An urban micro-climate model for assessing impacts of Water Sensitive Urban Design

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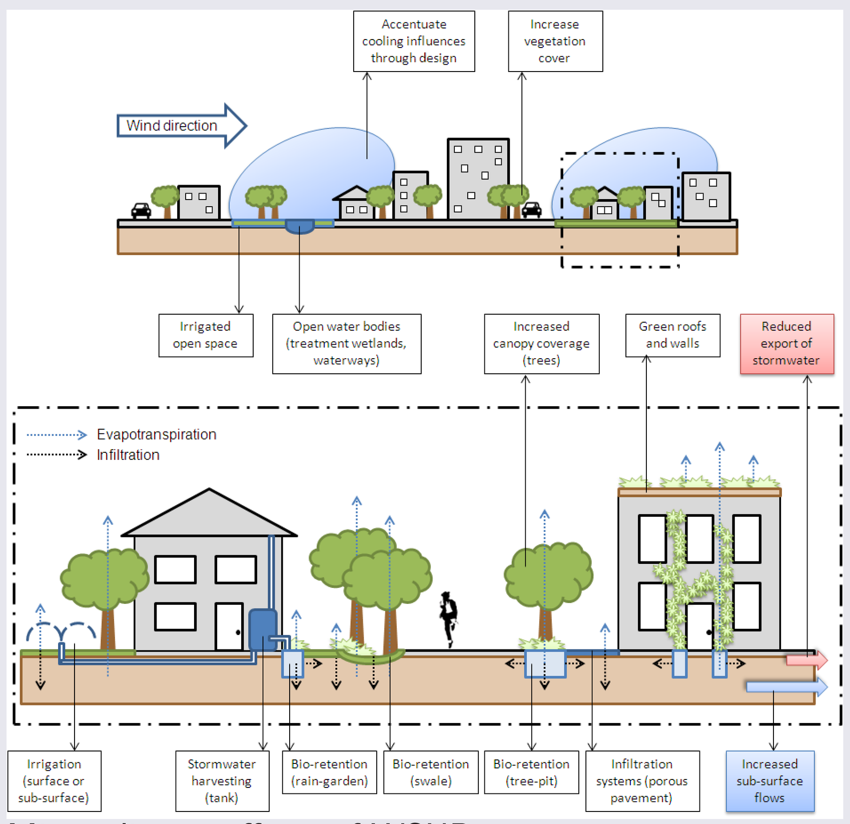
Introduction

- Assessing positive climatic impacts on human thermal comfort (HTC) of Water Sensitive Urban Design (WSUD), through associated increases in vegetation and water in urban areas, requires a suitable modelling tool
- Observation studies have shown that increased tree cover is effective in promoting positive HTC in urban areas (White et al., 2012).
- Modelling HTC at a microscale must fully account for both physical and physiological properties of vegetation, as well as the full soil/plant/atmosphere water cycle. No models were found which fulfilled this requirement.
- The TUF-3D model (Krayenhoff and Voogt, 2007) was modified in a novel way to tile the MAESPA tree model (Duursma and Medlyn, 2012) within the TUF-3D urban canyon and calculate vegetation radiation transmission.
- The modified model (TUF-3D/MAESPA) provides parameters of air temperature, radiant temperatures, wind, and humidity at a suitable scale to assess HTC in urban canyon simulations.
- This tool can be used to determine optimal positioning of vegetation to maximize the impact, as well as determining the climate response of each tree and its relative value in urban canyons.

WSUD and the CRC for Water Sensitive Cities research overview



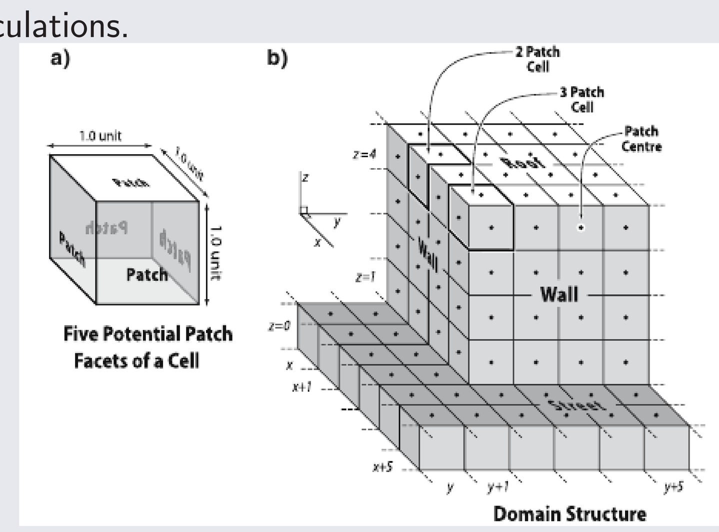
Micro-climate effects of WSUD (Coutts et al., 2012)

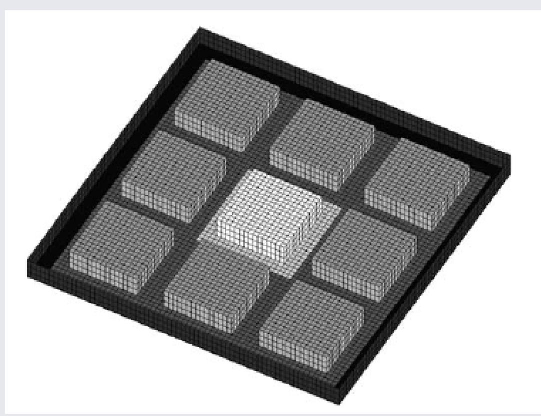
Project B3.1 Green Cities and Microclimate, and B3.2 The Design of the Public Realm to Enhance Urban Microclimate

- Meet challenges of drought & water restrictions, poor vegetation health, strained water supplies, degraded stream health
- Integrating Water Sensitive Urban Design features throughout the urban landscape as a natural cooling mechanism and UHI mitigation strategy
- Increasing vegetation in the landscape AND providing water for vegetation health
- Enhanced infiltration and evapotranspiration

Modelling tool for WSUD HTC assessments

- TUF-3D, a 3 dimensional raster model, simulates energy balances, modelling radiation, conduction, and convection in order to predict fluxes of sensible heat, conduction, and radiation fluxes. However, TUF-3D currently doesn't support vegetation, latent energy fluxes, or water cycles.
- Solves energy balances of domain surfaces by iterating through line of sight radiation movements, reflections, and absorption.
- The model's structure and scale allows resolution of surface and air temperatures across an urban canyon needed for HTC calculations.

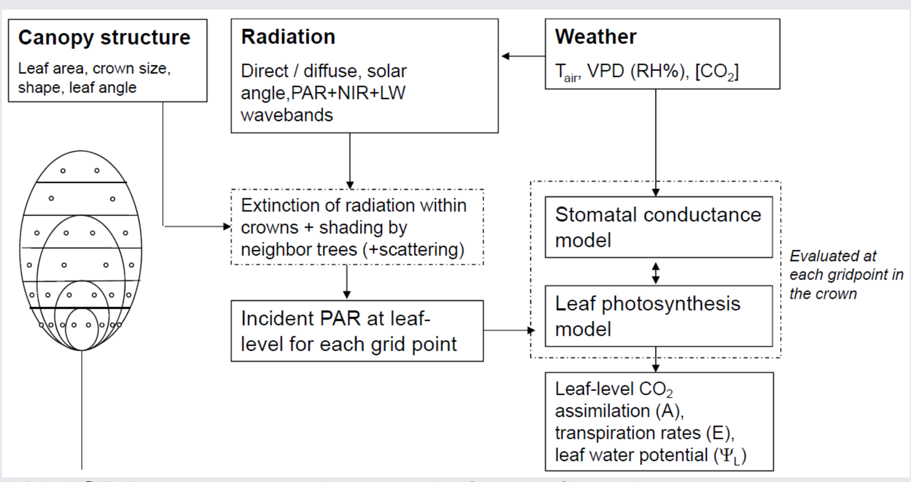


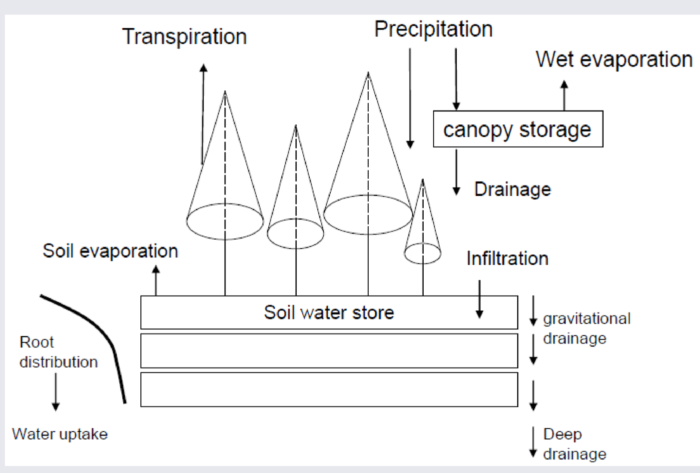


Cube and facet structure of TUF-3D / Sample urban canyon domain (Krayenhoff and Voogt, 2007)

MAESPA tree model

- MAESPA is a soil-plant-atmosphere model and provides forest canopy radiation absorption and photosynthesis functionality, in addition to water balances at fine temporal and spatial scales.
- MAESPA can model a forest stand or a single tree along with its associated soil and canopy and soil water storage and transpiration.





MAESPA process and water balance flowcharts (Duursma and Medlyn, 2012)

Modifications to TUF-3D radiation modelling

- Modifications allow TUF-3D to resolve urban canyon radiation flux movement using placeholder vegetation structures which call MAESPA vegetation absorption, transmission, and reflection routines.
- TUF-3D/MAESPA uses cube shaped structures (as TUF-3D uses to represent buildings) to represent vegetation. These cubes store the surface properties and states and interact with the rest of the TUF-3D domain.
- The vegetation's true shape is represented in MAESPA and calls underlying MAESPA routines to calculate the vegetation's interactions with the urban canyon and radiation movement.

Coutts, A.M., Tapper, N.J., Beringer, J., Loughnan, M. and Demuzere, M. (2012), Watering our Cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. *Progress in Physical Geography*.

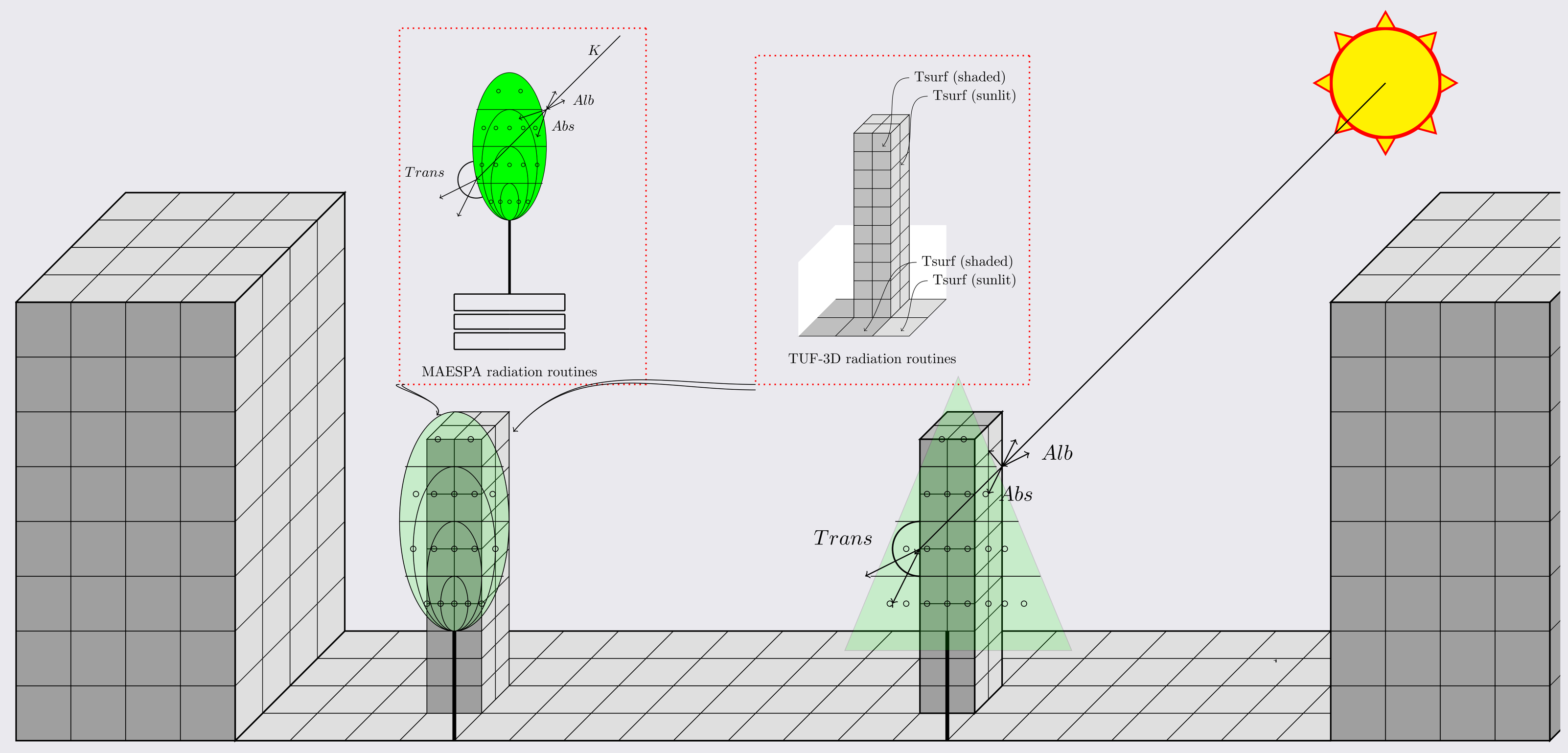
Coutts, A., Beringer, J. and Tapper, N. (2008), Investigating the climatic impact of urban planning strategies through the use of regional climate modelling: a case study for Melbourne, Australia. *International Journal of Climatology*, 1957:pp. 1943–1957.

Duursma, R.A. and Medlyn, B.E. (2012), MAESPA: a model to study interactions between water limitation, environmental drivers and vegetation function at tree and stand levels, with an example application to [CO2] x drought interactions. *Geoscientific Model Development*, 5(4):pp. 919–940.

Gebert, L., Coutts, A. and Beringer, J. (2012), Response of trees to the urban environment. Technical report, Monash University.

Krayenhoff, E.S. and Voogt, J.A. (2007), A microscale three-dimensional urban energy balance model for studying surface temperatures. *Boundary-Layer Meteorology*, 123(3):pp. 433–461.

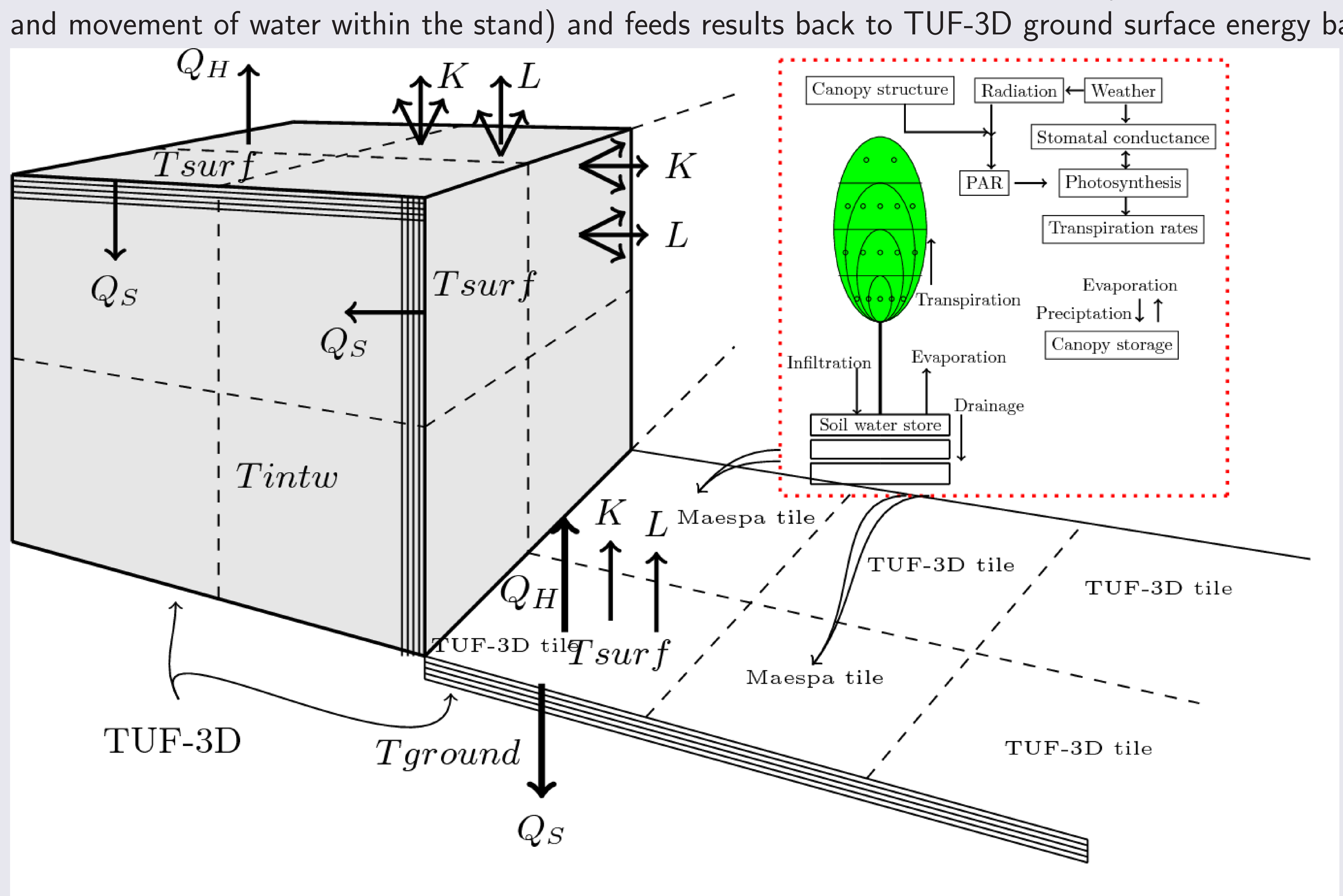
White, E., Coutts, A., Tapper, N. and Beringer, J. (2012), Urban microclimate & street trees: Understanding the effects of street trees on human thermal comfort. Technical report, CRC for Water Sensitive Cities, Monash University.



Integration of MAESPA tree model into the TUF-3D model radiation fluxes routines

Modifications to TUF-3D, tiling MAESPA within TUF-3D

- Using a novel approach, MAESPA tiles replaces TUF-3D ground surfaces with vegetated MAESPA surfaces and use MAESPA's photosynthesis and water cycle routines to modify TUF-3D's energy balance calculations.
- Each embedded MAESPA surface calculates a full 3 dimensional tree or tree stand (along with associated soil and movement of water within the stand) and feeds results back to TUF-3D ground surface energy balances.

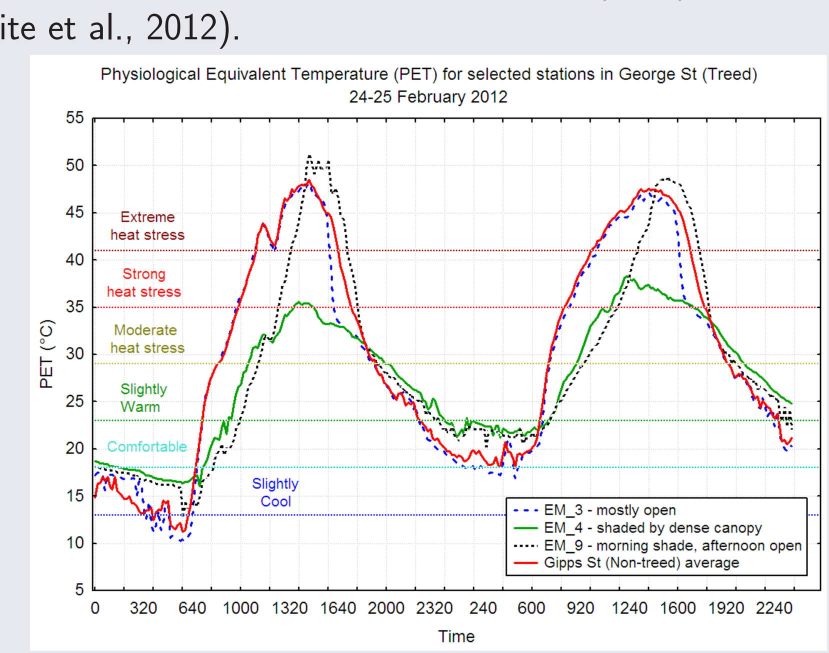


TUF-3D energy balance modelling with new MAESPA tiles

TUF-3D/MAESPA validations using unique datasets

- Model modifications require a comprehensive set of validations to ensure proper functioning of these new features.
- Validation process includes accurate reproduction of energy balances compared to Preston flux tower observation sets (Coutts et al., 2008).
- Vegetation effect validations using observations of Physiological Equivalent Temperature (PET) impacts on urban canyons due to street tree positioning (White et al., 2012).

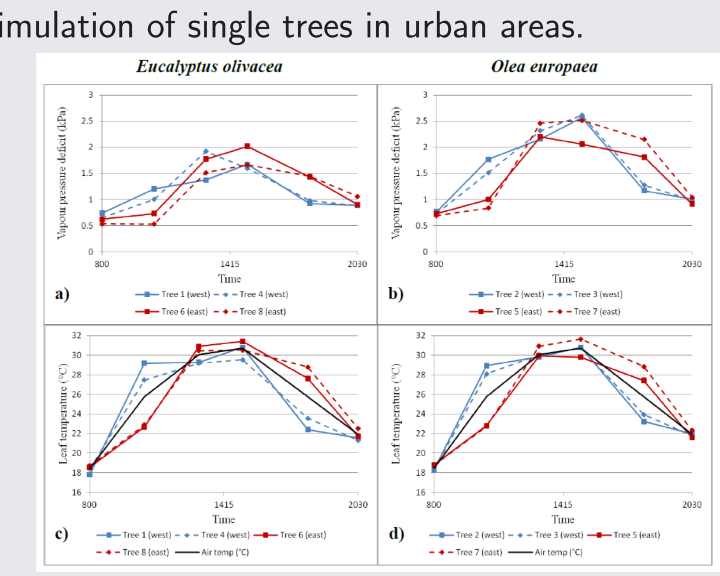
Preston flux towers (Coutts et al., 2008)



Urban PET levels varying by street tree location (White et al., 2012)

- Validations using diurnal leaf-to-air vapour pressure deficit and diurnal leaf temperatures observation of street trees data sets (Gebert et al., 2012) to ensure accurate simulation of single trees in urban areas.

Urban micro-climate and street tree gas exchanges measurements



Urban tree vapour pressure and leaf temperature observations (Gebert et al., 2012)

Conclusions

- Integration of MAESPA tree model into TUF-3D creates a tool suitable to model HTC impacts of WSUD.
- Future work on TUF-3D/MAESPA:
  - Completion of modifications
  - Full validation testing
  - Running comprehensive set of WSUD scenarios