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DEPARTMENT OF INFRASTRUCTURE

MASTER OF SCIENCE THESIS

HABITAT
THE SUBSURFACE ENVIRONMENT

By Annika A. Lundkvist
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Abstract

General interest and enthusiasm in communities around the world to use underground space is an ancient phenomenon which is highly dependent on regions and local traditions of building and utilizing space. The interest and use of underground architecture and spaces will strengthen in coming decades as human communities continue to expand, environmental changes persist, and societies begin looking further and more seriously into utilization of space which may have previously been considered as "alternative," namely, underground space.

Psychological issues are, and will remain, a heavy factor integrated into the acceptance and idea of human occupancy of underground space. This paper intends to look closer at these issues and to validate and explore the potentials of underground space for human occupancy.

The author recognizes that some of the contents presented here demand intense further analysis.

Keywords

Progressive
Subsurface[1]
Geo-space[2]
Nexus
Psychology
Architecture

1 Subsurface, Subterranean and Underground are all terms indicating, in this thesis, the same spatial frame and are used interchangeably throughout the paper.
2 See Glossary

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Method

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Foreword

This is a Masters thesis written for the Masters in Spatial Planning Program at the Department of Infrastructure at Kungliga Tekniska Högskolan (Stockholm, Sweden).

At the beginning of the International Masters in Spatial Planning Program 2001/2002, one of the professors in his opening welcome to the students, proposed that one of the goals of the program was to train the students to be ”Managers of Change”. This proposition has come back to resonate during the writing of this thesis.

The topic of this thesis- The Subterranean Environment- was chosen out of steadfast interest in the field of subsurface utilization and development. This paper intends to shed a margin of light and one perspective as to how certain spatial developments can evolve more dynamically and organically, with the cultivation of a collaboration which reflects a nexus between specific disciplines.

Interest for the field of subsurface development is significant, spreads worldwide and does involve the participation of a range of disciplines. Interest for this development will strengthen in coming decades as changes initiated by communities, particularly with regards to spatial developments and decisions, *and* changes enforced upon those same communities by a variety of environmental pressures, provoke and demand progressive concepts of utilizing space. Promotion of the use of underground space will play a critical role in response to these changes.

This is a text for a range of readers. Those who are very familiar with issues related to subsurface development, in reading through much of the text, may recognize certain spaces or issues discussed or referred to as they have been documented at least once before. For the reader who is ignorant to even the concept of underground architecture and development, and all the spaces it entails, this paper should serve as a good introduction. And for those who are, from the outset, simply skeptical as to the real potential benefits of human occupancy of the underground, this paper may at least offer a challenge to the skepticism, and a subtle provocation.

There is, within the intent of the entire thesis, an invitation to the reader to simply consider, according to today’s developments and demands, what role various spaces will play in future human communities, and more specifically, what role the underground will play. What will the human response be to this role and will human interest in the underground grow?

For all of the readers, the issues of human habitation and psychological issues related to the underground could provide among the most interesting. There is still significant research to be done, in general, in both categories. Research up to date on both themes is minimal, and during the authors literature review, there was an infrequently stated, yet clear consensus among researchers in the field of underground development, that psychological issues for humans in the underground are one of the most under-explored categories. What is presented in this paper is by no means comprehensive, yet strives to highlight the primary concerns of the research, as well as to provide preliminary suggestions, relative to working methods and research foci, which may be committed to the aim of more habitable underground spaces

Formal guidance for the thesis was provided by Göran Cars and Lars Orrskog. The author would like to thank Annica Nordmark for her support and advice, particularly in the stages when the construction and concept of the thesis was just taking form.

PART 1
INTRODUCTION

The spatial challenges of urban planning today have encouraged those involved in its development to seek new solutions. Subsurface space is one solution in the form of an entire domain.

In the past century, development of subsurface space has been predominantly related to military facilities, storage of a variety of materials, utilities networks and transportation. Facilities beyond these uses *have been* developed around the world, in some places more extensively than others.

Provocation is often an inherent quality in the presentation of progressive models, and while subsurface use as a general concept is not a progressive idea, certain applications and uses in the field *are*, from both the eyes of the community and those involved in decision making related to spatial developments. Yet from the community's eyes, as well as from the perspective of developers and decision makers, use of subsurface space is not a focal concern. Economic demands for underground projects as well as regional traditions related to use of subsurface space are instrumental in these perspectives as well as in advancing, or halting, underground projects.

A critical factor in the encouragement of subsurface development relates to issues of human response to using facilities placed underground. With regards to this development, Carmody and Bergman state,

> *…. one of the most intriguing research areas relates to human habitability in underground space. Human habitability issues are controversial but are also crucial to understand since they will affect the acceptance and marketability of underground space and ultimately place limits on what types of functions can occur there.*

Statements such as this abound in the research and literature on the development of subsurface space. It is generally agreed by researchers and specialists in this field, that the range of human's psychological and physiological response to occupying underground space, is a sector of understanding demanding considerably more attention. There is still much to learn with regards to the general interest humans have to use subsurface facilities as well as the emotional responses and prejudices evoked from the very idea of "underground space".

A visionary element addressed in this paper is with regards to increasing human occupancy of subsurface space. This element is labeled here as visionary as it is not yet truly manifest. The reality, in recent and modern times, is that increased human occupancy of subsurface space often occurs in times of crisis, threat and war. Proposing the potential for human occupancy of subsurface space on a regular basis, in facilities commonly found on the surface, is precisely the type of suggestion which invokes critical disinterest from some, and strong curiosity from others. Such proposals are not found on the common agendas of the subsurface development community, and their presence is often a cause for skepticism and hesitance.

This paper does not present a rational plan for the creation of subsurface environments which would support human occupancy on a more permanent basis than exists today, yet it does address issues that will be highly relevant to the creation, maintenance and optimal habitability of such environments.

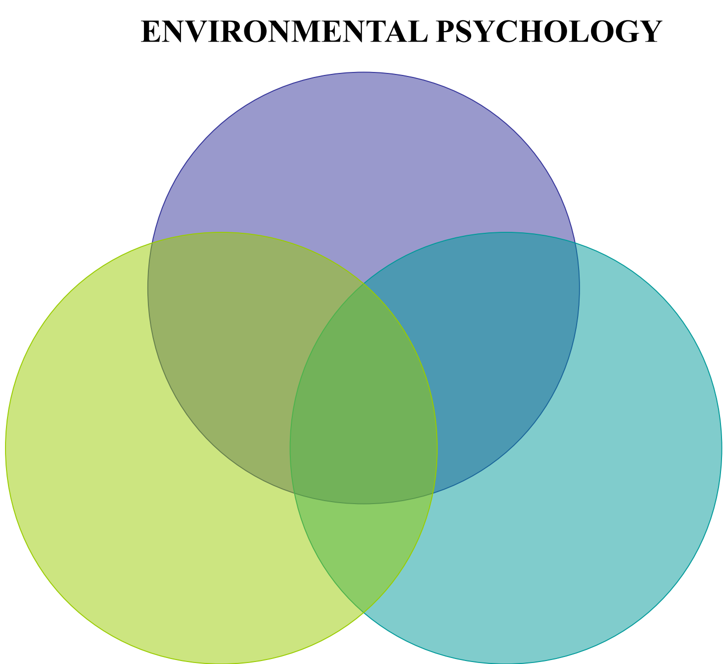
1.1 Background

Spatial planning, at its core, relates to how we structure the environments we inhabit and the dynamic processes which occur to organize and achieve the changes deemed necessary. Psychological factors are often primary components of this field, as a keen, working awareness of human and community wants, needs and patterns are critical for effective planning to occur.

In the foundation of this thesis is the question of how we have evolved to *perceive space* and *inhabit space.* A critical pressure for communities of the future will be availability and use of space. This is already a dominant concern and forefront on planning agendas today.

Figure 1, The Nexus Approach, illustrates three fields and specializations, Spatial Planning, Environmental Psychology, and Architecture, and a system of simple inter-laps between them. Cooperation between two fields demands only a portion of work and attention from the entire sector of that discipline, and only a small area is found where all three intersect. Yet this point *is* the nexus, and when we apply such a diagram to a specific issue, e.g. underground developments, we can forecast an intent towards cooperation and exchange. .

Though inherently connected to Urban and Regional Planning processes, Subsurface Development demands a field of research and specialists of its own, drawing from all three disciplines shown in Figure 1, in addition to more. This network already exists and is growing.



SPATIAL PLANNING ARCHITECTURAL CONCEPTS

Figure 1 The Nexus Approach[3]

As stated, this model may be best analyzed when applied to a specific project or niche of work. Underground planning is precisely such a niche. Cooperation between disciplines need not indicate active collaboration on a regular basis, but an agreement to keep in mind the contribution and potential worth of the other fields aims, research and development in concert with ones own field and profession.

1.2 Purpose

The intent of this thesis is to address the issue of human occupancy of underground space and to confirm the need for further research and development of concept and design solutions connected with human habitation needs in the underground. Encouraging intensive, deliberate exchange and dialogue between disciplines, (as discussed in the Background), with regards to the development of underground spaces is also in the main interest of this thesis.

1.3 Method

Resources available at the time of writing were literature on the theme and a growing network of contacts who provided appreciated assistance and advice to further the authors understanding of the issues and various actors involved in field of subsurface development. The paper is largely a result of research and literature reviews as well as formulations of the authors own concepts and suggestions relative to the theme.

Attendance to The 9th International ACUUS Conference: Underground Space: A Resource for Cities, was also performed during the writing of the thesis and provided an invaluable frame of reference as to the present focal concerns in the network of those who are involved in subsurface spatial developments.

In order to fulfill the purpose of the paper, a fourfold methodology was chosen. Figure 2 illustrates four aims, each connected with the central theme of human occupancy of subsurface space.

[3] See Section 4.4 for further discussion on Figure 1

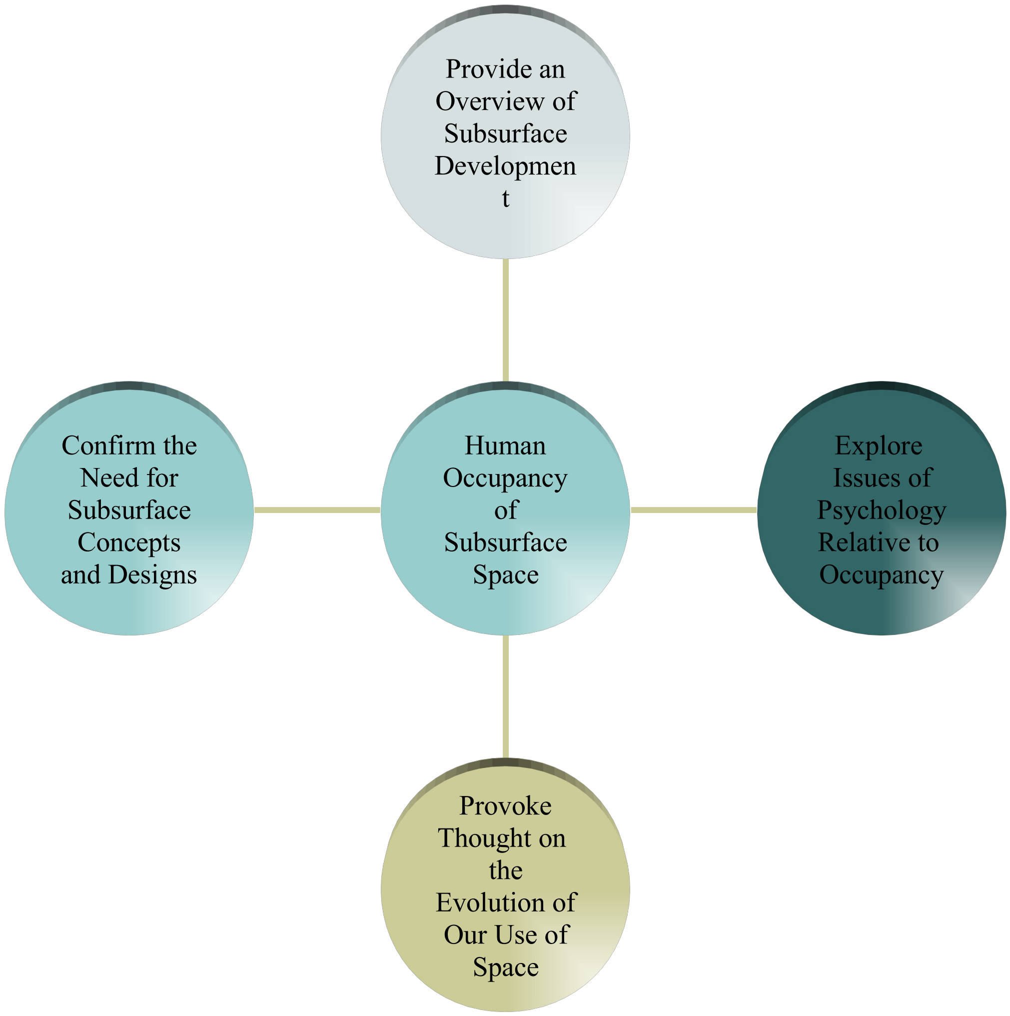


Figure 2 Fourfold Methodology

Part Two serves to provide an *overview of subsurface space development* via discussion of the various motivations for such development, provision of a classification table of facility types, as well as highlighting some historical and regional trends in underground architecture.

Part Three most clearly handles the *exploration of psychological issues relative to human occupancy*. Part Four continues with this exploration in discussing the basic concept of how fit underground space is for humans. Part Four progresses to deal with the *need for subsurface concepts and designs* as well as address research issues regarded as crucial for the further exploration of the discussed psychological and physiological issues linked to human's occupancy of the underground.

The entire thesis serves to *provoke thought on the evolution of our use of space*.

PART 2
SUBSURFACE DEVELOPMENT

The downward prolongation of the city, connecting with its roots, has twofold interest. On the one hand, is the intrinsic value of creating this new atmosphere underground and on the other hand, it decongests activity on the surface.
(Junca-Ubierna, 1995)

In recent decades, it is primarily the technologically advanced countries that have been serious and intensive in efforts to develop and integrate subterranean space into their urban networks. These efforts stem from a variety of observations and initiatives, the most striking being the recognition of growing tension with use and availability of land and the acknowledgement of the underground as a very valuable resource for communities.

2.1 Motivations

For those initially uncertain of the benefits involved in furthering the development of subsurface space, or for those unaware of the modern prevalence of such use, it is useful to briefly outline the most common reasons for placing facilities and structures in the subsurface environment.

A popular question in the field of subsurface development itself is “Why go Underground?” (Godard, 2002), in addition to *what* should be placed underground, *how* and *where*. Who will want to use it is also a critical question. Exploring the issue of specific human interest to use a range of subsurface facilities is core to this thesis, but it is necessary to first address the issues of why the interest to develop and use this space exists.

Land Use
Climate
Energy Efficiency
Isolation
Preservation
Defense

Figure 3, Reasons for Going Underground[4]

Land Use

The level of crowding occurring in urban areas across the globe today, increasing land prices, preservation of land for agriculture, and general preservation of surface landscapes are all important factors which have served as arguments at the forefront of recent subsurface developments.

Subsurface use also offers the possibility to construct passages in close range to existing facilities, a particular advantage in areas where the surface has been densely developed (Godard, 2002). An oft cited representative for underground passage networks is Montreal, Canada, which hosts the “Underground City”, a network spanning over 30 kilometers and connecting a vast range of facilities and services in the city.

Regional and geologic considerations are also a strong factor. In addition to benefiting highly urbanized areas, subsurface space use is extremely beneficial for mountainous regions, where such a

[4] Adapted from ITA Publication (Godard, 2002)

use is a spatially logical response to difficult terrain. Underground and intra-mountainous developments offer the possibility to link regions and communities with efficient passages.

Climate

Climactic motivations to develop the subsurface domain serve as one of the most ancient and basic reasons for human interest in the space. Use of subsurface space has particularly obvious and practical benefits in extreme climate zones. Hot, dry climate zones, such as Australia, and Northern Africa, as well as colder, dry zones, such as central Canada, Siberia and Northern Scandinavia, are particularly suitable to develop and integrate progressive use of subterranean space into their local building culture. Some communities in these places have done just that.

Cities and towns with drastic climates or extreme fluxes between day and night temperatures can greatly benefit from placing facilities underground. Individuals in such zones may also be more open to the idea of new forms of living and working space as it serves to function in relation to their difficult climates.

The benefits of building underground in a region with an extreme climate are related to the thermal conditions within the subsurface environment. Within subsurface space, no diurnal temperature fluctuation occurs and around a depth of ten meters, the seasonal temperature becomes stable. It takes approximately one season (three months) for air temperature to reach the ten meter depth. Summer air temperature reaches a depth of ten meters by winter season, and vice versa. (Golany et al., 1996). The retaining of summer heat provides natural warmth in the winter months and temperatures of winter provide the convenient cooling effect in the summer season. The slow and gradual response of the mass of earth between the underground facility and the surface level of land provides for a considerable range of energy conservation possibilities, as well as significant issues related to human comfort in occupancy. Thermal maintenance paralleled with careful construction is critical however.

The stabilization of the interior climate because of these natural thermal factors provides the possibility for increased energy efficiency in maintenance due to internal climactic conditions and is highly relevant for communities who must correlate energy and design factors in their construction to distinct seasonal, or diurnal, changes in climate.

Energy Efficiency

The deeper a structure penetrates into the Earth, the greater the structures interior will benefit from the energy conserving properties of being located underground. Facilities such as cold storage often benefit from being placed in a deep mined space, and maintenance is often less than it would be in a surface facility for the same industry. The potentials in providing subsurface locations for facilities that would greatly benefit from such energy conserving properties is of highly relevant interest.

Maintenance of underground buildings is often minimal in comparison to surface structures as they are not exposed to external damage, weathering or decay (Quarmby, 1997). What is thus designed has the potential of providing a long life to the community and a potentially wide range of use. In studies done at Gjøvik Mountain Hall, Norway, for example, it was found that by placing the Hall underground, the energy efficiency of the structure was 40% greater than if it had been placed on the surface (Grande et al., 1995).

Economic factors play a critical role in assessing the future of subsurface development, as underground construction costs are typically higher than those of surface buildings. Cost analysis is a vital sector of research as is assessing the “life span” of the structures and proving that in terms of maintenance costs and related energy conservation characteristics, underground facilities can in fact prove to be more cost effective in the long term. The benefits of climate and related energy efficiency of subsurface structures can be considered a significant offset to the substantial economic costs in the construction stage. The enormity of economic demands related to underground infrastructure is one of the critical setbacks in development, yet spatial demands being made on urban regions and investigations of the energy efficiency potential of underground facilities, are crucial counteracting factors to further the active promotion of subsurface spatial development.

Isolation

Underground space offers natural protection and isolation for a range of activities and infrastructures, from utilities to military operations. Isolation is provided by means of mechanical, thermal and acoustic characteristics (Godard, 2002).

Climactic isolation, as has been discussed, is relevant here. Isolation and protection from noise and vibration on the surface, provided by natural acoustic properties of subsurface space is also a special characteristic to be assessed when deciding what facilities could benefit from being placed underground. Subsurface structures are also typically designed to support substantial loads of earth and so are sometimes immune to extensive structural damage in the event of an earthquake, whereas surface structures suffer more damage.

Preservation

The need to preserve surface open space cannot be emphasized enough. Revitalization of natural surface landscapes and allowing wildlife to continue to flourish is the clearest motivation behind this need. Allowing the city to green again by converting squares and surface spaces into even more densely vegetated regions and allowing buildings previously used for services and city facilities to be converted into accommodations (Quarmby, 1997), is among the more progressive notions about what subsurface development could mean for preservation of the surface landscape.

The increasing criticism being shed on the manifold detriments of sprawl and a range of urban complaints and pressures is one clear motivator backing the development of certain “utopian” underground concepts. Ecological considerations play a strong role in these ideas and examination of how maintenance of plant life and animal habitats can be achieved to a greater extent with subsurface as opposed to surface development should play a strong role in future promotion of underground use to support preservation of surface land.

In addition, subsurface structures are also simply less visually imposing. The development of car parking facilities in cities across the world reveal the understanding that surface space is becoming ever more precious and should not be further degraded with the proliferation of necessary, yet mundane facilities such as car garages. Subsurface space is indeed highly suitable for the placement of infrastructure and facilities which are difficult to integrate into the surface landscape, for economical, spatial and environmental reasons. In the past, what has been found as suitable in this respect are utilities and transportation networks, storage of various materials and transportation. In the future, it is possible that what is found as suitable for the underground may extend beyond such systems.

Defense

Subsurface spatial developments on behalf of military and national defense interests have been significant over time. Security is often heightened within a subsurface structure as access points are limited and, in principle, easily secured. In addition, the choice of a subsurface location may enhance the desire or need for privacy as the structure itself may be largely unnoticed or hidden from general public view.

Local and national defense interests continue to fuel significant developments in subsurface expansion. Subsurface extensions of existing governmental buildings in historic settings, for example, are often executed in order to minimize site impact as well as for security purposes.

2.2 History

Medieval space raised itself above the earth; it was not yet by any means an abstract space. A large- though diminishing- portion of 'culture', of impressions and representations, was still cryptic*, still attached to places that were holy or damned or haunted- to caverns, grottoes, dark vales, tombs, sanctuaries, and underground chambers.*

(Lefebvre, 1974)

Humans have made use of subterranean space since ancient times. Caves and natural earth sheltered dwellings served among humans earliest habitats. Examples can be found throughout the world of variations of indigenous uses of subsurface space, the structures largely formed with response to climate and environment and specifically shaped by culture. The primary uses of subsurface space through history have been for habitation, food storage, defense (against climate and/or invaders), mines and burial.

Three major indigenous communities are commonly cited and referred to for their tradition of an extensive use of subsurface space: the Loess soil zone in China, Cappadocia, Turkey, and Matmata, Tunisia. In the Loess soil zone of Northern China, an estimated 35 to 40 million people live in underground dwellings, both in rural and urban areas. Cappadocia, Turkey hosts a vast and actively utilized underground network which is still used for storage and living. Underground "cities" here are also reputed to be able to support up to ten thousand inhabitants. Tunisia is renowned as the place where the largest number of subsurface structures can be found, inspired centuries ago by the Berber tradition of subsurface building to provide protection from a harsh desert climate. The common links amongst these three underground indigenous communities are climate (semi arid environs with extremely hot days and very cold nights), unique architecture and design, development over history and adaptation to a strenuous climate and environment (Carmody et al., 1993).

Historical examples of underground space do not always meet the modern technological and aesthetic standards of construction. Yet the motivation behind the subterranean occupation of space is useful to note, as the same motivations remain in developments today- climactic and environmental pressures, room for expansion whilst preserving surface space, extensive room for storage, protection, defense and energy efficiency.

The genesis and development of more recent underground constructions is found in the modern, large scale underground projects initiated in Europe during the industrial period. These developments were primarily related to systems for utilities, transportation, storage and civil defense. More recent developments show that the focus on the underground is largely related to exploiting its space for the same systems, though now with increased quality and efficiency of technology.

World War II was a significant period for the advancement of subsurface development. Several nations constructed extensive subsurface facilities related to military and defense use during this time. Significant developments occurred particularly in Japan, Switzerland, Germany, Sweden, France, and the United States. This period of development is critical for it is one of the few intensive periods of subsurface construction to occur during the 20^{th} century, and to include the construction of a range of facility types.

In the past few decades, subsurface development has seen tremendous progress in urban areas across the globe. Contemporary trends reveal the most significant use and development of subsurface space occurring in technologically advanced countries, who can afford the utilization of tunneling technology and who are also in recognition of the pressures and tensions related to use, cost and demand of space. Yet the use of subsurface space in regions around the world is simultaneously extensive and exclusive, with regards to the motivations discussed previously.

2.3 Domains of Use and Classification

Specific developments of subsurface use are highly dependent on continent, regions, climate and culture. To understand the greater range of historic, modern, and potential future uses of subsurface space, it is helpful to classify the existing facility types.

FACILTY TYPE	EXAMPLES OF SUBSURFACE USE	OCCUPANCY INTENSITY*
RESIDENTIAL	Troglodytes, Earth Sheltered and Subsurface Homes	5
COMMERCIAL	Offices, Shopping Centers, Stores, Restaurants	5
RECREATIONAL	Sports halls, Swimming Pools, Community Centers	4
ENTERTAINMENT/ EXHIBITION	Theaters, Auditoriums, Museum, Public Displays, Studios	4
EDUCATIONAL	Libraries, Classrooms, Computer Rooms, Research Facilities	4
RELIGIOUS	Churches, Temples	3
MEDICAL/ EMERGENCY	Crisis Communication Centers, Shelters, Hospitals	5
TRANSPORTATION	Pedestrian Ways, Mass Transit, Parking Garage	3
MILITARY	Bases, Strategic Centers, Storage/Production	4
INDUSTRIAL/STORAGE	Manufacturing, Cold Storage, Archives, Warehouses	2
STORAGE	Cold Storage, Archives, Warehouses	1
SYSTEMS	Utilities, Service	1

Table 1 Classifications of Subsurface Facilities and Examples of Use
*Occupancy Intensity relates to general frequency humans will inhabit the facility
1- No to very minimal occupancy, not demanding human presence on a regular basis
2- Minimal occupancy
3- Minimal to average occupancy, often characterized by heavily transient use, and periodic emptiness
4- Frequent occupancy, yet not necessarily consistent and with highly regular user rotation
5- Very high, ≥ 12 hours consistent occupancy daily

Residential

Indigenous underground housing is the primary available example of the use of subsurface space for dwelling. Troglodytes are of particular interest here. Troglodytes are made as caves vertically dug into the ground and originated within the Saharan architectural tradition. Over the past centuries they have spread all over the world and find significant representation in North Africa and southwestern Europe.

Although residential use probably represents the oldest use of subsurface space by humans (Carmody et al., 1993), few people would step forward to promote active modern development of residential habitation of underground space. A handful of researchers and figures within the field and history of subsurface space promotion and development have shown interest in the residential aspect, yet this interest is by no means integral to the mainstream dialogue on subsurface space development.

The late Gideon Golany, a noteworthy researcher and promoter of vastly exploiting geospace [5] was developing a basis for analyzing indigenous subterranean housing in Cappadocia, Turkey, to see if it could serve as a model for modern underground housing. Such projects and comparisons could prove fruitful in offering foundations for new models of underground housing, as well as to simply generate dialogue on the very theme of residential underground space. It should be noted that developments of underground space (particularly in "earth sheltered" style) for residence have been occurring, in the past few decades, most notably in Australia and the United States. Such developments are largely out of private will and design.

Commercial

Commercial use of subsurface space is one of the domains which is on a rise, specifically in North America, Europe and Japan. Such use has, in the past few decades, come to be even more integrated into urban networks. Commercial services are often largely connected to public transportation services located in the underground, yet also find considerable representation as stand-alone facilities (i.e., not in direct spatial connection with a subway system). Montreal, Canada hosts the largest indoor underground network which consists of a vast range of commercial facilities used by the community. Toronto, Canada hosts a similar, though smaller "underground city". In the rest of North America, underground commercial facilities are rare and highly region specific.

Extensive underground shopping centers can be found in the major urban nodes in Japan. In Scandinavia and continental Europe, underground commercial amenities are not rare and often connected with the neighboring presence of a subway network.

Recreational

Provision of subsurface recreational facilities can serve to not only save surface land for other use, but also to further acquaint communities with accessing underground space. Underground recreational facilities are not uncommon developments and in certain areas are finding significant representation. Scandinavian countries, for example, could be considered as resting at the forefront of this development of subsurface use.

The indoor sports hall at Gjøvik, Norway, for example, is the largest rock cavern purposefully made and opened for public use on a permanent basis and serves as a phenomenal example of design, development and contribution of a subsurface recreational facility to a community. The Gjøvik Olympic Mountain Hall is buried 120 meters into hill and rock (Grande et al., 1995). Finland has also developed substantial facilities underground related specifically to community and recreational use, and other examples can be found, yet by no means profusely, across the globe.

[5] see Glossary

Entertainment/Exhibition

Theatres, cinemas, studio spaces, art schools and museums are highly appropriate facilities to be considered for placement underground as they are often naturally windowless spaces. A subsurface placement can emphasize the control of interior effects and climate that are often desired and necessary for the maintenance of entertainment and exhibition spaces. Such facilities already commonly have subsurface levels integrated into their structures. These spaces can also double as shelter in times of crisis and war.

Educational

Several libraries located almost entirely underground, or with substantial subsurface levels, exist worldwide, particularly on university campuses. Research laboratories and computer rooms, which are occasionally designed with the need to be windowless, can also be found in underground levels, and increasing their placement there could prove to be a spatially functional move.

Religious

Churches, temples and other religious architecture often have underground levels and rooms. The Temppeliaukio Church in Finland, constructed in 1968-69, is one example of an underground religious structure. It was constructed below the surface mainly for aesthetic reasons but also to preserve Temppeliaukio Square, near the city centre. Other interesting examples of subsurface religious structures can be found worldwide. In Colombia and Poland, for example, vast portions of salt mines have been converted into underground cathedrals.

Medical/Emergency

Around the world, medical and emergency facilities are often placed underground for civil defense and peace operations. Subsurface level extensions to hospitals worldwide are not uncommon and in particular, crisis and emergency shelters often need an underground locale for the very demand of secrecy and safety. There are likely numerous examples of underground locales used for emergency facilities, yet as such facilities are often connected to governmental agencies and agendas, their locations are not always known and public access often not granted.

Transportation

Subsurface development for the purpose of transit systems is one of the primary exploitations as the resulting benefit of decongesting surface space is recognized. Tunneling for the purpose of roadways and public transportation is a dominating arena in the entire field of subsurface use.

Questions of human comfort, safety, appreciation of environment and willingness to use the system are quite critical. Technologically advanced countries such as Japan, Sweden, Great Britain, France, the United States and Canada have executed remarkable projects of urban transportation networks involving extensive exploitation of the subsurface domain.

Transportation is already a primary sector of interest and use for the underground (the term "underground" in some places, automatically referring to the subway system), and this continued development will also likely bring with it parallel developments of underground commercial facilities, specifically in the case of the subway. Yet this development also possibly restricts the very concept of underground use, to the public eye, as a space merely for *passage*.

Military

Military and defense facilities are highly associated with the underground as they provide a secure refuge and secrecy. Military constructions in the underground involve all of the domains of use discussed here.

Industrial/Storage

Industry is a special sector of underground use and, coupled with transportation, is often what people first think of when considering appropriate facilities for underground placement. There are numerous examples of industrial locales located in subsurface, or semi submerged structures and a large percentage of medium to large sized cities worldwide host such facilities. Storage benefits of underground space have also spawned numerous underground storage facilities worldwide and this sector of use, in addition to utilities and transportation, is one of the dominating utilizations of the underground.

Utilities

Utilities refer to the systems which constitute the city's 'lifelines': water, sewage, electricity, communication lines, and heat supply, all of which are found in high distribution underground.

Subsurface Use	Characteristics
Earth Sheltered	**Primarily above ground** **Integrated construction with Earth**
Semi Below Ground	**≤ 3 meters from ceiling to soil's surface**
Below Ground/Subterranean	**≥ 3 meters from ceiling to soil's surface**
Deep Mined	**≥ 10 meters deep**

Table 2 Nomenclature for Range of Subsurface Use and Characteristics

Earth Sheltered

An earth sheltered structure is one which is predominantly above ground and enveloped by a layer of earth. This type of structure is commonly recognized as useful for its ability to minimize energy consumption (specifically diurnal heat gain and loss), although its capacity for heat retention is limited. Earth sheltered structures were a common form of construction by Native Americans, primarily in the dry southwestern regions of the United States, and significant modern interest appears to exist for them in Australia and the United States. This form of structure has also been used since ancient times in regions with climactic stress, such as the Middle East, the Mediterranean and Northern China.

Semi below ground

Semi below ground structures are constructed partly above the surface of the earth and partly below. This type of structure constitutes a large portion of buildings which are generally classified as underground space. In North America, the house with a basement is a good example of a commonly used semi-below ground space, as are semi-basement levels to be found in structures throughout Europe. Another example are the terraced cliff habitats found in Northern China, Southern Tunisia and Southwestern North America.

Subterranean

Subterranean/below ground structures are found entirely under the Earths surface and typically involve a distance of at least 3 meters from the ceiling to the soils surface. Good examples are the common development of an underground level, or a few, to an above surface facility, although numerous examples of completely subterranean facilities do exist. This style is also often used for development within limestone or granite.

Deep mined

Mined space is typically strictly connected to defense centers, and systems related to utilities and mass transit. Some exceptions do exist, such as office space located in Kansas City, which has been converted from its previous use as a limestone mine as well as offices and research space found in deep mined space under the University of Minnesota. The heightened climate control provided at deep mined space, via the increased thermal resistance and insulation of earth, is optimal for facilities such as computer rooms, laboratories and a variety of storage facilities.

Golany (1996) goes to some length in describing the usefulness of the varying grades of depth as related to human occupancy. In sum, shallow sub-surface layers will be the most intensively and extensively used by humans, day and night, as well as have the most obvious connection with above ground space. The deeper the space extends, the lower the frequency of human occupancy is suggested to be.

PART 3
SUBTERRANEAN PSYCHOLOGY

One of the key aspects for the future in underground urbanism will be to go deep into the study of the human behavior in underground spaces, paying special attention to the psychological aspects and running researches in the topic of persons comfort and confidence when studying and living in the underground built environment.
(Junca-Ubierna, 1995)

Focusing on the psychological response and general interest of humans to use underground space is critical to subsurface development. Psychology is not the first domain people think of when considering issues related to subsurface development, but some of the starkest concerns are quite clearly *".....most closely related to environmental psychology and architectural design"* (Carmody et al., 1993).

Psychology, like many other disciplines, is a field which is constantly changing, expanding to include new theories and methods as well as new dimensions of research and interest. Environmental Psychology is a branch of the greater field of Psychology, which has only in recent decades come to the point of substantial representation.

Environmental Psychology is an interdisciplinary field which demands the expertise, contributions and cooperation of a range of disciplines including architects, planners, and psychologists. In concise and basic terms, it is the study of the relationship between the environment and human behavior. Consistent in varying definitions of Environmental Psychology is the emphasis on the exchange and dynamic reciprocity between humans and the environment.

Originally, this branch of psychology was highly focused on the built environment and its influence on human behavior. The field of study had, at the time, the appropriate title of "Architectural Psychology" (Cantor, 1970). As the field evolved, and research interests and efforts expanded beyond the sector of the built environment, the term "Environmental Psychology" took form as a more appropriate heading for the discipline. Issues of the social, natural and built environments influence upon humans, crowding, urbanization, personal space, environmental stress factors and weather's effect are among the interests that became familiar themes to the field of Environmental Psychology (Cassidy, 1997).

The manner of delving into psychological issues of humans in subsurface space is largely an environmental psychological task, as assessing the behavior and response of humans to use the space, demands a focus both on the structural environment within the subsurface domain, as well as the subjective biases often inherent in use of this space.

This section plans to introduce the psychological factors commonly cited as relative to the issue of human occupancy of the subsurface, to progress into a deeper discussion on the psychological and physiological value of light, and to discuss what design techniques and conceptions may have to contribute to the largely psychological complaints and obstacles related to subsurface space use.

3.1 The Main Conflicts

Psychological and physiological issues are commonly cited as one of the “problems” associated with human use of underground space. Comparable research to this theme focuses on living and working conditions in space crafts as well as surface structures with minimal or no window openings. Research on the latter has focused largely on workplaces and has produced distinctively varying results, often highly dependent on the facility type.

Research has been conducted in specific niches concerning issues of safety and physiological and psychological response of humans working underground during *construction* phases. However, with regards to the *operational* stage, Jansson et al report

> *…there has hardly been any research carried out directly aimed at plotting the implications for human beings of spending time and working underground… . it can be stated that the physiological effect on the human organism of time spent underground has been investigated to a very incomplete extent.*
>
> (Jansson et al, 1977)

Since the 70’s, the implications of Jansson’s observation have changed little in the opinions of researchers and individuals working in the field of subsurface development.

Survey conduction on this matter is a difficult task. Individual sensitivities with response to the environment are extremely difficult to factor out or efficiently include in a structured survey format. While satisfaction levels regarding noise level, ventilation, safety aspects, temperature and level of light are factors that can be surveyed, conclusive findings as to causes of stress or negative response to the environment are often difficult to produce.

To further promote development of subterranean space, and its multifunctional use, it is critical to examine the perceptions people have for the space, how they may range in different regions and develop steps which can be taken to evolve a more conscious, aware and positive acceptance of the underground parallel to its rational utilizations.

What follows here is a discussion of some of the psychological problems related to human use of subsurface space.

Claustrophobia

Claustrophobic responses to use of underground space are not uncommon. Fear of entrapment, enclosure, stale air and suffocation are all factors behind a claustrophobic response. A sense of disconnection to the surface “natural” world, can also contribute to the formation of claustrophobia in this situation.

Claustrophobic reactions in subsurface space are not easily dealt with or resolved. Individuals who dislike subterranean spaces on the basis of fear of enclosure and confinement are prone to simply avoid use of such space. Claustrophobic reactions range in intensity and are not easily measured, but it is clear why such a reaction would occur in underground space. Many individuals with no experience or history of claustrophobic reactions may still have such a response in entering and using an underground facility, if even temporarily. Most of this is highly dependent on the facility being occupied.

Conception of Space

General public attitudes and conceptions of underground space may prove to be one of the most constraining and challenging factors for those who wish to drive forward subsurface development for a range of uses demanding regular or frequent human occupancy. Personal opinions regarding the prospect of humans using the underground to a greater extent vary tremendously and a great deal of skepticism as to the benefits as well as sheer likelihood of underground developments occurring is well alive in many communities. Those involved in promotion of underground space for use and development, particularly for use beyond the commonly accepted subsurface utilization for transportation and utilities, should be cognizant of this particular resistance.

A negative perception of underground space can stem simply from its spatial logistics. It is often difficult to recognize underground space, because the entire structure is submerged and lacks any traditional architectural image or reference point. Accesses and entry points also may be typically downward oriented, invoking a variety of phobic reactions.

The reality of underground use being dominated by transportation in many regions (the subway and garages) and for sewage, water treatment and waste, creates resulting perceptions that the underground is not necessarily a *habitable* zone, but a place for transitional movement of humans or materials or storage, and facilities which are not inclusive of temporary or frequent human use, and by no means attractive for long periods of human occupancy.

Associations of underground space as a place for burial and enslavement can also dominate an individuals' conception of the space. Quite simply, it is not uncommon that individuals express a keen opposition to humans using underground space for any period of time extending beyond transitional.

Light Sensitivity

Lack of natural light is one of the most critical deterrents to human interest to use subsurface space. Poor lighting can lead to the development of real physiological and psychological ailments. The importance of qualitative lighting sources specifically geared for underground space cannot be overemphasized. [6]

Physiological Concerns

Psychological stresses also have the capacity to provoke development of psychosomatic ailments, and physiological ailments and stresses can also occur with response to the underground environment itself.

Potential Physiological Problems Related to Human Occupancy of Subsurface Space

1.General fatigue
2. Eye fatigue
3. Disturbance of circadian rhythms
4. Insomnia
5. Headaches
6. Difficulty breathing

Figure 4, Physiological Concerns

The importance of ventilation cannot be overstated as poor air flow has the capacity to create not only physiological ailments, but hazardous conditions to work in, particularly in underground space. Problems with ventilation and lighting can be primary factors in health complaints, such as those cited in Figure 4.

[6] Section 3.2 handles the issue of light to a greater extent

Safety is, in addition, a critical aspect of both the spatial logistics and the psychological response to underground space. Underground space is not uncommonly developed with heightened security and protection in mind, yet the threat of fire or explosion, or other crisis, and the resulting possibility of entrapment and/or disorientation in the space is part of the fear inclusive in the negative psychological response.

As is to be expected, notable dissatisfaction with human use of subsurface space can be linked to working conditions in jobs which are monotonous and provide little activity or movement. People may also have a lower tolerance for certain conditions, such as poor lighting or unsatisfactory design, than they would have in a surface facility.

3.2 Windows and Light

Natural light is highly valued by humans and for an appropriate reason. The lack or complete absence of windows in subsurface structures and facilities is one of the major contributing factors to the hesitance to occupy underground facilities for long periods of time. Acceptance of windowless environments may occur with significant relevance according to the use of the structure in focus.

Windows are beneficial for a range of purposes:

- Ventilation/air circulation
- Visual contact with environment
- Possible emergency exits
- Provision of lighting
- Creating a sense of spaciousness
- Provision of acoustic information

Related to the ventilation provided by windows, is the provision of acoustic information as well as visual contact with the environment. All of these connect with a sense of "atmospheric connection", the possibility for human beings to see the environment as well as to have sensory access to the atmospheric cues related to weather changes, safety issues, as well as general acknowledgement of the conditions beyond a single room or enclosed space. One study produced results that blind people surveyed reported missing windows more than sighted people, as the smells, sounds of weather and activity provided by the windows provided a crucial source of information and stimulation for them (Carmody et al., 1993).

Windows remain a mainstream amenity in most homes and other facilities humans occupy. Their function needs to be carefully regarded in the development of the concept of underground space. The most critical loss deriving from the lack or absence of windows is the provision of natural lighting. A view and sunlight are the values that most people associate with windows. The whole range of sensory information which windows offer needs to be recognized and then the subsurface environments capacity for provision of the same, or similar, information assessed.

While windows are generally conceived as a structural asset, the research and evidence which reveals productivity and comfort which can be developed in spaces without windows must be continued. Previous studies have looked into how windowless environments may actually facilitate production and eliminate outside interference (Golany, 1996). Caution needs to be taken, however, as reviewing varying sources produces highly contradictory sentiments as to whether windowless environments are, in general, a healthy space for people to work and occupy on a regular basis. One source, for example, advised that underground and windowless spaces for offices and work conditions for humans should be completely avoided (BRI, 2001).

In this aspect of investigation, it is important to look at the design and conditions of structures which are often typically windowless (Quarmby, 1997), as well as possess an average to high human occupancy rate. Facilities such as department stores, gyms, swimming halls etc. are often designed with minimal to no windows. Whether users register this design feature in retrospect, and their response to it is an important factor in assessing how people can and do adapt to windowless environments. This could lead to an improved understanding of what facilities many people will and will not tolerate for placement underground.

Humans not only treasure natural light in their environment, but also have a very fundamental need of exposure to natural light on a fairly regular basis to sustain optimal health. This knowledge is one of the foremost deterrents to increased interest in substantial underground human occupancy. This issue is vital and complex.

The potential of disturbing and altering circadian rhythms, the human inner clock which is largely responsive and set from environmental light input, is high and the changes that will occur are a worthy domain for future research interest. Changes in individual circadian rhythms as relative to light conditions in the underground, combined with psychological response and interest in use of subsurface space, may produce interesting findings.

That humans *need* light for their psychological and physiological health, and that windows are often viewed as a fundamental element in structures is a given. That human's can not only function, but thrive, in spaces with minimal or no windows is the next step in understanding and perhaps promoting the use of the subsurface environment for an even greater range of activity.

3.3 Towards Optimal Human Habitability

Design is one of the primary routes through which *interest* in the use of subterranean space can be directly transformed. In conjunction with Architecture, it can significantly contribute to altering the psychological constraints and biased negative attitudes linked to subsurface space (Golany, 1996). Aesthetic considerations are crucial in the use and development of subsurface space for human use.

Atmospheric connections are also relative to design and architectural features of the subsurface structure and some interesting developments have occurred in relation to enhancing a sense of connectivity for individuals in the underground environment. For instance, in one attempt, responding to the lack of perceptual weather information, a notice board was hung in underground workshops to report cloud cover and weather conditions. It is clear however, that such a method, though satisfying an informational need, by no means replaces experiences of direct perception of weather (IVA, 1988).

Studies have also been underway in places which already have substantial underground public facilities, such as Japan and Montreal (Canada), as to designs affect on the user of subsurface space, and specifically, links between design, safety and spatial orientation (Zacharias, J. 2002; Nishi et al., 1995).

Architecture and Design's role in subsurface developments may even intensify as the potential for a greater range of facility types to be placed underground calls for creative designs. Table 3 refers to the primary elements of design which are highly relevant for creating optimal habitability conditions in underground space.

Design Features	Characteristics and Function
Entrance	Structure's image and accessibility
Exterior	Structures image, aesthetic role in area
Orientation and Layout	Landmarks, spatial markers, relative to safety and user appreciation
Light sources	Type of artificial illumination, degree of natural light, integration of skylights, reflective mirrors
Interior Elements	Complexity in layout (i.e. alcoves), applied color, exposure of natural elements (i.e. rock walls)
Sense of Spaciousness and Connectivity	Ceiling height, interior windows, mirrors
Ventilation	Health and structural necessity
Safety	Critical for human, design and architectonic features

Table 3, Design features relative to subsurface space facilities and their noteworthy characteristics and function (Carmody et al, 1993; Dieci et al, 1995)

In a more recent development, a concept was proposed which reflects the evolution of information and communication technology applied to the underground. A small group of Italian engineers and architects have devised a model for an optimal communications network which would allow data, video and voice transmission for users of underground space with individuals on the surface. It is called the "WINDOW concept" and allows people to communicate via window interfaces and transmit necessary data (Battistelli et al., 2002). Such a concept is highly relevant to the evolution of ambient intelligence and will play a meaningful role in the parallel developments of underground environments.

Issues key to the design and research of space stations are also important links for design research and experimentation related to underground spaces. NASA's interest in lunar and Antarctic habitation for research purposes may provide important tips for the design of underground networks, work stations and temporary habitats (Horsbrugh, 1997) and vice versa.

The very sense of novelty inherent in regards to the prospect of intensifying use of underground space can be further built upon in designing an environment with the collaboration of its users, as well as taking the steps of creating more workable and livable (if even at first experimental) spaces in the underground.

"Experimental" indicates not only a courageous approach to using subsurface and subterranean space for a far greater range of facilities than presently utilized, but also a progressive architectural conception of the interior space. For instance, Carmody et al., (1993) suggest to:

> *….make individual spaces…more geometrically complex in order to increase the perception of spaciousness in underground buildings. Subdivide large simple volumes into interconnected smaller spaces using lofts, alcoves, and half height walls….*

Complexity of the organization of space is a potential basis for stimulation. The human interest in stimuli is tightly linked to the human *need* for stimuli. Variation is a fundamental need for humans. As subsurface environments are largely self controlled, climactically, and in terms of illumination, it is important to focus on the balance of monotony and variance present in the environment. Whether the very work or activity occurring in the subsurface environment is monotonous or provides for stimulation is also a crucial factor in the perception of stagnation in the environment.

Increasing human time spent underground would definitely propose a new way and rhythm of interacting with space for many people and could be alternately, an unwelcome or exciting concept in many regions of the world. The need for new forms and perceptions of space will be a marked feature in the coming decades, particularly related to habitats, and the marriage of design concepts for the underground with a psychological awareness should pave the way for a necessarily tense, yet creative and resourceful response and interaction with space.

PART 4
ADAPTATION

Cities are getting so crowded these days,
and real estate so expensive,
that humans may have to start learning
how to live underground.
(Paksukcharen, 1999)

In many cities, particularly in Europe, but elsewhere around the globe, inhabitants have underground space integrated firmly into their cognitive maps because of daily transportation by the subway. Extending the perception of this space to other utilities is the challenge and excitement offered in conceiving the range of infrastructure which can soon be further incorporated into subsurface *and* geospacial developments.

Modern conventional acceptance and perception of what should be placed underground is one of the keys to allowing or preventing the expansion of a range of facilities to be included in subsurface development in the near future.

It is largely the responsibility of those involved in design issues to tackle and evolve the possibility of what people conceive as being suitable for the underground. Table 1 [7] charts 12 different facility types which have varying degrees of representation in the global subsurface environment. The rating system referent to intensity of human occupancy indicates the degree to which the structure will be inhabited. Structures of high level occupancy, e.g. homes, offices, shops, do have their representation in subsurface space, yet to what degree are communities, or individuals, willing to see and ready to use more of their kind in the underground?

Developing underground space often implicates to people the notion of "moving underground", and although the development of qualitative design and research for subterranean and geospacial habitats is promoted by the author[8], it is clear that permanent underground occupation is neither the goal nor interest in the field of subsurface development today.

In fact, provision of increased quantitative and qualitative living area at the surface is commonly cited and agreed to as one of the primary tenets of why we should increase the placement of facilities below ground.

4.1 Fit for Humans?

Psychological aspects always feature
on top in windowless places. Basically
it's a question of prejudice of inhabitants.
Psychologically only experiences of tunnels
and underground space will change these attitudes.
(Rönkä,1995)

Is the underground fit for human habitation? This is debatable. Humans have been living in caves and underground dwellings for ages, and continue to do so in specific regions of the globe. Yet in most urban settings today, modern underground dwellings would be considered extreme and "backwards". To what degree of occupancy are underground spaces really fit for humans?

It must be clarified, particularly for those hesitant with regards to the idea of increasing human occupancy of underground facilities, that working and living environments located in subsurface space need not always detract from the appreciation and demand for natural light. Particularly with regards to living environments, unique and progressive models can be found, in subsurface spaces, which allow

[7] See Section 2.3

[8] The author is strongly in favor of furthering the development of underground networks to include living spaces, yet acknowledges that such a development is not easily incorporated into the modern agenda.

for ample light into select regions of the habitat. While deep mined spaces obviously do not hold a high potential for providing this, semi submerged spaces and structures are capable of the provision of sufficient light.

It can be inferred, however, without any survey or sophisticated research technique, that general interest in modern communities all over the globe is *not* to live underground. Certain countries even have regulations concerning the necessary amount of window space, or degree of allowance for the entry of light, which a home should have and this again relates to cultural and regional traditions of building as well as climactic influence on the cultures appreciation of the presence of light.

It is a strange prospect to many people, even a sad and lonely prospect, to consider a future, or a present of living underground. People may associate this development with impoverished subterranean spaces, and the upper echelons of society being granted the much vied for surface habitats with a view, while living conditions “below” would be cheaper, in price, quality and design.

What must be realized is that this latter attitude is the real lonely and sad prospect and hints at a cataclysmic division of “above and below” spatialities being corresponded to hierarchies of societal “classes."

Highly creative solutions formulated on behalf of architects, designers, and planners, to show how fit subsurface space *can be* for humans will be a necessary development. Affecting public perception, as well as the opinion of “decision makers” on the range of potentials of underground utilization as well as, very critically assessing, within the filed, the realistic as well as most extreme potentials of subsurface use, are all necessary steps to confirm and express the range of functionality the underground serves for human use.

Though subterranean space may be perceived as underexploited in the present time, and for a good reason, there is increasing evidence of interest available to analyze what potentials are really portrayed there, and how we may achieve them.

4.2 Demand for a Progressive Use and Conception of Space

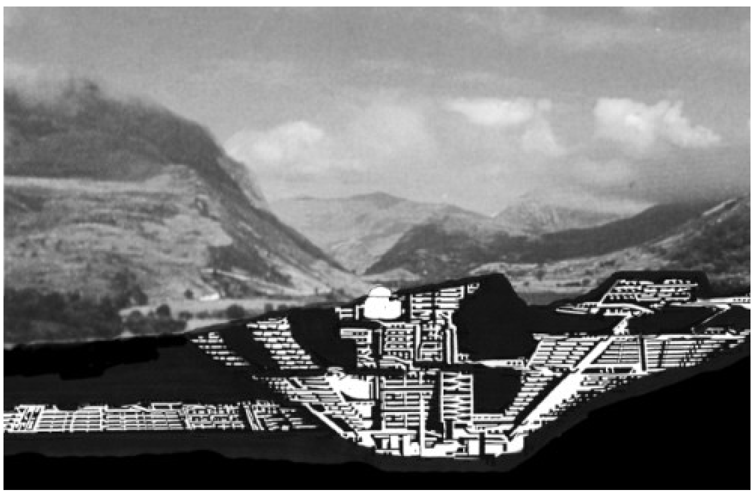
Emphasis on intensifying three dimensional spatial developments will be crucial for the future, and the subsurface domain plays a role in offering specific energy conservation potential, correspondent to defense interests, specific climate control and a new model for evolving human’s relation to space. One may even speculate that such intensification is also relative to our survival (Horsbrugh, 1997).

The concept of the underground, and geo-space, as a new frontier is a dialogue increasing in substance and ideas, particularly at this time, the turn of the century (Argenti, 2002), and particularly in relation to concerns about the pressures of urbanization. Concepts of inhabiting and further “urbanizing” the subterranean world are the most extreme, and perhaps the most interesting, ideas in this dialogue, for they force us to consider precisely why such a development would be pursued, and the resulting consequences for quality of life issues.

Poets have written about it (Argenti, 2002), the theme pervades mythology, actual examples exist in indigenous communities, architectural concepts serve as infrequent yet compelling testaments to the ideas, and even figures in the history of urban planning have promoted the possibility of pursuing intensive habitation of the underground, often to be silenced by their own colleagues, or the community at large, as it was not, in the eyes of many, a rational nor desirable, proposition.

If one of the primary foci of an agency such as NASA (among other space research organizations), is to "enable humans to live and work permanently in space" (NASA, 2002), is it so unreasonable to project the possibility for humans to occupy and work in underground locations, in temporal frames significantly greater than occurring now, and in the healthiest, most comfortable conditions possible?

Planners, in general, are notably engaged in issues of 'stewardship' and sustainable developments. Cultivating progressive models of using and conceiving space are inherent in this. If we look at some of the visions humans have of utilizing space for the future, the most striking being that of literally inhabiting 'outer space' and increasing human occupancy in terrains off Earth, it seems a very valid proposition indeed to welcome individuals and communities to look closer at what lies beneath the surfaces of their communities and how this space may come to be of benefit in the near future and for societies which will be building upon and inhabiting what we have created in the present time.



Human beings who live underground must use mechanical devices to provide the necessities of life: food, light, even air. Nature provides only space. The underworld setting therefore takes to an extreme the displacement of the natural environment by a technological one. It hypothesizes human life in a manufactured world.....the defining characteristic of the subterranean environment is the exclusion of nature, of biological diversity, of seasons, of the sun and the stars. The subterranean laboratory takes to an extreme the ecological simplification of modern cities….

Figure 5, Design for the Future or the Now?[9]

(Williams, 1990)

Gesospace is coined by researchers, particularly Golany and Horsbrugh, as the next frontier, as the ultimate interior (Golany, 1996; Horsbrugh, 1997). Geospace is a term meant to expand the notion of underground space, to be inclusive of intra-mountainous space, and any space which exists below the surface of the Earth, whether in a horizontal or vertical direction. Horsbrugh in particular discusses the need for qualified "geotects and geoscape designers" to take part in the architectural, engineering and interior design disciplines in order to capably set forth qualitative designs and tools for the development of geospace (Horsbrugh, 1997). This is important as it will allow for a very specialized niche in spatial planning to gradually gain the expertise of individuals who, while pursuing the professional knowledge of a greater discipline, such as architecture or design, consistently apply their expertise to projects which may serve to enhance the field of subsurface, or as Horsbrugh or Golany would say, *geospacial* development.

Both Golany and Horsbrugh support the prospect of "geotectural habitation", which can be likened precisely to the concept of experimental underground habitats discussed earlier. In their discussions, which are noteworthy as they are among the few in the field of subsurface development to directly

[9]Design by Quarmby, 1992

approach and promote living in subsurface spaces, Golany and Horsbrugh acknowledge the vital need to assess not only the effects but the consequences of humans inhabiting the spaces proposed.

It is important to emphasize the fact that a concept such as the underground city does not exclude frequent use and access to the surface environment. Yet the concept of the underground city is at the least, mildly controversial. Elements which need to be focused in relation to this concept are the vast opportunity to contribute to the preservation of surface space and environment as well as to increase the health and habitability of not only growing urban centers, but entire regions. Advancing understanding and necessary design techniques for subterranean and geospacial dwellings will be critical in their promotion and acceptance. This will also ensure models for communities of the future to use and expand upon.

Progressive minded approaches in spatial planning are about seeing the possibilities of development, how they will influence and what they will demand from present communities, as well as, how they will influence, what they will contribute and what they will demand from communities of the future.

4.3 Future Research

> *…. further research and innovative design concepts, especially in the areas of working conditions, health benefits (physical and mental), sleeping conditions, creative accomplishments, and psychological impact, are needed in order to improve the usage of such space and make geo-space a completely viable option for the future.*
>
> *(Golany, 1996)*

Interest in the underground is of inarguable future relevance. For qualitative progression of subsurface development to occur, it is necessary to cite areas of research, whose development will contribute to the greater and general theme of subsurface development, yet also further develop certain niches of interest within the field, some of which remain heavily under explored.

None of the areas can be cited as more or less important, in terms of attention and urgency of research and development. In order for the subsurface environment to be evolved into healthy, safe and attractive zones for human occupancy, all aspects must be equally, often simultaneously weighed.

Research Theme	Purpose
Lighting	Developing optimal lighting conditions for humans' psychological and physiological health
Biopsychology	Increasing understanding of bio-psychological issues and patterns which could occur with regular users of underground space
Design Concepts	Improving comfort and functionality of human underground environments
Housing	Exploring human habitability potential in the underground
User Attitude and Appreciation	Evaluating user response, critique and suggestions on underground environments

Table 4, Future Routes of Research

It should be noted that in addition to these are numerous other issues which demand further research for contributing to the successful development of subsurface space. In general, the field of Engineering is where significant present progress in research is occurring, as tunneling technology is vital for subsurface development to even continue and present projects to be executed.

Safety is another domain of research whose existence and further development is utterly critical for underground spatial use by humans to exist and continue. With the development of deeper and more isolated spaces, safety issues are fundamental, and in general, understanding of solutions for a variety of emergency situations is necessary for developers and concept bearers of underground architecture and networks.

Lighting

Studies in environmental and artificial lighting are profuse and will no doubt provide very important guidelines for those involved in working with manmade underground spaces. Popular lighting research thus far has focused on luminance ratio and correspondent levels of work activity, user content, the effect of different artificial lighting sources on behavior and concentration and the cost effectiveness and energy efficiency of different lighting sources. All of these areas of lighting research are relevant to underground design and interior architecture and ensuring that underground work spaces provide optimal situational comfort. User response and content with regards to various artificial light sources is especially crucial as health concerns such as concentration and fatigue are often strongly linked to source of lighting.

Carmody et al (1993) note that "… Scandinavian underground spaces are generally quite brightly lighted and ventilated, compared with similar facilities elsewhere in the world" and it is clear that research in Scandinavia could provide a profound contribution here. Extensive studies done on light in Scandinavia, in terms of both the physiological and psychological effects of drastic seasonal fluxes of natural light and the influence of different sources of artificial light on work and living environments has an intrinsic link to the developments necessary for optimal conditions in underground space.

Bio-psychology

Bio-psychologists are among the most capable to develop relevant tests and studies for research relative to light, and their contribution and collaboration could be a useful propellant to a healthy advancement of underground use by humans. Other issues relative to potential bio-psychological research for the underground include the maintenance and change of circadian rhythms in subsurface environments, time orientation, and sleep patterns in users of short term underground habitats (e.g. military facilities).

Horsbrugh (1997) even goes to the point of declaring that underground spaces will not properly evolve without correlated "medical and biological researches" as well as analysis of historic underground and geospace habitats.

Design Concepts

In confirming the need for designs and concepts for the underground, the field of Architecture comes to fore. Architecture often deals directly with vision correlated to structure and then proceeds to assess the reality of its potential construction. Architects have and will continue to play extremely frontal roles in the promotion of developing and using spaces not typically or frequently inhabited by humans. The underground is no exception. As development continues and the very concept of underground space gains steam in dialogues, the role of the architect will be vital, not only in presenting attractive and functional models for underground use, but also in recognizing the role that exposure of underground architecture will have upon the general perception of the public.

Housing

The issue of housing is highly controversial. There appears to be a minimal, yet strong interest and support for the development of underground networks to include housing. In order for this vision to gain sustenance, it is necessary to begin a discussion about medium to large scale underground networks which would demand an average to high human occupancy (that is excluding low and predominantly transient occupancy). Any medium to large scale underground network with facilities for human occupancy which exceeds transient or minimal use demands a similar attention and concern that an underground housing project would. In order for the aim and interest for housing to be realistically developed, discussion and conception of these networks must proceed.

Pilot studies and experimental habitation of underground space may prove to be the most direct means of attaining a clearer understanding of what needs to be attended to in future research and the corresponding expertise applied. The reality is that, up to now, there is both a limited amount of literature on the theme and the research that has been done is only reflective of the complex variance in interest to utilize underground space for any long period of time for human occupancy. The modeling of medium to large scale experimental living and work centers in subsurface space and projecting the range of psychological factors and risks involved in such a project would be one vital step in this dialogue and development. Such a project would no doubt be a fascinating and challenging arena for research and exchange between several disciplines.

Particularly interesting turns in research and development of using underground space have been seen in Japan and will continue to progress. Japanese designers have introduced pioneering concepts of how multipurpose human activities can occur in "geo-space" at depths of 50 meters or more (Golany, 1996). The interest and pursuit of research of deep subterranean space for transportation is active in Japan, as well as a concentrated network of research occurring related to issues of human occupancy of subterranean space. With one of the highest rates and interest of development of subsurface space, and related environmental pressures in the urban nodes, it is not unlikely that Japan will be forerunners and play a critical role in qualitative development of underground facilities which are highly frequented by humans.

Advancement and correlation of confined space studies are relative to this sector of research. Such studies are underway, and continuing them will be beneficial for both sharpening the understanding of the human psychological response to underground space, as well as to developing design concepts which *work* for humans in the underground. On the forefront of confined space studies are the interests of space agencies who utilize such studies to assess the reaction of humans psychologically and physiologically to confined spaces and to contribute to the improvement of shuttle and space station habitability. Such studies work from, essentially the same interest as underground confinement studies would, simply with a different spatial frame.

User Attitude and Appreciation

Studies surveying psychological responses to underground spaces are difficult to compare. Evaluating the range of user attitudes and critique of subsurface environments raises the question of what technique to use and how to organize, use and possibly present the statistics.

Cultural perception as well as different regional and national trends in underground construction, play a major role here. An employee working in an underground environment in urban area in Japan, for example, where there are more instances and general public acceptance of underground facilities, might have an entirely different response to the interior of their underground environment, than an employee working in an underground office in New York, even if little differences were to be found in the design of the two spaces.

Assessing user attitude and appreciation of a range of underground facilities is however extremely necessary, as firsthand reports of content with the interior environment are instrumental in possibly influencing future decisions and developments with reference to the space and its function.

4.4 The Nexus Approach

The Nexus Approach, as illustrated in Figure 1 [10] aimed to present a basic working concept in which key disciplines are encouraged to strike up both dialogue and collaboration in order to further generate the development of concepts for the underground, as well as to assess the range of usefulness various facilities will serve there.

Architecture and Spatial Planning have the most obvious links and concepts in common: development and improvement of human environments. Environmental Psychology operates entirely with the same focus in mind, yet from a, typically, separate base of theories and method of research and work. The case for the role of Environmental Psychology, but even more specifically, Architectural Psychology should be clear here. It is commonly agreed upon that to be a good architect one must have a working interest and understanding of human wants, needs and patterns, and thus allow this understanding to be incorporated into a functional design (Mikellides, 1973). Psychologists themselves are wholly focused on the entire gamut of issues related to those wants, needs and patterns, and amongst them can be found those who harbor a keener interest in issues highly relevant to the architect, and planners, work. Increasingly, the field of Environmental Psychology, parallel to its own academic and professional growth, is revealing its own place in conjunction with the interests of Spatial Planning and Architecture. When collaboration occurs among the disciplines, whether through the work of one individual or on a team of professionals, it is possible that the space itself (and its' users) will gain from the dynamism.

One key discipline not included in Figure 2, is Engineering. Engineering is a vital profession for the advancement and execution of underground projects. The field of modern subsurface development and interest is largely populated by Engineers. This thesis has lent its' entire focus to issues which are of more interest to the disciplines of Architecture, Psychology and Design, yet Engineering will always be a critical profession for the actual realization of many underground projects.

The Nexus Approach was also illustrated out of a hypothesis that Architecture and Design may provide the missing link in the cycle of dialogue and exchange on subsurface developments. How can Environmental Psychologists provide practical assistance to this field of development, largely dominated by a profession (i.e. Engineers) which consider Psychology a soft science and not easily integrated with their work? The promise of a real dialogue occurring between Engineers and Psychologists regarding subsurface space is highly unlikely, and perhaps not even vital to the field. Architecture and Design, however, can be seen to stand at the midpoint, the nexus where work can be exchanged and models logically and progressively evolved.

Increased dialogue and exchange between all three disciplines of focus, with regards to subsurface development may contribute concepts of interest as well as initiate a new series of projects and necessary research.

[10] Section 1.1

Concluding Remarks

What this paper, at its core, aimed to present, were preliminary ideas and even guidelines for spatial models for the underground to develop in the future. Architectural concepts to develop in coming years will be highly instrumental for this development, as well as new adaptations to space and environmental pressures that trigger the development of both.

Some researchers deem the prospect of subterranean accommodation as “inevitable” (Horsbrugh, 1997), as a natural, albeit perhaps forced response to conditions on the surface. While such views can be considered by some, particularly in the field of planning, as negative and cataclysmically focused, it is important to look at where the views stem from. If we consider the living conditions that will pervade in our community in our lifetime, such views may not be relevant. If we turn our attention to the living conditions that could prevail in our community in 3 generations time, and may already prevail in other cities and communities on Earth, such viewpoints can humble us into really considering the range of impact current developments are having and what our communities will look like, and demand from their inhabitants, five (or fifteen!) decades from now.

In some cities, most notably New York City, habitation of the underground is a notorious theme, as those who populate it are “homeless”, and living conditions in the underground are in a state of absolute urban disgrace. This is part of the dismal side of underground habitation and deserves critical observation and attention, as conditions such as these can tend to entirely shadow the notion of “underground occupancy”. Again, designers, architects and planners will be instrumental in removing this stigma, via creation of attractive, habitable and functional models for increasing occupancy of the underground.

A decisive focus, on behalf of planners, architects, decision makers, researchers, specialists and the community, as to the benefits and potential of increasing use of subsurface space now will be a tremendous benefit for communities of the future, and perhaps even to the development of habitable, and appreciated community networks which are well connected to the surface of the Earth.

The Network

Understanding a field and its history of development involves a familiarity and comprehension of the actors involved. Listed below are some of the organizations which are critical nodes in the network of subsurface space dialogue and development.

ACUUS: Associated Research Centers for the Urban Underground Space, is an international, non governmental organization whose purpose is the promotion of interdisciplinary partnership of all those involved in the research and use of urban underground space. The idea for ACUUS was proposed in 1992, at the 5th International Conference in Delft (The Netherlands). The organization was officially created in 1995 at the 6th International Conference in Paris (France) and its formal establishment occurred in the fall of 1996, in Sendai (Japan). Its founding members were from France, Japan, Canada and the USA. The ACUUS is instrumental in the organization and coordination of international events and conferences related to the use of urban underground space, its research and development. ACUUS is also dedicated to further promoting academic and professional exchange and dialogue on issues related to the urban underground, to support and service research centers and organizations with similar focus, and to raise interest and awareness in the private sector, the government, and the general community on issues related to urban underground utilization and development. The ACUUS Secretariat is located in Montreal, Canada.

Espace Souterrain: Espace Souterrain is a France based organization which serves as a nexus for a range of disciplines (architects, engineers, sociologists, urban planners, geologists, geographers etc.) and other organizations that research and promote the use of the underground. Their focus is the improvement of technology and equipment related to the development of underground facilities.

ITA/AITES: International Tunneling Association/Association Internationale des Travaux En Souterrain, is a core part of the heart of the field of subsurface development. ITA was founded in 1974 in Oslo and
today is composed of 52 Member Nations, all active in the promotion, research and development of subsurface space, and specifically, issues relative to tunneling. ITA's aims are the encouragement of planning of subsurface use and the development of the technology, techniques, construction, and investigation related to this use. The ITA Secretariat is located in Laussane, Switzerland.

USJ: The Urban Underground Space Center of Japan is composed of individuals from private and public sectors and has as its main goal the investigation and research of multifunctional utilizations of underground space as well as incorporation of the various perspectives necessary for the development of this utilization (e.g. planning, environmental, engineering, etc). USJ is located at the Institute for future Urban Development , in Tokyo, Japan.

Underground Space Center, The Underground Space Center located at the University of Minnesota served as *the* node of research on underground space occurring in the USA as well as a major reference point in the global research occurring on issues related to subsurface space. The Center was closed in 1995 due to funding withdrawals and a correlated change in university administration.

Several other organizations and research centers exist, e.g. The Underground Space Centre of Finland and the Research Center for Underground Space at the Politechnico di Torino, yet these often include a highly regional or national focus for promotion and development of subsurface space, whereas the abovementioned have a characteristic international focus in mind.

In addition to the organizations mentioned are numerous national Tunneling Organizations and Societies, most of them linking to ITA, the heart of the field of tunneling worldwide. These Organizations serve to promote development and exchange in the field of tunneling technology and subsurface use.

Within the network of underground interest there also exists organizations, often highly localized, yet with broad international communications, whose purpose is geared towards historical aspects of underground interest and use (e.g. the documentation and or re-discovery of man made underground spaces which may have for long been out of use). Berliner Unterwelten, located in Berlin, Germany is one such organization, among many. Berliner Unterwelten's specific attention and energy are dedicated towards the exploration and documentation of bunkers remaining from the War. Other such organizations, with specific local interests, exist worldwide, and the communication between the agencies is a vital process for the network to continue generating solid dialogue and progression of concept developments related to the underground.

GLOSSARY OF TERMS

Habitat: the natural home of an organism

Hypogeal: existing or growing underground[11]

Geo Space: Indicative of space built within the Earth, inclusive of underground, intra mountainous and any space that exists beyond the Earths surface. Geo-space is a current term of usage in Japan to describe spaces and structures which are fully submerged in the Earth, and has come to be used often by some researchers and promoters in the field of subsurface utilization, namely Gideon Golany and Patrick Horsbrugh.

Nexus: a bond or connection[12]; In the context of this paper, more explicitly refers to the meeting point and shared space of interest between disciplines.

Subsurface: The area beneath the surface of the Earth. This is the popular and more formal term used in the field of "subsurface" development and utilization.

Subterranean: Indicative of the same terrain as both subsurface and underground, yet invokes additional connotations of mythology

Troglodyte: An underground dwelling dug out and lived in by humans

Underground: Indicative of the same terrain as both subsurface and subterranean. In some place, this word alone refers to the subway system. "Underground" also invokes connotations of attitudes of movements and groups (i.e. underground political movements) and some interest to identify the negative and characteristic implications this term has come to attain has taken place (Lesser, 1987).

[11] Concise Oxford Dictionary
[12] Concise Oxford Dictionary

History of Conferences[13]

First International Earth Sheltered Buildings Conference: Energy Efficient Buildings with Earth Sheltered Protection. August, 1983, Sydney, Australia.

Second International Earth Sheltered Buildings Conference: Advances in Geotectural Design. June, 1986, Minneapolis, Minnesota, USA.

Third International Earth Sheltered Buildings Conference: New Developments of Underground Space Use. 1988, Shanghai, China.

Fourth International Earth Sheltered Buildings Conference: Urban Underground Utilization. December, 1991, Tokyo, Japan.

Fifth International Earth Sheltered Buildings Conference: Underground Space and Earth Sheltered Structures. August, 1992, Delft, Netherlands.

Sixth International Earth Sheltered Buildings Conference: Underground Space and Underground Planning. September, 1995, Paris, France.

Seventh International ACUUS Conference : Underground Space: Indoor Cities of Tomorrow. October, 1997, Montreal, Canada.

Eighth International ACUUS Conference: Agenda and Prospect of the Underground Space for the turn of the Century. September, 1999, Xi'an, China.

Ninth International ACUUS Conference: Urban Underground Space: A Resource for Cities. November, 2002, Torino, Italy.

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[13] This list is by no means a comprehensive recording of all conferences related to underground space to have taken place. It focuses on a series of conferences arranged under the similar organizational bodies as well as whose history includes the development of ACUUS.

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To contact the Author
for comments
or dialogue
write to
habitat@mail2world.com