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Assessment of the future resilience of sustainable urban sub-surface environments

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ABSTRACT

Urban sub-surface environments have consistently been used to house a wide variety of urban infrastructure, but often developed in a relatively haphazard way. An important aspect to overcome this is an enriched understanding of the current and potential future uses. Therein Geoscientific information should be considered indispensable, if this space is to be developed in a resilient and sustainable way. This will require a clear understanding of what is or could be located within underground space, together with its properties, in order to assess its true potential as an urban resource. This information will inform urban developmental choices allowing sustainable and resilient development of underground space use to take place regardless of what the future may hold. However, such information needs to be integrated into decision support systems for conventional types of underground construction, in order for any development to occur in a consistent and manageable way.

This paper presents the development of a new sustainable underground use resilience evaluation (SUURE) framework that will allow the quantification of both spatial and temporal impacts of today's underground urban (re)development solutions, in light of future economic, environmental and social changes. The framework uses a broad range of plausible, yet divergent future scenarios in order to ensure core objectives of sustainability and resilience are met. Within this paper it is used to evaluate the utilisation of Multi-Utility-Tunnels – MUT's (i.e. flush-fitting, shallow and deep) in Birmingham Eastside, UK, as an alternative utility placement technique to traditional (open-cut) trenching. The flush-fitting MUT was found to be having the highest overall baseline (i.e. present-day) performance with a resilience index ratio of 0.739 (mean value), the shallow MUT came second at 0.656, and the deep MUT came last at 0.212.

1. Introduction

Urban Underground Space (UUS) has been used for many centuries; nonetheless acceptance that it is an irreplaceable, valuable, and in-demand resource has only materialised recently (Parriaux et al., 2007; Bobylev, 2009; Sterling et al., 2012). UUS can be defined as space beneath urban areas that provides direct service to a city (e.g. groundwater supply or geothermal energy). UUS encompass geologically formed rocks and soils, and artificial structures, as well as caverns of various origins. Parriaux et al. (2007) have identified four basic UUS resources: space, materials, water, and energy. These resources have different degree of renewability, depending on their use and/or rate of extraction (Sterling et al., 2012). UUS embodies a significant potential for adoption of future solutions in the development of living conditions for mankind and these have to carefully considered (Godard, 2004; Jefferson et al., 2006; Simpson and Tatsuoka, 2008; Rogers, 2009; Hunt et al., 2011). In terms of its need, it cannot be avoided that underground construction whether it be utilities, transport or foundations underlies and underpins any construction project. Therefore city planners should qualify a more efficient and better designed utilisation of this space to ensure its long-term provisioning can be planned for, managed and maintained. In essence UUS functions in the role of a dynamic terminal through which interdependent anthropological systems and the ecosystem services interact and impact with each other. The recognition of this interdependence is vital to understanding sustainability (conceived here to be a balanced approach to all three pillars: economic, social and environmental – including natural resources) as it pertains to civil engineering. Moreover if cities are to adopt more appropriate UUS solutions that can last the test of time they must be resilient to whatever the future holds (Hunt et al., 2012; Rogers et al., 2012). The burgeoning consensus points to the fact that realising a sustainable (and resilient) built environment must begin through a transparent decision-making process that integrates all considerations and viewpoints for sustainability and resilience at the planning and design stages of an infrastructure construction project

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(Braithwaite, 2007; Hunt et al., 2008; Rogers et al., 2012). However, development and usage of UUS often goes undetected to the everyday users of urban environments, and therefore it comes as no surprise that there is a prevalent absence of important and wide-ranging planning efforts to regulate and organise its use (Jefferson et al., 2007). This begs the fundamental question of how one might fill this gap. By reviewing present-day sustainability evaluation frameworks (e.g. SPeAR) in an accompanying paper within this special edition (Hunt et al., 2016) it has become clear that much literature exists highlighting a complete absence of the availability of decision-making tools for assessing (i.e. pre-evaluating) and modifying designs for UUS based on sustainability and resilience. Therefore this must be a primary area for research to address. [Sustainability according to Brundtland is about *ensuring that current generations meet there own needs without compromising the needs of future generations* (United Nations, 1987). In contrast Resilience is typically portrayed as *the capability of a system to withstand shocks whilst preserving function, structure, response capabilities, and consequently distinctiveness* (Nelson et al., 2007; Walker et al., 2006; Walker and Salt, 2006). A more enriched discussion on similar and contrasting elements of each can be found in Hunt et al. (in this special issue).]

As such this paper presents the development of the sustainable underground use resilience evaluation (SUURE) framework that will allow the quantification of both spatial and temporal impacts of today's underground urban development and regeneration solutions, in light of future economic, environmental and social changes. Thus enabling the sustainability and resilience of any potential solution [for UUS] to be assessed whatever the future may hold. The SUURE framework is demonstrated through evaluating the utilisation of Multi-Utility-Tunnels – MUT's (i.e. flush-fitting, shallow and deep) in Birmingham Eastside, UK, as an alternative utility placement technique to traditional (open-cut) trenching. Section 2 sets the context for MUTs as a solution in Eastside before presenting the methodological approach adopted within the SUURE framework in Section 3. Key results are shown in Section 4 then discussed in Section 5, conclusions are drawn in Section 6.

2. Eastside and multi-utility tunnels

The city of Birmingham is the UK's second largest city which is constantly changing to keep apace of current needs and demands. Much of this change occurs due to redevelopment projects where declining areas offer up opportunities to embrace innovation.

One such area of 130 hectares (420 acres) occurred at the turn of the 21st century in Birmingham Eastside, which resides in the zonal extents of Digbeth besides the Aston triangle, in the northern quadrant of Birmingham city centre, UK (Fig. 1). Utility service provision is a vital and inevitable first course of action for all regeneration schemes, not least Eastside. Its ability to be further expanded and thus account for expected future growth in demand (increased capacity required by e.g. increase in population density) will determine whether a forward-looking development can be sustained. Despite the fact that best practice guidance for utility service provision exists (NJUG, 2003) and utility placement via traditional trenching methods is governed by legislation (Traffic-Management-Act, 2004; DfT, 2010), they are not compulsory mechanisms and therefore not always adhered to in practice (Hunt and Rogers, 2005).

MUT's are an alternative 'solution' to traditional trenching practices which can significantly aid achieving more sustainable utility placement and yet in the UK have gathered relatively little attention (Hunt and Rogers, 2005; Rogers and Hunt, 2006; Hunt et al., 2009, 2014). An MUT is defined as '*any system of underground structure containing one or more utility service which permits the placement, renewal, maintenance, repair or revision of the service without the necessity of making excavation; this implies that the structure is traversable by people and, in some cases, traversable by some sort of vehicle as well*' (APWA, 1997). As shown in Fig. 2 MUT placement can be 'flush-fitting' within or slightly below the pavement, 'shallow' beneath roadways and other transport modes or 'deep', in other words subterranean as adopted in Finland and Denmark (Rogers and Hunt, 2006; Hunt et al., 2014).

The SUURE framework developed herein helps decision-makers assess location potential for each MUT (utility placement) option. The methodological framework is now described.

3. Methodology

The SUURE framework consists of 10 logical steps as shown in Fig. 3, a more detailed description of which follows:

Within the confines of this paper it is possible only to give a brief overview of the steps involved (not least Steps 6–9 which describe the AHP and Fuzzy Logic methodology) therefore the reader is directed to Makana (2015) for a much fuller description of these.

> *Step 1* – The first step in the SUURE framework identifies the sustainability solution 'goal'.

In this case the goal is defined as 'MUT placement for collocation and coordination of utilities for sustainable use of UUS'.

> *Step 2* – This step identifies the '*necessary conditions*' to achieve the goal taking into account local conditions in Birmingham Eastside.

The placement of an MUT is therefore reconceived as a Multi-Criterian Decision Analysis (MCDA) problem using ANP (Analytic Network Process, Bobylev, 2011) which requires a wide-ranging array of influencing criteria (see Fig. 4). In this case a total of 20 criteria were carefully chosen from appropriate published engineering articles (ITA, 1987; Godard and Sterling, 1995; Haasnoot et al., 1997; Edelenbos et al., 1998; Ronka et al., 1998; ITA-WG4, 2000; NJUG, 2003; Butler and Davies, 2004; Godard, 2004; Legrand et al., 2004; Chen and Wang, 2005; Hunt and Rogers, 2005; Canto-Perello and Curiel-Esparza, 2006, 2013; Bélanger, 2007; Duffaut and Labbé, 2008; Canto-Perello et al., 2009; Yang et al., 2010; He et al., 2012; Sterling et al., 2012; Hunt et al., 2014). In the evaluation method, five readily practicable principal clusters are adopted within ANP network structure (Miller, 1956) differentiated by way of (15) compensatory criteria (i.e. biophysical environment, location aspects, constraints, factors affecting the physical environment and socio-economic aspects) as well as (5) non-compensatory criteria (i.e. constraints). The influences that exist between the respective elements are expressed accordingly.

> *Step 3* – This step involves exhaustive process of raw data acquisition for the case study.

This comes from a range of sources (e.g. Ordnance survey, Open Street map, British Geological Survey – borehole records, GSI3D and national archive, Office of National Statistics (ONS)) and was carried out for the five clusters in Birmingham, Eastside.

> *Step 4* – By using the raw data developed in Step 3 this step allows for a series of thematic GIS maps to be constructed considering all 20 criteria defined in Step 2.

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