*International Proceedings of Chemical, Biological and Environmental Engineering, V0l. 93 (2016)*
*DOI: 10.7763/IPCBEE. 2016. V93. 5*

# Biomimicry Method for Implementing Natural Lighting Performance in Underground Buildings

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**Abstract.** The purpose of this research is to develop a biomimicry method for implementing natural lighting performance in underground buildings. Existing planning techniques and lighting principles in forest canopies were studied to derive a unique way to implement natural lighting performance in underground buildings. The main goal was to develop a lighting system which can be used in buildings with upper floors. Upper floors unable planning open spaces which are existing techniques for introducing natural lighting into underground spaces. Introducing even ambient lighting to deep spaces was also an important matter. This method can help avoid planning large open spaces and increase design-flexibility for planning underground ¯spaces. As inducing air flow and transferring rainwater to lower trees are also functions founded in forest canopies, the result of this research can be further developed to also show other environmental functions.

**Keywords:** biomimicry, underground spaces, planning method, natural lighting, forest canopy

## 1. Introduction

Cities like Seoul, Montreal, Tokyo, Berlin and etc. are developing underground spaces to create a linkage between underground transportation and other parts of the city. The underground spaces in Place Ville Marie, a transportation hub in Montreal, are connected to underground floors of surrounding buildings. This type of space structure is favourable to users because of the extreme weather in Canada. The merits of developing underground spaces meet the needs of today's society. It can become a solution for urban problems; shortage of land, growth of land values, environmental problems, and etc. However, environmental limitations of living underground need consideration when planning underground buildings.

The lack of natural light and view is, both psychologically and physiologically, the single greatest concern related to underground space. [1] Therefore, this research has focused on the natural lighting environment in underground buildings. The purpose of this research is to develop a biomimicry method for implementing natural lighting performance in underground buildings. Existing planning techniques and building cases were studied to understand the limits in relevant cases. The biological strategies in forest canopies were studied to suggest a method which can overcome these limitations. Main principles were abstracted from biological strategies and were applied to planning techniques for underground buildings. Results of this research can be used in buildings with less open spaces to implement natural lighting performance in terms of psychological and physiological consideration.

## 2. Biomimicry Strategy

### 2.1. Biomimicry

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The definition of ‘Biomimicry’ is ‘learning from and then emulating natural forms, processes and ecosystems to create more sustainable designs.’[2] Applying principles learned from nature to building designs can result in innovative solutions for environmentally friendly designs. Preceding research (Zari & Storey, 2007) has asserted that not only principles learned from organisms but also understanding about ecosystems should be applied to Biomimicry architecture for an even more sustainable and effective results. However, because of the inter-connected nature of ecosystems and the ways in which they function, it is difficult to organize generalized principles into a neat list which accurately encapsulates the complexity of the relationships between each principle. [3] Therefore, the existing method of searching for biological solutions, which is using relevant keywords or databases, is not appropriate and effective for finding solutions from complex ecosystems. Because the ecosystem has multiple functions, study of this field need to be carried out before searching for relevant problems in the field of architecture. This is similar to the solution-based process of biomimicry. However, the problem-driven process of Biomimicry is similar to the actual process of designing buildings. Also, problems in the field of architecture constantly changes due to environmental and cultural changes in modern architecture. Research for defining problems in architecture needs to be carried out in order to set goals for applying biomimicry to architecture.

Table 1: Problem-driven & Solution-based Process of Biomimicry

| Problem-driven (Team A) | Solution-based (Team B) |
|---|---|
| ***Problem Definition*** | ***Biological Solution Identification*** |
| ***Reframe the Problem*** | ***Define the Biologcial Solution*** |
| Biological Solution Search | ***Principle Extraction*** |
| ***Define the Biological Solution*** | Reframe the Solution |
| ***Principle Extraction*** | Problem Search |
| ***Principle Application*** | - |

By considering these characteristics of Biomimicry architecture, this research has been followed by both the problem-driven and solution based process of Biomimicry. Search of problems in buildings and study of biological strategies were proceeded by different teams. Similarity was founded between underground spaces and the ecosystem of forest canopy through discussion between both teams. The form of the forest canopy can explain the introduction of natural lighting in deep spaces. Organisms in these forests has adapt and created mechanisms to survive in this dark environment.

### 2.2. Problem Definition and Reconstitution Method

Defining problems and reframing it is considered an important step for applying biomimicry to designs. Helms et al. (2009) proposes two steps for defining problems: functional decomposition and functional optimization. Functional decomposition takes a complex function and decomposes it into sub-functions and functional optimization defines a function or set of functions in terms of an optimization problem or equation. [4] For instance, considering light inflow opposes to controlling thermal environment because natural lighting can result in indoor temperature increase. Therefore, relationship between sub-functions should be clarified and optimized in this step. Vattam et al. (2008) proposes how technical problems can be reframed into biological terms. For instance, the goal of designing an underwater micro-bot with locomotion modality that would ensure stealth can be “biologized” as: “how do marine animals stalk their prey or avoid predators without being detected?”

In order to define and reframe problems for underground natural lighting, current natural lighting techniques and underground space characteristics have been studied. Limits of natural light implementation techniques were focused on to establish a research goal for this study.

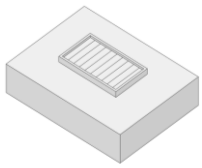
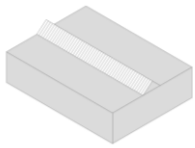
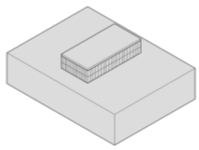
## 3. Natural Lighting Environment in Underground Buildings

### 3.1. The Necessity and Relevant Cases of Implementing Natural Lighting

New benefits of daylight are constantly being uncovered: daylight improves learning in school, improves recovery rates in hospitals, improves productivity in workplaces, and improves psychological wellbeing nearly everywhere. [5] The usage of daylight also benefits energy saving. Because there is limitation in installing windows in underground buildings, various approach have been made to implement natural lighting performance. Since the 1970s, architects, developers, and psychologists have cooperated on research aimed at understanding how to make underground buildings more acceptable and appealing. [6] Psychological anxiety can occur due to the enclosed underground environment. Many architects designed underground buildings using skylights, open spaces, etc. as a solution for this problem.

Although designers employ many variations and combinations of techniques, there are only a few basic approaches to provide natural light and exterior view to below-grade spaces. This approach by itself is capable of providing light and view only to the spaces on the building perimeter. [7] Existing techniques and planning methods either input light into underground spaces or diffuse light to maximize effects. Lighting input methods are usually considered by planning floor openings; skylight, atrium, light well, and etc. Light diffusing methods uses technology which reflect, refract or track light to create a brighter atmosphere. This kind of light diffusers are usually combined with light input methods. Although planning skylights, atriums, etc. is proven to be an effective designing method to implement natural lighting, this can only be applied to buildings with enough open space above the underground building. However, buildings in major cities lack of extra land space that can be used as an entry for daylight and not for building higher floors. Also, introducing natural lighting through top openings are suitable to underground development near the surface.

Table 2: Relevant Cases of Natural Light Implementation Techniques

| Natural Light Implementation Technique | | Case of Application |
|---|---|---|
| Light Inflow | Skylight<br>Atrium<br>Light Well<br>Clerestory<br>Etc. |   <br>(Skylight : atrium type) (Skylight :arcade type)<br>(Clerestory) |
| Light Transmission | Mirrors<br>Lenses<br>Prism<br>Daylight duct system<br>Heliostats<br>Fiber-optic System<br>Etc. | Complex application cases<br>· Mirrors : Using flat or curved mirrors, natural light will be transferred to a specific spot where a secondary mirror can be used again for long distance transmission.<br>· Prism+Mirrors: A prism can concentrate inflow light onto mirrors that are installed indoors. This is proven to be effective for maintaining light intensity.<br>· Lens+Optical Fiber: Convex lens can concentrate light and send to to optical fibers which is able to transmit light to far places. |

One of the quality goals for lighting design in general buildings is to supply fairly even ambient illumination throughout a space. Windows are planned to get more light deeper into the building both to raise the illumination level and to reduce the illumination gradient across the room. [8] Because planning windows are limited in underground spaces, a different approach is needed to introduce even illumination. Most of the building cases uses skylights, atriums, and etc. in order to introduce light to the center of the building. Light diffusers are used in order to enhance performance. However, because windows can only be installed on the roof of underground buildings, upper floors are likely to benefit natural lighting performance more than floors on the lower level.

Common fact about studied cases was that the above-ground level were used to create large entrance for natural lighting. Upward facing openings were made to create large light wells for indoor environment.

Although this technique is already acknowledged as an effective method for improving indoor lighting environment, limitation exists in directly applying this technique to most buildings located in urban areas. This is because open land spaces are actually scarce in urban areas due to high land value. Also, in case of Seoul city, large scale underground constructions are focused in areas near major public transportation point. For instance, IFC Mall, which is one of the main underground buildings in Seoul, is connected to a subway station. Also, underground spaces of Place Ville Marie in Montreal, are connected to basement floors of surrounding office buildings. Similar cases show that underground spaces in urban areas are becoming networks which links existing underground spaces. Therefore, natural lighting methods which can be applied to existing buildings are needed.

Based on the study above, several questions can be raised.

- How can natural light be introduced to lower floors?
- How can introduced light show even ambient illumination?
- How can natural lighting be implemented in existing underground spaces with minimum moderation?
- How can maximum amount of light can be introduced without large open spaces and openings, like atriums or arcades?

Questions above can be extended "biologized" questions as bellow.

- How do plants obtain needed amount of daylight?
- How is light introduced in dark habitats (underground, deep sea, deep forest, etc.)?
- How do animals or plants obtain light despite the existence of other restricted conditions?

## 3.2. Research Goals

From the characteristics of existing daylighting methods, the need of a much universal planning method have been understood. Research goals were established base on the search of solutions for the questions above. This research has focused on developing a lighting system based on the following goals.

- Greater design-flexibility
- Fairly even ambient illumination
- Introduction of light to deep spaces

## 3.3. Biological Strategies (Forest canopy)

The amount of light which enters the forest depends on many relevant elements; the angle and shape of branches, the size and shape of the leaves, the orientation of leaves, the length of branches, the overall size of the crown, and etc. [9] Studying the characteristics of a forest canopy can help bring out ideas for planning underground buildings with daylight performance. Underground environment is similar to the environment found in deep forests. Because of difficulties in installing vertical windows, daylight mostly enters through openings which faces upwards. Trees and plants in canopy regions also rely on daylight which enter through gaps made by the upper canopy. Light penetration through a forest canopy maintains understorey vegetation and determines the degree of suppression or vigour of its growth. [10]

Canopy regions were delineated as follows: [11]

- Upper canopy:
  Above – over the uppermost canopy leaves; exposed to direct light
  Within – approximately 10cm below the uppermost canopy leaves; light diffused with only one leaf layer overhead.
- Lower canopy:
  Sun fleck – leaf surface within 2m of ground level that received a transient beam of direct light.
  Shade – leaf surface within 2m of ground level that received no direct light
  Gap – area wider than 3m on the forest floor with direct light

At recently created edges, light enters the forest diagonally, creating a bright zone beneath the crown canopy. [12] Within the lower recesses of the canopy, wavelengths that are most useful for the photosynthetic process may often be lacking (Bjvrkman & Ludlow, 1972). A forest consists 4 main layers. The tallest trees are the emergent layer which mostly are broad-leaved, hardwood evergreens. [13] Because leaves are exposed to direct sunlight, skin layers are thick in order to regulate high temperature. Trees are widely spaced which helps the vegetation in the lower layer. [14] The canopy layer is the primary layer of the forest and forms a roof over the two remain layers. [15] Leaves are oval shaped in order to drip rainwater to the lower layers. These mechanisms maintain the ecosystem in the forest and also influence biological diversity.

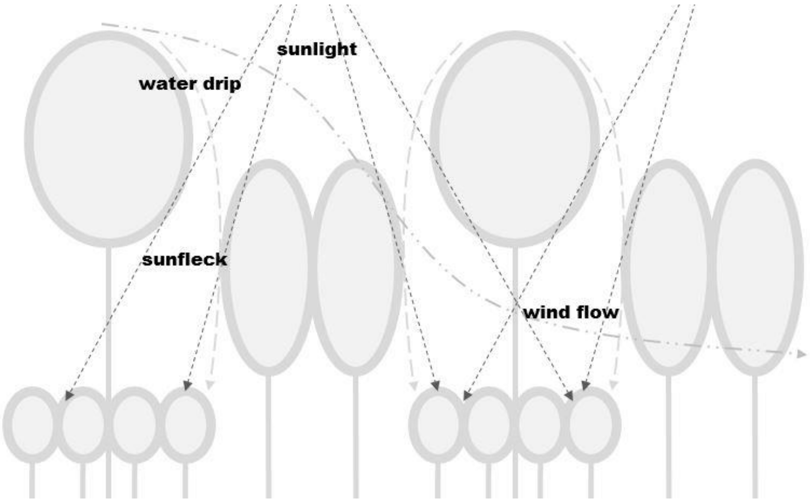


Fig. 1: Diagram of Microclimate in Forest Canopy

# 4. Implementation of Natural Lighting Performance in Underground Buildings

## 4.1. Concept

To achieve energy efficiency and to create a bright atmosphere in underground floors, this research has figured out what type of daylighting system is needed for typical underground buildings. Common spaces, such as ventilation spaces and staircases, can be used to introduce and deliver daylight to deep surfaces in underground floors. As an integrated design approach, this plan also uses light diffusers and reflectors to send daylight through minimum and diagonal open spaces. As the amount of light which enter through the ventilation space and staircases decreases in lower floors, light which are sent through diagonal open floors merges and brighten the center of the floor which gives an even lightness to the deep surface. Light reflectors are installed on each floor to raise effectiveness.

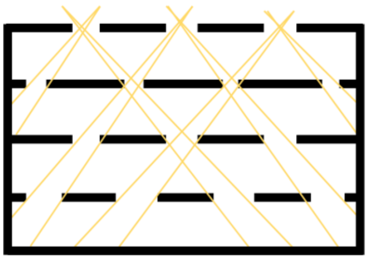


Fig. 2: General Concept

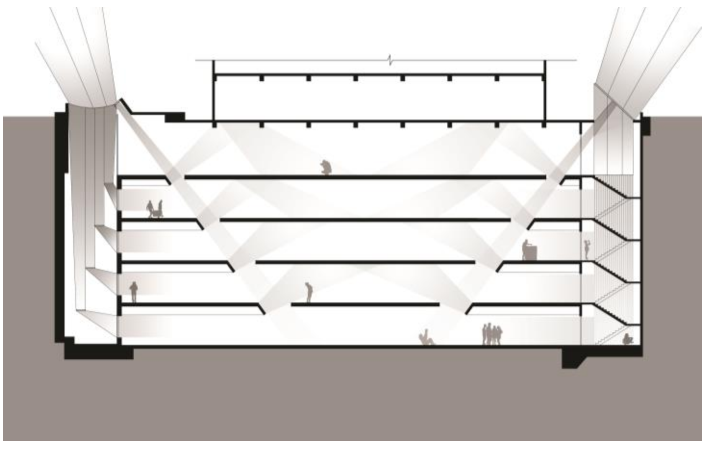


Fig. 3: Application Concept

## 4.2. Detail

### 4.2.1 Ventilation spaces as light well

Ventilation spaces in large buildings are installed to light and ventilate underground spaces. Lighting underground floors through ventilation spaces has limits in buildings with deep floors. The function of ventilation spaces can be supplemented by applying the principles founded in the forest canopy. Existing research used lenses to prevent glare from natural lighting. Condensing lens were used in this research to deliver light to deeper places. Reflectors installed in ventilation spaces reflect light to each floor.

### 4.2.2. Staircase as light well

Most of stairs in staircases have a gap between, and this gap can be used to convey light. This possibility has developed as an idea that the space can become a "Narrow atrium" at a staircase in underground spaces. Narrow atrium between stairs uses a pairing of two primary daylighting techniques, a narrow and tall shaped skylight to bring sun light into a duct coupled with a south facing mirrored reflectors right behind the opening and louver shaped structure for diffusing light. The mirrored reflector and duct allow daylight into the deep under-level of a staircase, and the louver shaped structure gives effective general illumination by diffusing light.

The design of narrow atrium has been considered to fit in usual size spaces of staircases. The space between stairs is mostly 2500mm long and 150mm width. The duct has slight long aperture on the wide side so that daylight illuminates interior of upper level staircase (B1-B3). A large amount of daylight can enter into lower stories as the duct blocks diffusing light. Louver shaped structure overlapped inside of the duct so that light easily start to scatter illuminating the structure.

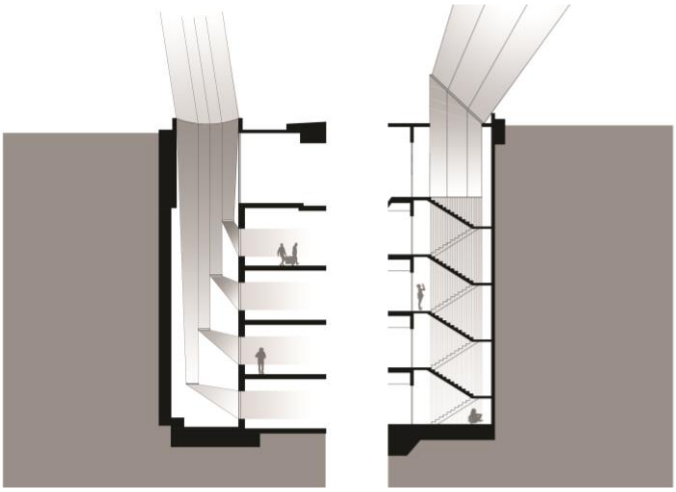
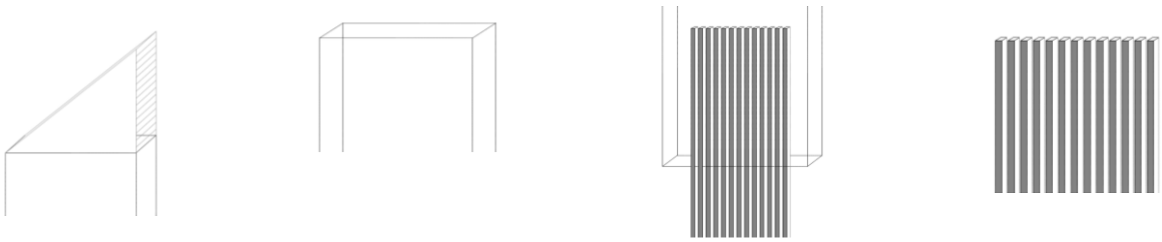


Fig. 4 Method of Using Ventilation Spaces and Stairways for Daylighting



(Entrance of natural light), (Deliver light through duct, B1-B3), (Lighten louver0like structure, B3), (Lighting structure, B3-B9)

Fig. 5 Details of Lighting System for Staircases

## 5. Conclusion

The results of this research can be used to design underground buildings with natural lighting performance. Minimum open spaces are capable to introduce and implement daylight. By applying and modifying the presented lighting system, underground spaces can be planned with more flexibility and also with advanced lighting environment. Through further research, simulation of this system will be carried out to evaluate actual effects and to concretize the details of this concept. It is also expected that this system can be developed in ways to show other environmental functions. The shape of forest canopies have evolved not only based on natural lighting, but also based on creating an ecosystem which can enhance airflow and transfer rainwater to lower layers. By developing the results of this research, other environmental functions like air flow and temperature control can also be considered.

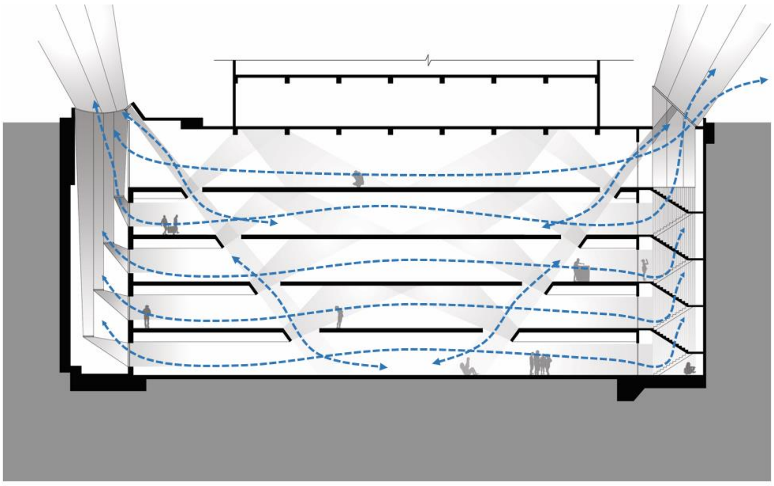


Fig. 6: Potential of Further Development for Ventilation and Temperature Control

## 6. Acknowledgements

This research was supported by a grant (15CTAP-C077364-02) from Land Transport Technology Promotion Program funded by Ministry of Land, Infrastructure and Transport Affairs of Korean government.

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