From TORUS to MONTUS: we learned from each other

High-Performance Computing in urban and architecture fields

Urban form, Urban climate, Climate change and perspectives

- Serge Faraut – LRA – ENSA de Toulouse
- Tathiane Martins – LRA – ENSA de Toulouse

- Marion Bonhomme – LMDC – INSA Toulouse

From TORUS to MONTUS: we learned from each other

High-Performance Computing in urban and architecture fields

Urban form, Urban climate, Climate change and perspectives

- Not a complete state of the art...
- Context of some research projects developed in the LRA (Architecture Research Laboratory)

→Where and how the potentiality of High-Performance or Cloud Computing technology could be used to solve some of the experienced problems ?

Urban and architecture domains

In urban and architecture research (or professional practice) fields, the use of specific **intensive computational resources** is often needed.

These research fields are very close to few other typical domains of **geoscience/geospatial data** processing and general **physics-based simulations**.

But some can have quite specific characteristics and constraints, such as :

- **the urban land use or urban cover**
- and **the urban scale physics simulations**

We will present them briefly before describing some of the research projects of the LRA.

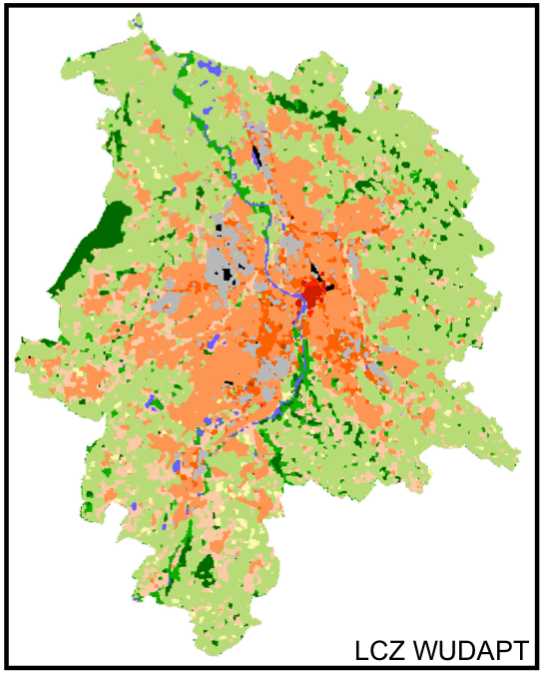
Urban Land Use / Land Cover

Objectives:

→ Manage and process vector spatial or raster data

→ Spatial statistics or analysis

→ Use of efficient extraction/Classification methods



LCZ WUDAPTS classification of Toulouse area

Context:

- Large datasets : size of data, number of files
- Vector data: cadastral parcels, building footprints, hydrography, roads, …
- Raster data: georeferenced orthophotos (aerial or satellite images), visible or multispectral, aerial oblique views (bird's-eye view), ground-level views,...

Problems to solve:

- deal with these large datasets
- challenge of finding and evaluating the best interpretation/classification method
- potentially intensive data processing : spatial analysis, numerical, geometrical and morphological urban (or socio-economical) indicator calculations

Urban Scale Physics-based energy Simulations

Objectives:

- Energy simulations : different kinds of energy consumptions (heating, cooling), or energy productions (solar energy potential);
- Urban climate simulations: complex atmospheric phenomena modelling over urban areas;
- Sensibility analysis driven by simulation results: for aided design tools or decision support tool (methodological guide tools, digital assessment tools)
- Also used for urban form optimization based on energy criteria

Context:

- Large datasets : size of data, number of files
- Vector data : cadastral parcels, building footprints, hydrography, roads, …
- Use of specialized tools and software for architecture, urban climate and urban planner professionals

Problems to solve:

- Potentially very intensive data processing
- Complexity of models dealing with multi-scale modelling and multi-criteria analysis
- Lack of interoperability between tools and data

Research project examples

- **EPICURE - Étude paramétrique de la Performance de dispositifs Urbains pour un Rafraîchissement Environnemental**
  (Parametric Study of Urban Device Performance for Environmental Cooling)

- **IFU - Ilots de Fraîcheur Urbains**
  (Urban Cool Island)

- **MApUCE - Modélisation Appliquée et droit de l'Urbanisme : Climat urbain et Énergie**
  (MApUCE - Applied Modeling and Urban Planning Law: Urban Climate and Energy)

- **Multiplicités - Optimisation énergétique multi-échelle et modélisation multicritères des formes urbaines**
  (Multiplicities - Multi-scale energy optimization and multi-criteria modeling of urban forms)

GAME
CEJU CIRTA
FNAU
IRSTV
LAVUE
LIENSs
LISST
LRA

MULTIPLICITES

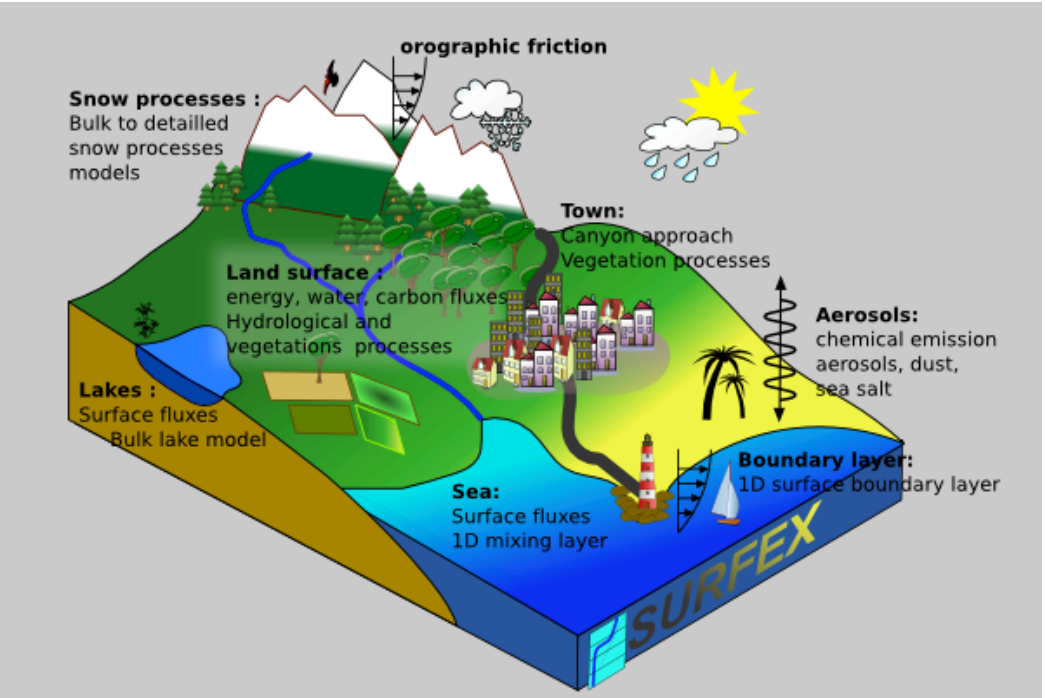
(http://lra.toulouse.archi.fr/lra/activites/projets)

EPICURE - Étude paramétrique de la Performance de dispositifs Urbains pour un Rafraîchissement Environnemental

(Parametric Study of Urban Device Performance for Environmental Cooling)

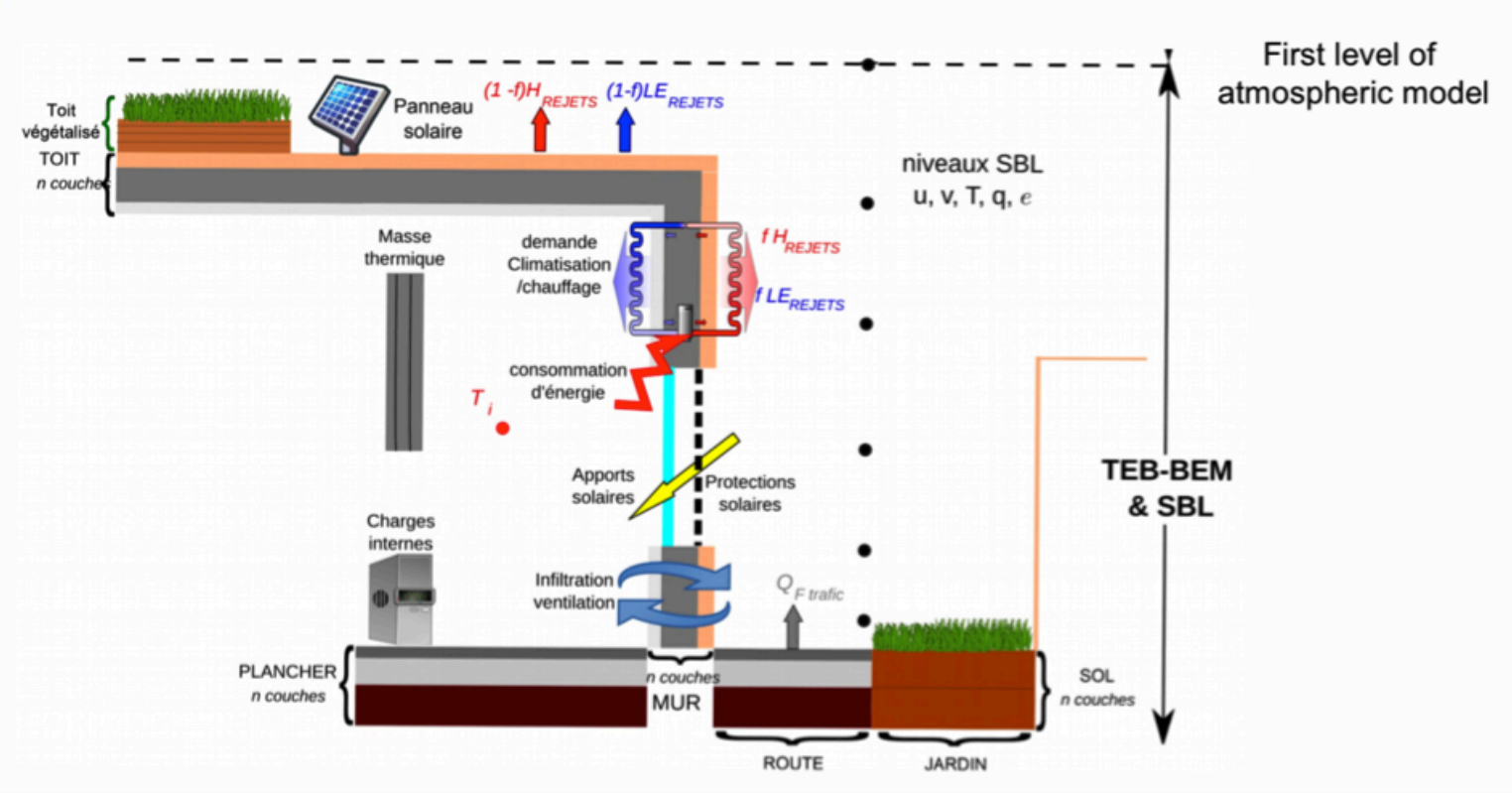
→ sensibility analysis on building's material characteristic and construction devices:

- use of SURFEX tool (Surface Externalisée, in French) (https://www.umr-cnrm.fr/surfex/) which is a (complete) surface modelling platform developed by Météo-France in cooperation with the scientific community



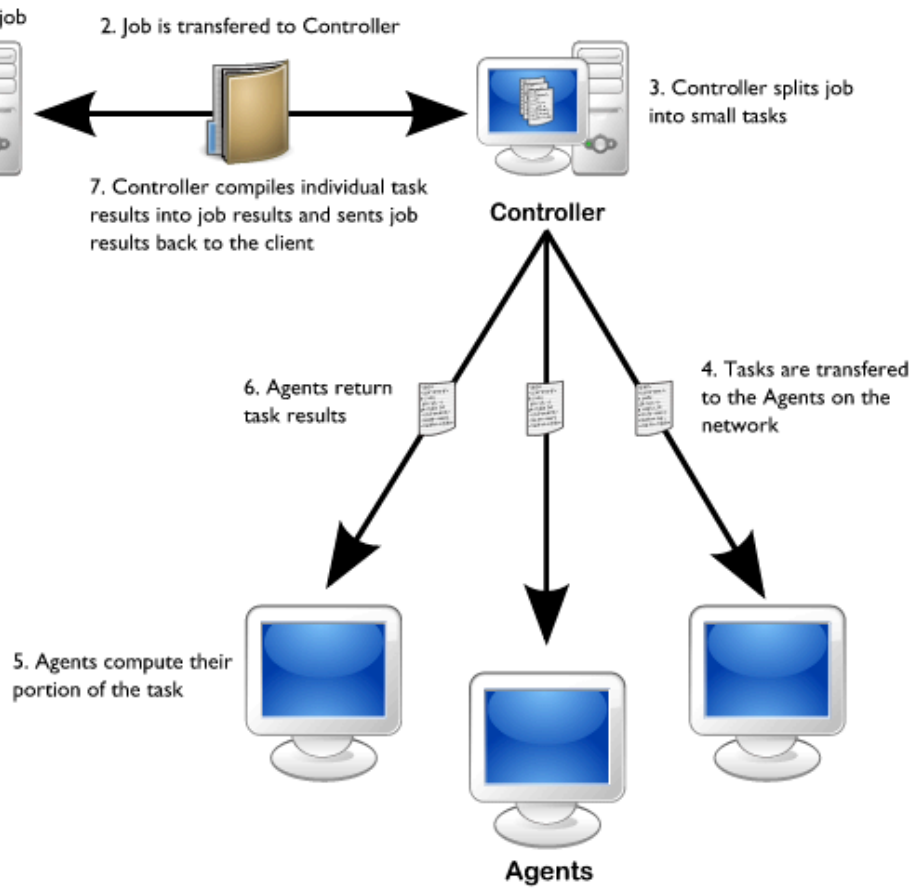
EPICURE - Étude paramétrique de la Performance de dispositifs Urbains pour un Rafraîchissement Environnemental

- coupled with TEB-BEM (Town Energy Balance – Building Energy Model) : building energy model implementing urban canyon model, usage, and material characteristics
- Fortran calculation code freely available (Open-SURFEX) using a CECILL-C License



EPICURE - Étude paramétrique de la Performance de dispositifs Urbains pour un Rafraîchissement Environnemental

- first experiment (2013) in distributed computing with developing of the « DeepMac project » platform, based on Xgrid (on Apple / Mac OS S platforms).



EPICURE - Étude paramétrique de la Performance de dispositifs Urbains pour un Rafraîchissement Environnemental

Context:

- Used only in 1D : one-dimensional simulation;
- used in stand alone mode (forced atmospheric model) without a complete atmospheric model but using weather measurement campaign (CAPITOUL) data as input.

Problem to solve:

- we didn't have MeteoFrance super-calculators for this project...
- even using all 12 computers (3 core used on each quadri-core MacPro machine) time calculations was still high, but much lower than single platform computer (1.5 days instead of 2 weeks)!
- a rather high inefficiency of the global computational architecture even on rather good hardware because of big datasets and results transmitted over only 100Mbit/s network (at that time)…
- XGrid framework tool didn't provide tools for efficient data exchanges and errors management, requiring lot of specific development and hacks

IFU - Ilot de Fraîcheur Urbain

(Urban Cool Island)

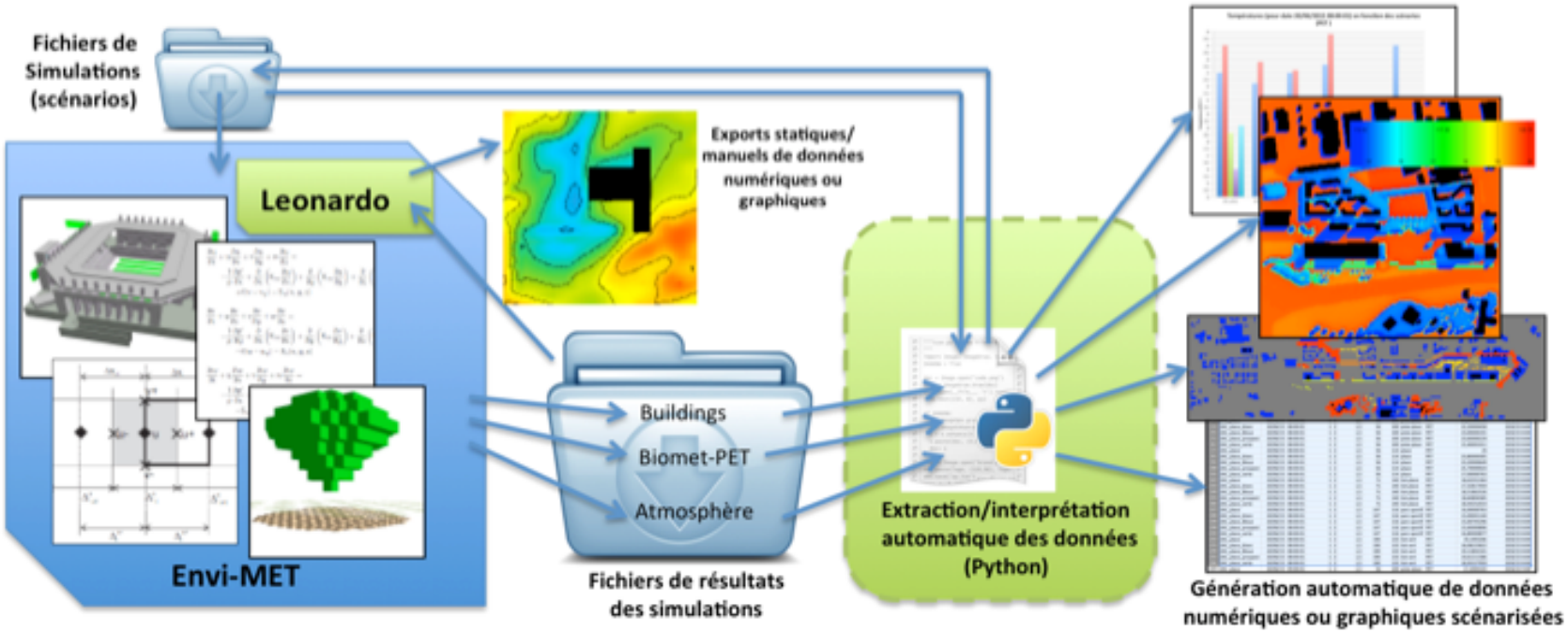
Objective:

→ urban heat island analysis for a new urban district of Toulouse (Montaudran district)

→ propose and evaluate several different urban planning scenarios for urban heat island reduction

Context:

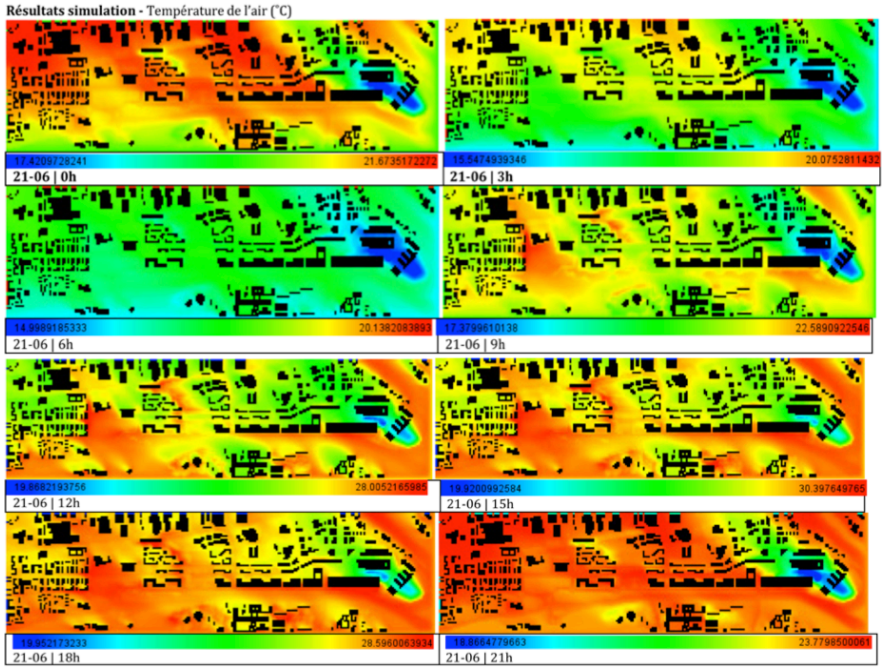
→ microclimate simulations using ENVI-met software for evaluation of different scenarios (complex atmospheric model, including surface-plant-air interactions, detailed building physics, vegetation model,…)



IFU - Ilot de Fraîcheur Urbain

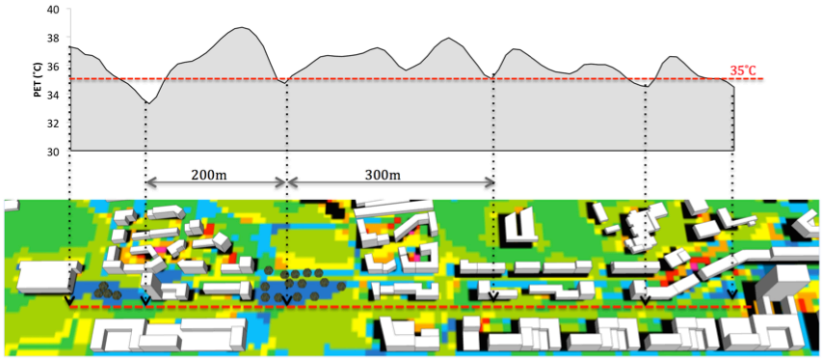
Results / Problems to solve:

- proprietary software – not well suited in importing/exporting data for all kind of processing and analysis;
- several weeks of computer calculations for a single simulation run (of 48h real-time simulation period);
- software not parallelized (single thread only at that time, or multithreaded now but only one physical processor,…)
- difficulties in data processing and interpretation – Need to develop tools to analyze the data produced for comparing the urban planning scenarios
- simulations scale problem in relation to the precision of the result and the limited spatial resolution (local/global and borders problems) → potentially explained by software limitation or hardware memory limitation



Distribution spatiale de la température de l'air entre 0h et 21h pour sur l'ensemble du projet de la ZAC

Assemblage géoréférencé de simulations individuelles



Graphique et carte de la Température Physiologique Equivalente avec itinéraire sur piste

MApUCE - Modélisation Appliquée et droit de l'Urbanisme : Climat urbain et Énergie

(MApUCE - Applied Modeling and Urban Planning Law: Urban Climate and Energy)

Objective:

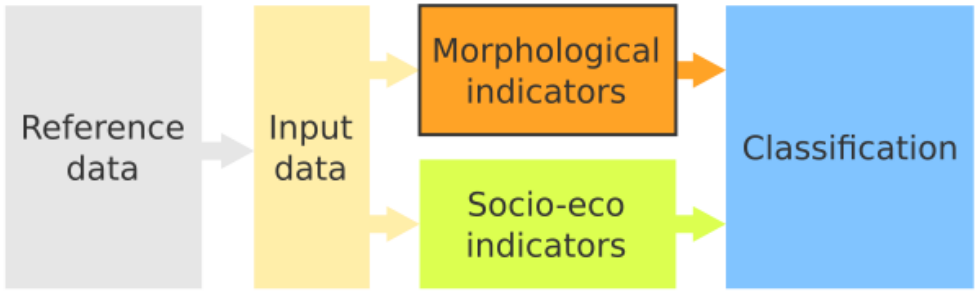
→ urban and socio-economical data analysis and classification for energy assessments at city/national scale

→ urban multiscale indicators calculation (big data and intensive calculations)

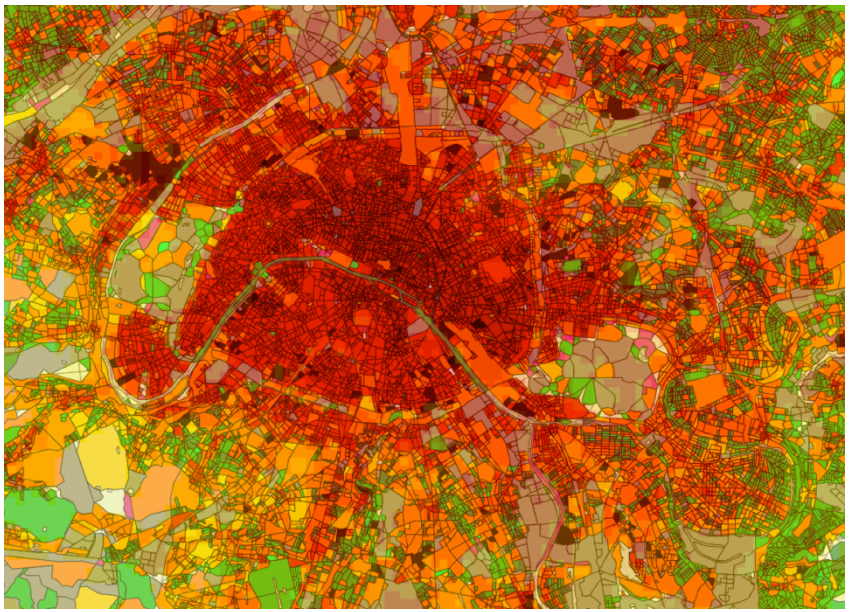
→ buildings characteristics used by energy building and urban climate simulations

→ Define a generic approach:

→ use of national databases : data provided by the French National Geographical Institute (IGN) and the National Institute of Statistics and Economic Studies (INSEE)



Main step of geoprocessing framework



Paris typologies map at district scale

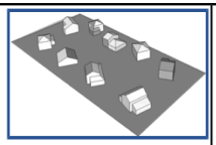
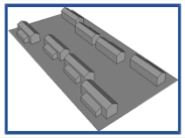
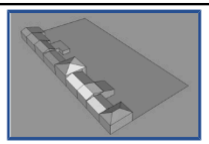
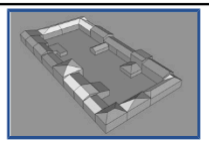
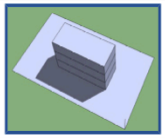
MApUCE - Modélisation Appliquée et droit de l'Urbanisme : Climat urbain et Énergie

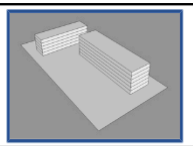
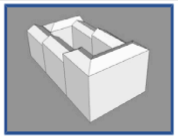
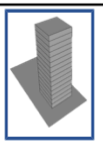
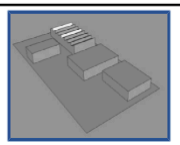
Context/Approach:

→ proposition and evaluation of a specific method for **automated analysis** and **supervised classification** method for typo-morphological determination of urban forms :

- at different scales (building, urban/building block, urban district)
- using **10 identified urban typologies**

→ based on an « Architectural Database » which can provide building's material properties for context-related typologies (depending on location, construction period, usage)

1	PAVILLON DISCONTINU **PD**		La typologie "pavillon discontinu" correspond aux îlots composés de bâtiments d'au moins quatre façades, RdC ou R+1, souvent implantés au centre de chaque parcelle.
2	PAVILLON SEMI CONTINU **PSD**		La typologie "pavillon semi-continu" correspond aux bâtiments de type maison jumelée, implantés dans des lotissements ou cités jardin.
3	PAVILLON CONTINU SUR ILOT OUVERT **PCIO**		La typologie "pavillon continu îlot ouvert" correspond au bâtiment de type maison en bande, ou maison de ville, mitoyenne sur deux faces, en alignement sur rue.
4	PAVILLON CONTINU SUR ÎLOT FERME PCIF		La typologie "pavillon continu îlot fermé" correspond aux bâtiments à patio en bande, constructions en chartreuse dans les centres urbains, à l'habitat intermédiaire.
5	IMMEUBLE DISCONTINU **ID**		La typologie "immeuble discontinu" correspond aux bâtiments généralement implantés au centre de l'îlot avec quatre façades.

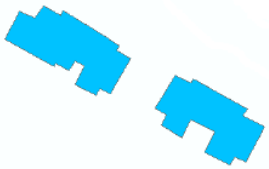
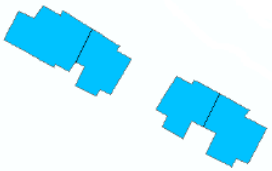
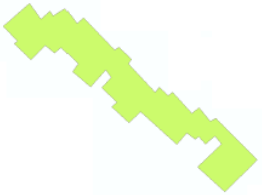
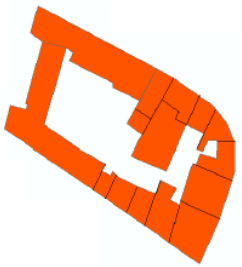
6	IMMEUBLE CONTINU SUR ILOT OUVERT **ICIO**		La typologie "immeuble continu sur îlot ouvert" correspond à un ensemble de bâtiments en partie alignés sur rue.
7	IMMEUBLE CONTINU SUR ILOT FERME **ICIF**		La typologie "immeuble continu sur îlot fermé" correspond aux bâtiments dont l'implantation constitue un îlot fermé.
8	BATIMENT DE GRANDE HAUTEUR		La typologie "immeuble de grande hauteur" correspond aux bâtiments d'au minimum 12 niveaux appelés aussi « tour », « barre d'immeuble » ou « gratte-ciel ».
9	BATIMENT D'ACTIVITE **BA**		La typologie " bâtiment d'activité " est représentée par les bâtiments industriels, commerciaux ou agricoles voire les équipements sportifs.
10	ILOT INFORMEL	–	La typologie « îlot informel » correspond aux constructions éphémères, non répertoriées par les cadastres.

10 identified typologies

MApUCE - Modélisation Appliquée et droit de l'Urbanisme : Climat urbain et Énergie

Classification approach:

→ Acquisition of typomorphological learning data : real state observation, from GoogleEarth and StreetView

Typologie	Photographie de la réalité	Représentation atypique irrélle	Représentation réelle attendue
psc			
pcio			
icif			

Typomorphological model of building's observed real state coupled with GIS data

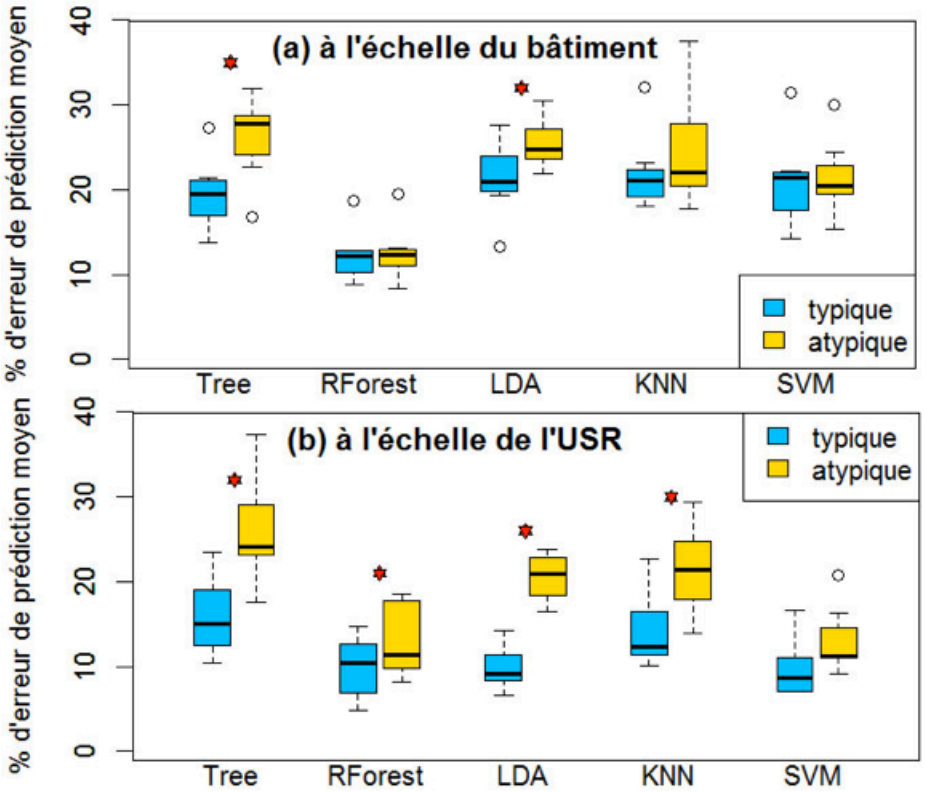
→ Learning data informations:

- 18 369 buildings
- 1 211 districts
- 7 references case study zones

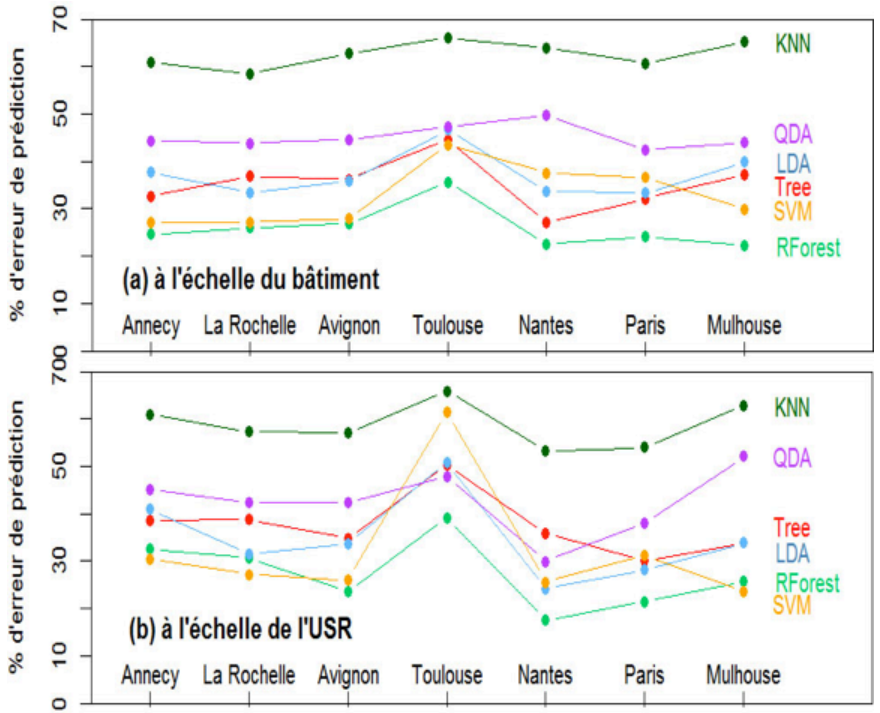
MApUCE - Modélisation Appliquée et droit de l'Urbanisme : Climat urbain et Énergie

Classification approach:

→ Study of several supervised statistical analysis for typomorphological classification (in R language):
→ selection of the best method (least prediction error) « Random Forest » for MApUCE classification model



Figures 4 : pourcentages d'erreur de prédiction moyens obtenus (a) à l'échelle du bâtiment et (b) à l'échelle de l'USR (îlot) avec données typiques et données typiques+atypiques.



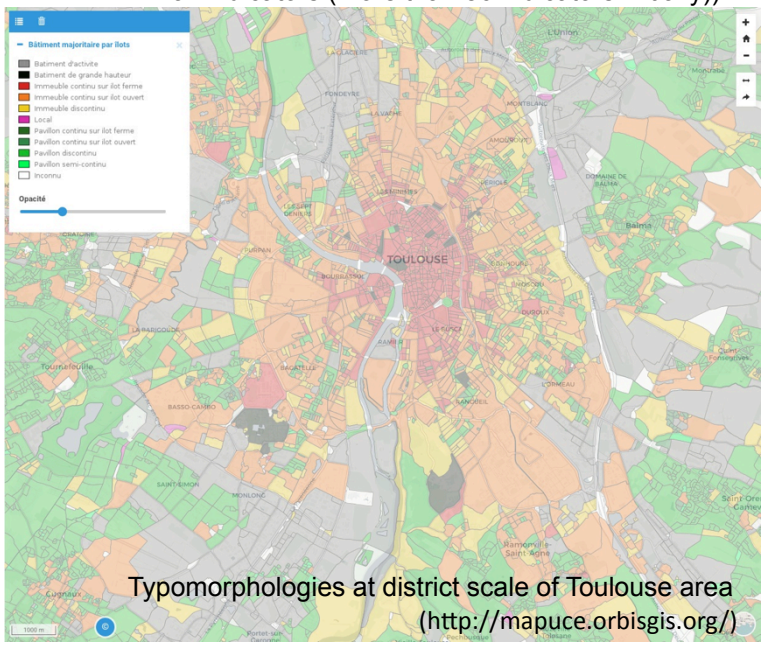
Graphique des pourcentages d'erreur de prédiction (a) à l'échelle du bâtiment et (b) à l'échelle de l'USR (îlot) pour chaque méthode de classification.

MApUCE - Modélisation Appliquée et droit de l'Urbanisme : Climat urbain et Énergie

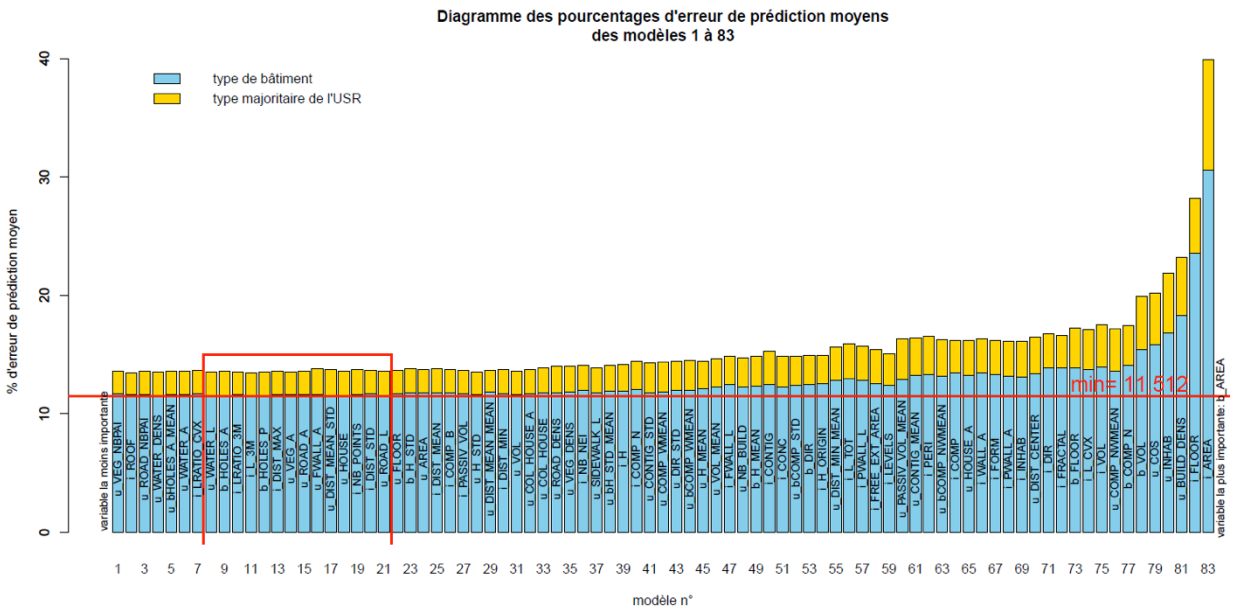
Problems to solve:

→ Potentially intensive usage needs :

- For initial data input processing :
  - for the calculation of some urban or building indicators (for example : « *passive volume* » of buildings, Sky View Factor,...)
- For the typomorphological classification
  - influence of the model training parameters : for example the number of trees of the Random Forest
  - for model validation: 70/30 test training method, between each individual case study zone compared individually or globally
  - for model optimization : determination of the most important criteria for the model (while evaluating the model exploring the combinations within all indicators (more than 80 indicators initially)).



Typomorphologies at district scale of Toulouse area (http://mapuce.orbisgis.org/)



Multiplicities - Optimisation énergétique multi-échelle et modélisation multicritères des formes urbaines

(Multiplicities - Multi-scale energy optimization and multi-criteria modeling of urban forms)

Objective:

→ Energy optimization of urban form and multicriteria approach

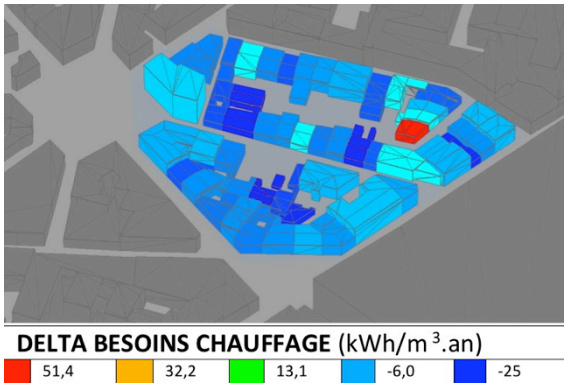
Context:

→ use knowledge of urban stakeholders to produce optimal urban form given energy objectives and multi-criteria decision support tools

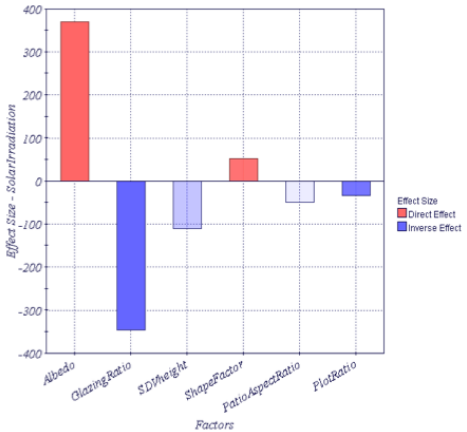
Method/approach:

- sensibility analysis
- optimization process using parametric architecture approach and multi-objective optimization technics

Generative parametric model of an urban island (type ICIF)



Comparative analysis of energy needs



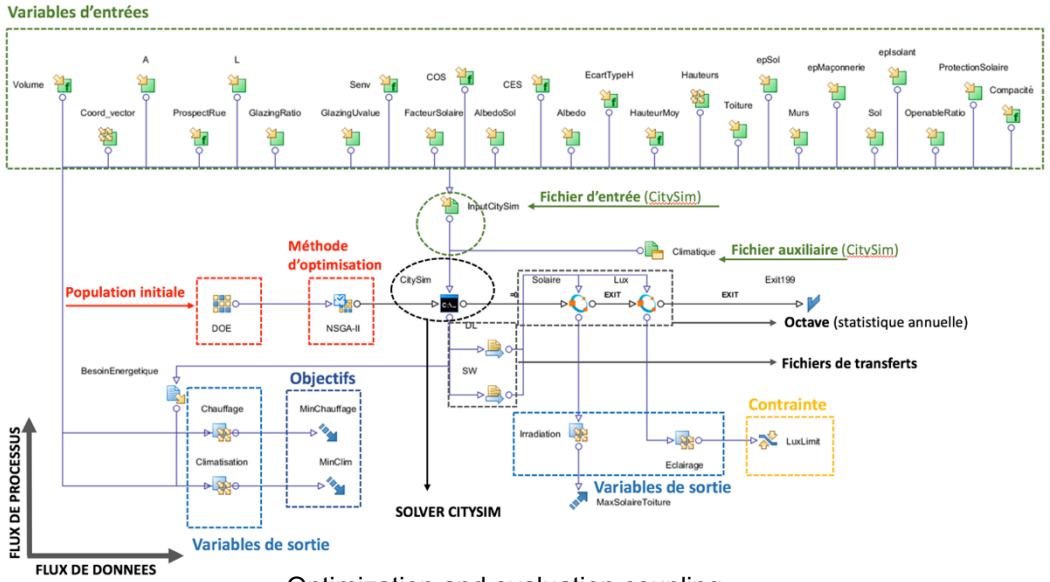
Sensibility analysis

Multiplicities - Optimisation énergétique multi-échelle et modélisation multicritères des formes urbaines

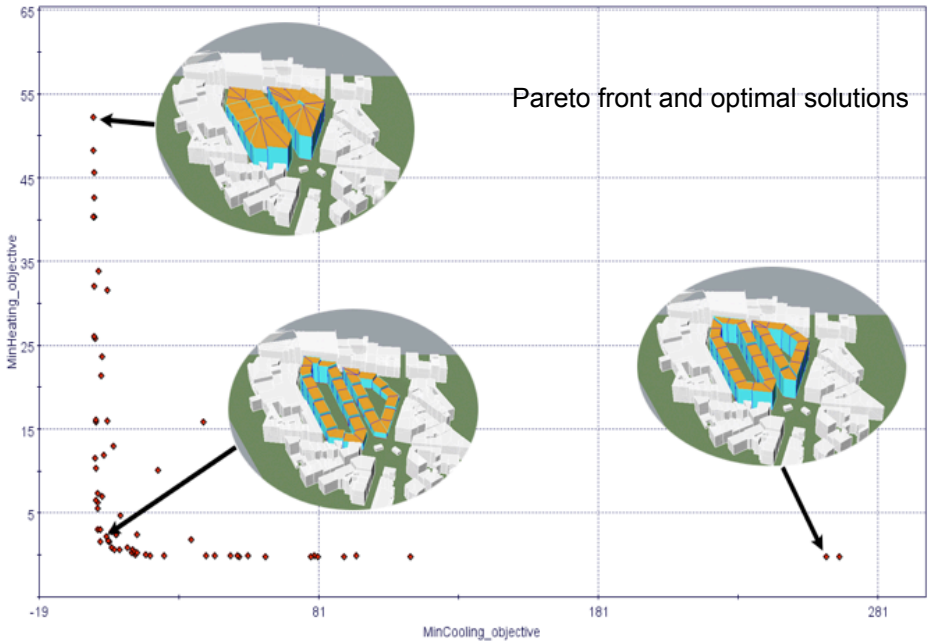
(Multiplicities - Multi-scale energy optimization and multi-criteria modeling of urban forms)

Problem to solve:

- very high number of intensive computation simulation runs to generate and to evaluate (DOE).
- the building's energy assessment tool used (CitySim) is not (yet) parallelized
- big volume of data produced (and to be stored) for each optimization process (in case of post-processing)
- have to deal with interoperability difficulties between each tool used (energy assessment tool - CitySim, parametric generative tool – Rhino/Grasshopper, optimization process control tool – ModeFRONTIER)
- use of proprietary specialized software (multi-host licence needed)...



Optimization and evaluation coupling



Conclusion

Some problems remain to be solved in using High-Performance Computing solutions:

- currently, mainly use of already available standard « low levels tools », but also of **very specialized « complex software »** (specially designed for professional use)
- most of the software used are **not « optimized »** : they usually cannot either be parallelized (constraints by physical modelling) or cannot be used directly in a parallelized way
- difficulties in **interoperability** between all tools to be used

All the toolchain must be suitable for this purpose, which could prevent using the already available tools or require **very heavy specific developments**.

If parallel computing can't be applied, **distributed computing** could potentially be used!
But only if all tools used are suitable for this purpose, which could prevent using the tools already available or otherwise will also require specific developments (or rewriting all tools from scratch...).

Perspectives

The way to go ? :

- Include (or promote) the HPC paradigm in all further developed tools for researcher and developers
- Make all tools and softwares opened, or make them use standard file formats or standard interchange communication methods, to ensure interoperability
- Make HPC technologies adaptable and easy to use for all non-Information Technology specialists… to make them discover new opportunities in their operational area of work !

And some new avenues to explore:

→ Better integration of automated raster data analysis (specially for vegetation, but also structural elements such as building roof or façade material,…)

→ Deep Learning applied to architecture or urban forms analysis…

From TORUS to MONTUS: we learned from each other

High-Performance Computing in urbanistic and architecture domains?

Urban form, Urban climate, Climate change and perspectives

Thank you !

- Serge Faraut – LRA – ENSA de Toulouse
- Tathiane Martins – LRA – ENSA de Toulouse

- Marion Bonhomme – LMDC – INSA Toulouse