Modeling Parameters and Remote Sensing Acquisition of Urban Canopies

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INTRODUCTION: The H2020 project URBANFLUXES aims to improve remote sensing (RS) efficiency for urban studies, with a focus on Basel, London and Heraklion. Here, the focus is on recent improvements for simulating urban RS images, albedo, and 3D radiative budget with DART (Direct Anisotropic Radiative Transfer) model, and calibrating them with RS images (e.g., Sentinel 2), in the short (①) and thermal infrared (②) wavelengths. We present also the operating process of DARTEB (③) that works with DART for simulating energy budget. Preliminary results illustrate the recent introduction of perspective projection in DART radiative transfer modeling, for simulating multispectral images of sensors with non null field of view.

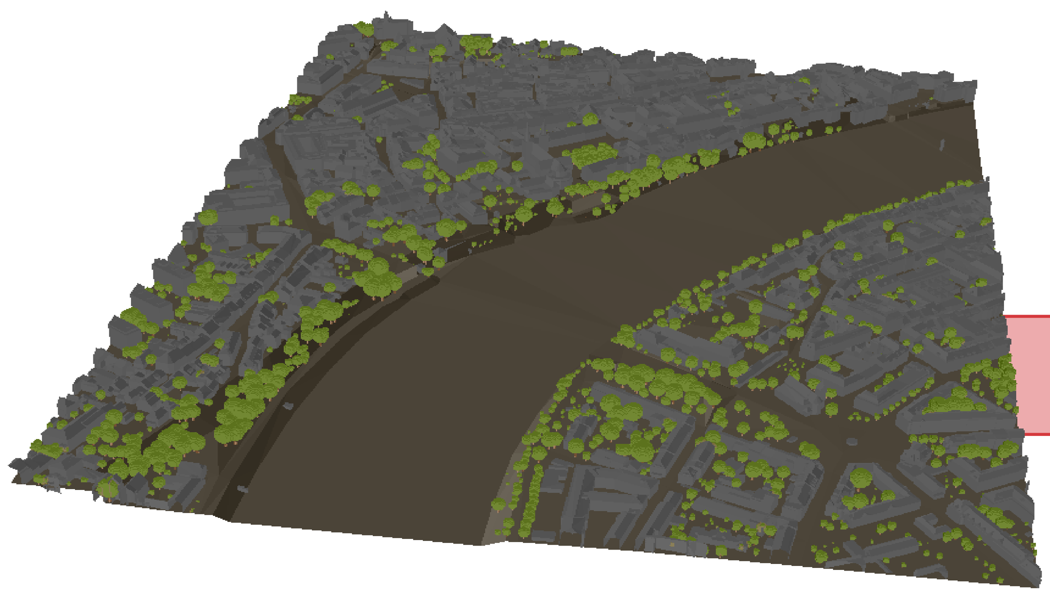


Figure 1: 3D model of the city of Basel, with added trees and Digital Terrain Model (DTM)

Inputs: - Earth landscape (tree, house, urban database, DTM, …)
- Atmosphere: database or other source (Aeronet, ECMWF, …)
- Optical properties: anisotropic reflectance, transmittance)
- Fluids (water, soot, …) and / or turbid vegetation, etc.

Earth objects = facets and/or fluid (water, soot, …) & turbid vegetation

DART MODEL

Outputs: - 3D radiative budget
- Satellite, airborne & in-situ camera/pushbroom images, …
- LiDAR waveforms / photon counting
- Sky view factor, etc.

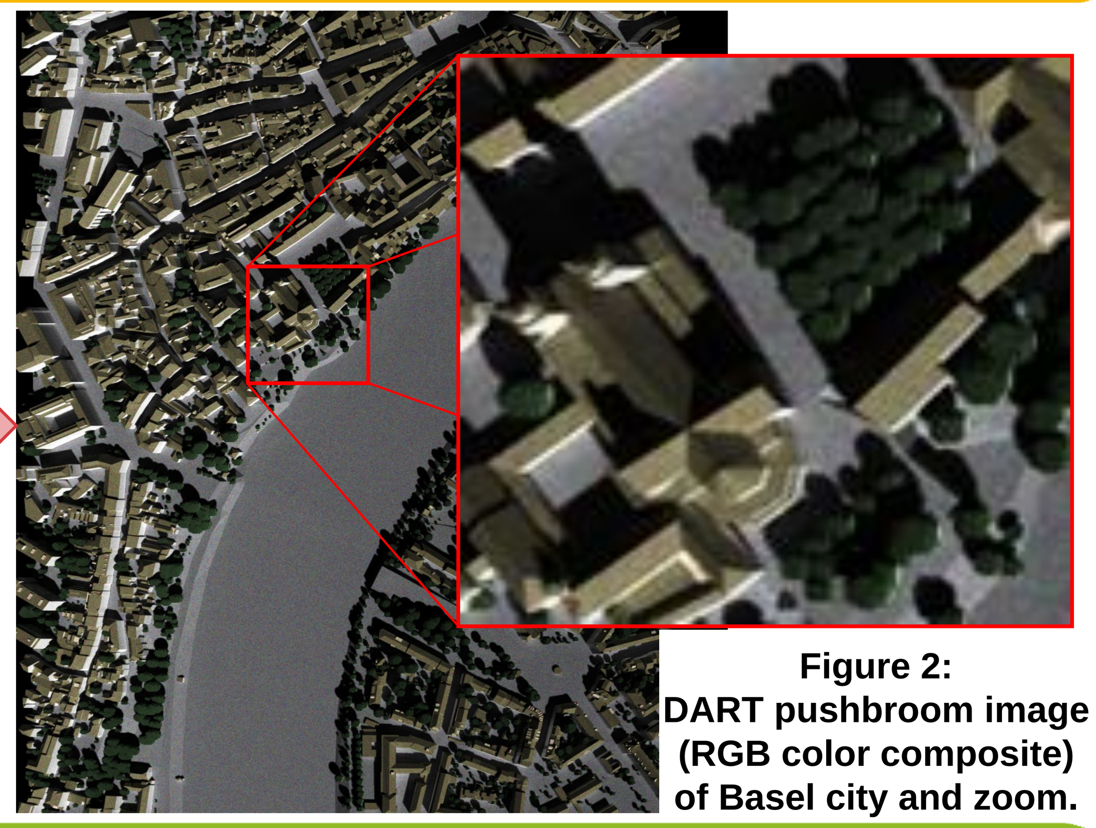


Figure 2: DART pushbroom image (RGB color composite) of Basel city and zoom.

① Calibration of DART urban short wave albedo and radiative budget with satellite images

1) DART computes landscape albedo $A_{DART,\Delta\lambda}$ (fig.3), radiative budget $RB_{\Delta\lambda}$ and atmospherically corrected satellite image for spectral band $\Delta\lambda$ and date t_{sat} (sun direction Ω_s), using "realistic" optical properties.

$$A_{DART,\Delta\lambda}(x_{DART}, y_{DART}, \Omega_s, E_{S,BOA}(\Omega_s), L_{atm}(\Omega), t_{sat}) = \frac{\rho_{dh}.E_{s,BOA} + \int \rho_{dh}(\Omega).L_{atm}(\Omega).cos\theta.d\Omega}{E_{s,BOA} + \int L_{atm}(\Omega).cos\theta.d\Omega}$$

2) DART radiance image $\rho_{dd,DART,\Delta\lambda}(x_{DART}, y_{DART})$: orthorectified + resampled to satellite resolution (x_{sat}, y_{sat})

3) DART radiance image $\rho_{dd,DART,\Delta\lambda}(x_{sat},y_{sat})$ is calibrated with atmospherically corrected high resolution RS image $\rho_{dd,sat,\Delta\lambda}(x_{sat}, y_{sat})$ as Sentinel2. Calibration factor: $K_{\Delta\lambda}(x_{sat},y_{sat})=\frac{\rho_{dd,sat,\Delta\lambda}(x_{sat},y_{sat},\Omega_s,\Omega_v)}{\rho_{dd,DART,\Delta\lambda}(x_{sat},y_{sat},\Omega_s,\Omega_v)}$

4) Calibration of DART radiative budget $RB_{\Delta\lambda}(x_{DART},y_{DART},z_{DART})$ and albedo $A_{\Delta\lambda}(x_{sat},y_{sat})$:

$$A_{\Delta\lambda}(x_{sat}, y_{sat}, E_s(\Omega_s), L_{atm}(\Omega), t_{sat}) = K_{\Delta\lambda}(x_{sat}, y_{sat}, t_{sat}).A_{DART,\Delta\lambda}(x_{sat}, y_{sat}, E_s(\Omega_s), L_{atm}(\Omega), t_{sat})$$

In the absence of satellite image, $A_{\Delta\lambda}$ is computed as a weighted sum of DART "white sky" & "black sky" albedos, using direct $E_{s,BOA}(\Omega_s)$ and atmosphere E_{atm} BOA irradiance:

$$A_{\Delta\lambda}(x_{sat},y_{sat},E_{s,BOA}(\Omega_s),E_{atm},t_{sat}) = E_{s,BOA}(\Omega_s).A_{DART,white\ sky,\Delta\lambda}(x_{sat},y_{sat}) + E_{atm}.A_{DART,black\ sky,\Delta\lambda}(x_{sat},y_{sat})$$

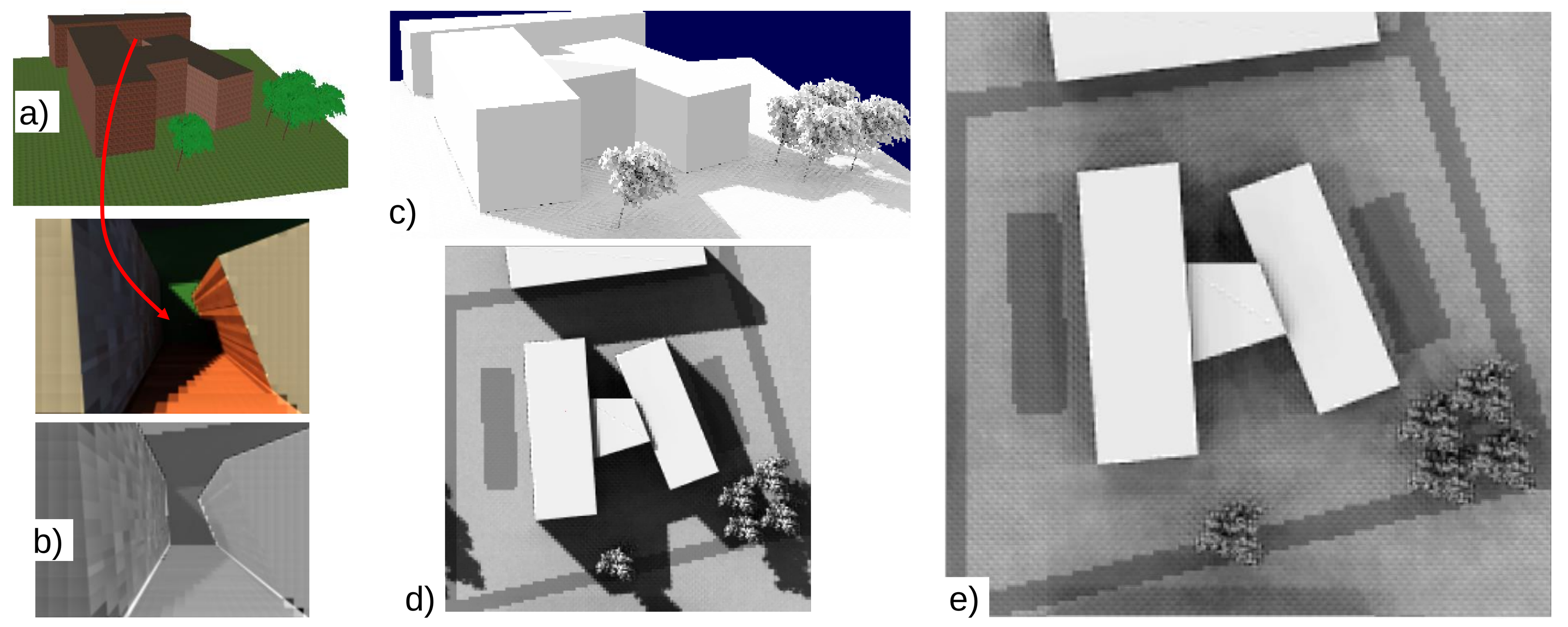


Figure 3: a) Mock-up of REC building, Reading University. b) Camera image of the canyon: RGB (top) and 10µm (bottom). c) 3D view of irradiance E(x,y,z). d) Albedo $A_{DART,\Delta\lambda}(x_{DART},y_{DART})$. e) Sky View Factor.

② Calibration of DART urban TIR radiative budget with satellite images

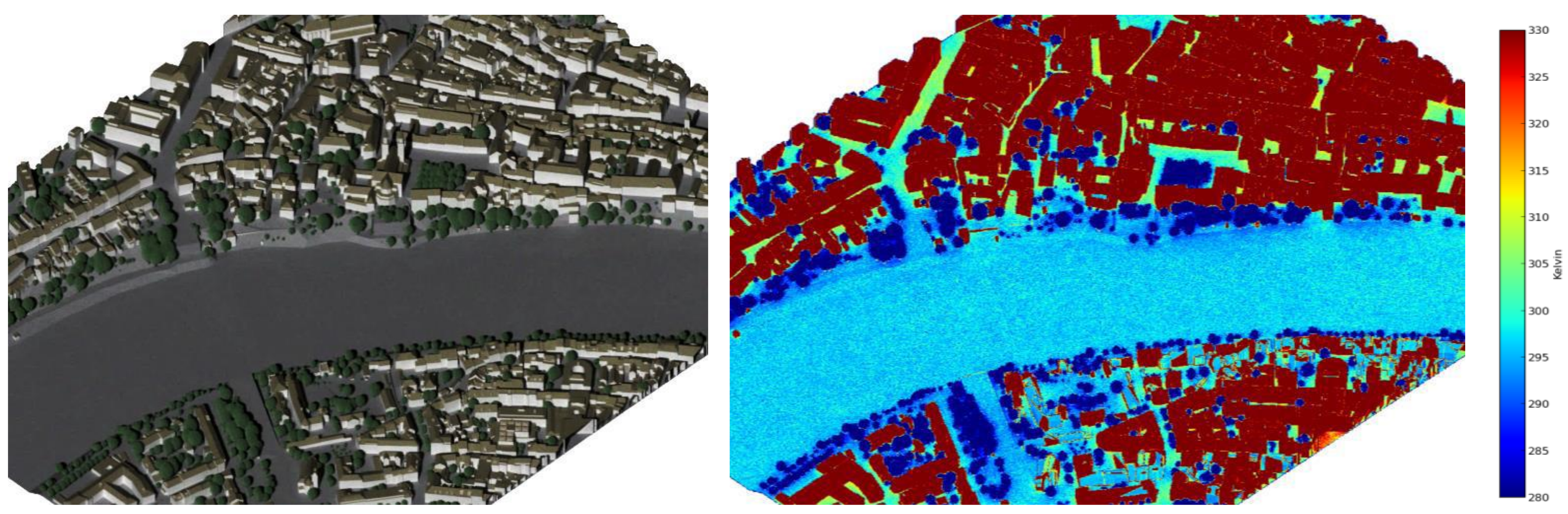


Figure 4: Satellite RGB simulated image (left) and simulated 3D temperature of the same scene (right).

DART simulates TIR radiative budget $RB_{DART,\Delta\lambda}(x_{DART},y_{DART},z_{DART})$ and brightness temperature $T_B(x_{DART},y_{DART})$ images (Fig. 4) using 3D temperature T(x,y,z) that it imports or computes with a "pragmatic" method that relies on 2 approximations: thermodynamic temperature of any Earth object of type n has a range [$T_{n,min}$ $T_{n,max}$] and is a function of its irradiance in visible domain.

Calibration with atmospherically corrected RS image $L_{sat,\Delta\lambda}(x_{sat},y_{sat})$ is as in short wavelengths (①):

1) DART TIR image $L_{DART,\Delta\lambda}(x_{DART},y_{DART})$ is resampled to satellite spatial resolution ⇒ $L_{DART,\Delta\lambda}(x_{sat},y_{sat})$.

2) DART radiative budget is calibrated:

$$RB_{\Delta\lambda}(x_{DART}, y_{DART}, z_{DART}) = K_{\Delta\lambda}(x_{DART}, y_{DART}, t_{sat}).RB_{DART,\Delta\lambda}(x_{DART}, y_{DART}, z_{DART})$$

$$\text{with } K_{\Delta\lambda}(x_{sat}, y_{sat}, t_{sat}) = \frac{L_{sat,\Delta\lambda}(x_{sat},y_{sat},\Omega_v)}{L_{DART,\Delta\lambda}(x_{sat},y_{sat},\Omega_v,t_{sat})}$$

③ DARTEB MODEL: coupled radiative transfer and energy budgets

Objective : to produce realistic energy budget taking into account 3D radiative transfer and energy balance processes

Description: DART pragmatic method (②) to compute 3D temperature is an approximation, because it neglects phenomena as thermal inertia. **DARTEB** brings a better solution: it simulates **heat conduction** and **turbulent heat fluxes**, based on the TEB surface scheme for urban canopies (Masson, 2000) coupled with the DART model. Each surface type (wall, soil, roof) of the urban canopy is discretized into layers to simulate conduction fluxes to/from the ground & building interiors.

Application: Figure 5 through 7 show the modeling of an urban canyon in Heraklion Greece.
Figure 7 shows the dynamics of wall surface temperature for one day.

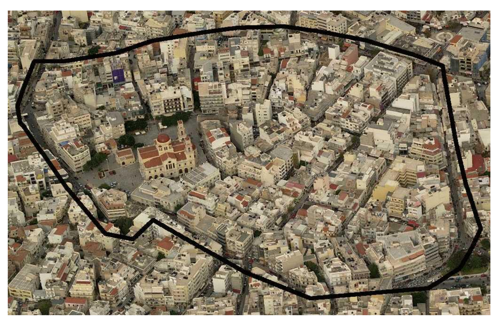


Figure 5: Heraklion District

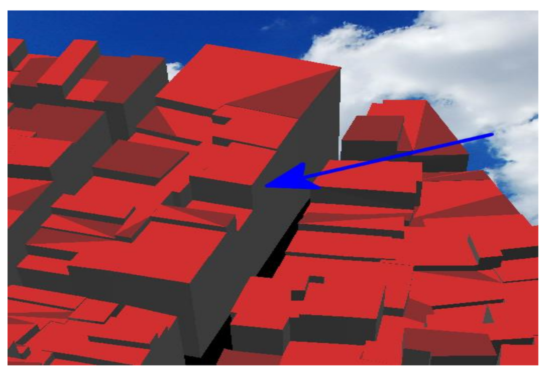
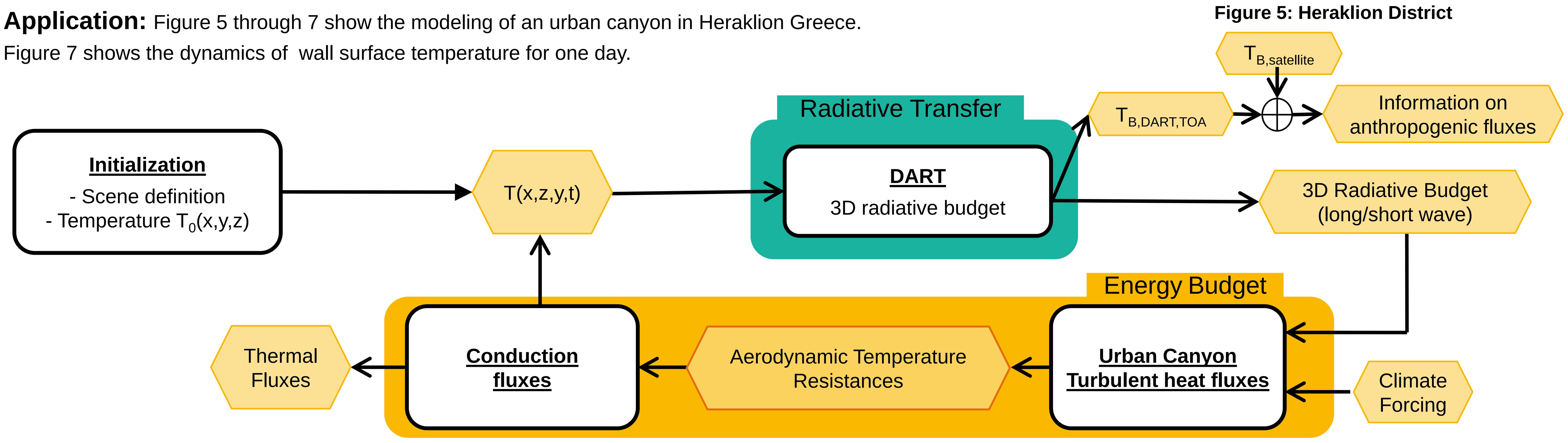


Figure 6: 3D model of a district of Heraklion, the blue arrow indicates the wall of interest



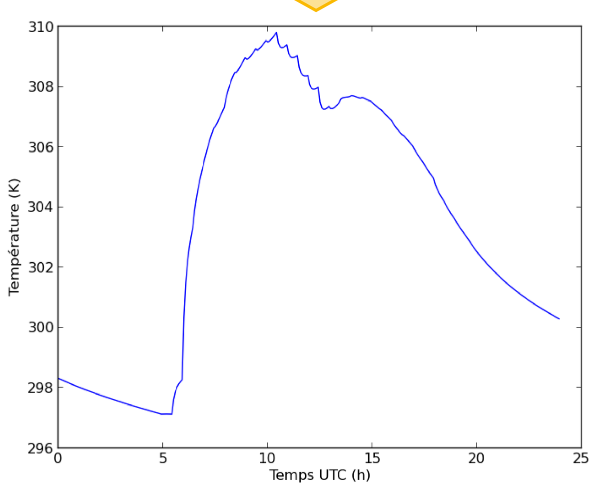


Figure 7: Temperature dynamics over 1 day of the wall of interest

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