WUDAPT'S NEXT GENERATION OF URBAN CANOPY PARAMETERS FOR ADVANCED MULTI-SCALE WEATHER, CLIMATE AND AIR QUALITY MODELS

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1. INTRODUCTION

The World Urban Database and Access Portal Tools (WUDAPT) project goal is to provide consistent information on urban form and function for cities worldwide that can support urban environment modeling. Information captured in the form of urban canopy parameters (UCPs) they provide the means for models to simulate the effects of urban surfaces on the overlying atmosphere. WUDAPT acquires, stores and disseminates such information at different levels of detail; higher levels provide more spatial resolved and value at greater precision. The lowest level employs the Local Climate Zone (LCZ) scheme that provides ranges of UCP values at the LCZ scale. Data generated at higher levels describe the spatial heterogeneity present in cities at different urban scales. This paper describes a pathway to gathering these data. An innovative Digital Synthetic City (DSC) tool that simulates the 3D building and road elements that make-up an entire city landscape is utilized. DSC tool requires readily available data to perform the simulation, and comparisons of outputs with real-world urban data are very encouraging. UCPs can be derived from this simulated landscape at any desired scale, meeting the fit-for-purpose goal of WUDAPT.

2. OVERVIEW: A FIT-FOR-PURPOSE MODELLING FRAMEWORK

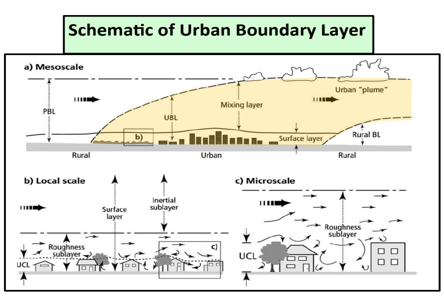

Fig 1. Schematic of the multiscale urban boundary layer.

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Urban areas are characterized by complex distributions of myriad of morphological stuctures and typologies; the resulting urban boundary layer structure shown in Fig 1.Therefore, the framework for science based modeling of urban area weather, climate and air quality will require suitable multiscale treatment of all the various vertical exchange processes concerning transport, energy and pollutant emissions, transport and deposition and chemical transformations. Urban canopy parameters (UCP) as description of these morphological features (Oke et al., 2017) provide a systematic framework for multiscale modeling of the urban boundary and canopy layers (Brown and Williams,1998) based on Navier Stokes equations and air quality modeling systems (Fig 2).

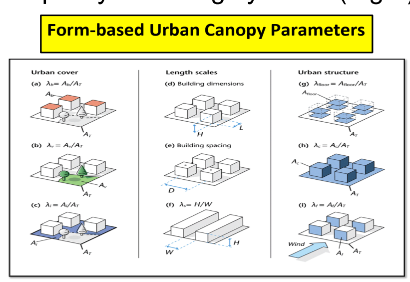

Fig 2. Set of urban canopy parameters (UCPs)

Examples of introduction of these UCP as used in WRF, a community based modeling system can be found in Urban Canopy models such as Kusaka and Kimura, 2001, Masson et al., 2000, Martilli et al., 2002, Salamanca et al., 2009, Dupont et al., 2004, Otte et al., 2004, Chen et al., 2010.

WUDAPT (www.wudapt.org) is a community based system designed to provide a means for urban modeling, capturing the multiscale essence of urban surfaces and supports urban modeling fit-for purpose modeling needs. First conceptualized by Ching, 2014), it is being implemented in a hierarchical structure. The framework for Level 0 is based on the Local Climate Zone (LCZ) concept of Stewart and Oke, 2012), Bechtel et al., 2015, Mills et al. ,2015, Ching et al., 2018. Here, urban surfaces are described and composed of 10 distinct urban classes for which a range of value of various UCPs for modeling is provided in look-up tables for each LCZ class (Fig 3). Currently, LCZ maps for more than a hundred cities have been successfully generated and quality assured at Level 0; and a number and variety of model applications have been utilized or underway for several of these cities. Level 1 and higher provide UCP data with increasingly greater spatial definition resolution and precision.

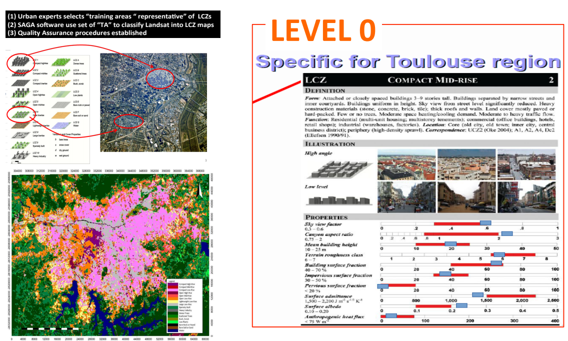

Fig 3. Local Climate Zones

The methodology development and testing of for the next levels in WUDAPT's data hierarchy is now underway. Where detailed municipal data on buildings, roads, vegetation, etc. exist (e.g. UCPs as NUDAPT type information (Ching et al., 2006), UCPs can be calculated at a selected level of precision. The challenge and objective of data at these levels is to generate equivalent urban scale UCP data *ab initio* but on a world-wide scope, and generated in a reasonable and practical manner. A prototype methodology has just been developed and its testing and initial implementation now underway is designed to meet these requirements and scope. The framework, innovations and preliminary results are described and shown in the next sections.

3. CONCEPTUAL FRAMEWORK FOR GENERATING GRIDDED UCPS.

3.1 Overview

Fig 4 illustrate the underlying approach for Level 1 and 2. In principle, from digitized details of urban surfaces shown as high-resolution satellite imagery one can calculate and generate form based UCPs (Fig 2).

The approach we take is based on this principle, but as an alternative to requiring and obtaining access to such data, we have developed a tool we call the Digital Synthetic City (DSC). The DSC is capable of simulating the spatial heterogeneity that characterizes urban landscapes at urban block scale. The generic DSC has the capacity to include the types of buildings (and materials) associated with cultural and historical practices that distinguish places. It is proposed that these building-scale parameters could be acquired using a combination of architectural typologies linked to crowd-sourced methods that would sample neighborhoods. The goal is the creation of UCP data that reflects the unique form and functions of individual cities and permits scalar variation to meet the needs of different models. As these form features of the imagery are digitized, all morphological form based UCPs can be computer generated and to any grid size.

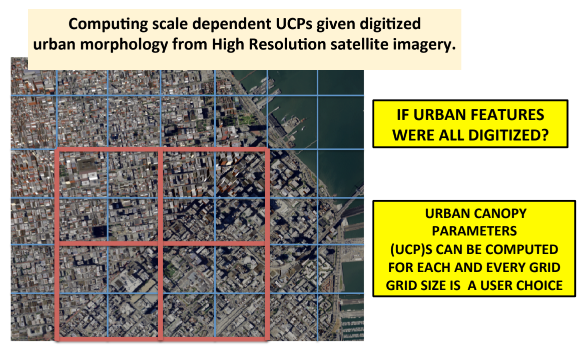

Fig 4. Computing scale dependent UCP using DSC.

3.2 The Digital Synthetic City (DSC) tool

Among other synthetic techniques, the DSC is a heuristic-based computer-assisted means of generating, from high-resolution satellite imagery, digital synthetic buildings that capture the essence of building dimensions and layout for cities with sufficient accuracy for many climate modeling applications. There are many techniques for creating 3D urban models of which procedural modeling (e.g., Vanegas et al. 2009a) and urban reconstruction (e.g., Musialski et al. 2013) are commonly used. Procedural modeling defines a set of rules and parameters to generate content and it has been successfully applied to urban spaces (e.g. Parish and Müller 2001; Vanegas et al. 2009b; Vanegas et al. 2012a). DSC automatically produces a 3D city model by linking three components: 1) procedural model generation, 2) parcel area estimation, and 3) procedural model optimization. Fig. 5 is a schematic of the Digital Synthetic City (DSC) workflow. The detailed formulation of the DSC framework, algorithm, and initial prototype are described in Aliaga et al. (2013). At its core is an inverse procedural modeling algorithm (e.g., Vanegas et al. 2012b) that is fully automatic and produces a 3D approximation of an urban area from satellite imagery and global scale data that includes road network, population, and coarse elevation data. DSC 'builds' the city by analyzing the data on parcels, buildings and their setbacks, population, and terrain elevation.

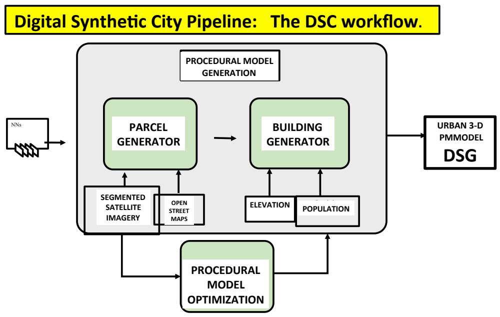

Fig 5 Schematic of the Digital Synthetic City tool.

The procedural model generation component takes as input geo-registered segmented and labeled satellite images and the corresponding Open Street Map (OSM) road network. Individual city blocks are extracted from the satellite imagery and an initial geography of building parcels is created using the freely available global elevation JAXA dataset (30-meter mesh, accuracy about 5 meters) and the LANDSCAN Global Population Data. The building generation algorithm estimates the building dimensions and distance from the parcel edge (i.e. the setback) by allocating one of six building types that correspond to combinations of low/mid/high rise with compact/open (that is, LCZ types 1-6). Specifically, the DSC uses: 1) Low-rise open, 2) Low-rise compact 3) Mid-rise open, 4) Mid-rise compact, 5) High-rise open, and 6) High-rise compact.

The parcel estimation component, used during model generation, use analyses of typical parcel sizes and building sizes in a city in order to train a neural network for robustly producing a set of parcel area networks. The neural network ingests the noisy and error-prone segmentation of a satellite image of a city block and produces crisp and reasonable parcel areas as output.

The procedural optimization component iteratively executes the generation process to increase the similarity between the synthetically created building outlines and a small calibration dataset comprised of actual building footprint areas. By making use of the calibration dataset (e.g., a few percent of ground truth building footprint areas), the system parameters are tuned to in the end produce a significant improvement in the overall accuracy. The DSC tool automatically generates a complete fully optimized 3D model of a city (with parcels, buildings, and roads) using satellite image and OSM in 15 to 120 minutes depending on the urban area size.

The DSC has the capacity to integrate other information (e.g. building materials and architectural features) to greatly enhance the product. For example, the DSC tool has two provisions: (1) the Building Type Refinement (BTR) to handle inputs of building properties such as albedo, heat capacities, and thermal admittances as probability distribution functions or other formats and (2) Partial Building Knowledge (PBK) to accommodate architectural variations based on additional data including materials. The BTR and PBK are being developed as either tools of the portal-based DSC or as part of downloadable software (Fig 6).

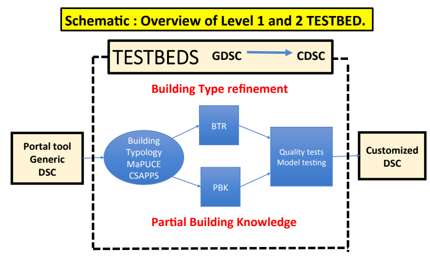

Fig 6. Schematic: customizing the DSC.

These tools of the DSC makes it feasible and possible to customize the DSC to specific cities with data based on crowdsourcing Apps (CSAPPS) which will be implemented using the city-specific Testbeds described below.

3.3 Design implementation approach utilizing city specific Testbeds.

Each city and regions in the world have unique morphological structures, building construction materials and cultural features that need to be captured by the DSC before the final UCPs are generated. For customizing the DSC, Urban experts discern these unique features and provide samples of such features using crowdsourcing APPS and sampling approaches to collect such data and incorporate them into the DSC. Additional details and data on building materials energy use, at block scale and larger can also be collected and incorporated. Additional steps listed below are required for full implementation of UCPs for each large city through out the world; for this we propose setting up candidate cities as City Specific Testbed led by urban experts for the prototype testing and evaluation. The experience gained from this stage will provide the bases for the protocols of the final recommended approach. These Testbeds will:

1. Apply, customize and evaluate the DSC (C-DSC) for their city using the requisite high-resolution input satellite data (and were available OSM data, population and terrain elevation data, and available baseline data such as building and against a unique set of Sky View Factor (SVF) database (Middel et al., 2018).
2. Develop sampling strategy and deploy Crowdsourced APPs (CSAPPs) to gather further details on the buildings, then incorporate the CSAPP data into the DSC model to enrich the building data.
3. Perform, assess and evaluate a variety of model applications using the C-DSC UCP data to ensure usefulness and adequacy of the W12 data.

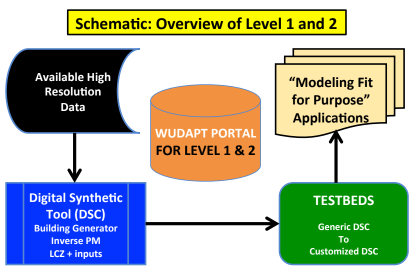

Fig 8. Schematic of Level 1 and 3 activities.

A summary of the overall approach to generating this higher level set of UCP is depicted in Fig 8.

4. PRELIMINARY RESULTS, DISCUSSION

We now present some initial limited results to illustrate the current state of the tool development.

Fig 9. Outputs of DSC to Google earth imagery.

4.1. Preliminary results of the DSC

We have used the DSC tool to generate 3-D models of several test cities worldwide. Fig. 9 visually contrasts the simulated and actual urban landscapes for comparison and Fig. 10 compares DSC output with actual building height and footprint area. Overall, the mean absolute error (MAE) is just 5.8%. We anticipate this error to be reduced further as additional data to customize DSC is implemented. The optimized column is the result of using a sample (5-10%) of building footprint areas measured across the study area – these data are available for many cities or can be easily generated.

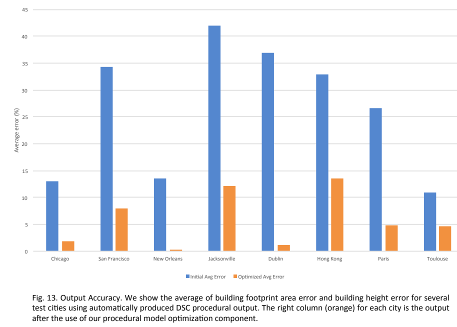

Fig 10. Outputs from DSC vs actual data for 8 cities

As an example of UCP computation, in Fig. 11 we computed the area-weighted building height (A_h) and building surface plan area ratio (λ_b) for Hong Kong.

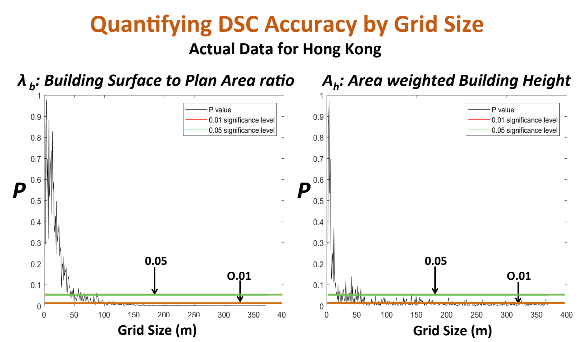

Fig 11. Accuracy of λ_b and A_b from DSC to actual values for Hong Kong.

This pilot test example shows how the DSC output can generate typical UCP values for different grid sizes. In this comparison, we aggregate each UCP type (i.e., A_h or λ_b) into a multiple sets of bins (see horizontal axis). As the number of bins in a set increases, it implies each bin is finer (or smaller). We aggregate the ground truth value into corresponding multiple sets of bins. Then, for each set of bins, we compute the statistical similarity between the DSC-based bins and the ground-truth bins at two different significance values (i.e., α=0.05 and α=0.01). The figure shows the number of bins at which the difference between DSC-produced and ground-truth is not statistically different. In particular, for area weighted building height (A_h), DSC and ground-truth bins are similar for bins as small as 6.8 m^3 (at α=0.05) and 4.1 m^3 (at α=0.05) – e.g., a bin of buildings that averages to 10 m tall and of area 100 m^2 (i.e., $10x100 = 1000$) is considered the same as a bin of buildings averaging 10 m tall and of area 100.4 m^2 (i.e., $10x100.41 = 1004.1$). Similarly, for building surface plan area ratio, the ratios using DSC outputs vs ground truth are similar with a granularity of at most 0.18 (at α=0.05) and 0.04 (at α=0.01). Hence, for reasonable bin-sizes the automatically produced DSC output can be used to compute fairly accurate UCP values.

4.2 Testbed Activities

At this time Testbeds for Chengdu, Guangzhou, Hong Kong, Beijing, Sao Paolo, Toulouse, Dublin, Hamburg, New York City, Taipei and Tokyo and several from India will be engaged similarly beginning with the accuracy checks against actual data, each examining the efficacy of various crowdsourcing approaches to generating the inputs for customizing DSCs and examining and assessing tradeoff issues between CDSC accuracy as a function of grid size. They will subsequently be engaged in a variety of model testing evaluating the use of CDSC UCP outcomes. A wide variety of modeling studies are under now being considered to determine the efficacy of CDSC generated UCPs. Model testing and applications including (but not limited to) using WRF, CMAQ, ENVI-met and LES techniques focusing on the use of advanced LCZ-based UCPs (WUDAPT Level 1) are planned. There is the potential for a for exploring the potential of using C-DSC as a platform for fine grid model applications for street level air quality exposure modeling (Shi et al., 2018) and Street-in-Grid air quality modeling; e.g., (Kim et al. 2018); one such study has already begun for Guangzhou (Wu and Wang, 2018). We also seek to build upon linkages to the Urban Multi-scale Environmental Predictor (UMEP) system (Lindberg and Grimmond, 2018).

4.3 Summary and Path Forward activities.

We are moving forward strategically towards a practical means to generate urban canopy data at WUDAPT Level 1 and 2 using a portal-based customized C-DSC tool. The data for the customization will be facilitated by applying the MaPUCE and crowdsourcing paradigms implemented by ad hoc activities of urban experts to their respective urban Testbed currently being established and now underway. The recommendations based on the synthesizing of the experience and best practice from these Testbeds will constitute the final methodology protocol. These Testbeds are from different regions around the world to represent regional variations. They each have specific guidance but yet sufficient flexibility to encourage diverse utility of the database. The timeframe for this is relatively short so as to meet the needs of the world community. We encourage all who wish to contribute to this effort. We anticipate a wide range of communities wishing to utilize WUDAPT, especially design and planning related communities. WUDAPT Level 1 and 2 data can be created at regular intervals going backward in time, permitting the development of a consistent time series and analysis of urbanization of any cities or regions on earth. Based on the extracted and developed historical urban morphological information, future land use patterns can be predicted as a reference for local planners and government officials especially for those in developing countries and regions under fast urbanization but lack of urban data. This developed data can also allow climatologists to run complex climate models to gauge the impact of urbanization on climate at local, city, and regional scales. The modeled results, when properly formatted and presented, may allow policy makers and industry stakeholders to draw up planning recommendation climate maps for their cities so as to guide better city planning decision making at various design scales (Ng & Ren, 2015).

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