture*, June, 1974, p. 59.

[28] Consider, too, that vegetative cover reduces erosion in the following ways: 1) by intercepting the energy of rainfall, 2) by decreasing the surface velocity of runoff, 3) by restraining soil movement, 4) by increasing the porosity of the soil, and 5) by

increasing soil storage capacity through water loss due to transpiration. *Soil and Water Conservation Engineering*, Schwab, Frevert, et al, Wiley & Sons, 1966, p.159.

29 Ecologist Paul Sears provides an excellent short discussion of the man-made "problem of water," in his article, "The Processes of Environmental Change by Man," in *The Ecology of Man: An Ecosystem Approach*, Robert Leo Smith, ed., Harper & Row, 1972.

30 *The Costs of Sprawl*, prepared by the Real Estate Research Corp., 1974, p. 72. (U.S. Govt. Printing Office)

31 A discussion of current planning thought regarding this occurs in "Towards Zero Runoff?" in *Landscape Architecture Quarterly*, Oct., 1974; see also reader responses in the following Jan. 1975 issue.

32 Eugene P. Odum and Sharon Davis describe how a carefully selected mix of different trees and shrubs (simulating the three-layered structure of a natural community) can increase both populations of bird species as well as species diversity; experimental evidence shows that a general decline in popularity of massed shrubbery contributes to the loss of variety in bird species commonly found at one time in urban areas. "More Birds in the Bushes from Shrubs in the Plans," *Landscape Architecture Quarterly*, October, 1969, p. 36.

33 An excellent example is architect Richard D. Kaplan's proposal for berm-type suburban community near Southampton, Long Island. It consists of 52 units on 56 acres, and includes 14 acres of open space and 8 acres of roads and parking. Landscape preservation was a primary determinant of his decision to go underground; a nonmowable ground cover such as Crown Vetch was Kaplan's choice for slope stabilization of the sandy, permeable soil. Published in *Progressive Architecture*, special issue, "The Earth," April, *1967*, p. 150.

34 *AIA Journal*, February, 1974, pp. 48-49. Architect Malcolm Wells is also exploiting public interest in subsurface housing by advertising builders' plans for a solar-heated, earth-covered house. Estimated construction cost is $40,000 for the three-bedroom, one-elevation exposed dwellings. From an advertisement for Edmund Scientific Co., promoters, in the *Smithsonian*, Feb. 1975, p. 154.

35 Lt. Lloyd Harrison, Jr., "Is It Time to go Underground?", *The Navy Civil Engineer*, Fall, 1975, pp. 28-29.

36 Thomas P. Bligh and Richard Hamburger, "Conservation of Energy by Use of Underground Space," in *Legal, Economic, and Energy Considerations in the Use of Underground Space*, National Academy of Sciences, 1974

37 "Saving by Going Underground," *AIA Journal*, *op. cit.*

38 *The News*, news-magazine of the State University of New York, issue on "Energy," February, 1974, p. 7; personal communication with Paul M. Sturges, president, Ecology House Associates, Inc., Feb., 1975.

39 Yeang, *op. cit.*

40 "Saving by Going Underground," *op. cit.*; house section by John Carmody, in Fairhurst, *op. cit.*

41 "Selected Details," *Progressive Architecture*, June, 1974, pp. 112-115.

42 "Molding Our Man-Made World," Wm. Morgan, *AIA Journal*, op. cit., p. 39. See also "Buildings as Landscape: Five Current Projects by Wm. Morgan," *Architectural Record*, Sept. 1972.

43 Student project by the author, Fall, 1971.

[1] This will include both human (as pertaining to environmental satisfaction) and physical (climatic suitability as well as geological "availability") factors which will be discussed throughout Part II.

[2] "A behavior setting is an ecological unit consisting of interdependent behavior and environment systems, in which the discernible pattern of behavior is independent of the specific persons involved." Kenneth Craik (after Barker), "Environmental Psychology" Part I of vol. 4, *New Directions in Psychology*, T.M. Newcomb, ed.; Holt, Rinehart, & Winston, Inc., 1970, p. 23.

[3] See Part III, p. 20-22.

[4] "Kansas City: A Model of Underground Development," pp. 10-12 from the transcript of a talk by Dr. Truman Stauffer, Sr., presented to the symposium, "Development and Utilization of Underground Space," March 5-7, held in Kansas City, Mo.

[5] See Wells' office illustration, Part I, and "Conservation Architecture," *Architecture & Engineering News*, Sept. 1969, p. 70. Illustration of Wells House proposal from the article by Wells, "Nowhere to go but Down," *Progressive Architecture*, Feb. 1965 (includes other proposals as well).

[6] Mort and Eleanor Karp, "The Ecological City," *Landscape*, Autumn, 1963, p. 4-8.

[7] It should be noted that the term "conservation" is used here in referring to the preservation of the visual landscape, and not necessarily to the processes and stability of nature as argued for by Wells. The Karps' concern with nature is primarily in utilizing the physiognomy of a local "ecology" to suggest architectural form, rather than tailoring the structure and purpose (or "strategy," as discussed in Part I) of the built environment to concur with the *processes* of local ecologic communities: "The purpose of architecture, as of every art, is the creation of significant form." (p. 5) So as to leave no question of this intent, consider the following quotes: "Here is a vocabulary of forms, in rocks, trees and plants that must be of lasting and untiring significance. In what is most simple and devoid of affection, we can escape the necessity for successively changing architectural styles... Let us go directly to the source for the only forms which are of permanent meaning to us, for those forms in which lie all delicacy, all strength. [concrete and fiberglass trees? —ed.] The forms of buildings should be the forms of the world in which they exist, so that, instead of obtruding, they will be a continuous part of the landscape, indistinguishable and integral."

[8] For a description and illustrations of Soleri's early work, see *Industrial Design*, July, 1964, pp. 56-61)

[9] See "Living It Up Way Down," *Life*, Apr. 24, 1964.

10 Many of these devices are covered under Swayze's patent, "Underground Buildings," #3,227,061. (U.S. Govt. Patent Office) Illustration from "Underground Home of the Future Debuts at Fair," *Electrical World*, April 20, 1964, p. 165; a similar article appears in *Today's Health*, Sept. 1964, p. 12.

11 From conversations with Mr. Swayze, March 1975.

12 Dr. Truman Stauffer, Sr., *Subsurface Uses in Sweden and France; A Report*; Dept. of Geosciences, Univ. of Mo. at Kansas City, 1975, pp. 10-17 (illustrated).

13 See, for example, *The Architecture of Aggression: A History of Military Architecture in North West Europe*, 1900-1945, Keith Mallory and Arvid Ottar, Arch'l Press, 1973, pp. 256-265; and *Design for the Nuclear Age*, NAS/NRC, 1962, #992.

14 Stauffer reports, e.g., that "the number of employees in stone production totaled an approximate 345, with an annual payroll of $3,000,000 for the primary rock production, whereas over 1,500 earned $13,000,000 in secondary use of mined out space... Secondary usage has now exceeded stone production as an economic factor in the Kansas City area by some 4.7 times in numbers employed and 4.3 times in annual wages." From "Kansas City: World's Leading Laboratory in the Development and Utilization of Underground Space," Dept. of Geosciences;, Univ. of Mo. at Kansas City, 1973. (More recent figures indicate some 2,000 employees earn in excess of $15 million in K.C.; Stauffer, 1975). See also p. II30 here.

15 Stauffer, "Kansas City: Model," *op. cit.*, pp. 4 & 7.

16 Stauffer, "K.C.: Lab.," *op. cit.*; also Richard Gentile, *Guidebook to Field Trips* (symposium, march 1975), Dept. of Geosciences, Univ. of Mo. at K.C., p. 57. Such staggering creation of leasable real estate is complemented by equally impressive statistics regarding its utilization. The Kansas City underground is said to house 10% of the nation's capacity for frozen food storage (including the world's largest single installation, of 3 million sq. ft.) plus 7% of all K.C.'s warehouse space; the Inland Storage Distribution Center claims that "the normal inventory stored in this (single) warehouse at any time would provide over a pound of food for every person in the U.S." The Great Midwest Corp. possesses the distinction of housing the largest Foreign Trade Zone in the U.S. with its 2.8 million sq. ft. (from Gentile)

17 Gentile, *Ibid.*, p. 50.

18 Kansas City is endowed with a particularly fortunate set of geological circumstances: most of the installations there are entered horizontally at the base of a series of bluffs that occur throughout the area. Not only is a competent rock layer (which is

not universally available) necessary for this type of development, but some convenient mode of access must also be present to make large scale development workable. Stauffer describes six physical (geological) factors which create the opportunity for development in Kansas City; they are summarized as (1) a massively bedded limestone of (2) sufficient thickness with (3) an overlying impermeable (waterproofing) shale and a (4) competent overburden. These satisfy the structural criteria, while a (5) nearly level stratigraphy and (6) natural accessibility provide the conditions for exploitation of the space potential. ("K.C.: Lab.")

19 Lester Dean, "How Underground Space Use Started in the Kansas City Area," a presentation to the Kansas City symposium, March 5, 1975.

20 *Ibid.*; Dean regards much of the early 1960's interest in U.G.S. as a response to the Cuban missile crisis and "Kruschev's pounding his shoe at the U.N."

21 Stauffer, "K.C.: Lab.," *op. cit.*, and Gentile, *op. cit.*

22 Gentile, *op cit.*, pp. 29-33.

23 The Brunson plant manufactures precision optical instruments used in nuclear submarines and the Apollo lunar program. The manufacturing process is held to tolerances of 50/1,000,000 in.; at the former surface site, calibration of precise instruments was restricted to the hours between 2:00 and 4:00 A.M., when traffic vibrations were minimal. At the current (U.G.) location, such calibrations may be made at any time of day or night. Gentile, *op. cit.*, Stauffer, "K.C.: Lab.," p. 14.

24 Thomas P. Bligh and Richard Hamburger, "Conservation of Energy by Use of Underground Space," in *Legal, Economic, and Energy Considerations in the Use of Underground Space*, N.A.S./N.R.C, 1974 (RAM report NSF/RA/ S-74-002); p. 109.

25 *Ibid.*, p. 110.

26 Stauffer, "K.C.: Lab.," pp. 15-16.

27 A survey by Truman Stauffer to ascertain the reasons for U.G. use preference disclosed the following results: ("K.C.: Lab.," p. 10)

Advantages of U.G. Location	No.	%
Convenience to market areas	14	12
Nearness to supply source	3	3
Low overhead and maintenance	35	30
Nearness to transportation	6	5
Low space rental or purchase	32	27
Compatibility of underground	25	21
Other	2	2
Total	117	100

28 Stauffer, "K.C.: Model," p. 8.

29 From a description of the facilities at the Great Midwest Corp., Gentile, *op. cit.*, p. 18. A similar claim for the facilities at Space-Center states, "Natural rock insulation holds normal underground temperature to a constant 57° with humidity at 50%. These levels can be raised or lowered at a cost at least 50% below that for surface buildings." (promotional literature, 1971)

30 John Muller, Vice President of Engineering, Refrig. Div. of Southeastern Public Service, K.C., Kansas, "Energy Conservation through use of the Sub-surface," a presentation to the Kansas City symposium, March 1975. Muller's point is that since typical ceiling heights (and therefore volume) for surface and subsurface facilities, tons/sq ft is not an accurate measure for energy comparisons. He also adds that since U.G. floor areas need to be greater than on the surface for the same storage volumes, more energy is expended underground on the horizontal distribution (by forktrucks, e.g.) of goods.

31 Stauffer, "K.C.: Model," *op. cit.*, p. 5. See also Stauffer, "Occupancy and Use of Underground Mined-Out Space in Urban Areas: An Annotated Bibliography;" Council of Planning Librarians, Exchange Bibl. #602.

32 Charles Fairhurst, "Going Under to Stay on Top," *Underground Services* (England), vol. 2, no. 5, 1974.

33 Figures presented here are from Irving Hoch, "The Three-Dimensional City: Contained Urban Space," in *The Quality of the Urban Environment*, Harvey Perloff, ed., Resources for the Future, 1969; pp. 121-124.

34 See p. II18.

35 "Above ground there is strangled traffic, polluted air and the highest land prices in the world. Below there is easy transport, air conditioning, and sites that are 40% less expensive. Is it any wonder that Japanese businessmen are going underground?" *The Economist*, Dec. 24, 1966, p. 1323.

36 "The whole underground shopping has been built at Shin-Umeda station on the Hanku Electric Railway. It consists of four floors above the outside main street and four below ground level. The upper floors are store, parking, and railway areas. The street with a river is on the second basement floor and fed from a pond, faced by about 70 shops, selling foodstuffs. Each floor deals with different groups of saleables from books to clothes." "Immediately below the shopping precincts comes the power house, emergency lighting generators, the ventilation control units and the water-pumping and fire-fighting equipment... Ventilation outlets are concealed in street level displays of sculptured art,

while danger from flooding and minor earthquakes is eliminated by double-wall construction and pumping equipment." From "Japan: Under Land and Water," Raymond Lamont Brown, *Building*, Jan. 25, 1974, pp. 87-88. For a description of the underground "river," see Japan Architect, Feb. 1970, p. LL.

37 *Architecture Plus*, Nov/Dec. 1974, pp. 31-32.

38 Hoch, *op. cit.*

39 Hoch, "Economic Trends and Demand for the Development of Underground Space," in *Legal, Economic, and Energy ...U.G.S., op. cit.*, p. 87.

40 Gunnar Birkerts, FAIA, *Subterranean Urban Systems*, Industrial Development Div., Inst, of Science and Technology, University of Michigan, 1974. "The top of the conduit is covered with excavated earth, and is transformed into a continuous landscaped park. Exits from the industrial and other inhabited spaces below are through the vertical support cores which project above the ground surface. Skylights and light cores introduce daylight and outside awareness into the spaces below. Workers in the universal spaces below can use the parquet surfaces for rest and relaxation during intermission time. High density residential areas, schools, libraries, and other buildings for public and cultural uses can be built along the linear conduit park." (p. 10) A synopsis of Birkerts' subterranean systems appears in the article, "Liberating Land: A Blueprint for Urban Growth," *Progressive Architecture*, March 1973, pp. 74-9.

41 From the program notes to the conference, "Underground Space as an Urban Resource," held March 14, 1974, Minneapolis, Minn; sponsored by the University of Minnesota.

42 The most rigorous study of these issues so far has been undertaken by the American Society of Civil Engineers; part of it will be reviewed in Part II and the appendix.

43 "Entopia," from *Ekistics* 228, Nov. 1974, p. 304. Perhaps Doxiadis' vision is not far in the future. A series of articles by H.P. Wallis in the magazine *Industrial Architecture* (England) discusses the land-conserving benefits of automated industry. The article "Going Underground," August 1965, pp. 468-70, deals specifically with the application and potential of underground factories, using several Swedish examples as models. Wallis states that in 1965, Sweden had more than 30 hydro-electric plants underground, producing over 1/2 of the entire country's electricity.

44 "Many of the adverse social effects [of underground development] have strong cultural overtones, and relate to conditions in this society at this time. For example, there is no question but what individuals presently consider "subsurface living" as a seri-

ous loss to their basic life quality. This psychological effect is quite real and constitutes one of the strongest adverse effects of greater use of underground space." *The Use of Underground Space to Achieve National Goals,* Underground Constr. Res. Council of the Amer. Soc. of Civil Engineers, 1972, p. 42.

45 See *Progressive Architecture,* April 1967, p. 144.

46 This practice, too, has a cultural heritage; consider the following passage from Thomas Knox's book of 1873, *Underground* (Hartford: J.B. Burr & Hyde): "The catacombs of Paris are not used, like the catacombs of Thebes, Rome, and Naples, as places of original sepulture; for they were once quarries from which the stone employed in building the city was taken...Their extent is estimated to be about 3 million square yards; and long before they were cemeteries, they served as refuge and shelter for thieves, incendiaries, assassins, and all the desperate criminals who for many centuries abounded in the city." Quoted from Stauffer, CPL Bibl., *op. cit.*

47 Donald G. Hagman, "Planning the Underground Uses," *Legal, Economic, and Energy...U.G.S., op. cit.*, p. 53.

48 A "window surrogate" is some device or object which substitutes for some window function (i.e., a view, changing stimuli, etc.).

49 There is very little literature of direct relevance to either underground or windowless normal working environments. Confinement and sensory-deprivation studies may provide some theoretical insights into psychological response mechanisms, but are of limited direct consequence because of the often conflicting nature of other psychological and social variables. A selected selected bibliography of some of these studies is included in Appendix II.

50 Robert Soramer, *Tight Spaces: Hard Architecture and How to Humanize It,* Prentice-Hall, 1974, pp. 114-119.

51 *Ibid.*

52 This is a complex study in itself, and will not be dealt with at length here. For a development of theory regarding the nature of environmental satisfaction, see Robert W. White, (excerpts from) "Motivation Reconsidered: The Concept of Competence," in *Environmental Psychology, Man and His Physical Setting*, Prohansky, Ittelson, Rivlin, eds., Holt, Rinehart, & Winston, 1970. A slightly different approach is offered by James Marston Fitch, "Experimental Basis for Aesthetic Decision," in the same text. The impact of cultural attitudes is discussed in "Cultural Variability and Physical Standards," Amos Rapoport and Nancy Watson, *People and Buildings*, Robert Gutman, ed., Basic Books, Inc.,

1972. (Gutman also includes Fitch's article)

53 Sommer, *op. cit.*; see some of the specific complaints quoted by employees, pp. 116-117.

54 Interview with Truman Stauffer, March 7, 1975.

55 Some effort might have to be made here to avoid creating a visual muzak!

56 See *The New Yorker's* response to Swayze's underground World's Fair House, "The Talk of the Town," July 18, 1964, p. 19.

57 "Nature Underground," Japan Architect, Dec. 1969, p. 13.

58 *Progressive Architecture*, April 1967, p.181.

59 Stauffer, CPL Bibl., *op. cit.*, p. 26.

60 Royce La Nier, *Geotecture*, University of Notre Dame, 1970, p. 49. (After the study *Inside the Black Box*, Jack Vernon, 1966)

61 Personal communication with C. Burgess Ledbetter, Research Architect, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H.

62 Faber Birren, "The Significance of Light," Part I of a series in the *AIA Journal*, Aug. 1972.

63 Bligh and Hamburger, *op. cit.*, p. 115.

64 *The Effect of Windowless Classrooms on Elementary School Children*, Arch'l Res. Lab., University of Michigan, 1965 (T. Larson, dir.)

65 Stauffer, "K.C.: Lab.," *op. cit.*

66 Gentile, *op. cit.*

67 ASCE, *op. cit.*; see p. 31 for a cost comparison of cut and cover vs. tunneling techniques (at a depth of 20 ft.)

68 "Saving by Going Underground," *AIA Journal*, February 1974, pp. 48-49.

69 Hoch, "The Three-Dimensional City," *op. cit.*, p. 122.

70 See Hagman's discussion, *op. cit.*; New York City has a recently-passed transit zoning easement that is claimed to be "the first ever to control what happens underground." (*Design + Environment*, Spring, 1975, pp. 40-41.)

71 Hoch, "The Three-Dimensional City," *op. cit.*; Lt. Lloyd Harrison, "Is It Time to go Underground?" *The Navy Civil Engineer*, Fall 1973, pp. 28-29.

72 Birkerts and Doxiadis, *op. cit.*; Harold W. Young, "A Planner's View of Underground Development," panel presentation in the

Kansas City symposium.

73 Arthur Drexler, forum discussion in *Progressive Architecture*, April 1967, pp. 179-180; see also Drexler's statements from the Aspen Design Conference presented at the end of this paper.

74 George Nelson, "The Hidden City," *Architecture Plus*, Nov/Dec 1974, p. 71.

75 Patrick Horsbrugh, from his presentation, "Geospace," at the Kansas City symposium. (also compare this to Drexler's statements from the Aspen Conference at the end of this paper)

76 Surface spaces which are interpreted as having the characteristics of geospace are described by Horsbrugh as "parageotectural."

77 Mayer Spivak, "Archetypal Place," *Architectural Forum*, October 1973, pp. 44-49.

78 Spivak's construct parallels a model of bio-behavioral needs described by Prof. Charles Thomas as the "biogram." Thomas emphasizes the variability of cultural adaptation to environmental stress, and how space or physical form may to a degree accommodate or aggravate such stress sources as they relate to the individual. (Charles Thomas, Professor of Anthropology, Washington University)

79 See, for example, Lee Rainwater's "Fear and House-as-Haven in the Lower Class," for a discussion of basic shelter needs and respective (sub) cultural attitudes toward shelter performance; originally published in the *AIP Journal*, Jan. 1966, and also appears in Gutman, *op. cit.*

80 Such a compromise is suggested by Bligh and Hamburger, although as early as 1950 a plea was made for maximizing underground living space as means towards providing climatic comfort. See "There's a Gold Mine Under Your House," Wolfgang Langewiesche, *House Beautiful*, August 1950, pp. 92-94+.

[1] See p. III4

[2] The foregoing descriptions are paraphrased after Alfreds, R. Jumikis, *Introduction to Soil Mechanics,* Van Nostrand, 1967; pp. 31-2. Other useful short descriptions of soils appear in Kevin Lynch's *Site Planning* (MIT, 1971), and an excellent survey of soil characteristics is presented in the American Society of Landscape Architect's Foundation publication, *Vehicular Circulation,* by Robert W. Zolomij.

[3] These descriptions also after Jumikis; charts adapted from pp. 84-86; *op. cit.*

[4] In conventional practice, slope gradients are expressed as a percentage (of rise to run), or as a ratio; slope ratios are stated in the relationship of horizontal: vertical. Angles in degrees are presented here for comparison and easier visualization.

[5] Richard Untermann, *Grade Easy,* ASLA Foundation.

[6] Robert L. Zion, *Trees for Architecture and the Landscape,* p. 148.

[7] Rankine's theory was presented in 1856 and may be considered somewhat obsolete, or at least imperfect; contemporary researchers conceive the soil mass in question as slipping along a more circular curve ("slip circle"), resulting in a far more complex and tedious calculation procedure. Rankine's "sliding wedge" is attractive in its simplicity, and is usually regarded as adequate for non-critical design of earthworks. For a more elaborate explanation of these issues see B. K. Hough, *Basic Soils Engineering,* Ronald Press, 1957; or John H. G. King and Derek A. Cresswell, *Soil Mechanics Related to Building,* Isaac Pitman & Sons, London.

[8] This does not imply that the soil is wet, but pertains to the fluid (flowing) behavior of the soil itself.

[9] These values are compiled from Gay and Parker, *Materials and Methods of Architectural Construction,* John Wiley ,and Sons, 1947; and Elwyn E. Seelye, *Design: Data Book for Civil Engineers,* John Wiley & Sons, 1945. Unit densities (w) are provided here for comparison. Gay and Parker define Equivalent Fluid Pressure (p. 518): "Any material not a fluid has less horizontal than vertical pressure or weight, but the horizontal pressure is proportional to the vertical in ratios which differ according to the angle of repose of the material. The term 'equivalent fluid pressure' (w') for a given soil, therefore, means the horizontal pressure per square foot at a depth of one foot." The Rankine expression $H^2/2$ modifies this for design depths.

[10] Gay and Parker, *op. cit.,* p. 521. Preceding loading analysis also from Gay and Parker, pp 518-520.

[11] Seelye provides a modification of the Rankine expression to

accommodate adjacent vertical surcharge loads. (Seelye, p. 3-21) This formulation will be presented in the Part III Appendices following this section.

12 "It is always suggested that the floor slab be designed for about 2 ft of hydrostatic uplift as a safety factor." From the series of articles, "Subgrade Waterproofing," in *Building Research*, Nov/Dec, 1964, p. 43.

13 R. W. Sexton, "Waterproofing," p. 356, *Time Saver Standards for Architectural Design Data*, J. H. Callender, ed., McGraw-Hill, 1974.

14 See explanation of buoyancy in Appendix III

15 Bldg. Res., *op, cit.*, p. 37

16 "Properly designed" implies a selection of well-graded aggregates to obtain density, as low a water/cement ratio as practical, thorough compaction in the formwork, and wet curing. (*Bldg. Res., op. cit.*)

17 Hydrated lime, iron filings, fatty acids and oils, aluminum, magnesium, and zinc fluosilicates are examples of such additives. These work to increase density (lime), to fill up pores by expansion (oxidizing iron), or by making the concrete water-repellent (fatty acids). Some (chemical) compounds have been found to have an injurious effect on concrete strengths, making inert additives (clay, lime, sand) more generally preferable. (Gay & Parker, *op. cit.*, and Sexton, *op. cit.*).

18 See *Time Saver Standards* for typical details.

19 Impervious surfaces may be objectionable for both aesthetic and natural reasons, although if runoff is a concern (see Part I), French or intercepting drains, such as that shown, can be used to hasten surface water's penetration into the soil.

20 *Bldg. Res., op. cit.*, p. 43.

21 Foundation drainage is sometimes routed into nearby storm sewers. In light of the contextual issues discussed in Part I, this is a practice that requires some re-examination.

22 Soil capillarity will become a design consideration whenever GWL approaches within several feet of the structure. As stated, a fast-draining underfill will eliminate most problems, although it should be kept in mind that very silty soils may draw water upward of more than ten feet. See "Soil Considerations in Subgrade Waterproofing," J. M. De Salvo in *Bldg. Res., op. cit.*

23 Among other considerations, mat foundations are used when the sum of the individual footing base area exceeds about 1/2 the total plan area of the building, to distribute loads from the periphery of the building over the entire building area, when the

soil bearing capacity is too low to support the loads by other kinds of foundations, to resist a hydrostatic pressure of water (uplift), and along property lines of adjacent sites and/or buildings. "Also, to reduce expenses in coping with groundwater, it is preferable to have a continuous foundation at a site rather than many small, isolated footings." These criteria from Alfreds R. Jumikis, *Foundation Engineering*, Intext, 1971, pp. 444-51.

24 "Upon immersing the structure in water, the sum of the acting forces on the base of the slab does not change, because the loss of weight of the structure is exactly balanced by hydrostatic uplift." "Thus the magnitude of the upward pressure to use in the static analysis of the mat slab depends only upon the structural dead and live loads R, but not, as frequently is assumed, upon uplift. Uplift merely exerts its influence on the pressure distribution." Jumikis, *Ibid.*, p. 443.

25 M. Paul Friedberg, "Roofscape," *Architectural and Engineering News*, Sept. 1969, pp. 24-9.

26 3' x 125 pcf (typical dense soil weight) = 375 psf; 5' x 125 pcf = 625 psf. Note Wells office, a building intended to support natural shrub cover, is designed for a loading of 500 psf (see Part I illus.)

27 Friedberg, *op. cit.* While good drainage is necessary to prevent bacterial growth and loss of soil oxygen, the need for regular watering can also become a problem; continuous earth cover may promote some soil moisture through capillary action, but this source is likely to be significantly diminished by the building presence.

28 *Landscape Architecture Quarterly*, Oct, 1962.

29 See rest stop proposal, Part I; prairie grasses may have root systems extending to a depth of eight feet.

30 Conversations with Jay Swayze regarding his former underground home in Plainview, Texas.

31 T. Kasuda and P.R. Achenbach, "Earth Temperature and Thermal Diffusivity at Selected Stations in the United States," Article No. 1914, ASHRAE *Transactions*, 1965.

32 *Climate and Man*; The Yearbook of Agriculture, 1941, p. 271.

33 Alfreds R. Jumikis, *Thermal Soil Mechanics*, Rutgers University Press, 1966.

34 Rudolf Geiger, *The Climate Near the Ground*, Harvard University Press, 1965.

35 Kasuda, *op. cit.*

36 "Survival Shelters," Chapter 15 of ASHRAE *Applications*, 1968, p. 1.62.

37 "... at a depth of 3 ft to 10 ft most soils are nearly constant in temperature." *Climate and Man, op. cit.* The depth of "stable" soil temperatures is variable and depends on the stated physical factors as well as the observer's interpretation of the term "stability." (Data used here was generally not presented in terms of ± values.)

38 Kasuda, *op. cit.*, p. 69.

39 *Climatic Atlas of the United States*, U.S. Govt. Printing Office (Dept. of Commerce)

40 *Ibid.*

41 *House Beautiful Climate Control Project*, published by the Bulletin of the American Institute of Architects, 1949- 1953.

42 Wind effect is represented in the heat loss equation by the external surface (or film) conductance coefficient, as follows:

$Q = A(t_1 - t_2)/(1/f_0 + R)$; where:
Q = heat transmission
A = surface area
$(t_1 - t_2)$ = difference between outside air and design temperature f_0 = ext. surface film conductance coefficient
R= thermal resistance of wall section

Surface conductance is defined as "the time rate of heat exchange by radiation, conduction, and convection of a unit area of surface with its surroundings. The surroundings must involve air or another fluid for radiation and convection to take place." (ASHRAE *Fundamentals*)

43 "The ground temperature adjacent to the walls of a heated basement is greatly affected by the heat gain from the basement. Unfortunately, complete data on ground temperatures adjacent to buildings is not available." ASHRAE *Fundamentals*, p. 459.

44 p. 145, adding, "It has been found that the loss from these surfaces has been frequently overestimated." McGuinness and Stein, *Mechanical and Electrical Equipment for Buildings*, Wiley and Sons, 1971.

45 "Survival Shelters," *op. cit.*, p. 163.

46 *The News*, Special Energy Edition, Feb. 1974, State University of New York, Albany, p. 7; personal communication with Paul Sturges, Pres., Ecology House Assoc, Inc, Feb. 1975.

47 This lower temperature may also have implications for the water-heating system, making hot water storage systems (and solar collectors) desirable.

48 Perhaps a more innovative approach needs to be taken towards exploiting subsurficial attributes. Swayze's underground house in Texas is equipped with a standby generator for emergency power that is water cooled for long term use; the water jacket circulates water which is pumped up from one well, and discharges it into a second well, providing a natural source of chilled water. How such a scheme might be adapted for heating or cooling requirement constitutes a problem, or realm of problems, worth pondering.

49 Miles Danby, "Design of Buildings in Hot, Dry Climates," *Build International*, Jan. 1973.

50 25 CFM is a liberal rate and is recommended by ASHRAE for adults where air space per person is 100 cu-ft. For 500 cu-ft/person, a rate of only 7 CFM is suggested. Harrison's article, "Is is time to go underground?" appears in *The Navy Civil Engineer*, Fall 1973.

51 *AIA Journal*, Feb. 1974; pers. communication.

52 *Electrical World*, April 20, 1964, p. 165.

53 "Conservation of Energy by Use of Underground Space," in RANN report NSF/RA/S-74-002, 1974.

Appendix I

Bibliography: Environmental Context

Ecology by its very nature is a complex study and one which does not readily lend itself to generalizations. The discussion presented in Part I is intended to provide a brief overview of principles pertaining to land use and urbanization, and therefore, does not address many other concepts central to ecosystems theory. Nutrient cycles, for example, are not truly "perfect" or "imperfect" on the global scale (or in terms of geological time), although these terms have been introduced elsewhere as planning concepts as the local level: nutrients that are "lost" from the land by erosion and leaching are subsequently entered into aquatic systems where they may cause enrichment (and eutrophication) and be actively refluxed, or may be deposited in sediments or other reserves (such as the guano deposits long exploited as a source of agricultural fertilizer). Similarly, the presumptions regarding diversity and stability are continually being re-evaluated on a theoretical basis. The following bibliography is presented for an elaboration on these issues, and to promote a better understanding of the systems within which architects and planners perform. Since many short articles appear in readily available anthologies, they will be listed here along with the principle reference.

Ecosystem Theory:

Commoner, Barry. *The Closing Circle*. New York: Knopf, 1971.

Dansereau, Pierre, ed. *Challenge for Survival*. New York: Columbia University Press, 1970.

Contained in Dansereau:

"Ecology and management of the rural and the suburban landscape," Frank E. Egler.

"Metropolitan air layers and pollution," Helmut E. Landsberg.

"The place of nature in the city of man," Ian L. McHarg

"Our freshwater environment," Ruth Patrick.

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Appendix II

Underground Space Use: Claims Pro And Con

The following list is compiled from references in the literature and from issues cited in documentation of design proposals; no attempt will be made here to identify those sources, as most of these issues are discussed in the text or should be self-evident, at least under certain conditions.

+ Amelioration of, and protection from climatic extremes (both constant & seasonal severity)
+ A more stable atmospheric environment (internal) with respect to temperature and humidity
+ Protection from many natural and man-made disasters, incl. tornadoes, hurricanes, fires, earthquakes, warfare, airplane crashes (primarily for near-airport locations)
+ Acoustical isolation: both internally and externally (keeps sound in, keeps sound out)
+ Increased security and control over both access and egress
+ A more suitable (by a multiplicity of factors) environment for some activities and functions (see Kansas City warehousing, e.g.)
+ Separation of conflicting and unrelated functions in space, e.g., pedestrian and vehicular circulation systems, utility lines (may also involve public safety)
+ Preclusion of land use districting as a result
+ Of disruptive and undesirable surficial applications (examples include highways, factories)
+ More intensive and more efficient land use, resulting in multiple economic returns
+ Economic savings due to decreased energy consumption
+ Savings due to decreased overhead fire insurance rates, maintenance, other operating costs
+ Preservation of open space in congested areas, of landscape in "natural" areas
+ Aesthetic gains through the elimination of "visual pollution" and the overtaxing of senses

- Restrictions imposed by climatic and physiographic region, and of geological circumstance
- Difficulties with condensation and high humidity
- Lack of visual identity, image, "presence"
- Modes of access less direct and perceptible
- Difficulties of linkage with surficial and other (present and future) underground facilities
- Higher initial cost of construction (investment)
- Objections to windowlessness and assumed effects
- Problems of palatability and public acceptance
- Inflexibility with respect to future expansion
- Economic gains primarily on long term basis

APPENDIX II-B: TERMINOLOGY

The terms "subterranean," "subsurface," and "underground" (and the French, "souterrains") space are the broadest and most encompassing of those usually found in the literature, and are routinely applied to any type of development beneath the earth's surface. Because of their generality, they fail to distinguish between degrees of "undergroundness," and are inadequate for critical discussion. Consequently, a number of new terms have been introduced to describe more precisely the specific forms of underground space.

Geotecture—from "geo," meaning earth, and "tectonicus," pertaining to building or construction (LaNier, 1970)—has been proposed to designate the design and creation of subterranean accomodation:

> The term Geotecture conveys the concept of subterranean construction to provide accomodation for a variety of purposes, to relieve the compression of conflicting land surface uses, and to achieve economies in the uses of energy and in maintenance costs by the provision of geospace. (Horsbrugh, 1973)

Royce LaNier, author of the book entitled *Geotecture*, succinctly states that "geotecture is to the subsurface as architecture is to the surface." (LaNier, 1970) Similarly, *Petratecture* has been submitted in description of the "design of accomodation within rocks," and *Lithotecture* as the "design of accomodation in the form of mining." (Horsbrugh, 1974)

Terratecture ("terra" also means earth) has been applied to the architecture of the near-surface, and of "earth-integrated" construction, i.e., using earth as some functional building element. (*Terratecture*, 1974) The use of "lithospheric living areas" was advocated by climatologist Paul Siple in the 1940's and 1950's; these spaces are so named because of their location in the lithosphere, the solid or rocky portion of the earth's surface (as opposed to the hydrosphere and atmosphere). (*House Beautiful*, 1949)

Two types of subsurface development have been identified by Dr. Truman Stauffer, Sr., that coincide neatly with the distinction made earlier between near-surface and deep space. These he refers to loosely as "basement-type" development—constructed by excavation from the surface—and "two-tier," or "Kansas City-type," created by subsurface excavation. Moreover, Stauffer has pointed out the urgency of adopting a standard terminology, suggesting the following spatial descriptions.

> *Terraspace* (earth type): underground space developed as a basement in the immediate subsurface, not geo-

logically separated from the surface, and developed from the surface by excavation

Lithospace (rock type): underground space developed in geological strata and geologically separated from the surface, being developed by mining

Geospace (geoidal): underground space developed or occurring naturally which exists as a cavernous chamber and may be used in storage of fluids or semi-fluids (Stauffer, 1975)

The logical extension of Stauffer's concept of geospace would require "geotecture" to be defined in terms of natural geological processes rather than of human activity. Since this conflicts with the previous descriptions, some clarification is in order. The author here will defer from final resolution of this matter, but submits the following definitions as they are used throughout this paper.

Terratecture: the design and creation of underground and earth-covered space in the immediate subsurface, as developed from the surface by excavation (most commonly by the technique known as "cut-and-cover")

Lithotecture: the design and creation of geological (deep) underground space by the process of mining (subsurface excavation)

Geotecture: the design and creation of deep (geological) underground space for primary purposes other than mining by prosesses of subsurface excavation.

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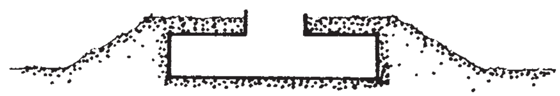
A SIMPLE TAXONOMY OF TERRA-TECTURAL TYPES; SEE ALSO LANIER, *GEOTECTURE*, & MORGAN, *P/A*, 1967 (APRIL)

BERM
NEW EARTH LEVEL RAISED ABOVE EXISTING GRADE

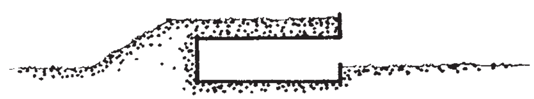
CHAMBER
BUILDING EXCAVATED BENEATH EXISTING GRADE

"TRUE" UNDERGROUND, internally similar to deep space by its isolation

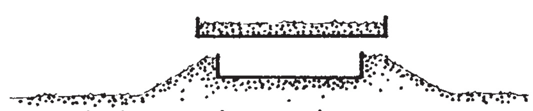
ATRIUM OR COURTYARD, used for entry, for light & air, for outdoor rooms

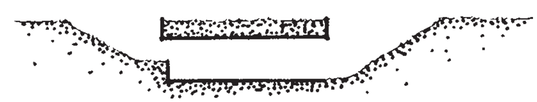


ELEVATIONAL, for windows, for doors, outside courts, to accomodate slopes



SIDE WALL PENETRATIONS, for light, air, access, view; expansion potential





ASCE STUDY: The tables presented on this and the following two pages are excerpted from the study by the American Society of Civil Engineers, *The Use of Underground Space to Achieve National Goals.* The table immediately below (p. 117 of the report) is an identification of benefits and relationships to other systems, while the following two pages present a display of perceived gains and losses derived from the use of underground space. These are evaluated by means of a cost/benefit analysis in the ASCE report which is too lengthy to summarize here; it is hoped, however, that a survey of the issues presented here provides some indication of the potential and scope of underground space use.

SHELTER SYSTEMS

Cost Category	Direct or Unique to System	Indirect Effect on Other Systems
Economic	Reduced costs due to reduced environmental interaction 1. Reduced structural design retirements (wind, snow & ice) 2. Reduced atmospheric control system requirements 3. Reduced storm water removal costs—guttering and storm drains Reduced exterior maintenance costs due to weathering/painting, rust prevention	
Time		
Land	Elimination of land requirement	Allows higher density-open space May now be above residential structures
Energy	Reduction in total energy required for environmental control-heating, lighting & air conditioning	Reduces water pressure requirements in distribution lines
Pollution Controls	Reduced water pollution during construction (erosion and consequent suspended solids in water) and operation (more natural drainage without external pollutants	Reduces visual and aural conflict with surrounding space uses
Safety		
Reliability	Reduced susceptibility to environmental damage (water, wind, snow & ice, and fire)	
Resource Expenditures	Savings in insulation material, architectural exterior material, & traditional roofing materials	
Social	Consider effect of visual isolation from surroundings	

ELECTRICAL ENERGY DISTRIBUTION

Cost Category	Direct or Unique to System	Indirect Effect on Other Systems
Economic	Reduced maintenance (due to weathering) Elimination of overload systems designed to cope with failures caused by adverse environmental interactions Structural design for environment reduced Reduced construction cost--specialized equipment for above ground work eliminated	
Time		
Land	Elimination of planning constraints	
Energy		
Pollution Controls	Elimination of visual pollution of unsightly poles and towers	
Safety	Reduced accidents from high work Reduced accidents Involving accidental contact between electrical and other systems	
Reliability	Improved reliability by eliminating failures caused by wind, snow and ice, and fire	Improved reliability of other systems dependent on electrical power
Resource Expenditures	Elimination of tower and pole structures Elimination or reduction 1n overload systems	
Social	Reduction 1n conflict over right-of-way location decisions	Aesthetically improved environment

PRODUCTION SYSTEMS AND INDUSTRIAL STRUCTURES

Cost Category	Direct or Unique to System	Indirect Effect on Other Systems
Economic	Reduced storm water control investment Reduced structural design requirements (wind, snow & ice) Reduced heating costs Reduced construction costs (due to sub-system eliminations) Reduced maintenance (painting, cleaning, rusting)	
Time		
Land Urban Rural	Land requirement eliminated (post construction)	Surface space required for access if transportation system is on surface
Energy	Elimination of A/C requirement Reduction of heating costs	
Pollution Controls	Unsightly buildings eliminated Noise pollution reduced	Reduced storm water input to storm sewer system
Safety	Increased construction safety due to reduced environmental interaction	
Reliability		
Resource Expenditures	Excavated material available for other use Reduced material costs	Reduced electrical (or other source) energy required
Social		

TABLE B-5 (Continued)

	Gains	Losses
ENVIRONMENTAL QUALITY	Elimination of visual pollution: poles, wires, etc.	---
SHELTER QUALITY, AVAILABILITY AND DENSITY	---	---
MENTAL HEALTH	---	---
ETHNIC EQUALITY	---	---
CONSERVATION OF NATURAL RESOURCES	Lower structural needs (e.g., no poles)	---
SPACE OCCUPANCY AND UTILIZATION	---	---
RESIDENTIAL SHELTERING		
ECONOMIC	Reduced costs due to elimination of environmental effects --reduced maintenance coats --reduced structural design requirements --reduced heat costs -reduced cooling costs --elimination of storm water removal costs (guttering, etc.) --lower deterioration and depreciation rate Increased income opportunity from excavation and construction Decreased mobility or transportation costs resulting from strategic development of the vertical diffusion placing shelters within short distance of most urban services, products, and jobs Lower site costs Tax losses on the surface would be offset by tax gain underground with some probable net gains due to alternative space uses on the surface Release of space for development on the surface Reduced insurance costs	Costs for environmental control --air circulation and control --waste control Costs for sufficient access to the surface Excavation costs Decreased potential profits on surface development land and structures Costs of abandonment of surface structures and facilities (sub-surface costs) High technological research costs
TIME	Decreased time consumption due to strategic use of the vertical dimension to reduce transport distances between shelters and services, products, and jobs Decreased surface transport time due to congestion relief Decrease in time loss from death and accidents due to decrease in mobility requirements Decrease in time losses from disease due to controlled environment	excavation and construction time consumption
PUBLIC HEALTH	Reduced injury from accident resulting from --lower vehicle use needs --improved control and fewer system failures --less exposure to environmental hazards Lower property loss due to --lower vehicle use needs --improved controls and fewer system failures --less exposure to environmental hazards --decrease in disease and accident rates Decrease in hearing loss	Injury from excavation and construction accidents
SAFETY	Lives saved or extended resulting from medical services in closer proximity of shelters due to use of vertical dimension Lives saved or extended due to environmental control (lower disease and accident rates) Lives saved or extended due to lower exposure to atmospheric hazards Lives saved due to decreased use of vehicles as a result of living underground	Death from excavation

	Gains	Losses
JOB OPPORTUNITY	Increased job opportunity due to excavation and construction	---
ATTRACTIVENESS	---	Costs due to bias against underground life by a portion of the population
AESTHETIC QUALITY	Some gains from lower visual pollution on the surface	Losses due to -restricted views -lower amount of plant life
ENVIRONMENTAL QUALITY	Considerable decrease in air pollution loads due to lower heating and cooling requirements --lower vehicle use due to use of vertical dimension --environmental controls underground Decreased water pollution due to reduction of pollution during construction and operation Decreased water pollution due to increased environmental controls on the effects of human behavior Decreased visual pollution	---
SHELTER QUALITY	Gains due to elimination on many unsightly surface structures	Loss due to lower design requirements
SHELTER AVAILABILITY	High gains due to release of space	---
SHELTER DENSITY	High gains due to release of space	---
MENTAL HEALTH	---	Losses to 5% of population due to windowless room effect
ETHNIC EQUALITY	High potential gains from use of increased space	---
CONSERVATION OF NATURAL RESOURCES	Savings in construction materials Savings in maintenance materials Savings in energy due to lower heating and cooling requirements Release of productive land	Increased energy consumption for lighting
SPACE UTILIZATION AND OCCUPANCY	High gains due to release of old and new space	---
COMMERCIAL, RETAIL AND PRODUCTION SYSTEMS*		
ECONOMIC	Reduced costs due to elimination of environmental effects --reduced maintenance costs --reduced structural design requirements --reduced heat costs --reduced cooling costs --elimination of storm water removal costs --lower depreciation and deterioration rate Reduced insurance costs Decreased mobility and transport costs resulting from strategic location of space relationships Lower site costs Release of surface space and development Cains from lower loss of time due to congestion Lower private pollution control costs	Costs for environmental control --air circulation and control --waste controls Costs for sufficient access to the surface Excavation costs Decreased potential profits on surface development land and structures Costs of abandonment of surface structures and facilities (subsurface costs) High technological research costs

TABLE B-5 (Continued)

	Gains	Losses
TIME	Decreased time consumption due to strategic use of the vertical dimension to reduce transport distances between shelters and services, products, and jobs Decreased surface transport time due to congestion relief Decrease In time loss from death end accidents due to decrease in mobility requirements Decreases in time losses from diseases due to controlled environment	Excavation and construction time consumption
SAFETY	Lives saved or extended due to medical services in closer proximity to functions Lives saved or extended due to improved environmental controls Lives saved or extended due to lower exposure to atmospheric hazards Lives saved due to decreased use of vehicles as a result of living underground	Deaths from excavation
PUBLIC HEALTH	Reduced injury from accident resulting from --lower vehicle use needs --Improved controls and fever system failures --less exposure to environmental hazards Lower property loss due to --lower vehicle use needs --improved controls and fewer system failures --less exposure to environmental hazards --decrease in disease end accident rates Decrease in hearing loss	Injury from excavation and construction accidents
JOB OPPORTUNITY	Increased job opportunity due to excavation and construction	---
ATTRACTIVENESS	High gains as a result of ability to place jobs close to residences	---
AESTHETIC QUALITY	Removal of --odor pollution --visual pollution --noise pollution	---
ENVIRONMENTAL QUALITY	Significant gains from removal of --much water pollution --air pollution --noise pollution --odor pollution These are functions of --lower vehicle use --underground controls --reduced water pollution from construction and maintenance --reduced water pollution from operations --decreased heat and cooling needs	---
SHELTER QUALITY, AVAILABILITY, AND DENSITY	---	---
MENTAL HEALTH	---	Losses to 5% due to windowless room effect
ETHNIC EQUALITY	High gains if new opportunities with space are used to develop now mix	---
CONSERVATION OF RESOURCES	Lower water loss Savings in construction materials Savings in maintenance materials Savings from lower vehicle use and wear Savings in energy Release of productive land	---
SPACE UTILIZATION AMD OCCUPANCY	High gains due to release of old and new space	---

*All dimensions commercial and retail systems employ same criteria as the dimension for production systems. They should be kept separate, however, since they comprise a separate general function and could be transferred independently, and also because the loadings on the dimensions vary from those for production systems.

COMMUNICATIONS SYSTEMS

	Gains	Losses
ECONOMIC	Reduced maintenance costs Reduced transmission costs Elimination of specialized equipment for surface work Reduction of structural requirements to withstand atmospheric conditions Elimination of overload systems designed to overcome failures from environmental effects Other lower failure costs Elimination of right-of-way and easement costs Reduced disruption costs during construction	Increased costs for failsafe systems and other controls
TIME	Decreased time losses due to fewer system failures Savings in planning time Time savings from fewer surface disruptions Time saved from reduced Injury and death	---
PUBLIC HEALTH	Reduced injury from --high work, construction, maintenance, etc. --system failures Reduced property loss due to --system failures --less environmental exposure	---
JOB OPPORTUNITY	Increased job opportunity due to system maintenance requirements	---
ATTRACTIVENESS	Very slight gain due to elimination of surface visual pollution	---
AESTHETIC QUALITY	Very slight gain due to elimination of surface visual pollution	---
ENVIRONMENTAL QUALITY	Elimination of visual pollution (poles, wires, etc.)	---
SHELTER QUALITY, AVAILABILITY, AND DENSITY	---	---
MENTAL HEALTH	---	---
ETHNIC EQUALITY	Some possible gains due to improved communications	---
CONSERVATION OF NATURAL RESOURCES	Lower structural needs (e.g., no poles) Reduction in number of overload systems Release of productive land	---
SPACE OCCUPANCY AND UTILIZATION	---	---

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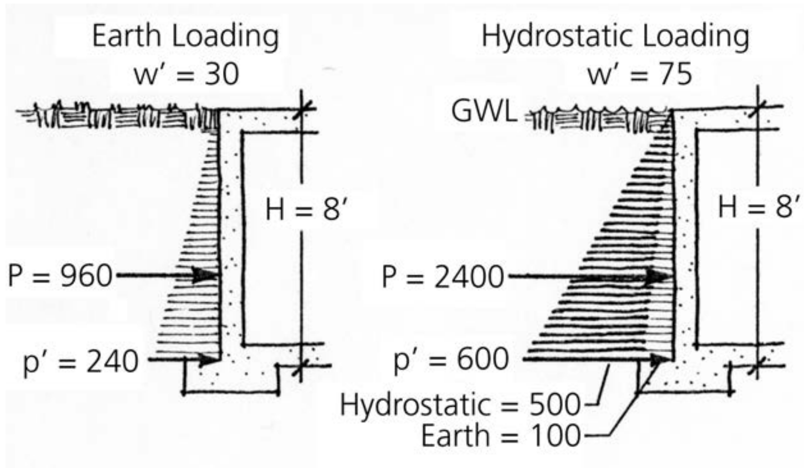
Appendix III

THE EFFECT OF BUOYANCY ON EARTH LOADING (TSS)

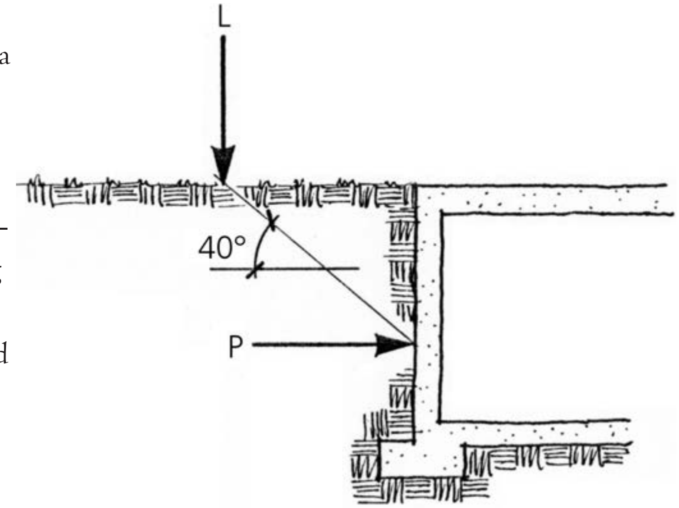


The magnitude of the buoyant effect is assumed to be the difference between the calculated hydrostatic loading and the Rankine calculation using a w' for the appropriate saturated soil. Consider the example above of an 8 ft head coincident with the roof slab and ground surface (no surcharge). Assuming a saturated loading of w' = 75 psf and H= 8 ft, P is found to equal 2400 psf, with a footing (base) thrust of 600 psf The hydrostatic head at the footing is calculated: 8 ft x 62.4 = 500 psf; therefore, the remaining 100 psf is contributed by earth pressure a-lone. Using a "dry" earth w' = 30, the resultant P by Rankine's formula is found to be 960 psf; pressure at the footing is then derived to be 240 psf.

The 140 psf reduction in earth pressure (at the footing, 240-100) is attributed to the "buoyant effect of the water on the soil particles." This is shown, but not fully explained, in *Time Saver Standards,* p. 351. See also *Building Research,* Nov/Dec, 1964, p.43.

SURCHARGE DUE TO AN ADJACENT VERTICAL LOAD

Seelye (p. 3-21) provides a technique for calculating imposed surcharges on sub-grade retaining walls using equivalent fluid pressures:



For L = load/linear foot,

P = horizontal loading/linear foot on back of wall caused by L,

And P = L x (w'/w)

Values for w' and w (for same soil conditions) are provided in the text here of Part III

(From E. E. Seelye, *Design: Data Book for Civil Engineers,* vol I, Wiley & Sons, 1945)

UNIT WEIGHTS OF SOIL FOR DIFFERENT CONDITIONS[1]

SOIL AND CONDITION	WEIGHT (pcf)
CLAY	
dry, hard	137
very dense	125
moist, loose	115
silty, dry	100
plastic	100
dry, & gravel	100
organic	88
GRAVEL	
wet	120-125
dense	100-120
dry, loose	90-105
SAND	
packed, dense	125
wet	120-125
10% moisture	120
fine, dry	100
dry	90-105
LOESS	100
SILT	115
PEBBLES	110
PEAT	70
CRUSHED STONE	100
"EARTH" (excavated)	
dry, loose	76
dry, packed	95
moist, loose	78
moist, packed	96
mud, flowing	108
mud, packed	115

SOIL AND CONDITION (cont'd)	WEIGHT (pcf)
WATER	62.4
LOAM	
loose dug	75
in situ, dry	80
in situ, wet	120
HUMUS	
dry	55
wet	82
SUBSOIL	
in situ, dry	110
in situ, wet ,	125
LIGHTENING AGENTS[2]	
coke, dry	40
coke, wet	50
vermiculite, dry	3.5 - 6
vermiculite, wet	35 - 75
styrofoam	2
Dorovon	1
perlite ("Perloam")	8

WATER HOLDING CAPACITY OP SOIL (AS % OF WEIGHT)[3]

SOIL TYPE	%
coarse sandy soil	15-30
light loam	22-34
stiff clay	36-50
sandy peat	53-60
peat moss[2]	25x
vermiculite[2]	10-12x

SOME ANGLES OF INTERNAL FRICTION (JUMIKIS)[4]

SOIL AND CONDITION	IN°	(AS RATIO)
CLAY		
firm (w = 10-15%)	20	2.75:1
moist	15	3.73:1
soft plastic	7	8.1:1
GRAVEL, dry	35-40	1.3:1
SAND		
dry	30-35	1.6:1
moist	20	2.75:1
saturated	15	3.73:1
SILT	5	11.4:1
LOESS	25	2.1:1

"The angle of internal friction for close-particled (permeable) soils is almost independent of moisture content of the soil. Regardless of whether wet or dry, the coefficient of internal friction of such soils varies considerably between about tanø = 0.45 to about tanø = 0.70. For clayey soils the tanø values usually range from about tanø = 0.20 to about tanø = 0.58 depending upon moisture content and the presence of sand. About 70-75% sand is required to make an appreciable difference in ø, because lesser amounts tend to "float" in a matrix of clay." "The value of this so-called angle of internal friction is a test parameter which depends upon the method used for determination." (Quoted from Jumikis, Fndn. Eng'g.)

Slopes of repose are determined by soil shearing strength, which is related to the angle of internal friction and cohesion. Cohesion is a sensitive property much affected by moisture content (see text), hence allowable slope angles must be designed with soil moisture considered carefully.

SOME ANGLES OF REPOSE, COMMON GRADING PRACTICE[5]

SOIL AND CONDITION	IN°	(AS RATIO)
CLAY		
firm (w = 10-15%)	(30)	1.75:1
damp, plastic	(18)	3.0:1
firm	45	(1.0:1)
wet	16	(3.5:1)
SAND		
clean	(33)	1.5:1
dry	38	(1.3:1)
wet	22	(2.5:1)
GRAVEL	(37)	1.33:1
EARTH		
firm, in situ	50	(0.84:1)
loose ("vegetable soil")	28	(1.8:1)
SAND AND CLAY	(37)	1.33:1
GRAVEL AND CLAY	(37)	1.33:1
GRAVEL, SAND AND CLAY	(33)	1.5:1
SOFT ROTTEN ROCK	(45)	1.0:1
AVERAGE SOIL	(37)	1.33:1

Safe slope commonly assumed in practice (for average soils) is 1.5:1 to 2:1 (about 26°)

For granular soils, a slope flatter than the slope of repose may be assumed as a safe slope without regard to height.

Slopes of cohesive material require flatter angles as the height is increased. This limiting height will vary as to the degree of compaction, compressive strength and angle of friction. It will also vary as to the foundation on which it rests. (These conditions quoted from Seelye)

SOME TYPICAL ROOFTOP/PLANTER SOIL MIXES[6]

MIX "A": 1/3 perloam, 1/3 peat moss, 1/3 topsoil

MIX "B": 1/3 perloam, 2/3 topsoil

NOTE: since peat moss is highly absorptive of water, in some cases it may be desirable to increase amounts of topsoil or to add sand, as in the following (these mixes exclusive of nutrient additives and conditioners, such as lime, bone meal, etc.):

MIX "C": 1/2 loam, 1/4 peat, 1/4 sand or perlite

MIX "D": 1/4 topsoil, 1/4 peat moss, 1/2 course sand

MIX "E": 2 pts hypnum or sphagnum peat, 3 pts Haydite or Basalite aggregate (3/8 in. to #8 screen), 3 pts Haydite or Basalite (#8 to 0)

FOR DETERMINATION OF LOCALLY APPROPRIATE SOIL-RETAINING GROUND COVERS, CONSULT A (LOCAL) LANDSCAPE ARCHITECT.

Some ground cover species and their associated maximum slope angles appear in *Off the Board and into the Ground*, Gary O. Robinette; editor (Kendall/Hunt Pub. Co., Dubuque, Iowa, 1968). See also Robt. Zion, *Trees for Architecture and the Landscape*, for a listing of hearty tree types recommended for rooftop installations.

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[1] These values are compiled and edited (i.e., most often cited values for the conditions stated) from the following sources:
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A. E. Weddle, ed., *Techniques of Landscape Architecture*, American Elsevier, 1967.
also:
Time Saver Standards for Arch'l Design Data, McGraw Hill, 1974 (Callender, ed.)
Architectural Graphic Standards, Ramsey and Sleeper, eds., 6th Edition.

[2] These values from M. Paul Friedberg, "Roofscape," *Architectural and Engineering News*, Sept 1969.

[3] These values from Weddle (see above)

[4] These values form Jumikis, *Fndn. Eng.* (see above); angles of internal friction are not usually expressed as ratios, but are transposed here for comparison with repose slopes.

[5] The values here are compiled from Weddle (above) and Elwyn E. Seelye, *Design: Data Book for Civil Engineers*, Wiley & Sons, 1945. Original values are stated as from texts, parenthesized values by my conversion for comparison.

[6] Mixes "A" & "B" from Friedberg (above), "C" & "D" from Robinette (at left), "E" from Kaiser Plaza plan (see *Landscape Architecture*, Oct 1962)

Earth Temp. Station/1	Air Temp. Station/2	Maximum		Minimum		Spread		Spread Diff.	JAN DD (1)	UDD (2)	Savings (3)
		E	A	E	A	E	A				
Auburn, AL	Montgomery, AL	74	81	56	49	18	32	14	543/2	279	49
Decatur, AL	Huntsville, AL	71	81	48	43	23	38	15	694/2	527	24
Terape, AZ	Phoenix, AZ	81	90	59	50	22	40	18	474/2	186	61
Tucson, AZ	Tucson, AZ	85	86	65	50	20	56	16	471/1	0	-
Brawley, CA	Yuma, AZ	90	95	68	55	22	40	18	363/2	-93	
Davis, CA	Sacramento, CA	76	75	56	44	20	31	11	614/2	279	55
Ft. Collins, CO	Denver, CO	63	72	37	29	26	43	17	1128/2	868	23
Gainesville, FL	Orlando, FL	80	82	69	62	11	20	9	220/2	-124	-
Athens, GA	Athens, GA	77	81	57	45	20	36	16	642/1	248	62
Tifton, GA	Albany, GA	80	83	62	51	18	32	14	400/4	93	77
Moscow, ID	Idaho Falls, ID	57	69	37	16	20	53	33	1550/2	868	44
Argonne, IL	Chicago, IL	64	75	38	25	26	50	24	1209/2	837	31
Lemont, IL	Chicago, IL	65	75	39	25	26	50	24	1209/2	806	33
Urbana, IL	Springfield, IL	67	76	39	27	28	49	21	1135/2	806	29
Urbana, IL	Springfield, IL	68	76	42	27	26	49	23	1135/2	713	37
W. Lafayette, IN	S. Bend, IN	66	71	38	25	28	46	18	1221/2	837	32
Burlington, IA	Burlington, IIA	71	77	38	24	33	53	20	1259/1	837	34
Manhattan, KS	Concordia, KS	69	80	41	28	28	52	24	1163/2	744	36
Lexington, KY	Lexington, KY	68	76	42	33	26	43	17	946/1	651	32
Lexington, KY	Lexington, KY	70	76	46	33	24	43	19	946/1	589	38
Up. Marlboro, MD	Washington, DC	70	77	42	36	28	41	13	900/4	713	21
E. Lansing, MI	E. Lansing, MI	63	71	37	24	26	47	21	1262/1	868	21
St. Paul, MN	Minneapolis, MN	62	74	34	15	28	59	31	1631/2	961	41
State U., MS	Meridian, MS	79	81	55	48	24	33	9	543/2	310	43
Faucett, MO	Springfield, MO	65	78	43	33	22	45	23	973/2	682	30
Kansas City, MO	Kansas City, MO	66	81	42	30	24	51	27	1052/1	713	31

Earth Temp. Station/1	Air Temp. Station/2	Maximum E	Maximum A	Minimum E	Minimum A	Spread E	Spread A	Spread Diff.	JAN DD (1)	UDD (2)	Savings (3)
Sikeston, MO	Springfield, MO	71	78	43	33	28	45	17	973/2	682	30
Bozeman, MT	Billings, MT	56	73	33	23	23	50	27	1296/2	992	24
Huntley, MT	Billings, MT	64	73	36	23	28	50	22	1296/2	899	31
Lincoln, NE	Lincoln, NE	69	79	39	24	30	55	25	1237/1	806	35
Norfolk, NE	Norfolk, NE	66	76	40	19	26	57	31	1414/1	775	45
New Brunswick, NJ	Newark, N.J.	65	75	42	32	23	43	20	983/2	713	28
Ithaca, NY	Syracuse, NY	59	73	39	26	20	47	27	1271/2	806	37
Raleigh, NC	Raleigh, NC	73	79	52	41	21	38	17	725/1	403	45
Columbus, OH	Columbus, OH	65	74	41	30	24	44	20	1088/1	744	32
Barnsdall, OK	Oklahoma City, OK	74	82	54	37	20	45	25	1165/2	341	70
Pawhuska, OK	Oklahoma City, OK	74	82	50	37	24	45	21	1165/2	465	60
Corvalis, OR	Eugene, OR	66	67	46	38	20	29	9	80 3/2	589	27
Pendleton, OR	Pendleton, OR	67	75	39	31	28	44	16	1017/1	806	21
Calhoun, SC	Columbia, SC	76	81	52	47	24	34	10	570/2	465	18
Madison, SD	Huron, SD	61	75	33	14	28	61	33	1628/2	992	39
Jackson, TN	Oak Ridge, TN	71	78	49	38	22	40	18	778/2	496	36
Temple, TX	Waco, TX	82	86	58	47	24	39	15	536/2	186	65
Salt Lake City, UT	Utah (same)	63	78	40	29	24	39	15	1172/1	775	35
Burlington, VT	Burlington, VT	63	70	35	18	28	52	24	1513/1	930	39
Pullman, WA	Walla Walla, WA	60	76	36	32	24	44	20	986/2	899	9
Pullman, WA	Walla Walla, WA	58	76	38	32	20	44	24	986/2	837	15
Seattle, WA	Seattle, WA	61	65	45	39	16	26	10	738/1	620	15

(1) From *Climatic Atlas of the U.S.*, for location of earth station (1) or air station (2), as noted, month of Jan. (coldest for atmos. DD)

(2) "Underground Degree Days": (65° - Min. Earth Temperature) x 31. Coldest Earth temp, over "integrated average" 10 ft depth generally occurs during Feb. Min. temp, here is assumed for duration of 31 days for comparison.

(3) Comparison of atmospheric DD and "UDD" is calculated for respective minimum and maximum of each.

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Final Notes

To get back to the idea of an imaginary architecture, which is seen as the process of perfecting the earth. From time to time I go to visit students at different schools... and I love this because when I walk into a studio, the tables are covered with models... The stages of the construction of the model are to me the moat significant part of the education and miseducation of architects. Invariably, I have to walk past a model... that is merely a contour study of the site before the thing has been set down on top of the model... You know how they're all done, they're tiers, and tiers, and tiers of cardboard or balsa wood... cut out to follow the contours of the land. They're extremely beautiful. Why shouldn't they, be? Often the land is very beautiful. These contour maps—these models of the earth—are already architecture. Nothing else is needed to make a building, you know, except to pull out one or two of these layers and make a space between them. Think how many thousands of buildings in the United States could slip into the earth. Instead, the students think of architecture as the making of things in opposition to the earth.

(Arthur Drexler, at the 1962 Aspen International Design Conference. Quoted in Landscape, Autumn, 1963, p. 8)

Urban sprawl has consumed much of the open area between our cities. Much of this is unsightly, and is costly to dismantle and replace. Glass cubes designed to let in the outside environment are wonderful spaces to accommodate certain portions of our waking hours, but the cost of heat removal makes these buildings inefficient for many uses. The modern factory encloses itself, to provide a controlled atmosphere wherein efficiency can be developed. There is no reason why a factory cannot be built below the ground, leaving the open land and natural environment for those functions requiring it. Is this not also true of a shopping center, a community government complex, or many other habitats of man which do not need the forces of the environment acting upon their shells?

Man's continuous return to nature hints at a historical cycle of development. Primitive man left his cave because he was better able to secure his food by traveling with the herds, and relied on his capability to live off the land. It is logical that man's own genius has developed a life pattern whereby his knowledge will allow him to return to the cave, with the highest degree of technology used to improve his environment. Here he has achieved supreme livability, with greatest safety, and at lowest cost.

...although we see the subterranean environment as a protective shield in today's bomb shelter solutions, building below the ground may be a major step in our cultural development. From the evil of today comes the seed of tomorrow's culture.

(Milo D. Folley, introduction to Design for the Nuclear Age, National Academy of Sciences, National Research Council, 1962)