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Modeling parameters and remote sensing acquisition of urban canopies

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1. Introduction

In the frame of the H2020 project, URBANFLUXES (http://urbanfluxes.eu/), new modeling is developed to improve the efficiency of the study of urban canopies with remote sensing, with the modeling of satellite and in-situ acquisitions (reflectance, albedo, brightness temperature), and also 3D radiative and energy budgets. The 3D radiative transfer model DART (Direct Anisotropic Radiative Transfer) (www.cesbio.ups-tlse.fr/dart) is adapted and used with its coupled model DARTEB to simulate the 3D energy budget of urban scenes. Here we present DART improvements to simulate imaging spectroscopy of urban landscapes with atmosphere, including the perspective projection of airborne acquisitions, and also the operating process of DARTEB. Applications conducted in the frame of the H2020 project URBANFLUXES are presented.

2. DART

DART (Discrete Anisotropic Radiative Transfer) model is one of the most comprehensive physically based 3D models to simulate the Earth-atmosphere radiation interaction from visible to thermal infrared wavelengths. It has been developed at CESBIO since 1992 and was patented in 2003. It simulates optical signals at the entrance of imaging radiometers and LiDAR scanners on board of satellites and airplanes, as well as the 3D radiative budget, of urban and natural landscapes for any experimental configuration (atmosphere, topography,…) and instrumental specification (sensor altitude, spatial resolution, UV to thermal infrared,…). It uses innovative modeling approaches: multi-spectral discrete ordinate techniques with exact kernel, RayCarlo method, etc. Paul Sabatier University distributes free licenses to scientists. Here, we present recent improvements

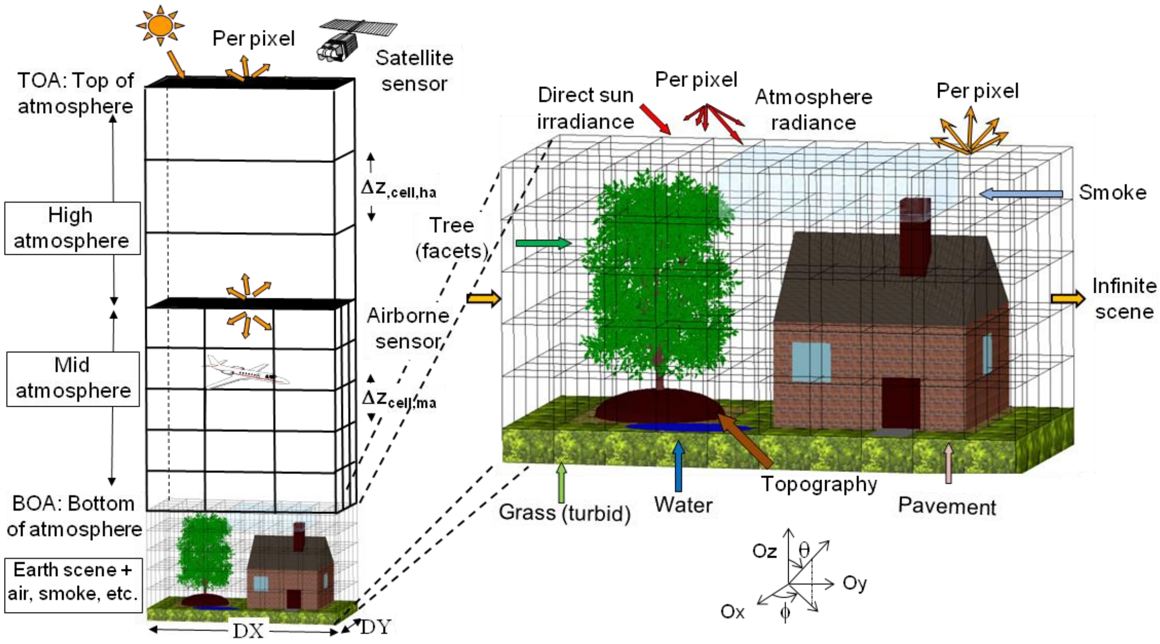


Figure 1: DART cell matrix of the Earth / Atmosphere system. The atmosphere has three vertical levels: upper (i.e., just layers), mid (i.e., cells of any size) and lower atmosphere (i.e., same cell size as the land surface). Land surface elements are simulated as the juxtaposition of facets and turbid cells.

Camera and pushbroom: in-situ and airborne / satellite acquisition

Comparison of actual and simulated remotely sensed data is difficult since simulated data are not realistic in terms of both radiometry and geometry. A new modeling considers the multi-directional acquisition within sensor field of view (FOV) for simulating realistic images of Earth surfaces, as acquired by passive sensor with a finite FOV, either in-situ, airborne or satellite. For that, DART is coupled with 3-D perspective projection. Current radiative transfer models (RTMs) assume that all parts of an observed landscape are viewed along the same direction. However, passive imagers acquire energy in a FOV with a non zero solid angle. Hence traditional RTMs cannot account camera model and its image projection geometry (e.g., perspective projection for camera and parallel-perspective projection for cross-track imager). This situation is particularly problematic for airborne acquisition with low sensor altitude and wide FOV. The new modeling solves this problem: rays that enter a sensor can come from various directions. For that, during ray tracking, each passive sensor acquisition is simulated for the exact view direction, which is the instant vector from the scattering point to the sensor position. Camera and cross-track imager are both modeled for most classical configurations. It results that DART provides original simulations and assessments for various research domains, including: 1. Passive sensor imaging; 2. Video captured by unmanned aerial vehicle (UAV); 3. Local hot spot (HS) effect in a RS image; 4. Pixel-wise comparison between simulated orthorectified perspective-projection images; 5. Study of radiance variation between images acquired by airborne and spaceborne systems. 6. Accurate pixel-wise comparison between simulated and acquired RS data, for any configuration.

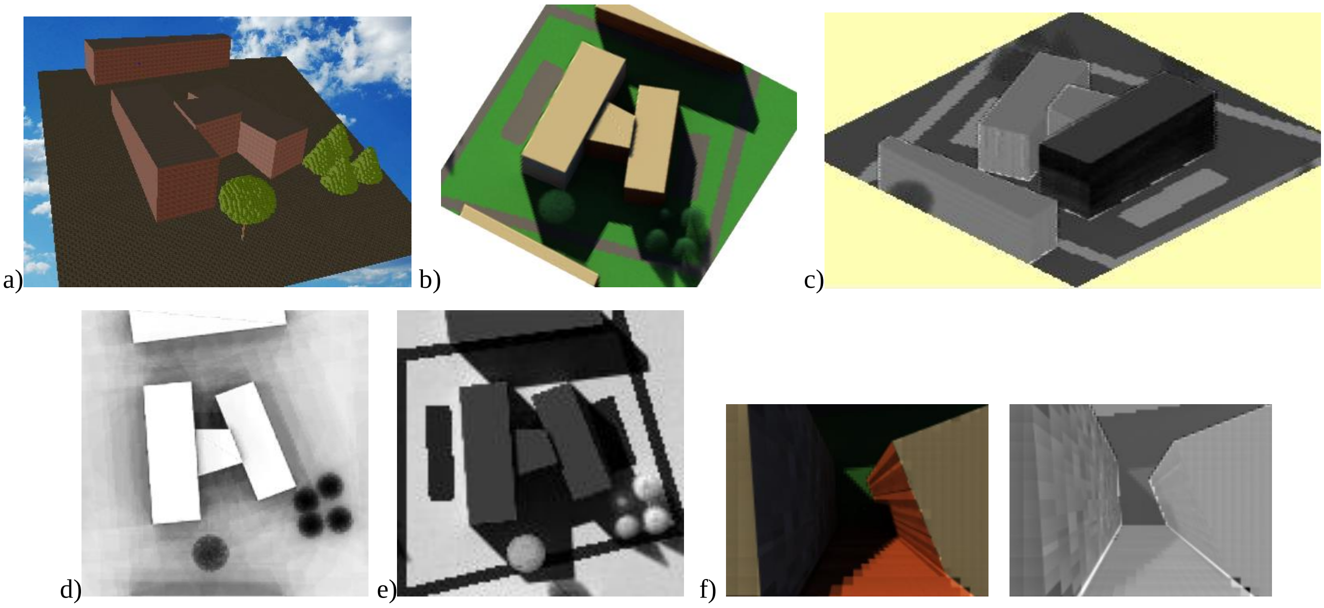
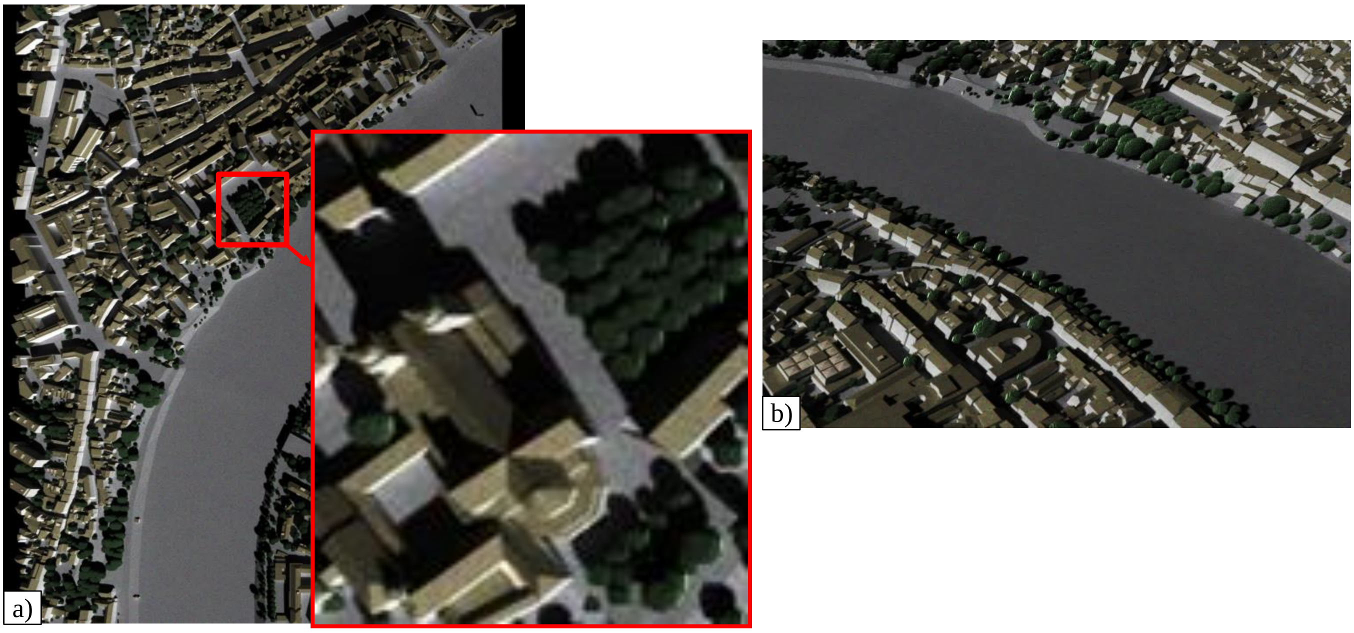


Figure 2: a) REC building, Reading University. DART camera images: b) RGB color composite. c) 10µm radiance (front building has dark tones (., lower radiance) because it is simulated with metal material (low emissivity). f) In-situ camera above the canyon: RGB (left) and TIR (right). d) Sky view factor. e) Albedo ρ_{dh} (mean value: 0.264).



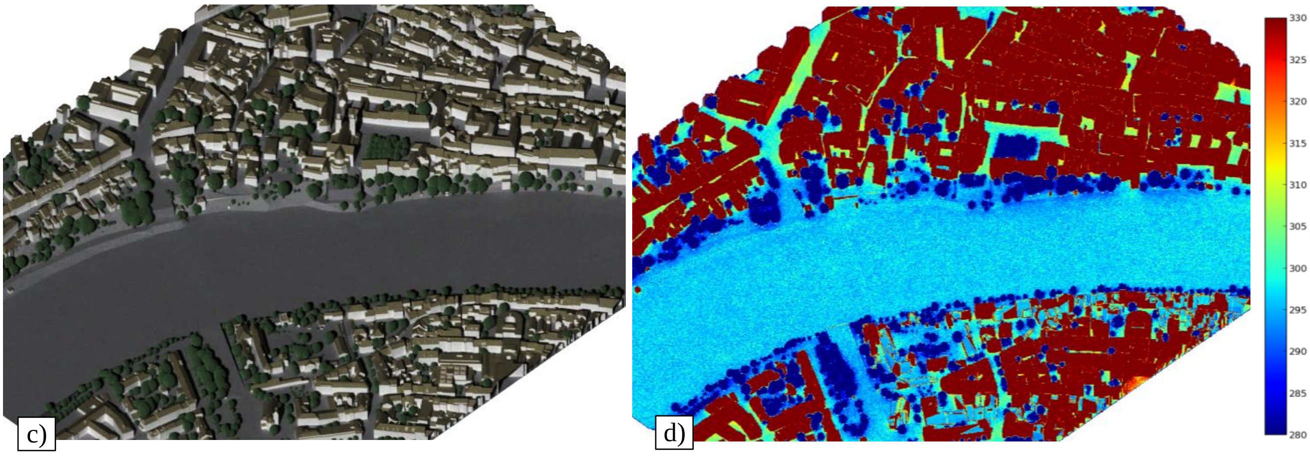


Figure 3: DART simulated images of Basel, Switzerland. a) Pushbroom image with zoom. b) Camera image. c) Satellite RGB image. d) Satellite TIR image.

A major objective of the H2020 project is to drive parameters of urban canopies with satellite data. It is typically the case for the albedo. DART computes the albedo $A_{DART,\Delta\lambda}$, for any hour and date, possibly with actual atmosphere data (e.g. ECMWF or Aeronet network). It is determined with the following formula:

$$A_{DART,\Delta\lambda}\left(x_{DART}, y_{DART}, \Omega_S, E_{S,BOA}(\Omega_S), L_{atm}(\Omega), t_{sat}\right) = \frac{\rho_{dh} E_{S,BOA} + \int \rho_{dh}(\Omega) L_{atm}(\Omega)\cos(\theta)\, d\Omega}{E_{S,BOA} + \int L_{atm}(\Omega)\cos(\theta)\, d\Omega} \quad (1)$$

with: - $A_{DART,\Delta\lambda}$: albedo computed by DART, for spectral interval $\Delta\lambda$.
- x_{DART}, y_{DART}: coordinates of the point considered in the DART simulated scene
- Ω_S: solar direction
- $E_{S,BOA}$: solar irradiance at the bottom of the atmosphere
- $L_{atm}(\Omega)$: atmosphere radiance
- t_{sat}: time at satellite acquisition
- ρ_{dh}: direct-hemispheric reflectance computed by DART

DART albedo, radiance and reflectance products (ρ_{dd}, ρ_{dh}, ρ_{hd}, ρ_{hh}) are computed with optical properties as realistic as possible. For example, optical properties derived from APEX spectroradiometer data will be used for the Basel case study of the URBANFLUXES project. Actually, optical properties cannot be exact. Hence, DART products will be calibrated with atmospherically corrected satellite data (*e.g.*, Sentinel 2), after being resampled to the satellite spatial resolution (x_{sat}, y_{sat}). For example, for albedo, we get:

$$\begin{aligned} &A_{\Delta\lambda}\left(x_{sat}, y_{sat}, \Omega_S, E_{S,BOA}(\Omega_S), L_{atm}(\Omega), t_{sat}\right) \\ &= K_{\Delta\lambda}(x_{sat}, y_{sat}, t_{sat}).\, A_{DART,\Delta\lambda}\left(x_{sat}, y_{sat}, \Omega_S, E_{S,BOA}(\Omega_S), L_{atm}(\Omega), t_{sat}\right) \end{aligned} \quad (2)$$

with

$$K_{\Delta\lambda}(x_{sat}, y_{sat}, t_{sat}) = \frac{\rho_{dd,sat,\Delta\lambda}(x_{sat}, y_{sat}, \Omega_S, \Omega_V)}{\rho_{dd,DART,\Delta\lambda}(x_{sat}, y_{sat}, \Omega_S, \Omega_V, t_{sat})} \quad (3)$$

MODIS and DART BRF (Bi-directional reflectance) will be compared for validation purpose.

If direct sun irradiance $E_{s,BOA,\Delta\lambda}$ and sky irradiance $E_{atm,\Delta\lambda}$ are known (e.g., ECMWF, Meteo France, in-sut measurements,…) and if if there is no high resolution satellite image, the albedo is computed as the sum of "white sky" and "black sky" albedos weighted by $E_{s,BOA,\Delta\lambda}$ and $E_{atm,\Delta\lambda}$:

$$A_{\Delta\lambda}\left(x_{sat}, y_{sat}, \Omega_S, E_{s,BOA}(\Omega_S), E_{atm}, t_{sat}\right) = E_{s,BOA}(\Omega_S).\, A_{\text{DART,white sky},\Delta\lambda} + E_{atm}.\, A_{\text{DART,black sky},\Delta\lambda} \quad (4)$$

with:

- White sky albedo: $A_{\text{DART,white sky},\Delta\lambda}(x_{sat}, y_{sat}, E_{s,BOA}(\Omega_s)=0, L_{atm}=\frac{E_{atm}}{\pi}, t_{sat})$
- Black sky albedo: $A_{\text{DART,black sky},\Delta\lambda}(x_{sat}, y_{sat}, E_{s,BOA}(\Omega_n), L_{atm}=0, t_{sat})$, with N directions Ω_n for atmosphere radiance

These two albedo products simulated by DART will be compared to the 500mx500m MODIS White and Black sky albedo products.

A similar approach will be used for TIR radiometric quantities. DART uses a pragmatic approach for computing 3D temperature in the scene. It assumes that the thermodynamic temperature of a given type of Earth surface is a function of its irradiance in the visible and that this temperature belongs to a specific range $[T_{min}, T_{max}]$. The number of types of Earth elements can be as many, as the number of temperature ranges $[T_{min}, T_{max}]$. Ranges of temperatures can be derived from in-situ measurements or other data (ECMWF, Meteo-France,…). This approach is an approximation, because phenomena such as thermal inertia are not considered. However, it provides interesting results provided the temperature ranges are realistic. In order to obtain more accurate results, one must use a model that calculates the energy budget. This is the objective of the DARTEB model that is being developed at CESBIO. It is presented below.

3. DARTEB

DARTEB (www.cesbio.ups-tlse.fr) is a coupling between DART 3D radiative transfer model and 1D energy balance model, with coupling done through the exchange of 3D surface temperature. It simulates major energy mechanisms (heat conduction, turbulent momentum and heat fluxes, soil moisture, etc.) that contribute to the energy budget. For urban canopies, it adapts equations from the TEB urban surface scheme (Masson, 2000). Each surface type (wall, soil, roof) is discretized into layers for simulating conduction fluxes to/from the ground and building interiors.

The 3D radiative budget and 3D temperature are assessed with a prognostic approach. A two way coupling is done at given time steps through surface temperature. Temperature values at time t lead to the 3D TIR (Thermal Infra Red) and energy budgets at time t+1, which allows one to compute the 3D temperature distribution at time t+1, using the 3D visible and NIR radiation budget at time t+1. This process is summarized in *Figure 4*.

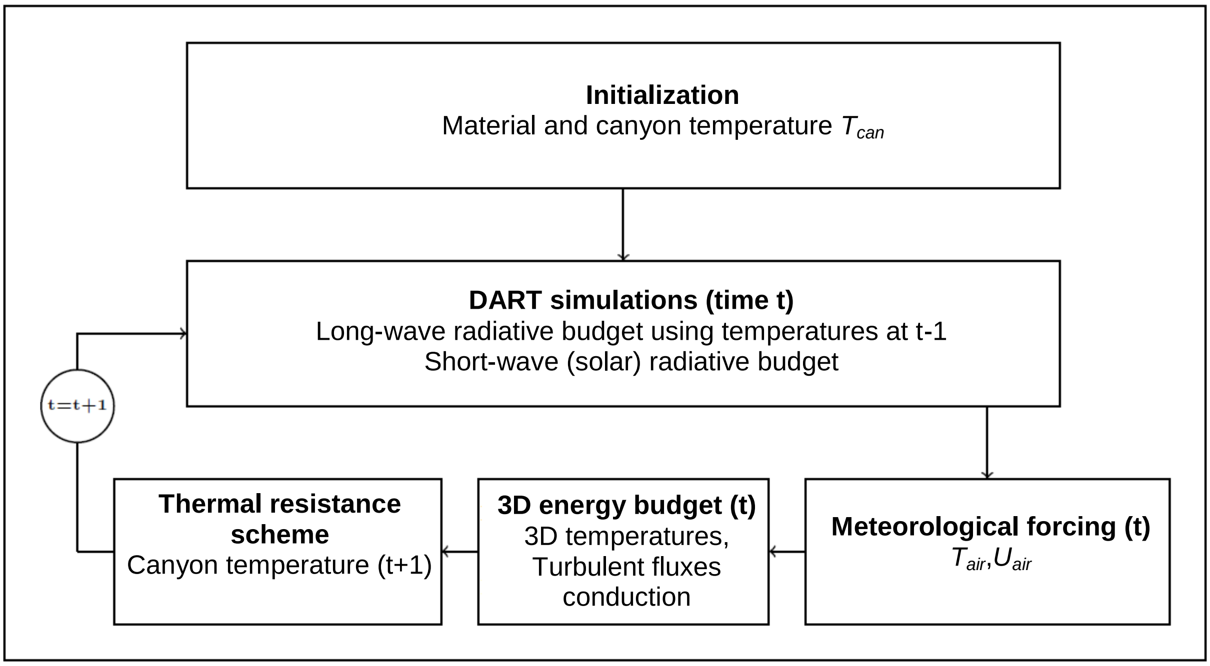


Figure 4: DARTEB processing chain

Although, it uses an actual 3D radiative budget and it applies TEB equations at each point of the 3D scene, DARTEB is not a full 3D model (e.g., 1D wind profile is used instead of 3D wind distribution). It was successfully tested in the frame of the CAPITOUL project (www.cnrm.meteo.fr/IMG/pdf/masson-capitoul.pdf) of Meteo France for simulating the time evolution of the temperature of walls in a street of Toulouse (France). *Figure 5* shows the test site for validation (Alsace-Lorraine street, Toulouse) and some results. The model was also applied to the Heraklion, Greece site which is part of the H2020 project study sites (Figure 6).

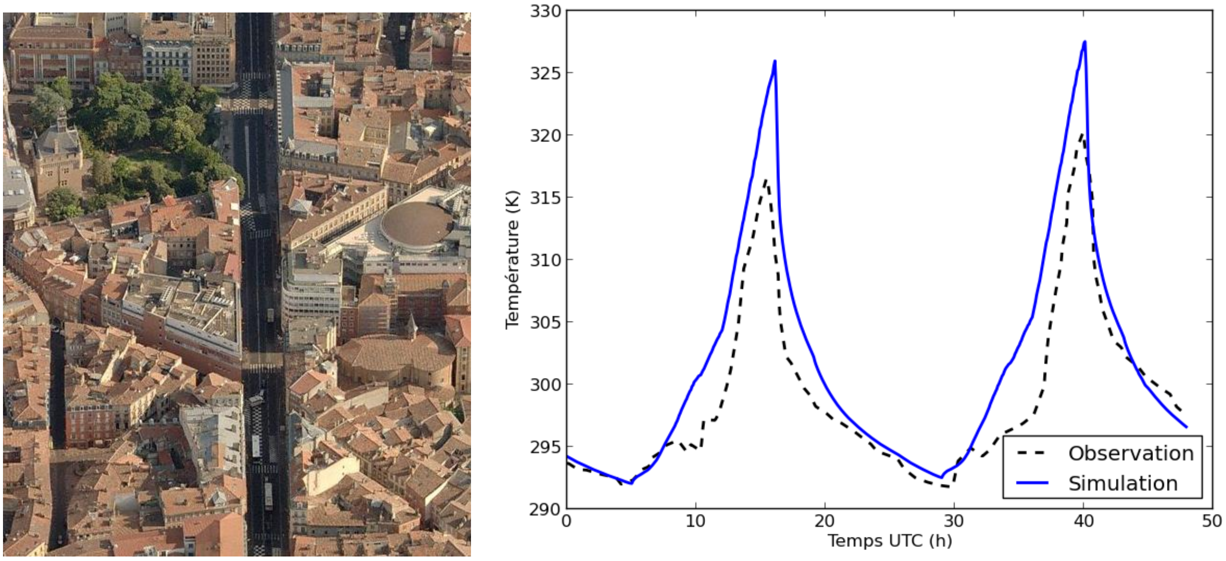
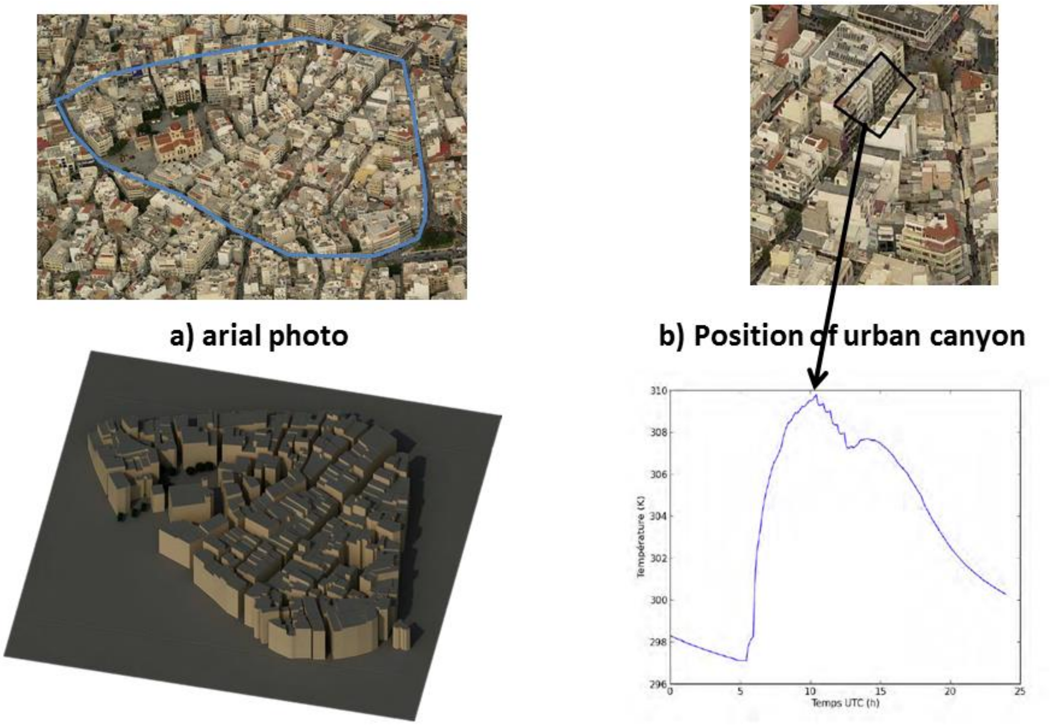


Figure 5: Photography of the evaluation site, Alsace-Lorraine street, Toulouse. Time profile of the temperature of the west wall. Simulated temperatures are in blue, measured temperature profile is in black



a) arial photo

b) Position of urban canyon

c) 3D model

d) DARTEB –wall temperature

Figure 6: Application of DARTEB model to Heraklion, Greece.

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