Daylight in Underground Architecture

Research Paper

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Abstract: The use of natural light in (underground) architecture is beneficial for both the human wellbeing as well as the quality of the architecture. However innovative systems are needed to bring natural daylight in underground spaces. The daylighting systems, which are classified as light guiding systems and light transporting systems have been reviewed and compared. The advantages and disadvantages of each system are summarized in order to be able to choose a system that fits within the architecture of the underground 'building'.

Keywords: natural light, technical daylight systems, subterranean architecture, underground space development

Introduction

70% of human perception is visual. It is through our vision that we experience spaces shapes, textures and colours. (Purves, Williams et al. 2004) Therefore the relationship between light and architecture is inevitable.

The evolution of architecture over the centuries has been synonymous with the evolution of the window. Starting with letting in light and air, the window evolved throughout history into a tool that provided impressive interiors of great buildings. (Phillips 2004)

Unfortunately, with the introduction of the electrical lights in the 20th century, the relation between the window and architecture weakened. The windows primary purpose, of letting in daylight, was no longer of great importance. Light bulbs replaced their role and became a great source of illumination. They even led to high quality new interior designs. (Lechner 2014)

However, the energy crisis in the 1970's caused people to find new approaches to lighting. Since then, new daylighting methods and devices have been gaining more and more importance. (Lechner 2014)

Interesting is that with the (re) discovery and further development of daylighting techniques and systems, the potential of subterranean living also has been growing. As cities get more crowded by the day, the underground is a field that designers of the future should definitely explore.

Logically, in order to bring daylight in underground structures one needs more than windows and architectural solutions. Therefore the main question of this paper is: "What are the technical possibilities for using daylight in underground architecture and what are the limits of the existing techniques?" The objective is to find a system fits into the architecture of the underground building that will be designed.

This paper starts with elaborately exploring natural light and its importance in architecture. Following, it examines several advanced daylighting systems. Hereby advantages and disadvantages will be summarized. To conclude, a system that has the most potential will be chosen for the upcoming design.

Light

What is Light

To fully understand the importance of natural light we first need to understand what it actually is and how it works.

Light is a combination of electromagnetic waves with different wavelengths that stimulate the sight sense of the human body. Each wavelength causes a different color experience in the retina of our eyes. So when looking at a picture, it is not the color of the picture itself we are experiencing, but the wavelength of the light that comes from the sun and that is reflected by the picture. The level of brightness of the light that the human experiences solely depends on the surrounding. (Omar 2008) "What we see, what we experience and how we interpret the elements is affected by how light interacts with us and with the environment." (Fontenelle 2008)

The importance of daylight to underground architecture.

When being underground the level of brightness is none. In other words total darkness. Therefore light is an indispensable medium for creating perceptions of the space underground. However, daylight is not the only medium that leads to basic visual perception.

The importance of daylight lies among other things in the fact that it has many benefits to the human's both physiological as psychological wellbeing. No electrical lamp can match that. There are many studies proving that our bodies are literally designed for natural light. When the human body receives daylight, it produces more vitamin D, helps the absorption of calcium, improves the metabolism and betters the secretion of hormones. (Omar 2008) A lack of daylight can lead to deficiencies within the body and can have a great impact on the overall health of humans. (Mohirta 2012)

Also, daylight has a better 'light quality' than electric light in terms of distribution of light and colour radiation. Daylight has a better distribution of light because it is a diffuse source that enlightens surfaces more evenly in all directions. The colour radiation is much better because is looks much more natural. Electric light sources tend to be stronger in some areas of the light spectrum, whereas daylight has a continuous spectrum causing better colour radiation, making colours look much more vivid. (Mohirta 2012)

So it is not only good for the human body but also for the perception of architecture.

The application of daylight

There are three stages that are important when it comes to using daylight. Collecting, concentrating and transmitting.

In order to be able to collect daylight efficiently it is important to understand that natural light comes in direct and diffuse form. Direct light is the light that comes from the sun without being reflected from other surfaces. Meaning that the light travels from a straight path from the sun to the collector. On a clear day around 85% of the sunlight is direct light. Diffuse light, on the other hand, is scattered at many angels by particles in the atmosphere. Nevertheless, both direct and diffuse sunlight are always in movement. So when collecting this light, a system that is able to track the movement is required. Systems that are able to track the movement are called active collecting systems. (André and Schade 2002)

Direct sunlight is easy to concentrate. Diffuse light, on the contrary, has many directions and comes from all over the place. Therefore it is much more difficult to concentrate it. Concentrating sunlight is necessary if one needs to distribute it to spaces where the illumination is needed. So daylighting systems will not function without concentrating the light first. (André and Schade 2002)

Once collected and concentrated, the light needs to be transported to the spaces where it is needed. Daylighting systems do this by either a tube with a reflective interior or a series of optical fiber. (André and Schade 2002)

Advanced Daylighting Systems

Advanced daylighting systems are optical devices that can be used to transport daylight from exteriors to spaces with no windows or skylights. There are many ways to classify these innovative daylight systems. The classification used in this paper is based on the two main groups, light guiding systems and light transporting systems.

Light Guiding Systems

This group can be re-divided into diffuse and direct light guiding systems. Each of them can redirect natural light to distances up to 8 to 10m. Each system has its specific qualities and can be useful for different kinds of buildings in different contexts. (Nair, Ramamurthy et al. 2014)

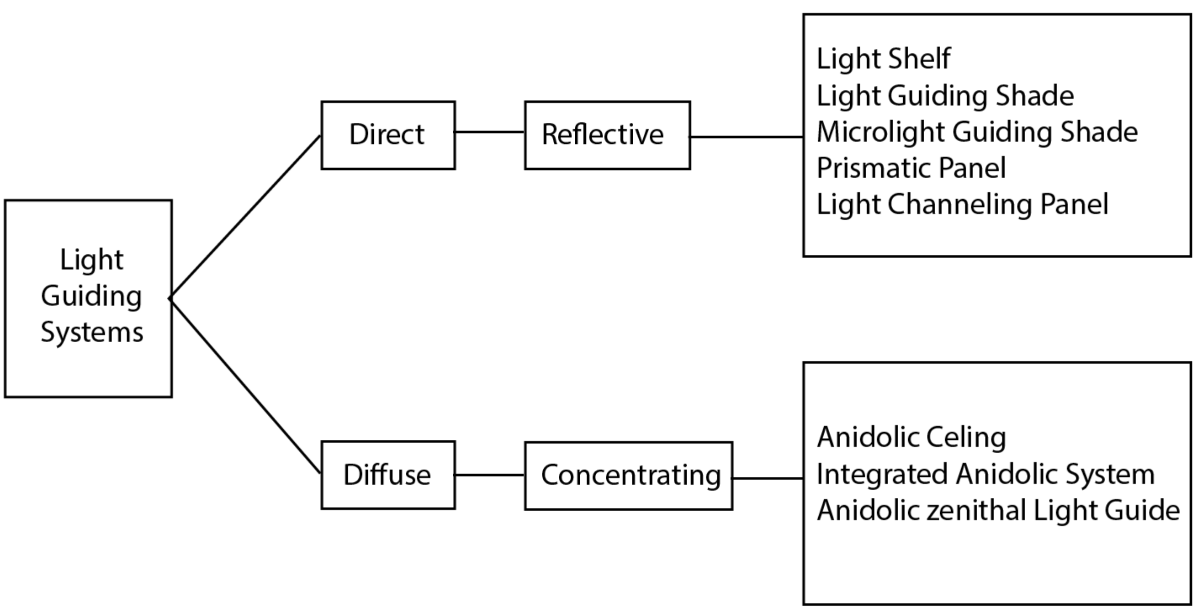

Figure 1. Classification of light guiding systems (Nair, Ramamurthy et al. 2014)

Direct light guiding systems redirect sunlight through reflection. Examples of these systems are light shelves, light guiding shades, micro light guiding shades, prismatic panels, and light channelling panels.

A Light shelve is simply a horizontal or tilted element placed on top of a window. It is an element with a reflective upper surface and diffusing under-surface. It can be positioned either inside or outside the window. Light shelves that are positioned inside can be used in rooms that have a low level of daylight at the back. Another advantage of internal light shelves is the fact that they reduce the illuminance near windows, which helps in the even distribution of daylight in the room. External light shelves also control and redistribute incoming daylight providing a virtual sky to spaces. At the same time they prevent a high angle solar radiation. Meaning, they also serve as a shading device. (Omar 2008)

A light guiding shade is a system that has an upper and a lower reflector. The upper reflector is straight unlike the lower one, which has a parabolic shape. The advantage of this system upon a light shelve is that it can maintain an uniform illumination inside.(Nair, Ramamurthy et al. 2014)

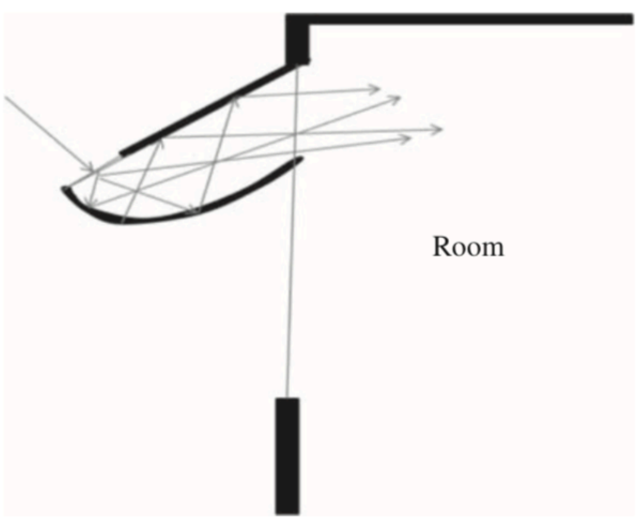

Figure 2. A light guiding shade where diffuse light is reflected by a parabolic reflector. (Nair, Ramamurthy et al. 2014)

Microlight Guiding shades are fixed shade panels consisting of two-dimensional micro-reflecting elements that can produce a parallel beam of light rays. This system is featured to have a transmittance between 50% and 80%. (Nair, Ramamurthy et al. 2014)

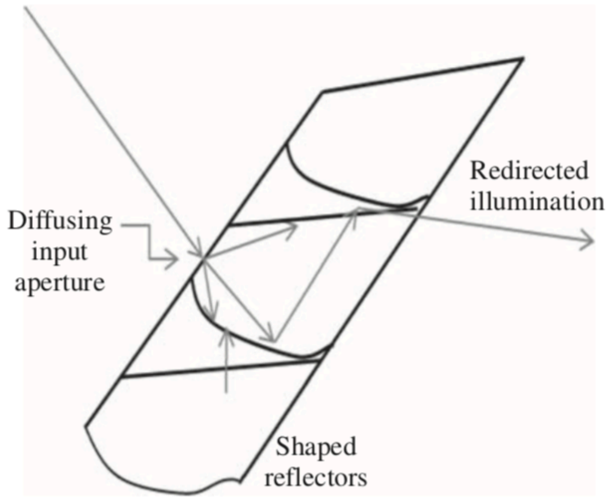

Figure 3. An example of a light guiding shade. (Nair, Ramamurthy et al. 2014)

Prismatic panels consist of two panels each with a series of smaller glass or plastic prisms on one side and a flat reflective surface on the other side. Most of the time the prismatic side is partially covered with an aluminium layer because of its high reflectance. The small glass or plastic prisms ensure that the daylight gets redirected to the interior of the room. Just like the external shelves and shades it can also act as a shading device. This system can be used vertically on windows as well as horizontally on roofs. (Santos 2009)

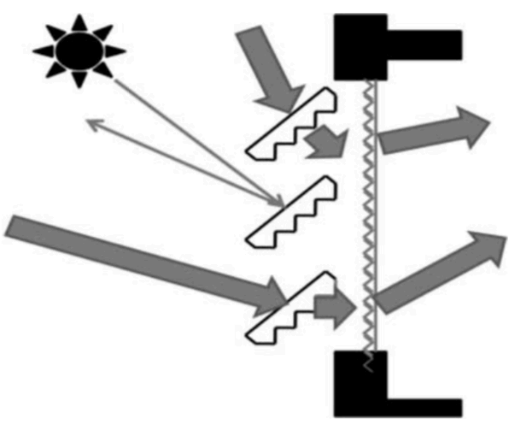

Figure 4. A prismatic panel system. (Nair, Ramamurthy et al. 2014)

Light channelling panels are formed from two thin transparent sheets of acrylic plastic. Each sheet consists of angled laser cuts forming reflective surfaces within the acrylic. The sheets are laminated together into a single panel containing channels that redirect light. They are combined with blinds. (Nair, Ramamurthy et al. 2014)

Diffuse Light Guiding Systems

Diffuse light guiding systems redirect diffuse light from specific areas of the atmosphere through concentrating it. These systems are proven to be useful in dense urban areas where light from the top is the only source of daylight. Examples of these systems are anidolic ceilings, integrated anidolic systems and anidolic zenithal light guides.(Nair, Ramamurthy et al. 2014)

Anidolic ceilings and integrated anidolic systems are both based on a system that collects daylight from the atmosphere by using a parabolic concentrator. The anidolic ceiling has an external part that sticks out of the façade and an internal part that is integrated in the ceiling. The external part has a collector that collects the light. A mirrored light duct integrated in the ceiling guides the light to the end where the distributor is located. The ceiling panels act as parabolic reflectors. The difference with the integrated anidolic system is, that the integrated system includes micro-louvres utilised for shading.(Nair, Ramamurthy et al. 2014)

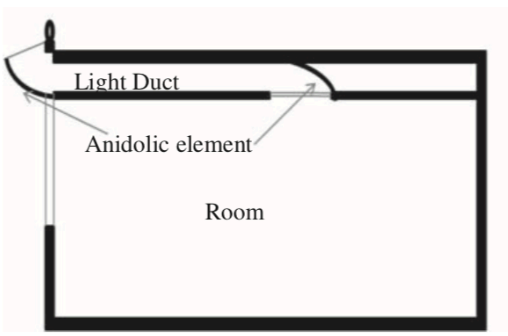

Figure 5. An anidolic ceiling. (Nair, Ramamurthy et al. 2014)

The anidolic zenithal light guide is a collector that consists of three plane mirror surfaces that are tilted at an angle. These surfaces redirect the diffuse light rays into a funnel parallel to its axis. Therefore reflections are minimized. (Nair, Ramamurthy et al. 2014)

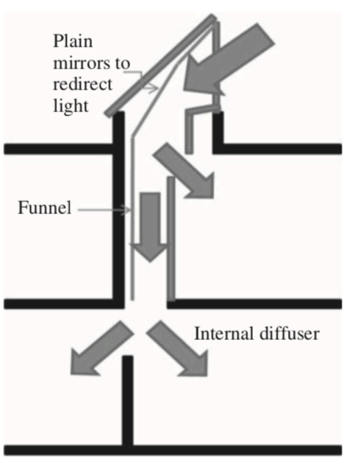

Figure 6. An anidolic zenithal light guide. (Nair, Ramamurthy et al. 2014)

Light Transport Systems

Light Transport systems have three main components: collection, transportation and distribution. First they collect the light and than they concentrate it, after which they distribute it in the form of diffuse light to the spaces where illumination is required. (Santos 2009)
Light transport systems exist out of three components, collection, transportation and distribution whereby most of them depend on direct light. Examples of the systems that are most used at the moment are devices that use fibre optics, lens systems and prismatic or mirrored light pipes. (Nair, Ramamurthy et al. 2014)

Collection

Light collectors can be divided into two groups, Passive Systems and Active Systems. The systems in both groups can again be categorized according to the way the light is collected, through light redirection or light concentration

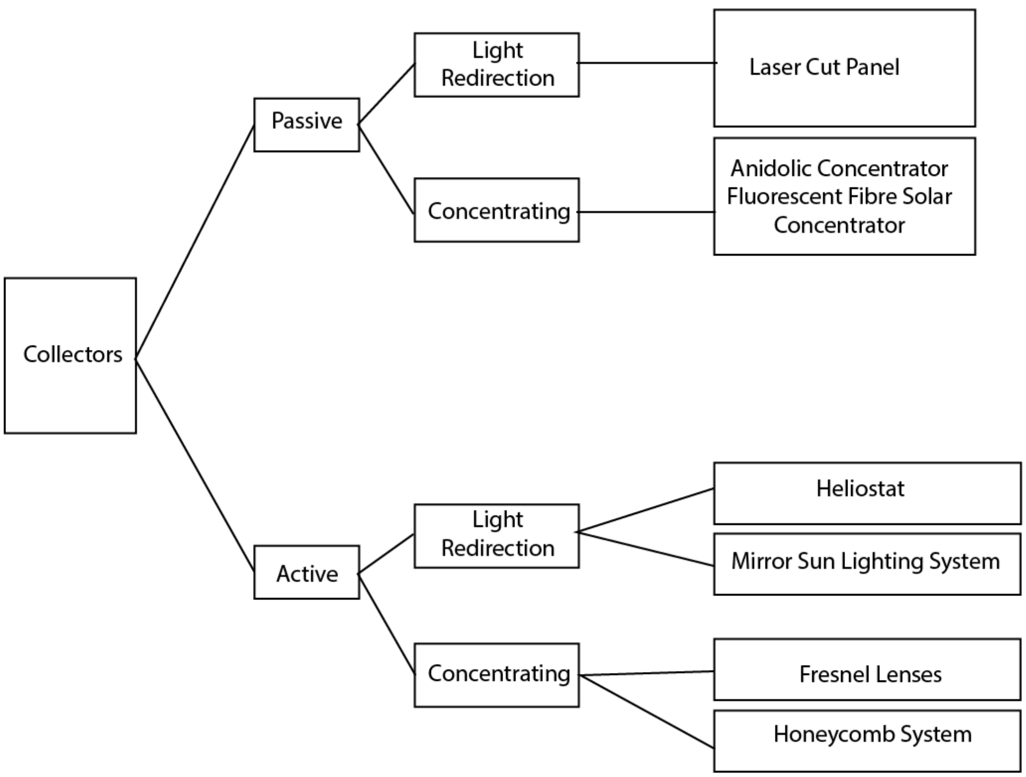

Figure 7. Classification of Light Collection Systems (Nair, Ramamurthy et al. 2014)

Passive Collection Systems

Passive collection systems are fixed installations that do not the motion of the sun. Examples of Passive Collection Systems are Laser Cut Panels, Anidolic Concentrators and Fluorescent Fibre Solar Concentrators.

Laser Cut Panels could be considered similar to channeling panels as they are made of parallel laser cutted acrylic panels that deflect light through an angle by refraction and reflection. At the input aperture it directs daylight into a collimated beam. (Nair, Ramamurthy et al. 2014)

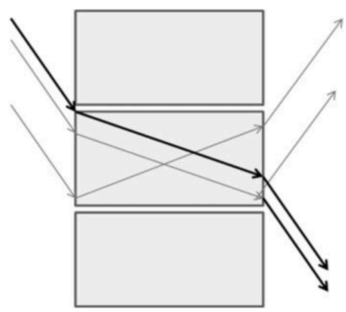

Figure 8. Laser cut panels. (Nair, Ramamurthy et al. 2014)

Anidolic Concentrators, also called Compound Parabolic Concentrators, are built with highly reflective material. Its parabolic form makes sure the concentration of light is achieved through the principle of non-imaging optics. First, light entering the aperture of the device is collected. Than the light is concentrated onto a smaller exit aperture where the receiver is located. (Nair, Ramamurthy et al. 2014)

Fluorescent Fibre Solar Concentrators consist of an optical fibre solar concentrator with a plate and three-colour fluorescent fibres. These fibres have quantum dots inside them. The coloured molecules absorb the light that is radiated on the plate and re-emit fluorescent radiation which in turn is transported to the edges of the plate by total reflection.(Nair, Ramamurthy et al. 2014)

Active Collection Systems

Unlike Passive Collection Systems, Active Collection Systems are not static and do follow the motion of the sun. These systems require large collector areas and large transport components. They have a tracking device that orientates the collector's position towards the sun. Examples of Active Collection Systems are Heliostats, Mirror Sun Lighting Systems, Natulite Systems, Fresnel Lenses and Honeycomb Systems. (Nair, Ramamurthy et al. 2014)

Heliostats are computer-controlled systems that follow, capture and concentrate the sunlight, redirecting the light to a mirror or lens. These mirrors or lenses than produce a concentrated light beam, which is transported through distribution or transmission systems. These distribution or transmission systems could be secondary reflectors or pipes. (Santos 2009)

Mirror Sunlighting Systems generally consist of two or three mirrors. The first mirror tracks the sun and reflects the light to a second mirror. The second mirror has a flat or concave surface that is able to turn in any direction and concentrates the reflected light. (Nair, Ramamurthy et al. 2014)

A Fresnel Lens is a thin transparent material that consists of a chain of prisms that redirect daylight. (Nair, Ramamurthy et al. 2014)

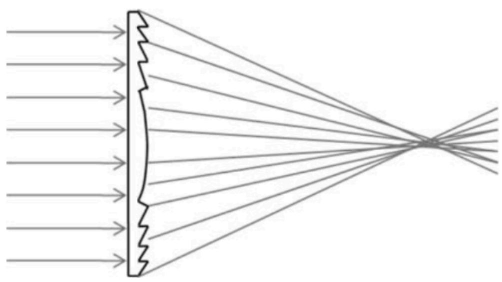

Figure 9. Light being concentrated through a Fresnel Lens. (Nair, Ramamurthy et al. 2014)

The Honeycomb system, also known as Parabolic Mirrors, collects light through its parabolic mirror and concentrates it into a small input aperture of the light transport guide.(Nair, Ramamurthy et al. 2014)

Transportation

Light can be transported in three ways: multiple specular reflection, total internal reflection and by convergence.

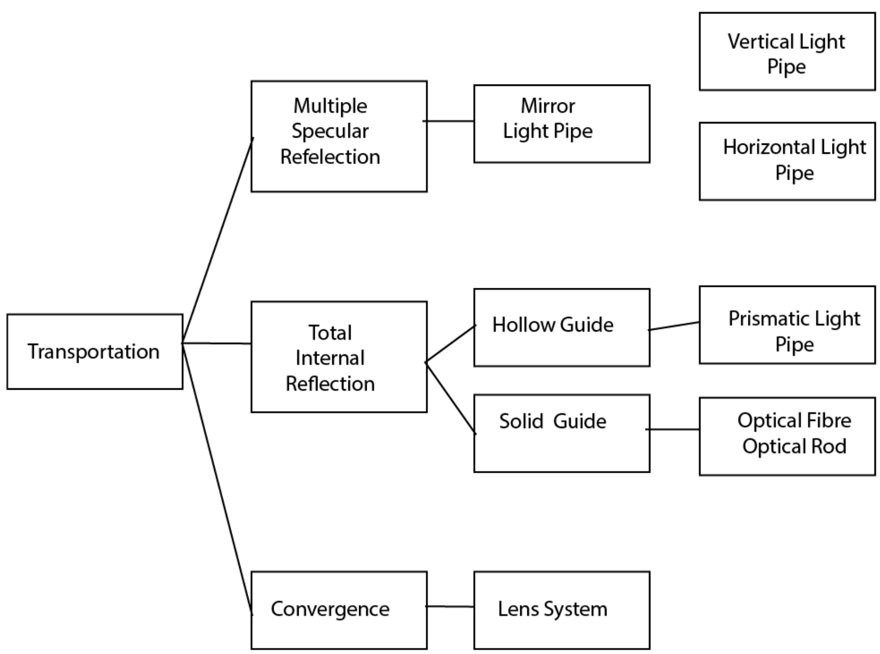

Figure 10. Classification of Light Transportation Systems (Nair, Ramamurthy et al. 2014)

Multiple Specular Reflection

When we speak of Multiple Specular Reflection, we speak of Mirrored Light Pipes. These pipes have a highly reflective metallic or mirrored interior in which the angle of reflection is the same as the angle of incidence. They can be categorised into vertical light pipes and horizontal light pipes. (Nair, Ramamurthy et al. 2014)

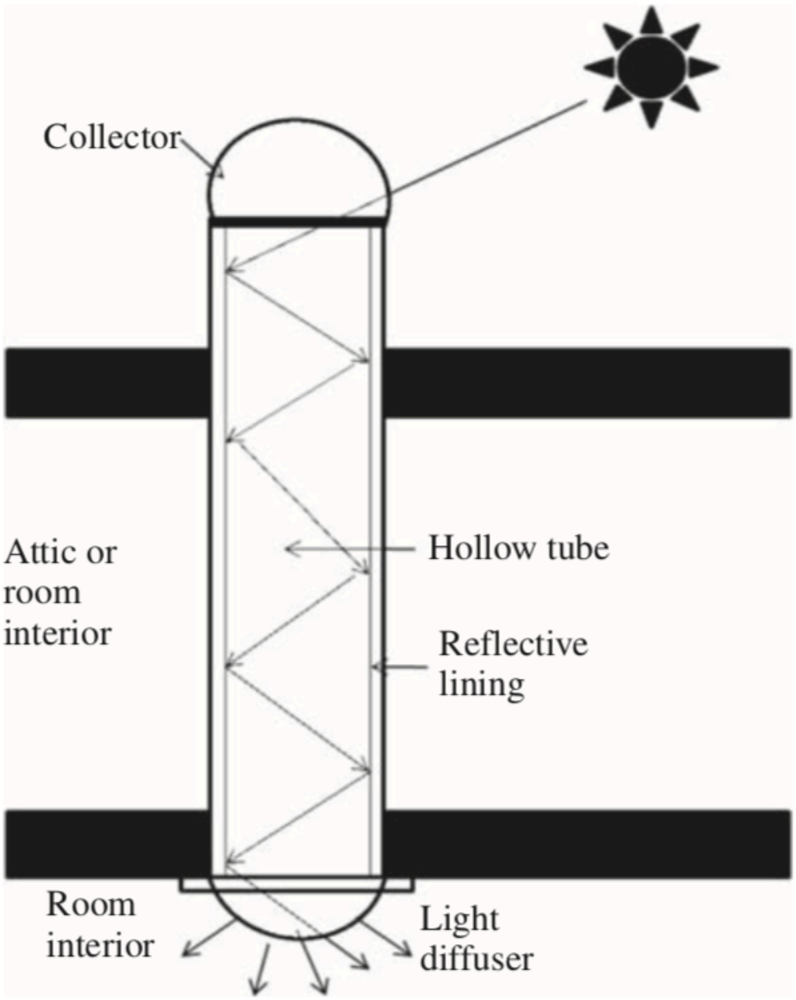

Figure 11. A vertical light pipe system. (Nair, Ramamurthy et al. 2014)

Total Internal Reflection

"*Total internal reflection occurs when a ray of light from a denser to rarer medium strikes the medium boundary at an angle greater than the critical angle with respect to the normal to the surface*." (Nair, Ramamurthy et al. 2014) Fibre Optics, Optical Rods and Prismatic Pipes are methods that use total internal reflection to transport light.

Fibre optics are flexible transparent fibres with a transparent core and a transparent cladding material that has a lower index of refraction.(Nair, Ramamurthy et al. 2014)

Optical Rods are made of acrylic and can transmit light over distances more than 4 meters. (Nair, Ramamurthy et al. 2014)

PLP's, shorter for Prismatic Light Pipes, are hollow tubes that are lined with prisms on one side and optical light film on the other. The light rays that hit the pipe, are reflected back into the pipe by total internal reflection.(Nair, Ramamurthy et al. 2014)

Convergence

The Convergence-Lens Systems converges the light to a focal point. After which the light can be diverged and re-converged to the next focal point.

Distribution

Last but not least, the last component of the Light Transport System, is the distribution of light. The device needs to provide a uniform distribution of illumination across a space. Prismatic panel emitters, optical fibres with Fresnel lens or glass diffusers at the end, are used for this distribution. (Nair, Ramamurthy et al. 2014)

Conclusion

The lack of natural daylight in underground structures has been one of the main drawbacks of underground space development. However, with the introduction and further development of innovative daylighting systems, the potential of underground architecture has grown.

The extended classification of Advanced Daylighting Systems show that each system has its advantages and disadvantages. Innovative Daylighting Systems need to be chosen considering factors like purpose, type of building and climatic conditions.

We can see that the level of reflection losses of Light Guiding Systems are high. Therefore they are perfect for spaces where the distance of light travel is short and no more than 10 meters. These systems can be used for deep-plan buildings that do have horizontal or vertical openings.

Light Transport Systems, on the other hand, do have the capability of transporting light over greater distances. Their reflection losses are low and therefor are perfect for underground developments in which natural light is demanded.

Based on the research done, the Japanese light transporting system, Himawari, will be applied. This is a Fiber Optic Daylighting System than can reach level of 40 meters underground and therefore will be perfect for the underground 'Cave Baths' project that will be designed next semester.

Bibliography

André, E. and J. Schade (2002). Daylighting by optical fiber.

Fontenelle, C. V. (2008). "The importance of lighting to the experience of architecture." Architecture Quality Issues, KTH Royal Institute of Technology, Stockholm, Sweden.

Lechner, N. (2014). Heating, cooling, lighting: Sustainable design methods for architects, John wiley & sons.

Mohirta, A. (2012). Natural Lighting and Psychological Barriers in Underground Space, Ph. D. thesis, Oxford Brookes University, Oxford.

Nair, M. G., et al. (2014). "Classification of indoor daylight enhancement systems." Lighting Research & Technology **46**(3): 245-267.

Omar, O. M. E.-s. (2008). Advanced daylight technologies for sustainable architectural design, Department of Architecture Faculty of Engineering, Alexandria University.

Phillips, D. (2004). Daylighting: natural light in architecture, Routledge.

Purves, D., et al. (2004). "Perceiving the intensity of light." Psychological review **111**(1): 142.

Santos, S. D. P. (2009). "Advanced Daylighting Systems: Comparative Study of Prismatic Panels, Laser-Cut Panels and Channel Panels."