12.2: THE WUDAPT APPROACH TOWARDS SUPPORTING MULTI-SCALE FIT-FOR-PURPOSE INTRA-URBAN ATMOSPHERIC MODELING AND ANALYSES APPLICATIONS.

J. Ching, G. Mills, D. Aliaga, A. Martilli, J. C. H. Fung, B. Bechtel, M. Demuzere, A. Middel, M. Neophytou, C. Ren, J. Feddema, V. Masson, N. Buckley, C. Reinhart, L. See, Y. Huang, F. Chen, N. Tapper, A. Baklanov, E. Ng, Y. Yamagata, K. Lau, M. F. Wong, F. Lindberg, X. Wang, W. Wang, M. F. Andrade, O. Brousse, H. Simon, T. Kropp, S. Miao, X. He, D. Duarte, P. Mouzourides, J. Hidalgo, Y. Roustan, Y. Kim, L. S. Ferreira, L. Zhao, N. Zhang, B. Bornstein, J. Gonzales-Cruz, and D. Niyogi

1. Introduction

In this, the centennial year of the AMS, we are focused on the critical aspects of weather as an omnipresent factor in the world, its daily and climatic impacts on our environment, society and its effect on each and every person on earth. For this paper, we reflect on weather and related issues when, at the time of this Centennial, urban areas are home to more than half the world's population. We recognize that the trend toward increased urbanization continues and disruptions to weather patterns from climate changes are in progress. We pause to reflect on sweeping concurrent technological advances and recognize the role of meteorological information and models as tools to support policies that addresses needs and situations impacting or are impacted by these momentous changes. In this regard, we provide a perspective on the role and context of an Initiative from the urban climate community on its WUDAPT (World Urban Database and Access Portal Tools) project to the meteorological and allied communities at this important juncture. For this context, we point out that while urban areas are 3% of the total land coverage, its influence is significant based on its role and impact on climate change as well as to its local weather, the latter due to the influence of urbanization factors that contribute to the structure and dynamics of the urban boundary layer. For this, WUDAPT was initiated with the goal to generate consistent information on urban form and function for cities worldwide that can support "fit for purpose" (FFP) scale dependent urban weather, climate, hydrology and air quality analyses and model applications (Ching et al., WUDAPT, An Urban Weather, Climate and Environmental Modeling Infrastructure for the Anthropocene, reported in BAMS, 99(9), 2018.

2.1 Context and strategy

From a brief historical perspective based on the Innovative Local Climate Zone concept (Level 0) we outline a pathway to generating scale dependent urban data for FFP models, the objective for next level of information (Level 1 and 2) in the WUDAPT hierarchical framework strategy (Figure 1). Urban areas are composite aggregates of various 3-D morphological structures, impervious surfaces, and natural biota, responsible for creating canopy boundary layers. From a modeling perspective, such properties when in form, fabric (material content) and functions formats as urban canopy parameters (FFF-UCPs) of building environments, can support, augment and improve Reynolds Averaged Navier Stokes, M-O Similarity Theory (RANS-MOST) boundary layer formulations soas to more aptly simulate weather and climate effects. Clearly characteristics of relevance is the extreme complexities in morphological features and surface heterogeneities characterize urban areas. This information provides the foundation for model applications and analyses studies of intra-urban scale risks and impacts on air quality, exacerbated heating, flooding, comfort, anthropogenic heating, GHG emissions and urban planning requirements. In light of such significant impacts resulting from aforementioned rapid urbanization and climate changes (Baklanov et al., 2018), the role of modeling becomes important as tools capable to providing assessments and guidance towards various policy considerations and themes e.g., sustainability, mitigation options, adaptation consideration, risk management and more.

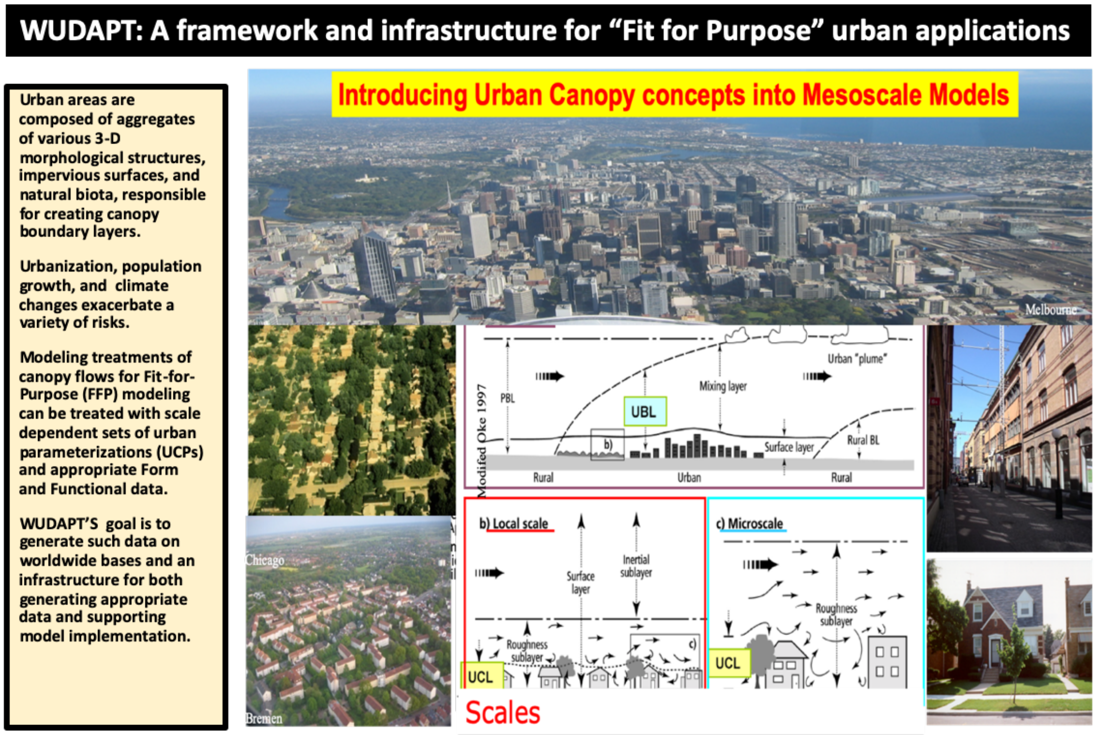


Figure 1: A framework and infrastructure for “Fit for Purpose urban modeling applications

2.1 Strategic Approaches

WUDAPT’s goal is to generate such data on worldwide bases and an infrastructure for both generating appropriate data and supporting model implementation. The paradigm for WUDAPT is shown in Figure 2; its elements include:

- **Community-based framework and implementation**
- **Global in scope, unique city specific distributions of Urban Canopy Parameter data generated based on readily available and accessible inputs**
- **Universal method protocols provide global data consistency**
- **Strategic hierarchical implementation approach**

WUDAPT is an ambitious effort that was made possible by the engagement of the international urban community. The huge scope and the need for timely response to addressing pressing and critical population change and climate change issues required innovative approaches achieved through the collective efforts, energies, imagination and collaborations of international urban communities (Ching et al., 2018, Mills et al., 2015). The initial (a) innovative approach (Level 0) is based on Local Climate Zones (LCZ) by and its accompanying lookup table of Urban Canopy Parameters, UCPs, (Stewart and Oke, 2012) and (b) implementation methodology by Bechtel et al., 2015. Initial applications were facilitated by the linking of such data to the mesoscale weather WRF modeling system to the microscale Envi-MET modeling systems and additional links to surface energy budget (SUEWS), thermal comfort (SOLWEIG), the latter two via the UMEP system (see www.wudapt.org for guides). With initial but increasing efforts and utilization interest amidst these growing numbers of city specific LCZ maps and modeling studies around the world, it became evident that LCZs have sufficient regional similarities making feasibility the generating of regional maps based upon common set of LCZ for each region (Demuzere et al., 2018). This has led to complimentary efforts now underway to prepare consolidated such maps for all other regions and continents throughout the world fulfilling the goal of creating a worldwide LCZ maps with known consistency (See Mills et al.,

2020) for additional details. These remarkable collaborations by experts from several urban communities has made possible the rapid degree of success of WUDAPT's Level 0, from its initial concept in 2012 with city specific prototypes to the generation of LCZ maps worldwide by 2019. Activities included model testing and applications using WUDAPT via links to various modeling systems for addressing issues and risk such as air quality, heat waves, flooding, adaptation and mitigation. Level 0 has demonstrated a pragmatic and timeliness means towards meeting WUDAPT's major FFP model applications objectives.

Building on the hierarchical approach and already successful Level 0 paradigm, the planning and a pathway strategy to Level 1 and 2 has begun. For this, several important innovative methods and tools are being developed and plans call for utilizing community collaborative activities to test, evaluate and demonstrating FFP model applications in this methodology driven approach. The objectives will be scale dependent gridded or vector data on the form aspects, material content and energy usage of morphological building and structures in various model useful formats (UCPs) with precision at block scale; outcomes will include scalable UCPs unique to intra urban, with sufficient precision to extend and enhance beyond the current Level 0 FFP model applications. An overview schematic of Level 1 and 2 approach is shown in Figure 3.

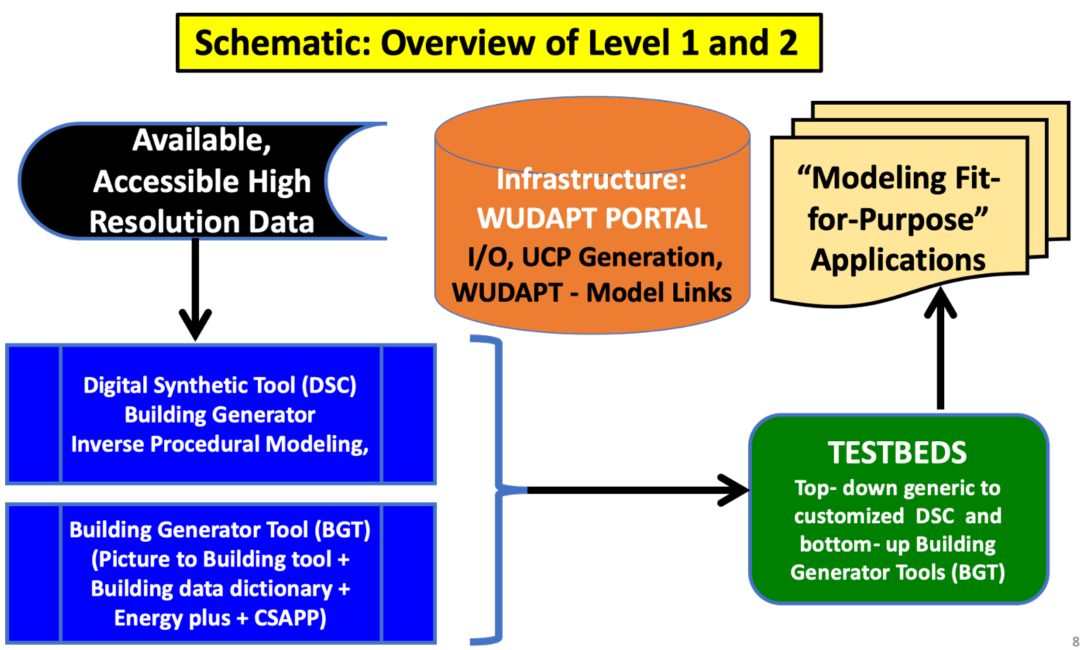


Figure 3: Schematic of Level 1 and 2 Overview.

For this, creative approaches and methodologies based on implementing several unique innovative Computer Assisted Tools are being invoked; Testbed teams of collaborating urban experts will compute and evaluate the buildings and details generated by the Digital Synthetic City CAD, or DSC, the Urban Building Energy Model or UBEM, (Figure 6) and the incorporation of the Picture to Building or P2B Tool. Testbeds will be demonstrating and performing a suite of model applications designed to demonstrate the utilization of the information generated. Figure 4 illustrates the DSC input pipeline; inputs of sample building elevation data, road maps from outputs of Open Street Maps (OSMs) and population data and procedural modeling approaches using Neural Network and deep learning methods (Ching et al., 2019, Mills et al., 2020) and capable of producing a digital outcome that is a reasonable rendition of actual high resolution data. Once digitized, form-based UCPs can and will be computed and rasterized (for user specified grid sizes) with minimum as block size throughout the urban modeling area domain (Figure 5).

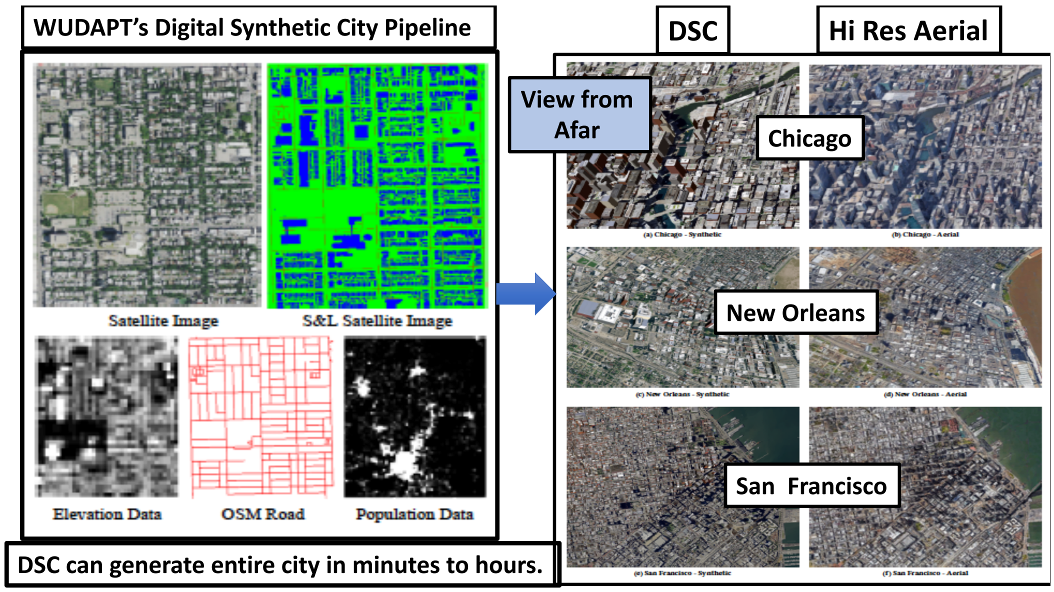


Figure 4: WUDAPT 1&2 Digital Synthetic City tool.

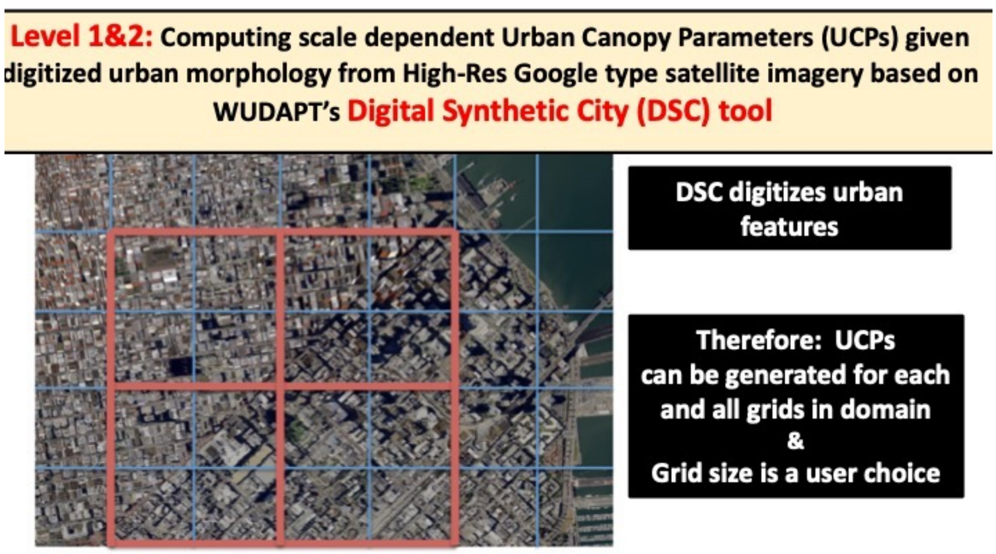


Figure 5: Generating form-based urban canopy parameters from DSC tool.

Another CAD tool, the UBEM building generator tool (currently under development) is the approach being pursued to generate information about the dominant building material and energy usage based on the TABULA building dictionary of building materials, insulation and energy usage utility for a variety of building associated with a range of building typology classes customized for each country (Mills 2020 and Figure 6). Tabula has been developed for a number of European countries. The UBEM will incorporate an Urban Modelling Interface (Davila and Reinhart, 2016) designed for simulating environmental performance of buildings at neighborhood scales; it employs a CAD program to generate the building database and DOE's Energy Plus to simulate their energy profiles. Further, it will incorporate another customized CAD Picture to Building or P2B tool (http://photo2building.com/). P2B provides a means to automate the generation of prototypic buildings based on procedural modeling by taking a photograph as example input. The output is not an exact reproduction of a building, but capturing its overall shape, the layout of its facade, and the style of its windows. Utilization of P2B with AI, Deep Learning and Crowdsourcing (CSAPP) techniques may feasibly extend the TABULA paradigm to be applicable everywhere else in the world. The output is not an exact reproduction of a building, but captures its overall shape, the layout of its facade, and the style of its windows. See Mills et al., (2020) for further details and discussions of these UBEM developments.

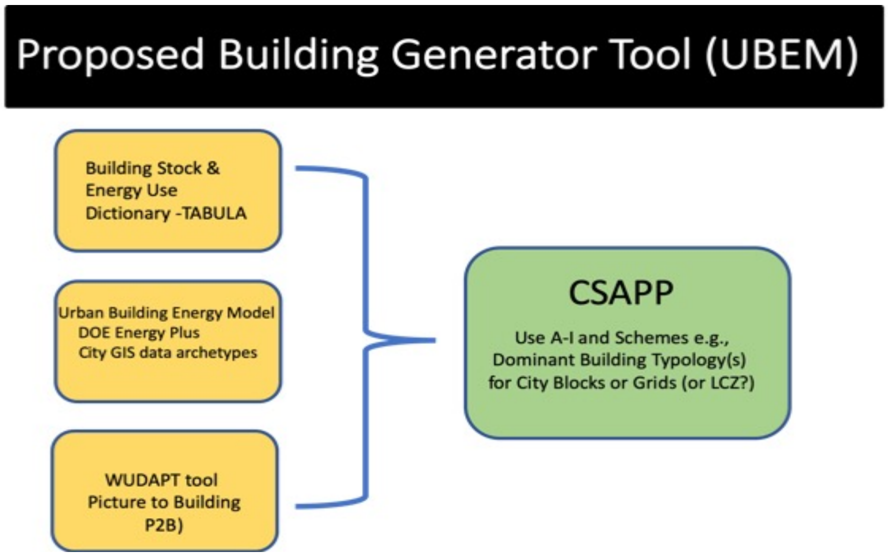


Figure 6: Components of the Urban Building Energy Model Tool

The ability to generate information, facilitate and make feasible extending and broadening the current Level 0 modeling application capabilities are the major objective and focus of WUDAPT 1&2 activities. The approach for running various fit-for-purpose model applications will be facilitated through links between WUDAPT and various modeling systems such as the aforementioned WRF, WRF-Chem, CMAQ, ENVI-Met and UMEP systems but extended to Level 1 and 2 type formats. We clearly envision links to other modeling systems such as Street-in-Grid (SING), Surface Energy Budget systems including SUEWS, and also TARGET and TUFT-3D. Figure 7. A Working Group from various urban communities will be invited to create and test linkages between WUDAPT 12 and various modeling systems such as those shown in Figure 7.

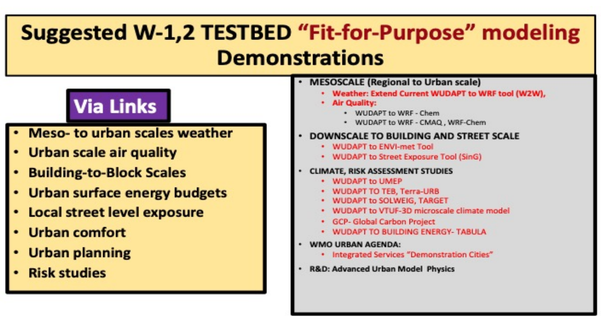


Figure 7: Examples of proposed modeling applications linked to WUDAPT 1&2

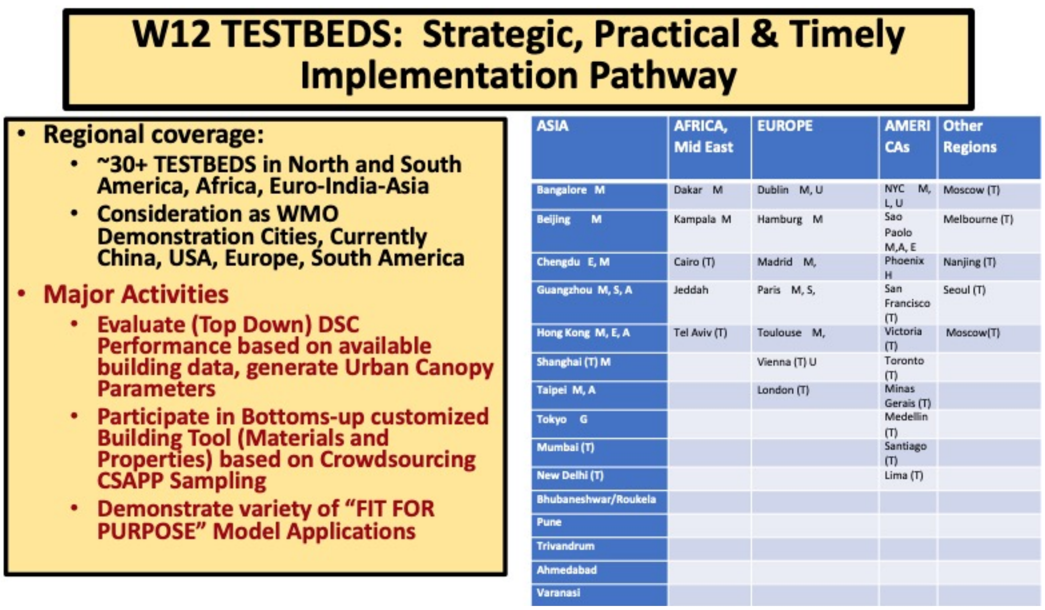
2.3. Implementation Collaborations

2.3.1 Workgroups and Testbeds

In addition to the development of the methodologies associated with the DSC, UBEM and P2B tools, two additional types of collaborative group activities provide keys to the eventual success of Level 1&2; Testbeds and Specialty Workgroups:

(1) Testbeds (Figure 8) have three critical roles, the first regards the implementing of the methodological procedures including applying, testing, evaluating the data generating DSC and P2B CADs and UBEM tools. Testbed teams of urban experts for 30 or so cities around the world have volunteered to collaborate providing the means to assure the quality and consistency of the WUDAPT Level 1 and 2 products. Secondly, they will compute form-based UCPs from the DSC outputs. Third, they will be engaged in demonstrating the utility of W12 in various FFP applications applying the links created by the WorkGroup on model linkages. (They are invited to participate and be involved in one of both Workgroups engaged in computing UCPS from DSC and or creating the model links to WUDAPT Level 12 (W12).

(2) Workgroups. The first workgroup is tasked to recommending the computing algorithms for generating the form-based urban canopy parameters. At a minimum, the list of UCPs will include (but not be limited to) the roughness scaling lengths, building characteristic including building height (and statistics), their thermal properties, and building plan area densities, Building (& trees) and surrounding environments (and statistics) including Packing densities or aspect i.e., building to- street ratio, tree area coverage, sky view factors or SVF, (with and without trees), and etc. The second will be engaged in creating Links from WUDAPT 12 to modeling systems such as WRF, UMAP, ENVI-Met (or extending existing links for Level 0).



ASIA	AFRICA, Mid East	EUROPE	AMERICAs	Other Regions
Bangalore M	Dakar M	Dublin M, U	NYC M, L, U	Moscow (T)
Beijing M	Kampala M	Hamburg M	Sao Paolo M,A, E	Melbourne (T)
Chengdu E, M	Cairo (T)	Madrid M,	Phoenix H	Nanjing (T)
Guangzhou M, S, A	Jeddah	Paris M, S,	San Francisco (T)	Seoul (T)
Hong Kong M, E, A	Tel Aviv (T)	Toulouse M,	Victoria (T)	Moscow(T)
Shanghai (T) M		Vienna (T) U	Toronto (T)	
Taipei M, A		London (T)	Minas Gerais (T)	
Tokyo G			Medellin (T)	
Mumbai (T)			Santiago (T)	
New Delhi (T)			Lima (T)	
Bhubaneshwar/Roukela				
Pune				
Trivandrum				
Ahmedabad				
Varanasi				

Figure 8: Implementation of WUDAPT Level 1&2: Role and Listing of Testbeds

2.3.2 The WUDAPT Portal

The scope and capabilities of the WUDAPT Portal are will need to be extended, initially to facilitate the activities of both WUDAPT's Testbeds and Working Groups and ultimately as a platform for FFP applications. The Portal will begin to host both the DSC and P2B, and eventually the UBEM tools and subsequently the recommended algorithms from the Working Groups tasked to computing and generating the UCPs from DSC results and the hosting of links to modeling systems for FFP applications.

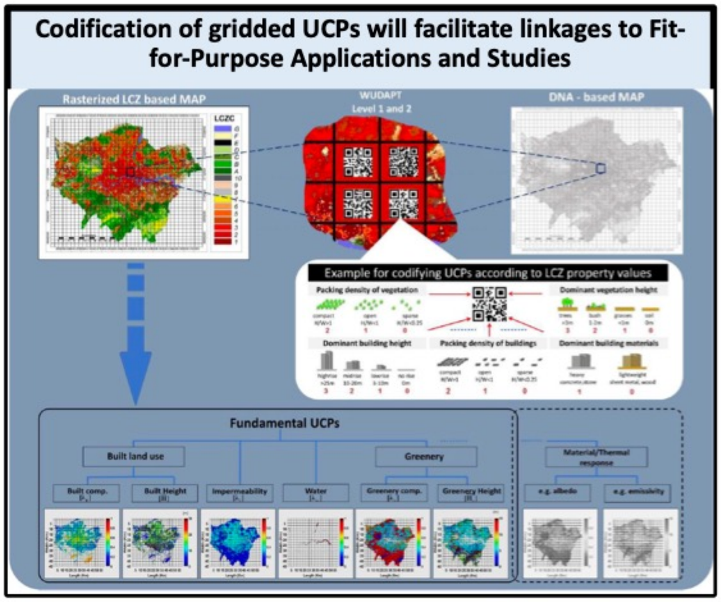


Figure 9: Proposed codification scheme of gridded DSC and UCP outputs for facilitating generalized modeling applications.

3. Summary:

WUDAPT Level 0 has successfully been demonstrated as a methodology capable of creating LCZ maps for any city in the world; and is now moving towards worldwide coverage; thus, making possible advanced UCP-based urban boundary layer modeling capable of supporting a variety of model applications anywhere in the world. Current efforts are now moving towards the hierarchical Level 1 and 2 capability that will augment the Urban Canopy Table Lookup range of values approach associated with the LCZ based WUDAPT Level 0 maps, to extend the modeling capabilities with unique gridded UCP values, and providing information on building material and energy usage at block levels throughout the urban modeling domain. The implementation of WUDAPT's Digital Synthetic City (DSC) Tool will make possible and feasible a practical and consistent means to generate codified UCPs at any desired grid mesh scale for worldwide scope and coverage. The innovative and emerging Urban Building Energy Model (UBEM) building tool methodological approach is designed to generate information on building materials and their energy usage. Workgroups implementing Level 1 and 2 approaches will (a) establish computing protocols for generating urban canopy parameters and (b) create linkages between WUDAPT 1 &2 and other modeling systems. Testbeds for several cities in each continent or regions around the world provide the means to (a) evaluate the universality of these prototypic methodologies against actual building data and (b) perform proof of concept and modeling application demonstrations addressing risks such as those listed above. The WUDAPT Portal will provide the infrastructure to support the development of WUDAPT Level 1&2 and operational links to facilitate the running of various FFP modeling applications at widely varying spatial and temporal scales and analyses studies. We envision invoking a generalized codification scheme of gridded UCPs towards facilitating the WUDAPT links as inputs to applications to various modeling systems (Figure 9). The success of WUDAPT 1&2 will again depend on collaborative efforts of the urban communities. We invite your interest and participation; you can make an impact to this bold, important and exciting venture.

4. * *Corresponding author address*: *Jason Ching, University of North Carolina, Institute for the Environment, Chapel Hill, NC e-mail: jksching@gmail.com*

5. References

Baklanov, A., CSB Grimmond, D Carlson, D. Terblanche, X. Tang, V Bouchet, B Lee, G Langendijk, R.K Kolli, and A. Hovsepyan, 2018: From urban meteorology, climate and environment research to integrated city services. *Urban Climate,* 23, 330-341.

Bechtel, B. Alexander, P., Beck, C.,Bohner, J., Brousse, O., Ching,J.,Demuzere, M., Fonte, C., Gal., T., Hidalgo, J., Hoffmann, P., Middel, A., Mills., G., Chao, R., See, L., Sismandis, P., Verdonck, M., Xu, G., Xu, Y., 2019: Generating WUDAPT Level 0 data – Current status of production and evaluation. Urban Climate 27, 24-45.

Bechtel, B., Alexander, P., Böhner, J., Ching, J., Conrad, O., Feddema, J., Mills, G., See, L. and Stewart, I. 2015: Mapping local climate zones for a worldwide database of form and function of cities. Int'l J. of Geographic Information, 4(1), 199-219. doi:10.3390/ijgi4010199.

Ching, J., G. Mills, B. Bechtel, L. See, J. Feddema, X. Wang, C. Ren, O. Brousse, A. Martilli, M. Neophytou, P. Mouzourides, I. Stewart, A. Hanna, E. Ng, M. Foley, P. Alexander, D. Aliaga, D. Niyogi, A. Shreevastava, P. Bhalachandran, V. Masson, J. Hidalgo, J. Fung, M. Andrade, A. Baklanov, W. Dai, G. Milcinski, M. Demuzere, N. Brunsell, M. Pesaresi, S. Miao, Q. Mu, F. Chen, N. Theeuwes, 2018: World Urban Database and Access Portal Tools (WUDAPT), an urban weather, climate and environmental modeling infrastructure for the Anthropocene. *Bull. Am. Meteorol. Soc.* https://doi.org/10.1175/BAMS-D-16-0236.1

Ching, J., D. Aliaga, G. Mills, V. Masson, L. See, M. Neophytou, A. Middel, A. Baklanov, R. Chao, E. Ng, J. Fung, M. Wong, Y. Huang, A. Martilli, O. Brousse, I. Stewart, X. Zhang, A. Shehata, S. Miao, X. Wang, W. Wang, Y. Yamagata, D. Duarte, Y. Li, J. Feddema, B. Bechtel, J. Hidalgo, Y. Roustan, Y. Kim, H. Simon, T. Kropp, M. Bruse, F. Lindberg, S. Grimmond, M. Demuzure, F. Chen, C. Li, J. Gonzales-Cruz, B. Bornstein, Q. He, A. Hanna, E. Erell, N. Tapper, RK Mall, D. Niyogi, 2019: Pathway using WUDAPT's Digital Synthetic City tool towards generating urban canopy parameters for multi-scale urban atmospheric modeling, Urban Climate.

Davila, CC., Reinhart, C./F., and Bemis, J.L., 2016: Modeling Boston: A workflow for the efficient generation and maintenance of urban building energy models for existing geospatial datasets. Energy, 117, 237-250.

Demuzere, M., Bechtel, N. Gorelick, R. Chao, E. Ng, G. Mills, J, Ching 2018: Towards a global LCZ map? Ext Abs, Paper 13B.2, Aug 10, 2018 ICUC10, CCNY, NYC, NY.

Mills, G., Ching, J., See, L., Bechtel, B., Feddema, J., Masson, V., Stewart, I., Neophytou, M., O'Connor, M., Chen, F., Martilli, A., Grimmond, S., Alexander, P., Foley, M., Gal, T., Wang, X., Mitra, C., Pereira, N., Steeneveld, G.-J. 2015: Introduction to the WUDAPT Project. Proceedings, 9th International Conference on Urban Climate (jointly with 12th Symposium on the Urban Environment), Toulouse, France, July, 2015.

Mills, G., N. Buckley, C. Reinhart and J. Ching, 2020, 12.1: Generating Urban Scale Building Data to Support Climate Modeling, 15th Symposium on the Urban Environment, Extended Abstract, AMS Centennial, Boston, MA.