Mitigating and adapting to climate change with a taxonomy of smart urban surfaces

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Abstract. Rapid urbanization is replacing natural land with dark, impervious surfaces. This has led to dire urban consequences including rising temperatures and stormwater deluge, resulting in significantly higher energy costs, greater stormwater damage, and associated health and comfort impacts. These issues can be mitigated using smart surfaces, those with high reflectivity and permeability, which can achieve sustainable and regenerative cities. The current literature on the benefits of urban surfaces is very segmented, focusing on either one specific surface type or one property of surfaces. A smart surface taxonomy with correlated heat, and water metrics has been developed to fill this gap. A range of city surfaces in three broad categories - roofs, streets and sidewalks, and parking lots - have been identified with various levels of reflectivity, permeability. Through literature review, the taxonomy reveals surface temperatures that range from 29.7°C for a green roof to 74.3°C for a black roof. Also, the taxonomy reveals Rainfall retention potential ranging from 1.27 mm for impervious pavement to 86.4 mm for bioswales. The development of a smart surface taxonomy with quantified benefits for mitigating or adapting to climate change will be critical for decision-makers to make informed decisions on city surface choices.

1. Introduction

Today, US cities have up to 66% hard surfaces [1][2] and most of these surfaces are dark and impervious, resulting in higher surface temperature and increased stormwater runoff amounts. The ongoing paving of cities has led to significantly higher temperatures with associated cooling energy use and carbon generation, as well as stormwater runoff and associated property damage. Two critical surface properties have limited attention in current city surfaces decision-making: reflectivity (albedo) and permeability (Curve Number). Albedo is the fraction of solar radiation reflected, ranging from 0 to 1, with 0 being 100% absorption and 1 being 100% reflection. High solar reflectance surfaces absorb less energy, resulting in lower surface and ambient temperatures, which correspond to lower energy demands with reduced greenhouse gas emissions. Permeability indicates the ability for water to move through material, often indicated by Curve Numbers. Curve Numbers are determined by the land’s soil type, plant cover, interception, surface storage and impervious area coverage [3]. Because current urban surface practices have increasing areas of impervious surfaces, this results in increased stormwater runoff amounts, leading to increased flooding and combined-sewer-overflow. These two properties are critical in mitigating (or aggravating) adaptations to climate change.
Current literature on city surfaces focuses on either one specific surface type (i.e. roofs) or one property of surfaces (i.e. reflectivity). Some studies focused on the impact of pervious surfaces versus impervious surfaces on stormwater runoff [4], others focus on the benefits of urban greenery [5] or the benefits of cool roofs and pavements [6]. However, there is limited literature combining heat and water metrics across a full range of urban surfaces. Further, the current studies are often too technical for city decision makers to make informed decisions when planning urban surfaces. As a consequence, there is a need to quantify a full taxonomy of urban surfaces and their heat and water benefits in a systematic approach for urban surface decision-making.

2. Methodology and outcome variables
A comprehensive taxonomy of urban surfaces relative to two performance outcome variables, surface temperature and rainfall retention, have been quantified to reduce technical gap for decisionmakers.

2.1. Surface temperatures of a taxonomy of urban surfaces
Surface temperature is directly influenced by reflectivity and widely used by both research experts and the general public. A systematic literature review supported comparisons of surface temperatures for a taxonomy of urban surfaces. Figure 1 reveals that while dark asphalt streets and parking lot surface reach 60°C on a 35°C day, light colored or reflective asphalt drops this to 51.7°C, and surface temperatures under tree canopies are 27°C cooler, even below outdoor air temperature [7]. For roofs, the shift from dark to light surfaces offers corresponding benefits. Despite Green roofs low albedo or reflectivity numbers, they can be as much as 44.6°C cooler than a conventional black roof, due to the evaporative cooling and shading effects [8]. PV provides additional shading of the roof surface and leads to 2.5°C lower surface temperatures, which in combination with green roofs can result in 27.2°C [9].

2.2. Maximum rainfall retention of a taxonomy of urban surfaces
Another way of increasing understandability of the performance of our urban surfaces is to translate Curve Number into maximum rainfall retention amount. Millimetres or inches of rainfall are widely used values in our daily weather forecast. From the literature, Curve Numbers have been identified for the range of surface types in the smart surface taxonomy. Equation (1) is traditionally used for calculating runoff amount, where \( Q \) is runoff amount (mm), \( P \) is rainfall amount (mm), \( S \) is the potential maximum soil moisture retention after runoff begins, which in turn is determined by Curve Number, indicated by equation (2). \( I_a \) is the initial abstraction, assumed as \( I_a = 0.2 \) S [3]. In this study, the runoff amount was set to 0.0001 and the minimum value of Curve Number in a range for a surface type was used to calculate the maximum rainfall retention amount. As the results shown in Figure 2, while the impervious surfaces generate 100% runoff, water storing 'blue roofs' retain 20.3 mm of rain per event and street and parking lot bioswales hold up to 86.4 mm of rain before any runoff is generated.

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Q = \frac{(P-I_a)^2}{(P-I_a)+S} \tag{1}
\]
\[ S = \frac{1000}{CN} - 10 \]  

Figure 2. Maximum rainfall retention per event scalar for urban surfaces across three categories.

3. Smart Surface Taxonomy Development

Based on the above results, a library of visualized surfaces has been developed to help city decision makers make smart, informed decisions on city surface choices. A ‘smart surface’ is not only the surface with high reflectivity and permeability, but also selected based on each city’s unique environmental and social-economic conditions. This library of surface components is divided into three categories - roofs, streets and sidewalks, and parking lots - ranging from dark impervious to light colored pavement with various permeability and greenness coverage. The averaged surface temperature and rainfall amount performance data for each type is calculated. The development of a taxonomy, with heat and water management values as well as other outcome benefits, is critical to improve communication with decisionmakers and for GIS analysis of existing conditions and the near term potential of informed decision-making to progressively improve our urban environments in the face of climate change.

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