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Impact evaluation of green–grey infrastructure interaction on built-space integrity: An emerging perspective to urban ecosystem service

Abhishek Tiwary [a,*], Prashant Kumar [b,c]

[a] Faculty of Engineering and the Environment, University of Southampton, Highfield, Southampton SO17 1BJ, United Kingdom
[b] Department of Civil and Environmental Engineering, Faculty of Engineering and Physical Sciences (FEPS), University of Surrey, Guildford GU2 7XH, United Kingdom
[c] Environmental Flow (EnFlo) Research Centre, FEPS, University of Surrey, Guildford GU2 7XH, United Kingdom

HIGHLIGHTS

- Green–grey interaction, i.e. impact of urban greening on built-up space is studied.
- A lateral ecosystem function of GI in built-space integrity is identified.
- Material surface recession for limestone and steel is computed under influence of GI.
- Material loss for steel is estimated to be over 5 times higher than for limestone.
- GI species selection and seasonal variation influence integrated ecosystem service.

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ABSTRACT

This paper evaluates the role of urban green infrastructure (GI) in maintaining integrity of built-space. The latter is considered as a lateral ecosystem function, worth including in future assessments of integrated ecosystem services. The basic tenet is that integrated green–grey infrastructures (GGIs) would have three influences on built-spaces: (i) reduced wind withering from flow deviation; (ii) reduced material corrosion/degeneration from pollution removal; and (iii) act as a biophysical buffer in altering the micro-climate. A case study is presented, combining the features of computational fluid dynamics (CFD) in micro-environmental modelling with the emerging science on interactions of GGIs. The coupled seasonal dynamics of the above three effects are assessed for two building materials (limestone and steel) using the following three scenarios: (i) business as usual (BAU), (ii) summer (REGEN-S), and (iii) winter (REGEN-W).

Apparently, integrated ecosystem service from green–grey interaction, as scoped in this paper, has strong seasonal dependence. Compared to BAU our results suggest that REGEN-S leads to slight increment in limestone recession (<10%), mainly from exacerbation in ozone damage, while large reduction in steel recession (up to 37%) is observed. The selection of vegetation species, especially their bVOC emission potential and seasonal foliage profile, appears to play a vital role in determining the impact GI has on the integrity of the neighbouring built-up environment.

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1. Introduction

Incorporating green infrastructure (GI) into the urban built-space is gaining popularity as a cost-effective and long term measure for mitigating climate change impacts associated with proliferating grey infrastructure globally (CABE, 2010; Hamdouch and Depret, 2010; Llausàs and Roe, 2012; MEA, 2005; Schäffler and Swilling, 2013; Thaiutsa et al., 2008). In essence, this is being achieved by utilising their ecosystem functions i.e. facilitating interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services (Defra, 2011; TEEB, 2012). The UK National Ecosystem Assessment (NEA, 2011) has identified the following four broad categories of ecosystem services i.e. benefit people obtain directly or indirectly from ecosystems: (i) supporting (i.e. facilitating habitats for species); (ii) provisioning (i.e. generating resources); (iii) regulating (i.e. moderating climatic and biological effects), and (iv) cultural (i.e. recreational and aesthetic). Exploring the potentials of quantitative and qualitative approaches for assessing ecosystem services is a relatively new science, developing rapidly through a combination of numerical modelling and spatial analysis tools (Busch et al., 2012; Scholz and Uzomah, 2013). Among the regulating services of GI, the majority of efforts till date have been concentrated on assessing the direct benefits, for example,

* Corresponding author. Tel.: +44 7866187059.
E-mail addresses: a.tiwary@soton.ac.uk (A. Tiwary), p.kumar@surrey.ac.uk (P. Kumar).

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ecological and human health implications. The application of ecosystem service values to a new area such as built-space integrity is a novel contribution to knowledge and understanding. Such knowledge development is vital for fostering an inclusive green–grey urban (and landscape) planning, with the consideration for the 'extended ecosystem service' to facilitate sustainable urban futures.

Ample efforts have gone in determining the role of vegetation on urban microclimates, with numerous studies applying detailed physical as well as CFD simulations to assess the modifications to pollution concentrations through coupled effects of building morphology and vegetation on pollutant dispersion. These studies fall under two schools of thinking, depending on the building-vegetation biophysical interactions. One, projecting their positive influence by considering them as pollutant sinks (e.g., filtration and absorption of particulates and NO_x; Buccolieri et al., 2011; Tiwary et al., 2006, 2009, 2013a,b). Two, elucidating their negative influence as obstacles to airflow i.e. hampering the mixing of pollutants in poorly ventilated areas close to streets and reduced air exchange with the above-roof ambient environment (Gromke, 2011; Vos et al., 2012; Wania et al., 2012).

The majority of vegetation studies on buildings have focussed mainly on the assessment of thermal comfort (Ali-Toudert and Mayer, 2007; Berkovic et al., 2012; Berry et al., 2013; Santamouris, 2012; Yu and Hien, 2006) and reduced building energy demands (Akbari et al., 2001; Bouyer et al., 2011; Yang et al., 2012). A more recent study evaluated the role of urban green commons – comprising mainly of collectively managed parks, community gardens and allotment areas – in developing resilience and environmental stewardship in cities (Colding and Barthel, 2013). However, to our knowledge, no dedicated assessment of the impact of GI on the integrity of the surrounding 'grey infrastructure', including bridges, car parks and historical buildings, through their coupled aerodynamic and biophysical interactions have been conducted so far. Developing such understanding is pertinent to the on-going emphasis on enhancing GI investments as a tool in large scale climate change adaptation strategies. Moreover, this would aid holistic assessment of GIs by integrating all relevant sciences to sustain ecosystem services (Lundy and Wade, 2011; McMinn et al., 2010). The relevance of such study is greater now in the face of recent projections suggesting accentuations in the theoretical building dose–response functions (DRFs; the metrics commonly used to assess integrated exposure of building materials due to air pollutants and meteorological parameters.) under air pollution and changing environment, mainly owing to the altered micro-meteorological profile and chemical withering of building materials (including concrete, steel, stone, wood) under changing weather patterns (Brimblecombe and Grossi, 2008; Kumar and Imam, 2013). Such impacts need to be understood fairly swiftly, for both inner city and free-field environments, in the context of the modifications brought by the upcoming GI interventions.

The aim of this study is to enhance the understanding of the role of urban GI in ameliorating the micro-meteorological parameters and pollutant concentrations in an urban space, and the impact of these alterations on the material recession of surrounding built structures, such as building walls and bridges. Essentially, the modelling approach applied here is somewhat a hybrid assessment of what people have seen until now in individual pockets. The case study demonstrates the ecosystem services (or disservices) from GI in terms of their impact of built-space integrity, which has not been adequately accounted for in the conventional evaluation of their ecosystem functions so far. In particular, the following three influences of GI on the existing built-space are assessed: (i) as *quasi* bluff bodies in modifying the wind fields and withering; (ii) in reducing ambient pollution, and (iii) in altering the micro-climate. All these collectively influence the integrity of neighbouring built-spaces. The study envisages promoting designing of cohesive green–grey infrastructures (GGIs) as future of sustainable city planning.

2. Methodology

2.1. Environmental modelling case study

The case study is designed to assess the role of GI for two contrasting seasonal conditions (summer and winter), typically representative of temperate climes. These were developed to understand the role of varying microclimatic effects from GI intervention on the integrity of 'inner-city' built infrastructure — both historical and new constructions. Keeping this in mind, the scenarios covered solid limestone wall structures (traditional buildings in European cities) and carbon steel structures (modern buildings). The domain comprised of a busy street canyon environment, exposed to traffic emissions, to ascertain the level of intervention offered by GIs in modifying the following two key factors influencing building integrity: (i) microclimate (wind, temperature, humidity), and (ii) pollutant profile (source/sink).

2.1.1. Base case

As a first step, a base case model was developed for business-as-usual (BAU) scenario. A fast response building-resolved Lagrangian dispersion modelling platform, QUIC — Quick Urban and Industrial Complex v5.81, with computational speeds and model complexities in between a Gaussian and a CFD model, was applied (Nelson and Brown, 2010). Its appropriateness for this task was ascertained based on its recent applications in urban flow simulations around built-up area (Hanna et al., 2011; Zwack et al., 2011). The modelling platform comprises of three sequential components — a city builder, a flow simulator (QUIC-URB or QUIC-CFD), and a dispersion calculator (QUIC-PLUME).

The QUIC model domain used a nested gridding with inner domain of 300 m × 300 m × 20 m (length × breadth × height), mainly covering the 'grey' infrastructure (buildings, bridges and car parks) (shown in Fig. 1). This was centred in an outer domain spanning 1000 m × 1000 m × 20 m, allowing for evolution of the flow in the urban boundary layer to satisfy the guidelines for applications of CFD to simulate urban flows (Franke et al., 2007; Tominaga et al., 2008). The wind fields and pollutant dispersion for BAU were computed for a typical inner-city street environment, comprising of cross-streets lined with buildings, car parks (CP1, CP2) and over-bridges (B1–B4) (Fig. 1a). The foot bridges (B1, B2) are located close to the cross-street intersection and the two cantilever car bridges (B3, B4) are located on approach to the two car parks, adhering to the design specification for over-bridges (DMRB, 2004). The meteorological inputs were acquired from a local weather station, including wind speed, ambient temperature, relative humidity, and ambient pressure.

As explained in Section 2.1.2, the wind direction was intentionally kept static at 210°. The road emissions were modelled as line sources for a typical European street environment (Table 1).

The simulation time period was set to allow the model to converge on a steady state solution. Pollutant concentrations for BAU were determined by quantifying the number of particles passing through a constant grid volume (5 m × 5 m × 2 m) during the time period of interest. Concentrations were calculated on 1-min average basis in each grid volume. Pollutant concentrations were not calculated until the first released particles had passed completely over the domain and exited the downwind side (starting at 300 s). This step ensured the model computations to surpass evolutionary phase of the plume in order to output steady state concentration (Nelson and Brown, 2010). Overall, 766,500 'QUIC particles' were released over the entire 2000 s simulation.

2.1.2. Inclusion of green infrastructure

Two important considerations were made while introducing the GI for influencing both the microclimate and the resulting pollutant concentrations: (i) selection of vegetation species, and (ii) location of the plantations. Use of large urban trees has been recommended in

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