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An introduction to connectivity concept and an example of physical connectivity evaluation for underground space

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ABSTRACT

Underground spaces will be the future frontier for urbanization due to surface land scarcity and environmental considerations. To improve the image and usage of underground space from the current planning, space connections, within underground and with above ground, must be improved to encourage the use of underground space. Connectivity of various parts within a large underground space complex has not been extensively studied. This paper introduces the concepts of connectivity in terms of physical, visual and implicit, and suggests that the physical connectivity can be measured and quantified. In the appendix, an example of developing physical connectivity evaluation methodology for underground spaces is illustrated, to show the possibility of calculating the physical connectivity that may provide input for underground space layout design and optimisation.

1. Introduction

Utilization of underground space is worldwide, driven by continuous urbanization. In many major cities, large-scale underground spaces are created as underground stations, shopping centres, and pedestrian corridors (e.g., Anttikoski et al., 1989; Bélanger, 2007; Boivin, 1991; Cui et al., 2013; Edelenbos et al., 1998; He et al., 2012; Howells and Chan, 1993; Rönkä et al., 1998; Takasaki et al., 2000). In the last a few decades there are clear trends using underground space in urban development for:

(i) Underground transport networks, particularly the underground metro system.
(ii) Underground space as part of building, mainly for parking and commercial uses.
(iii) Underground passage and corridors linking the commercial centres through basements.
(iv) Underground infrastructures such as rock caverns for storage and industrial facilities.
(v) Large underground space for commercial and institutional uses, such as shopping centres and libraries.

In Singapore, large underground space, including the Underground Science City (USC) have been studied, and more recently, the Underground Learning Centre (ULC) was proposed (Zhao et al., 1996, 2013; Zhou and Zhao, 2016), as shown in Fig. 1. The direction of underground space development is toward underground city of multiple functions (Bobylev, 2010; Li et al., 2013). As an integral part of the city, underground city requires well-connected network to link surface and subsurface spaces, both vehicular and pedestrian.

While underground space provides many advantages (Bobylev, 2006; ITA, 2000; Sterling, 1997; Subsurface Association, 1990), it also has negative factors compared to above ground space:

(i) Visibility at above ground: Underground space is not visible and is difficult to make it attractive through exterior design.
(ii) Accessibility to above ground: Access to underground space is limited by through shafts and inclined tunnels.
(iii) Visual contact with the natural environment: Lack of visual contact with sun, sky and above ground features leads to loss of direction and association with natural orientation.
(iv) Space interconnection: Particularly for deep underground space, e.g., caverns, interconnections are limited by intersecting tunnels.

One should also be aware that underground space, similarly to high-rise building, the spaces are in 3-dimensions. The interconnections are both horizontal and vertical.

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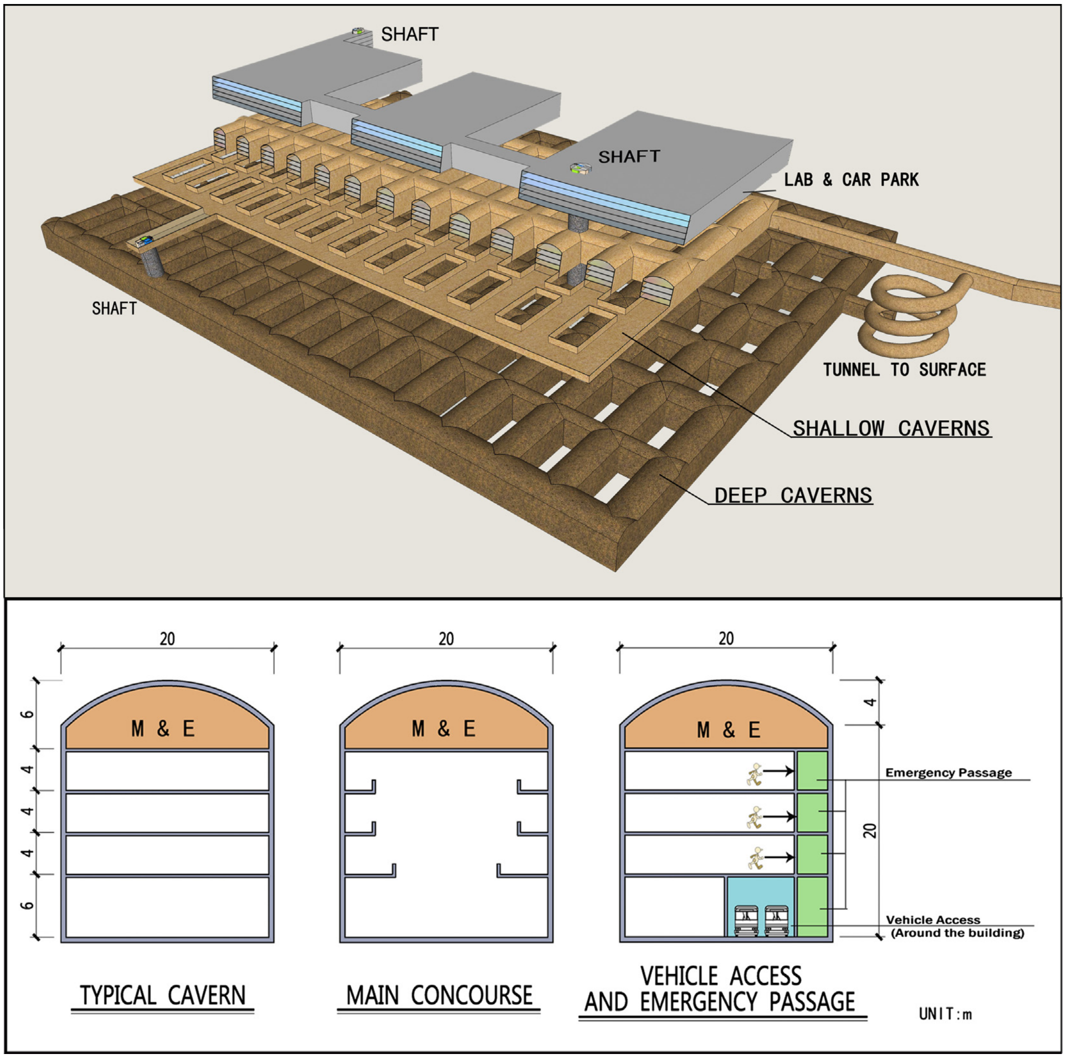

Fig. 1. Cut-away view (upper) and typical sections (lower) of rock caverns of the proposed Underground Learning Centre at Nanyang Technological University of Singapore (Zhao et al., 2013).

The current planning and design of underground space are primarily at project level and with specific applications. As we are moving towards large underground space in the scale of underground cities for people to use, and to encourage the use of underground space, we need to improve the image and the usage of underground space, to allow for better connections between spaces and movements of people, within underground and with above ground.

Connectivity is one of the key factors for urban mobility and liveability, in urban planning and development. However, connectivity of large underground space has not been extensively studied, both connectivity of various parts within a large underground space complex and connectivity between underground and above ground space. The objective of this paper is to introduce the concepts of connectivity in terms of physical connectivity, visual connectivity and implicit connectivity, particularly for underground space.

As an attempt and an example, the paper also shows a procedure for developing a methodology to evaluate physical connectivity of underground spaces based on the typology. Such an evaluation can be used for calculating and comparing the quality of physical connectivity, and serve as a basis for optimal planning and design of underground facilities in term of accessibility, mobility and usability.

2. General typology of space connectivity

Spaces may be connected by different means. The following three types of connectivity are suggested: physical, visual and implicit connectivity (Künzli, 2013). The allocation principle of the connectivity typology relies on the following aspects:

- Purpose
- Means of connection
- Execution period
- Hierarchy (importance)

Physical connectivity aims to physically connect spaces and comprises the physical connection network and mobility means used for locomotion. Given that physically connecting spaces is the strongest way of connection, physical connectivity may be considered the most important type among the suggested three. The conception of physical connectivity occurs during early stages of an underground project, in which decisions concerning the emplacement of surface access points must be taken. It is for this reason that physical connectivity consists in the type with less flexibility.

Visual connectivity intents to connect spaces visually. In this regard, different levels of view in or out from spaces may be

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