Tunnelling and Underground Space Technology xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Underground space as an urban indicator: Measuring use of subsurface

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ARTICLE INFO

Article history:
Received 25 July 2015
Received in revised form 22 September 2015
Accepted 9 October 2015
Available online xxxx

Keywords:
Urban underground space
Urban indicators
Urbanisation
Sustainability
Resilience
Density

ABSTRACT

Use of Urban Underground Space (UUS) has been growing significantly in the world's biggest and wealthiest cities. UUS has been long acknowledged to be important to the urban development agenda: sustainability, resilience, livability, and creating a better urban environment in particular. These issues are traditionally monitored using urban indicators, however UUS has not been properly included and considered in urban indicator lists (sets or systems) yet – the gap this paper is aiming to bridge. The paper reviews existing approaches to the composition of urban indicator lists, highlighting indicator types, challenges related to data collection, and agencies that are concerned with the issue. Further the paper has identified the importance of UUS inclusion in the lists that give integrated assessment and monitor urban sustainability, resilience, climate change adaptation and mitigation, as well as progress towards smart, livable, and compact cities. Existing global quantitative data on UUS have been examined in 8 cities; and three key indicators (descriptors) were suggested to monitor UUS use: Developed UUS volume (m^3); UUS use density (m^3/m^2); and Developed UUS volume per person (m^3/person). Current average UUS use densities in cities are identified as up to about 0.05 (m^3/m^2) (which can be interpreted as a virtual depth of UUS use of 5 cm), and the developed UUS volume per person is up to about 10 m^3/person; while city central areas (central business districts) can have a virtual depth of developed UUS of several metres (m^3/m^2). Compatibility, comparability, uniformity, and sustained monitoring of urban indicators data (including UUS indicators) found to be posing significant challenges to the research across geographies, and industry/economic sectors.

1. Introduction

Urban Underground Space (UUS) use has been growing significantly in the world's biggest and wealthiest cities. Arguably, the main driving factors of this growth were lack of surface space and a need for a better environment, including abatement of motor traffic and pollution problems. Generalising, we can suggest that awareness of *the urban sustainability agenda* and a need to make cities more liveable have been growing concurrently with intensification of UUS development.

Indeed, UUS development can contribute a lot to urban sustainability, ranging from local renewable energy provisioning to urban space cohesiveness and aesthetics. Sustainability issues related to UUS use were raised by Carmody and Sterling (1993), Sterling (1997), Bobylev (2006, 2011), Rogers (2009), ITACUS (2010), and systematised by Sterling et al. (2012).

Measuring sustainability is an important subject, both in scholarly terms and as a policy informing tool. Lists of urban indicators or urban sustainability indicators have been adopted by many cities, countries, and international organizations to monitor progress in sustainable urban development. Sustainability is just one of the concepts that require to be informed by urban indicators; most recently the concepts of *ecosystem services*, *resilience*, *smart cities* have been developed and require input of urban data. Thus urban indicators become a more general notion, pertaining to developing, collecting, and analysing data from different aspects of urban life and then applying this knowledge to develop a better urban environment.

Usually urban indicators are presented in a form of lists where individual indicators are grouped according to a subject or knowledge area. Data behind these lists have different degrees of comprehensiveness and accuracy in terms of indicator monitoring. Specific indicators can have a variety of methodologies of data collection, ranging from field monitoring and comprehensive numerical data to expert estimations and rankings.

In spite of acknowledgement of UUS importance to the concepts and urban issues highlighted by use of urban indicators (e.g. sustainability, resilience), this subject has not made it yet into routine urban indicator lists. The importance of UUS as an urban activity sector is on a par with long established urban sectors as transport

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http://dx.doi.org/10.1016/j.tust.2015.10.024
0886-7798/

(widely used indicator: motorisation rate), land use and planning (widely used indicator: built stock density), environment (widely used indicators: air pollution, water quality).

The undeservingly marginal role of UUS in urban sustainability and resilience discourse is reflected by the fact that the UUS topic has not made it yet into executive summaries of the most known *policy documents related to urban development*, i.e. United Nations Human Settlements Programme State of Cities Reports (UN Habitat, 2006, 2013a); United Nations Environment Programme Geo Outlook (UNEP, 2012); The World Bank Annual Reports and Urbanization Reviews (World Bank, 2012); Organisation for Economic Co-operation and Development Infrastructure Outlooks (OECD, 2006, 2008). However, the progress regarding mainstreaming UUS into urban agendas has been made. The United Nations Secretary General's formal address to the International Tunnelling Association conference in Bangkok in 2006 highlighted UUS relevance to global development and urban sustainability agendas (UN, 2012b). Famous architect Norman Foster highlighted the strategic importance of UUS as well: "One of the greatest challenges facing mankind is to achieve higher density while at the same time improving urban existence. The underground has enormous potential for realising spatial benefits" (Foster, 2011).

This paper argues that considering UUS in urban indicators lists will help to better understand the role that UUS plays in urban sustainability, resilience, and creating a better urban environment and life in general. Considering underground space as an urban indicator will help both: (1) better urban policy informing, and (2) better understanding of UUS sector industries needs and directions for development.

One challenge is arguing and promoting UUS inclusion into urban indicators; another one is to suggest how to do it. The paper will review existing approaches to composition of urban indicator lists, highlighting indicators types, problems related to data collection, and agencies that are concerned with the issue. Further the paper will examine existing data on UUS globally, trying to make sense of what actually can be measured in UUS and how this could help to better inform sustainability and resilience agendas. Finally, some possible UUS related indicators and their descriptors will be suggested, along with available data cross-sector analysis and comparisons.

2. Urban indicators

2.1. Emergence, systems, agencies

The emergence of *the urban indicator theme* stems from *the Sustainable Development Concept* (Brundtland Commission, 1987), and one of the first widely accepted set of indicators was part of the Local Agenda 21 (United Nations, 1995). Attempts for a singular comprehensive indicator set were made by United Nations Sustainable Development office (1998), comprising the list of 134 sustainability indicators. During about two decades of urban indicator research numerous lists, sets or systems of indicators have emerged. These lists were adopted by a variety of agencies and at a variety of levels (from national to local), which suggests the importance of diversity and fine turning of indicator lists. The need for development and structuring of urban indicators in a specific context was reflected in recent scholarly publications dealing with regionalization (e.g. Gonzalo et al., 2015; Michael et al., 2014; Shen et al., 2011), and the development of different indicator tools that aim to analyse urban sustainability (e.g. Castanheira and Bragança, 2014). Some questions regarding UUS and indicators include whether UUS should be featured in any specific lists (i.e. pertaining to a certain level or developed for any specific purpose), and/or if it is appropriate to have UUS in any lists dealing with topics of UUS concern: e.g. sustainability.

Urban indicator lists, sets, or systems have been developed by different *agencies*. The most famous of them aim on comprehensiveness and global applicability United Nations (2007), Organisation for Economic Co-operation and Development (OECD, 2004), the World Bank (World Bank, 2015), European Union (Eurostat, 2009), World Health Organisation (WHO, 1999), United Nations Human Settlements Programme (UN-Habitat, 2013b).

There is a number of specific *assessment tools*, that are in fact using urban indicators, as summarised and classified by Gonzalo et al. (2015), who considered 13 systems. Amongst them are certification systems developed for urban related industries: construction, planning, transportation. Major international systems are Leadership in Energy and Environmental Design (LEED) (US GBC, 2009), Building Research Establishment Environmental Assessment Method (BREEAM) (BRE Global, 2011), Sustainable Community Rating (SCR, 2015), Key Indicators for Territorial Cohesion and Spatial Planning (Daly and González, 2013).

A number of a *large scale research projects* were aimed at creating a comprehensive online databases of urban indicators: European Common Indicators (European Commission, 2003), Urban Audit (Urban Audit, 2004), European Thematic Network on Construction and City Related Sustainability Indicators (CRISP Project, 1999), Cities Environment Reports on the Internet (CEROI Project, 2010). Unfortunately, in majority of cases, the data update has been discontinued after the projects have ended, nonetheless, these projects remain an important methodological reference.

2.2. Types and classifications

The most traditional approach to create an indicator list would be to group indicators according *to three pillars of sustainability* (environment, economy, society). However nowadays a purpose-driven approach prevails in most urban indicator lists, i.e. broad indicator categories reflect agenda or concerns of the list proponent. Table 1 exemplifies aggregated indicator categories of the highest hierarchical level presented by several agencies.

As Table 1 reflects, indicator lists tend to be as comprehensive as possible, prioritising main concerns of the developer (e.g. note category "poverty" in the UN Habitat list). Urban indicator lists presented in Table 1 represent *different scales* – from global to national and a city one. Indicator assessment is done at an urban (city) level in any system, but the UN Habitat list is concerned with global relevance, while the Thessaloniki list is concerned just with the issues relevant to this particular city. Urban indicators bring *different meaning to different levels* (Lynch et al., 2011). At a local level the indicators are mainly used to monitor and inform urban development by city authorities; at the regional and national levels indicators inform development programmes and policies; at the global level the indicators are used to inform policies of international development agencies, including setting cross sector priorities (e.g. financing, climate change) that go beyond urban agendas.

Indicators differ in actual *approaches to measure them*. Significant division is between *quantitative and qualitative indicators*. This division can be referred to as different measurement methods, or different descriptors. An indicator formulation usually reflects what we want to know according to our (e.g. sustainability) goals e.g. "outdoor air quality"; the descriptor would reflect on available data we can monitor, e.g. "proportion of population exposed to SO_x above x mg/m^3", or "$PM_{2.5}$ mean annual exposure, % of population exceeding World Health Organisation guidelines level" (World Bank, 2015). Similar quantitative indicators in different indicator lists can have different descriptors.

Descriptors can differ in data collection methods, which could make comparisons amongst different indicator systems difficult (Bobylev, 2009b, 2010a; World Bank, 2011). Data on qualitative indicators is presented in a form of expert judgements, an example

Please cite this article in press as: Bobylev, N. Underground space as an urban indicator: Measuring use of subsurface. Tunnel. Underg. Space Technol. (2015), http://dx.doi.org/10.1016/j.tust.2015.10.024