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BUILDING A MODEL FOR ASSESSMENT AND SIMULATION OF PLANNING MEASURES ON CLIMATE CHANGE RELATED KEY FACTORS (MORPHOLOGY, LAND USE, ENERGY AND MOBILITY)

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SOMMARIO

Obiettivo del contributo è la presentazione di risultati preliminari di una ricerca incentrata sull'analisi delle relazioni tra effetti di cambiamenti climatici (in particolare, riscaldamento globale, ondate di calore e isole di calore urbano) e l'ambiente costruito in termini di morfologia, uso del suolo, consumo di energia e mobilità, relativi al disegno urbano e alla pianificazione alla scala di quartiere. Scopo ultimo della ricerca è la comprensione del contributo dei diversi fattori, al fine di contribuire alla conoscenza delle risposte possibili e alla progettazione di città maggiormente resilienti, tramite potenziale implementazione di un monitoraggio della risposta urbana alle misure di adattamento.

Cuore della ricerca è il calcolo e l'analisi di indicatori rappresentativi dei fenomeni coinvolti nel bilancio energetico di superficie (urban surface energy balance), attraverso al costruzione di un modello basato su GIS e DEM per il caso studio della città di Milano. La comprensione delle complesse relazioni tra gli indicatori conduce a interessanti valutazioni sull'efficacia e fattibilità delle misure di adattamento potenzialmente previste, oltre a valutazioni su sinergie e contrasti, e sulla sostenibilità delle stesse.

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1 Introduction

Climate change is happening, projected to continue and poses serious challenges for cities. Extreme weather events resulting in such as heatwaves, floods and droughts are expected to happen more frequently. At the same time three quarters of the population of Europe live in urban areas and this is where climate change will be most apparent in everyday life. and will have stark impact on cities economy and wealth. In particular, of those natural disasters occurring in recent decades, heatwaves have caused the most human fatalities. During the summer of 2003 the heatwave in Central and Western Europe was estimated to have caused up to 70000 excess deaths over a four-month period "(EEA, 2012)".

Both experimental and modeling studies have found that high temperatures are associated with factors such lack of green space, high building mass, and high production of anthropogenic heat per area.

On the one hand, over the last two decades, a large number of studies have found variable combination of tree planting and vegetation cover (including green roofs), albedo enhancements, and reduction in waste heat emissions to reduce city-wide temperature by between 1 and 7°C "(Stone *et al*., 2012)".

On the other hand, while several studies have focused their attention at the urban canyon level, few studies have estimated the contribution of those measures (on urban design, on land use) at the neighbor level "(Grimmond et al., 2010)". Additionally, synergies exist between measures designed to control greenhouse emissions and measured designed to limit the UHI effect, but they are currently underestimated "(Stone *et al*., 2012)".

2 The research questions

The aim of the research here presented is to provide a system-scale understanding of the inter-relationships between climate effects and the built environment (urban morphology, land use, energy and mobility) and to use this understanding to design cities that are more resilient and contribute to climate change mitigation.

A specific objective is to analyze key factors and build a GIS+Digital Urban Model for the assessment and simulation of measures to cope with climate change, and therefore building a spatial planning support system for monitoring and designing the "Responsive City".

- What are the key planning and design factors that influence CC at the urban level? (i.e. spatial configuration, urban morphology, land use planning, mobility planning) How can we estimate their relevance in contribution to CC mitigation and adaptation? (i.e. urban energy balance) What are the interactions between climate impacts and the functioning of the urban system? (i.e. UHI)

- What are the most effective measures that can be implemented to cope with CC at the urban level? At what cost can they be effective? (i.e. refurbishment of existing areas) Are there win-win synergies that work with both adaptation and mitigation? (i.e. green infrastructure) Are they coherent with smartness and sustainability? (i.e. improving quality of life)
- Which strategies and tools are most promising for policy makers, planners and designers to implement, measure and monitor city response to climate change? Is it possible to provide an integrated assessment model for urban simulation in order to manage urban environment quality? (i.e. GIS+DEM)

3 Theoretical model: Surface urban energy balance, radiation budget and selection of factors

Urban temperature and UHI can be understood as result of the equation ruling "surface urban energy balance" "(Oke, 1987)" at ABCD level (see fig. 1):

$Q^* + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A$

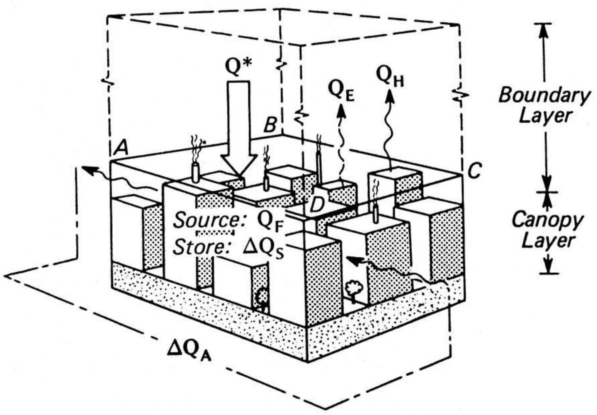

Fig. 1 - Surface energy balance of an urban frame (source: Oke, 1987)

where: Q* = Rn (net wave radiation), and comes from the "radiation balance" of longwave (L) and shortwave (K) radiation:

$Rn = Q^* = K{\downarrow} - K{\uparrow} + L{\downarrow} - L{\uparrow}$

Therefore, the temperature of in an urban "frame" is function of a complex relationship among factors involved in the equations:

- urban morphology (sky view factor, etc.) acts on radiation (Rn), energy consumption (anthropogenic heat, QF), advection heat (ΔQA)
- climatic data (cloud cover, wind, etc.) act on net radiation (Rn) and on sensible heat (QH)

- urban material proprieties (thermal and radiation: albedo, emissivity) act on heat storage (ΔQS) and on net radiation (Rn)
- land use (green and blue areas) act on latent heat (QE)
- urban mobility and urban energy consumption (emissions, combustion and waste heat) act on anthropogenic heat (QF)

The selection of indicators was based on the international urban energy balance models comparison project "(Grimmond, 2010)".

Additionally, besides urban energy balance, some factors affect other "climate change-related" aspects, such as water scarcity, air pollution, CO2 emissions. For example, energy consumption from summer air conditioning during heat waves can significantly contribute to urban temperature increase (anthropogenic heat, QF), though generating a vicious cycle.

See the first tentative Map (attached, fig. 5) explaining the complex relationship and first assumptions of indicators selected to describe the model (drivers, outcomes, input and output, and urban balances involved).

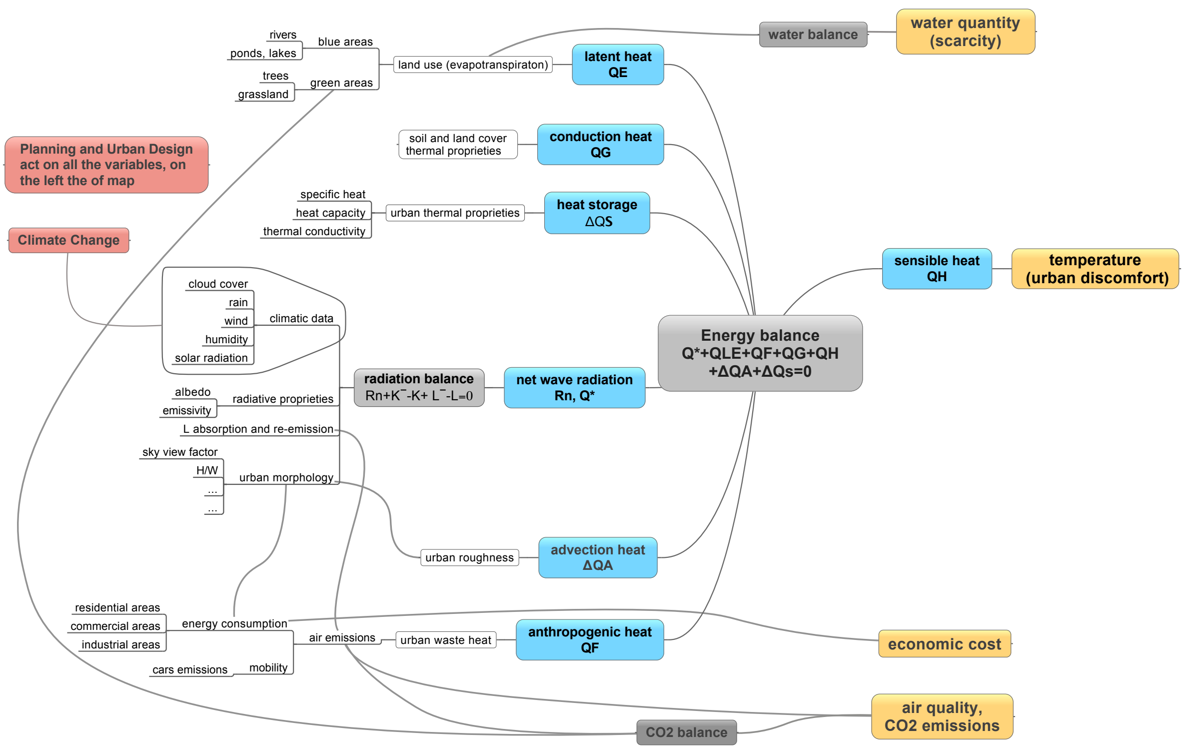

Fig. 2. First tentative Map explaining the relationship between factors involved in the model: drivers, outcomes, input, output, and urban balances involved (author elaboration).

4 Calculation of factors/indicators (Milan case)

Milan area is a good case for studying "climate modification by urban area" because is a place of those with lack of "extraneous effects due to topography", "water bodies", "and the downwind effect" "(Oke, 1987)".

The research aimed at calculating some indicators previously selected for all city areas divided into a number of frames that are related to the neighborhood level (see fig. 2).

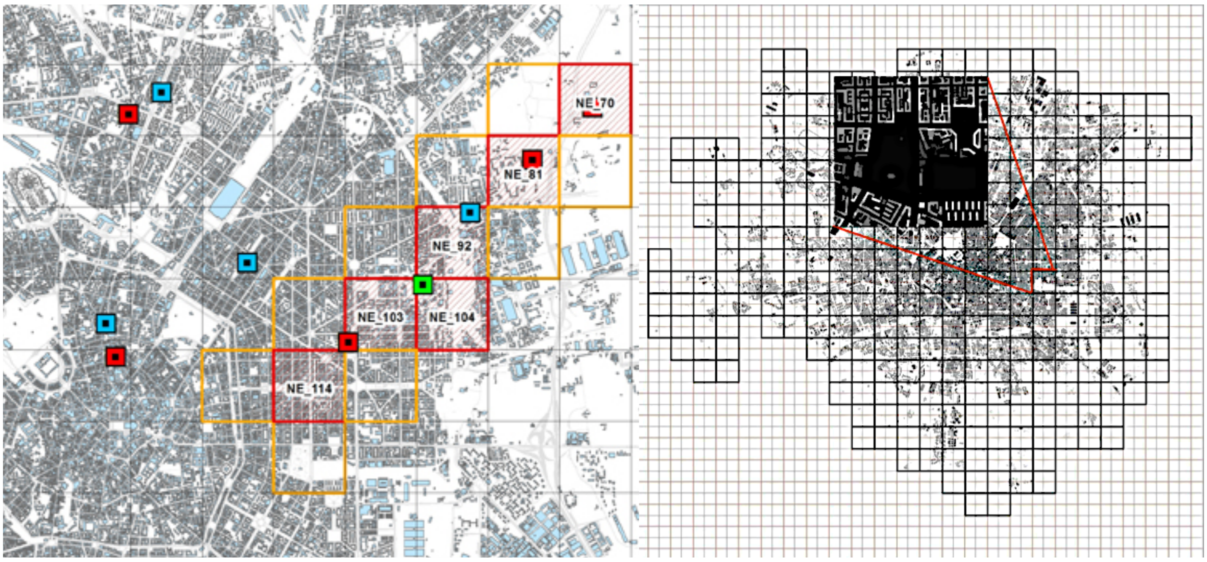

Fig 3 - The Milan city area is divided by frames. The frames underlined on the right are the ones chosen for the transect monitoring (Elaboration done at Urban Simulation Lab, Politecnico di Milano).

<u>Field data: monitoring temperature in a transect</u>

Collecting measurement of environmental data is an issue for cities like Milan since only a few weather-environmental stations are available, though data confirms summer heat waves and UHI (see figure 4).

Fig. 4. Difference of temperature (vertical axe, °C) in 29-30 June 2012 (hours, horizontal axe) in two EPA weather stations located in: urban area (Brera, in red), and sub-urban area (Lambrate, in green. (Elaboration done at Urban Simulation Lab, Politecnico di Milano).

A planned direct monitoring of a "Transect" (June 2013), will measure the temperature in different parts of the city, from rural/suburban to urban areas, during summer days (temperature will be measured in significant and representative frames, see fig. 3).

5 Data analysis

Indicators are calculated, visualized and overlaid on a GIS base (see fig. 5).

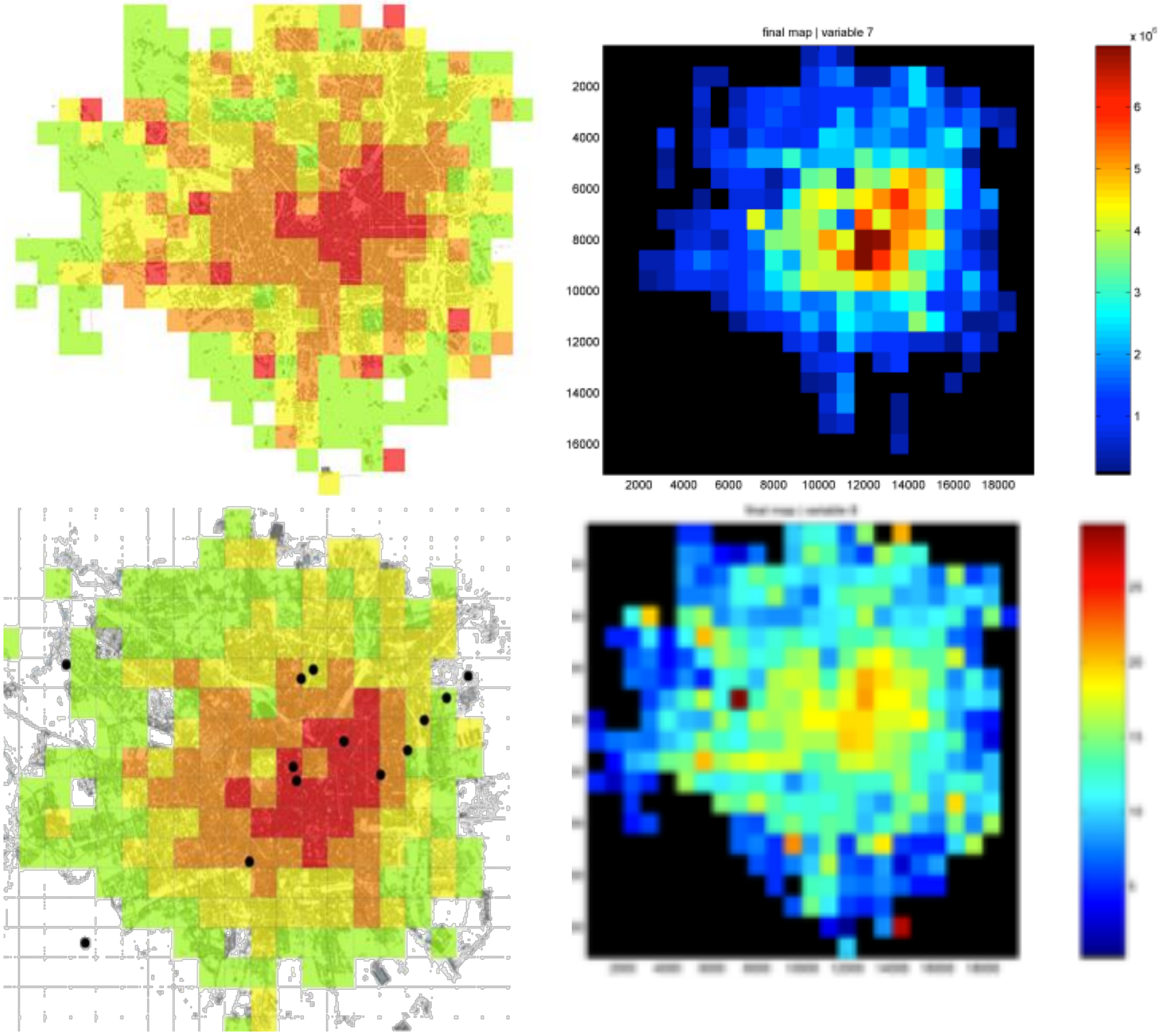

Fig. 5a - Visualization on a GIS environment (on the left) and on a MathLab environment (on the right) of indicators calculated; example of average building height (on the left) and of total m^3 built volume (on the right). (Elaborations done at Urban Simulation Lab, Politecnico di Milano).

First step. A Multi-Dimensional Analysis on the indicators explores the relationships among its elements (rows and columns) by recognizing (i.e., by suitably constructing) a limited number of new underlying variables sufficient to summarize the more relevant aspects of the description, with a tolerable loss of details. Principal Component analysis (PCA) is done to "urban morphology" indicators, as well as to other indicators.

Second step is the calculation of the surface energy balance for each frame.
After PCA analysis, a fewer number of indicators is being connected with proper "coefficients" to the heat fluxes (Q) of the energy balance. Coefficient estimation and relationship type with equation formula at first attempt is taken from literature "(Mariani *et al*,

2005; Ratti *et al.*, 2005 and 2006)". Afterwards, the energy balance equation will be tested for each frame, calculating and verifying the coefficients.

Besides temperature increase/decrease, thanks to the management of the complex relationship among the variables, the model also allows to calculate other factors, useful for the simulation of urban interventions to the city (to the frames):

- the amount of CO_2 emission and absorption
- the economic cost (related to energy consumption; see next paragraph).

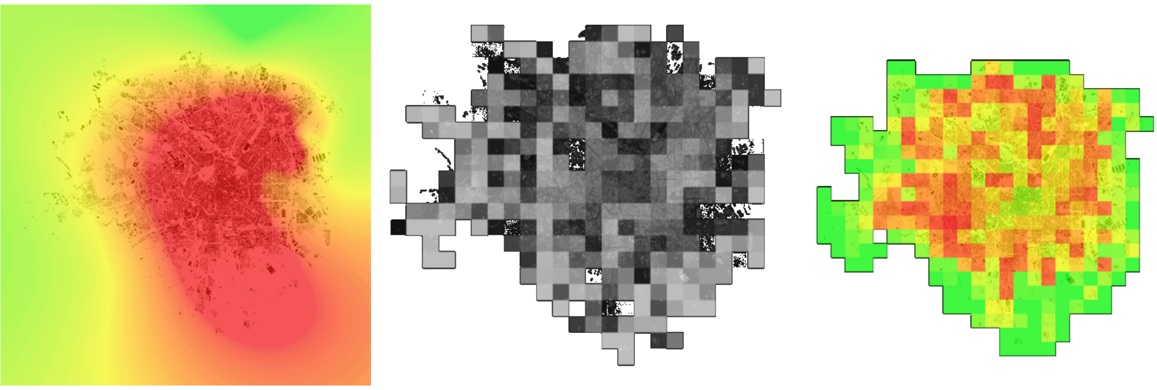

Fig. 5b - Visualization on a GIS environment of indicators associated to urban morphology and temperature (first image, (Elaborations done at Urban Simulation Lab, Politecnico di Milano, using ArcMap kriging).

See the table 1 for the first tentative list of indicators that are being calculated.

Tab. 1 - First tentative list of indicators explaining the relationship between city structure and climate effects

INPUT	affecting **OUTPUT**	**INDICATORS** available data	**dependent on time?** (if yes, it requires an encoding table)	**unit (input)** per frame (average per mq) per hour
urban trees	latent heat (Q_E) air quality and GHG emission	trees green volumes (per species) per frame	yes, seasonally	m3/m2
grassland	latent heat (Q_E)	green area per frame	yes, seasonally (and irrigation condition)	m2/m2
rivers, ponds, lakes	latent heat (Q_E)	blue area per frame	no	m3/m2
soil and land cover	conduction heat (Q_G)	thermal proprieties (…)	no	(…)
built environment	heat storage (ΔQ_S)	thermal proprieties: specific heat	no	MJ/K kg
		thermal proprieties: heat capacity		MJ/K m3
		thermal proprieties: thermal conductivity		W/K m
	net wave radiation (Rn)	radiation proprieties: albedo	no (except, albedo in snow season)	m2/m2
		radiation proprieties: emissivity	no (..)	m2/m2
building energy consumption	anthropogenic heat (Q_F) air quality and GHG emission cost (€)	buildings volumes (residential, offices, …), age, ..	yes, seasonally, and hourly (peak time)	m3/m2
car mobility	anthropogenic heat (Q_F)	mobility flux in main roads	yes, weekly and hourly (peak time)	n. running vechicles/m 2
urban form, texture (from urban DEM)	net wave radiation (Rn)	built volume, covered area, floor area, built perimeter, mean height of buildings,	no	m, m2, m3,
		sky view factor; H/W; surface to volume ratio;		m/m, 1/m
		% of S oriented vertical surfaces; % of SE to SW oriented vertical surfaces [%]; passive zones / non passive zones ratio [-]; urban canyon aspect ratios [-]		%, -

		...		...
	advection heat ΔQ_A	roughness		adimensional
climatic data	net wave radiation (Rn)	cloud cover	yes, seasonally, daily and hourly	adimensional
		radiation		W/m2
		humidity		%
		wind		...
temperature	sensible heat (Q_H)	air temperature (at ABCD level)		°C
distance from city baricenter	---- (PCA analysis)	distance from city center	no	m

6 Towards a system/tool to implement, measure and monitor city response to Climate Change over time

Once the model has reached a general understanding of the contribution of the main urban factors to temperature end emissions increase in Milan, most critical areas can be displayed. Different urban planning and design measures can be implemented in order to cope with climate change and urban climate: at the neighborhood level, they can both be mitigation or adaptation strategies, policies, tools.

The main focus of the measures is their action on existing urban areas (refurbishing/ redevelopment), but also measures for new development areas can be considered (see fig. 6). Based on the model previously created, with its complex inter-relations structure, a simplified version can be analyzed, based on Milan data (geography, climate, costs); it gives outputs in terms of UHI (temperature increase) and Emissions (CO_2 and pollutants increase) according to different inputs introduced (measures, see figure 6, and next paragraph).

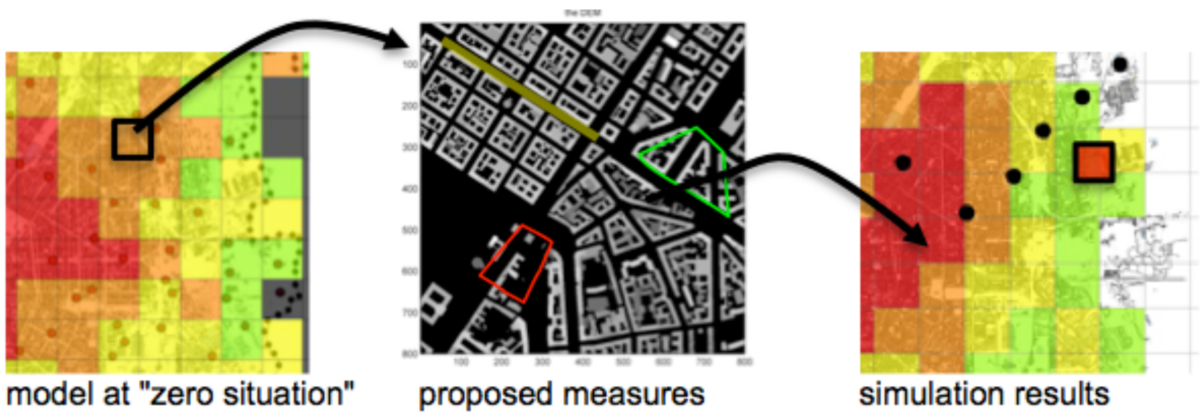

Fig. 6. Scheme of the process of intervention on the "zero situation" with proposed measures, and calculation of estimated results through indicators visualization (Elaboration done at Urban Simulation Lab, Politecnico di Milano)

7 Action on climate change: definition and assessment of mitigation and adaptation urban measures

First step is the definition of the measures and the framework (actions on CC causes, CC effect, influence on the urban energy balance); CC measures are commonly found in "Climate Actions Plan", "Energy Plan", "Building Code" (see box fig. 7).

Next steps are going to be:

- each measure will be represented by modified values of specific indicators (i.e: increase of 1mq of green area inside a frame);
- using the Model, calculation of the "new situation" in terms of UHI (-°C) and emissions (-CO2);
- analysis of effectiveness (action/-C°, action/-CO2) and cost-benefit (-C°/€, -CO2/€): estimation of unit effects (i.e.: 1 mc of a specific tree and calculation of its cost and CO2 absorption; i.e. by LCA), unit cost and others environmental effects (air quality improvement, storm water management, etc.);
- assessment of the data and outcomes (Multi-Criteria Analysis, Multi-Dimensional Analysis).

Fig. 7. Example of mitigation and adaptation measures that can be introduced to the model in order to estimate their effect.

Indicators for Measures under planning & urban design control (at neighborhood level):

- increase green areas (+m^2)
  - urban tree management
  - installation of green roofs…
- increase albedo with high albedo materials (+m^2)
  - highly reflecting roofing materials (cool roofs)
  - highly reflecting paving materials (cool pavements)
- increase buildings performances (-kWh/year)
  - increase U (+W/m^{2}K)
  - minimum insulation values in building codes
  - efficient light fixtures and appliances
- increase renewables:
  - requirements for wind, solar, geothermal… sources
- decrease use of private cars (-n)
  - ride sharing programs, transit investments, provision of pedestrian and cycling facilities
- change Urban Morphology:
  - buildings mean height (+m)
  - surface to volume ration (+1/m)
  - passive/non passive zones (+n)

8 Preliminary results and considerations

The model showed its potential in providing a system-scale understanding of the inter-relationships between urban temperature and the built environment (urban morphology, land use, energy and mobility), at the neighborhood level. A critical question remains of how useful it will be to have a quantitative estimate of the various contributing factors of UHI. The idea is that analysis of the measures' effectiveness by simulation through the model could lead

to reasonable recommendations and suggestions for policy makers, planners and designers to implement, measure and monitor city response to UHI and climate change effect.

A future development of the project can be anticipated.

Though Milan has smart infrastructures, such as bike sharing (stations and bikes) and network parking stands, that both already collect real time data, there is currently no integrated "monitoring system".

It would be useful and fairly inexpensive to manage the existing smart infrastructure to create a "diffused sensor network for environmental data", such as temperature, to make the smart city a responsive city.

Additionally, real time user data might be collected and managed in order to cover this lack of information inside the city, and help create a crowdsourcing information system.

9 References

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ABSTRACT
The aim of the paper is to show preliminary results of research focused on providing a system-scale understanding of the inter-relationships between climate change effects (specifically, global warming and Urban Heat Islands, UHI) and the built environment (morphology, land use, energy and mobility) and to use this understanding to design cities and territories that are more resilient. Core part of the research are analyzing key factors involved (agents related to the urban surface energy balance) and building a GIS+Digital Urban Model (case study: Milan area) for the (effectiveness and feasibility, synergies and contrasts, smartness and sustainability) assessment and simulation of adaptation measures. Analysis of the results will lead to reasonable recommendations and suggestion for policy makers, planners and designers to implement, measure and monitor cities and territories response to UHI and climate change.