NEW ENERGIES FOR THE CITIES

edited by

Alessandro Rogora and Paolo Carli

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PART II - Evaluation and Modelling Systems, and Tools

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PART II

SYSTEMS AND TOOLS FOR ENVIRONMENTAL EVALUATION, AND MODELLING

Using Open Source GIS to Support Energy and Carbon Flows Accounting in Urban Areas

Matteo Clementi and Marco Migliore

*This text focuses on the potential use of open source geographic information systems (GIS) and open data to develop project support maps, laying the foundation for a georeferenced database geared towards generative environmental design (*GED*).*
Starting from the awareness of the strategies normally used by a natural ecosystem in evolutionary processes, GED is mainly oriented towards the integrated management of the main dynamics that characterize the reference area with the dual goal of maximizing the energy efficiency of the system and at the same time guaranteeing circularity, basic conditions for achieving a zero emissions balance at the local scale.
To support the pursuit of these strategies, design tools should on the one hand help to know and map the salient features of the territory, and on the other understand the dynamics related to the main activities of the settled community. In particular the area as case study is the Corvetto - Chiaravalle district, in the southern part of Milan.

Introduction

The text briefly introduces a method and related tools useful for supporting regenerative design activities in an urban area. This paper focuses on the potential use of free and open source (FOS) Geographic Information Systems (GIS) and open data in order to develop project support maps, laying the foundations for a georeferenced database oriented to regenerative environmental design.

The regenerative environmental design, starting from the awareness of the strategies normally used by a natural ecosystem in the evolutionary processes (goal functions) (Fath et al., 2001), is mainly oriented towards the integrated management of the main dynamics that characterize a territorial reference area with a twofold goal:

- maximize the amount of local solar energy useful for doing work (Odum, 2006), in the specific case of the anthropized environment, useful for carrying out the main activities that characterize the local territorial metabolism, living and working, feeding and cleaning, transporting and communicating (Baccini, Brunner, 2012).
- ensure and maximize the circularity of matter. In fact, the inclusion of anthropic dynamics in natural dynamics implies maintaining the balance between production and consumption flows and stocks.

Both goals call into question the awareness of the main dynamics relating to local consumption activities and the resources available locally. In particular, the first asks us to verify how much of the solar energy incident in a territorial area defined as local is directly involved in satisfying the local demand for energy and matter.

The second refers to the possibility of understanding and increasing the possibility of locally closing the production, consumption, and regeneration cycles associated with the use of the materials. In particular, the second goal provides for full compatibility between the regenerative cycles of local ecosystems and the dynamics relating to the local anthropized system, consistent with the principles of the Generative economy (Kelly, 2012).

The proposed method is divided into the following steps:

- Retrieval of open data that can be processed via GIS and referred to the local urban context.
- Processing and mapping of cartographic data useful to assess energy and carbon flows (Chrisoulakis, 2015).
- Mapping of specific indicators able to support strategies consistent with the main goal functions of a natural ecosystem.

The contribution presents some of the results of the application of the method to a portion of the urban fabric, in a portion of the south-eastern municipal area of Milan.

In particular, the work presented here intends to support the pursuit of the PGT's themes that strictly refer to the implementation of carbon-neutral strategies (Comune di

Milano, 2020). The term PGT stands for the Italian acronym for Territorial Governance Plan, the tool that regulates building activity within the municipality of Milan.

The area under consideration is a portion of the urban fabric that delimits the southeastern part of the Milan municipality near the Southern Agricultural Park of Milan, in particular Corvetto, Porto di Mare and Chiaravalle neighborhood.

Notes on the territorial governance (PGT)

An approach oriented to regenerative planning foresees an attitude of the designer and of the political decision-maker oriented not only to maintaining the cycles of local ecosystems but to improving their functioning. The Territorial Governance Plan approved in 2019 by the Municipality of Milan approaches this strategy by adopting some simplifications in order to make the law applicable immediately. The initiatives promoted refer to the accounting of carbon flows and water management in order to associate energy-saving strategies with reactivation strategies of local natural ecosystems. In particular, the PGT goals are aimed at ensuring that the building interventions subject to authorization are aimed at reducing and balancing CO_2 emissions and at the same time improving the functioning of local ecosystems. This second goal is achieved through the creation of incentives that favor the increase of vegetated and permeable surfaces and at the same time the creation of new green areas financed with compensation processes. These compensation processes are adopted if the building design does not comply with the requirements imposed by the law and are aimed at financing projects within the municipal area to enhance local natural ecosystems. The inclusion of new renaturalized areas provides the opportunity to increase the networks of relationships and also to encourage the involvement of the inhabitants and the flows managed by their activities in the dynamics of local ecosystems. While such strategies would increase local circular flows of matter on the one hand, on the other hand, it would allow associating strategies for emission reduction to the involvement of local manpower in these regenerative processes.

This text explores the possibilities offered by thematic maps created with FOS software and open data in the quantification and communication of such information to support strategies oriented to carbon-neutral scenarios. In particular, it does so starting from what has already been proposed within the PGT to understand how these thematic maps can support the strategies promoted in the PGT and at the same time support administrations and designers in identifying systemic aspects that can support the triggering of local micro-economies based on the regenerative cycles of sustainable territorial metabolism.

The themes of the PGT that strictly refer to the implementation of carbon-neutral strategies applied to new and existing buildings are:

1. Solutions with high-energy performance
2. Renaturalization interventions

3. Technologies for reduced water consumption and the reuse of rainwater
4. Use of sustainable and/or recycled content materials
5. Adoption of surface finishes with a high solar reflectance coefficient (Floors, Roofs)
6. Solutions for sustainable mobility

The following paragraphs illustrate how thematic maps developed with open source and local open data GIS sw can support the application of these strategies.)

Free Open Source FOS GIS

The current development of the open source software allows to carry out operations of equal complexity compared to the proprietary sw and at the same time gives the possibility of using complex data even to actors who cannot purchase a proprietary sw such as local administrations, especially minor ones, and designers who are not directly involved in urban planning. These tools represent an important opportunity to process and communicate information to support decisions aimed at both planners and local administrations. The open source feature of these tools allowed the creation of specific institutions and related websites that report news relating to the current level of development of such tools, such as the Open Geospatial Foundation (https://www.osgeo.org/). Among the open-source GIS tools made available, the elaborations of this work used Quantum GIS (https://www.qgis.org) and GRASS-GIS (https://grass.osgeo.org).

Available Open Data

The main georeferenced data available identify three main types of cartographic documentation:

- R1 - vector maps elaborated from aero-photogrammetric surveys, which show the geometry of the buildings, the relative heights of the eaves, and the different land uses (Figure 2).
- R2 - vector maps of census blocks that store data relating to the resident population and the present work activities (Figure 1).
- R3 - Lidar surveys at a resolution of 1 meter per pixel that add additional information to the geometry of existing buildings and greenery, in particular trees and roof geometries (Figure 3).

Tools to support the choice of high-energy performance solutions

The following is part of this set of strategies:

- all interventions related to increasing the energy performance of the opaque and transparent envelope;
- interventions on improving the energy efficiency of thermal systems;
- the installation of devices for the production of energy from renewable sources.

FOS GIS and open data can support the first and third set of strategies, in particular, namely ‘interventions related to increasing the energy performance of the opaque and transparent envelope’ and ‘the installation of devices for the

Figure 1: Limits of the area considered in this work, in white the polygons of the various census blocks.

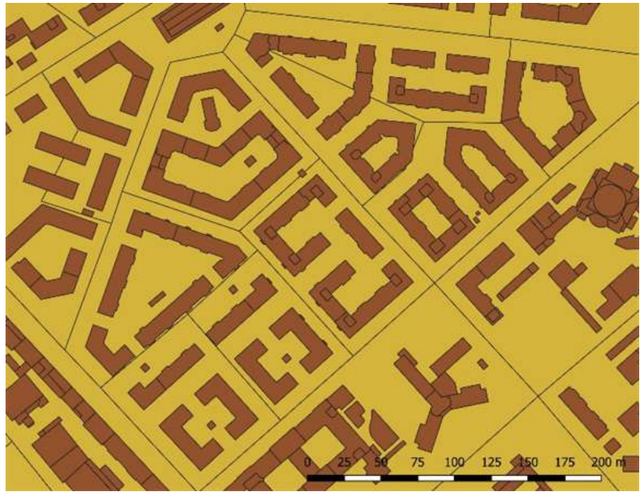


Figure 2: Portions of the area considered in this work, in brown polygons related to the volumetric units of the buildings, in light brown census blocks polygons.

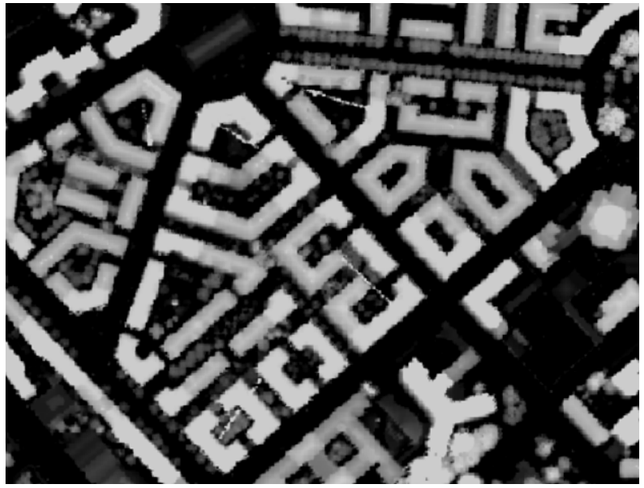


Figure 3: Lidar model of the same area, resolution of 1 pixel/m2.

production of energy from renewable sources'. As regards the first, it is possible to map data relating to the shape of the building useful for estimating the energy needs of the building and for a summary assessment of the possibilities of intervention on the building envelope. Starting from the data relating to the aerial photogrammetric survey of the built urban area, made available by the Municipality of Milan, it is possible to associate specific indicators to the polygons relating to the individual buildings, summarizing information on the geometry of the building and urban form (Morganti et al, 2021).

This information, together with what has been made available by Istat (the Italian National Institute of Statistics) (ISTAT, 2022) relating to the population and housing census, allows for a preliminary assessment of energy consumption and, in the hypothesis of use of natural gas, the related CO_2 emissions and to publish such information in thematic maps to support political decision-makers and the designers. Those data can be associated with three different spatial scales using GIS:

- the volumetric unit of the buildings, or the polygon representative of the profile of a portion of the building characterized by the same eaves height;
- the building, the ground profile of a single building that includes multiple volumetric units;
- the census section, a portion of urbanized territory that includes both buildings and open spaces and constitutes the highest resolution at which the open census data on population, housing, industries, and facilities are made available.

Starting from what can be read and processed through FOS GIS, it is possible to create specific thematic maps that publish significant data on the shape of buildings and the relationships between them and outdoor areas:

- the number of vertical surfaces exposed to the outside (Figure 4);
- the combination of TM1 with data relating to the number of inhabitants associated with each census block makes it possible to map the availability of different amounts of building surfaces per person to assess the per capita weight of building efficiency measures;
- building shape indicators such as the Exposed Surface to Volume ratio ES/V.

Maps of the building's energy consumption, if combined with information relating to the type of energy sources, can be used to assess the CO_2 emissions into the air associated with building energy consumption.

Local availability of solar energy

The availability of information relating to the height of the volumetric units of the buildings together with the data relating to the orography of the terrain allow you to use FOS GIS to create a high-resolution Digital Elevation Model. These are raster maps in which a pixel corresponds to a square surface of 0.5 m side which represents in the form of gray tones the different heights of the artifacts present in the analyzed urban area. Starting from this model it is possible to represent particular urban form indicators as the Sky View Factor (Figure

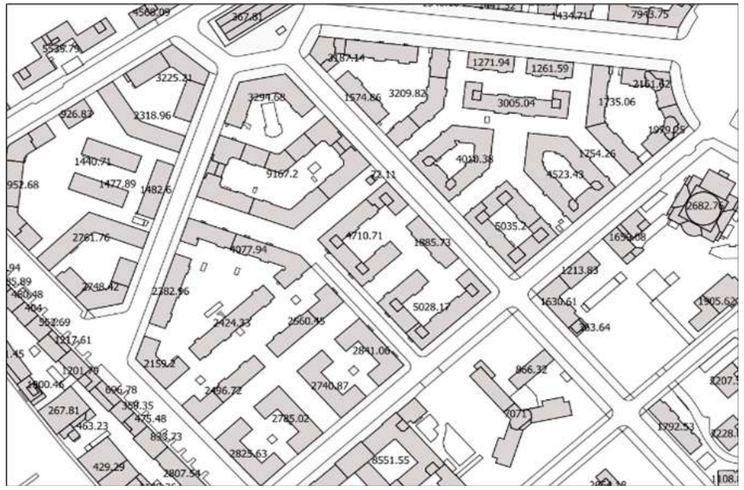


Figure 4: Amount of building vertical surfaces exposed (m^2/building).

Figure 5: Digital Elevation Model of the area, 1 pixel side equal to 0,5m.

5) and then proceed with the mapping of the incident solar radiation (Hofierka, Suri, 2002) (Figures 6, 7, 8).

This processing allows the creation of various types of thematic maps:

- mapping of solar radiation on the horizontal plane to associate production capacities with the building's rooftops;
- mapping of solar radiation on the horizontal plane, at different heights from the ground, to estimate the possibility of installing solar collection devices on the building's facades;
- mapping of solar radiation on open spaces.

This processing allows to create various types of thematic maps, for instance:

- direct solar radiation mapping on the horizontal plane to associate production capacities with the building's rooftop and outdoor areas (Figure 6, 7) (all the maps refer to the average daily monthly irradiation);
- direct Solar radiation available per person on rooftop and outdoor areas for each census block.

Furthermore, by using lidar surveys, the georeferenced database (DOGD) is enriched with important new information such as the geometric configuration of the existing roofs and trees. These data are of fundamental importance to developing maps of the local renewable potential from solar energy. At the current state of the study, the elaborations carried out on

Figure 6: Sky View Factor map of the chosen area.

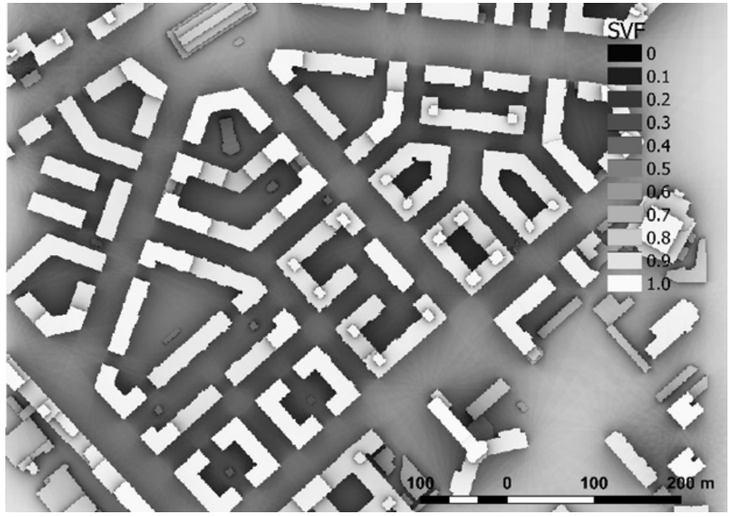
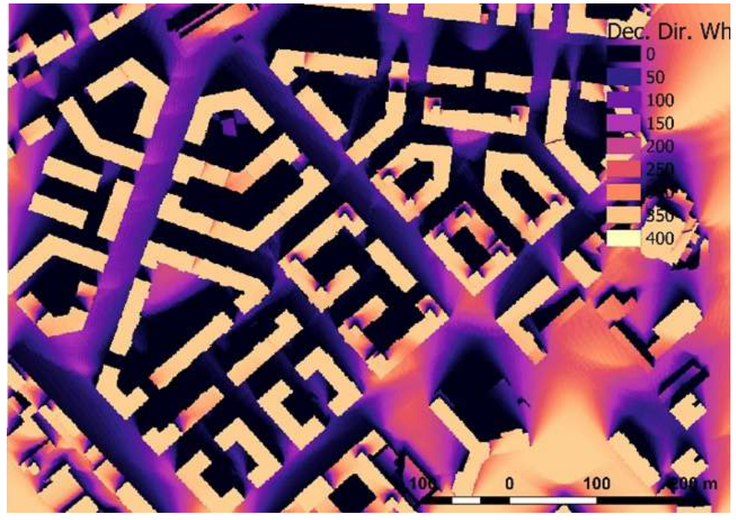


Figure 7: Direct solar irradiation representative of an average day in December (Wh/m²*day).



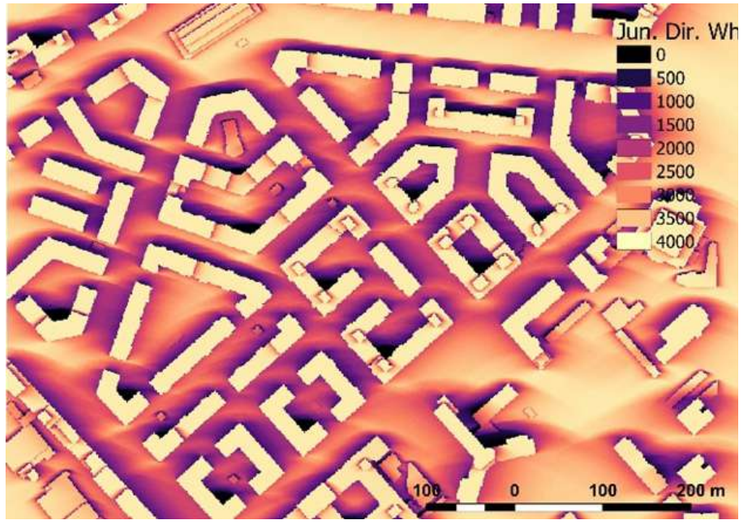


Figure 8: Direct solar irradiation representative of an average day in June (Wh/m²*day).

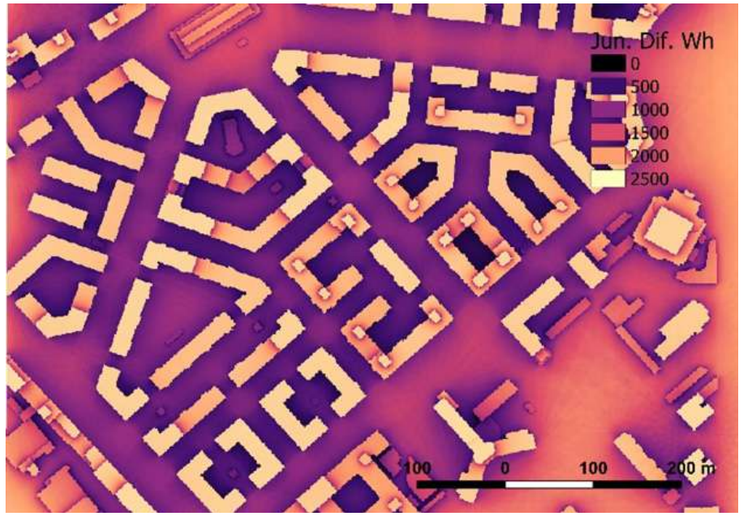


Figure 9: Diffuse solar irradiation representative of an average day in June (Wh/m²*day).

the lidar model have proved to be very effective in detecting the geometric consistency of the trees. As for those conducted on the roof coverings, they were found to be unusable due to the low resolution of the maps, 1pixel/m², they require future further elaborations, such as increasing the resolution in post production to one pixel/0,5 m (Figure 10, 11, 12).

Tools to support the choice of renaturalization interventions

The mapping of solar radiation on the ground, on the roofs, and on the facades can support the choice of herbaceous or tree species to be cultivated and the effective possibility of absorbing CO_2 based on the available energy. To facilitate the application of this strategy in the PGT, the green vegetated surface is currently associated with the ability to absorb annually 6 kg of CO_2 per square meter, and a tree with 50 kg of CO_2. Indeed, this capacity depends on the size of trees,

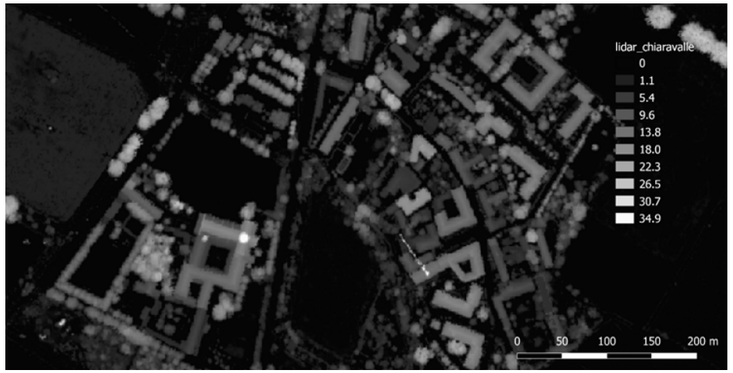


Figure 10. The portion of the lidar survey relating to the Chiaravalle area, the resolution is equal to 1pixel/m²

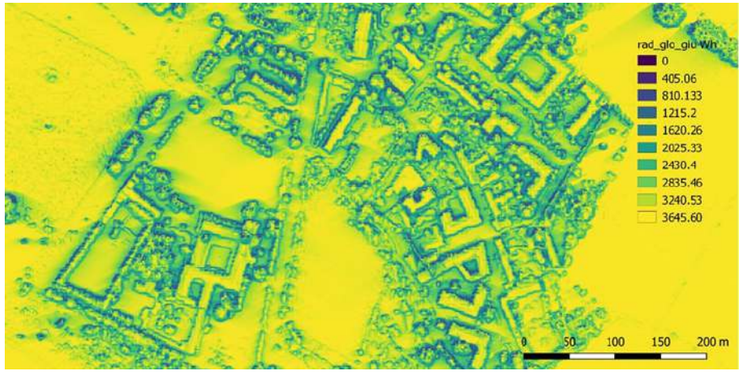


Figure 11. Map of global solar irradiation processed on a 1pixel/1 m² lidar survey, relative to a day in June.

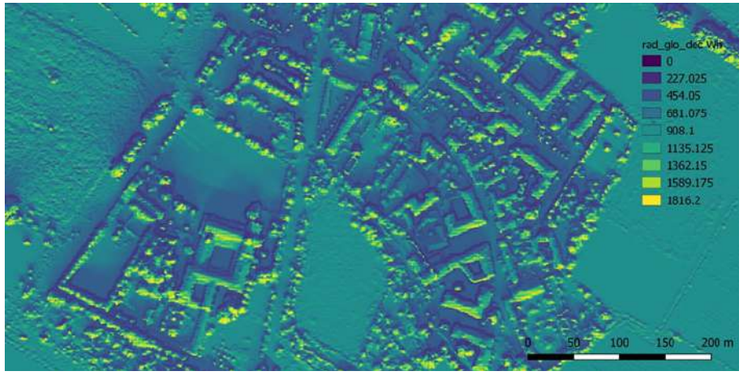


Figure 12. Map of global solar irradiation processed on a 1pixel/1 m² lidar survey, relative to a day in December.

Figure 13: Lidar map relating to tree volumes. To reduce the inaccuracies due to the low resolution, buildings have been eliminated from the map by using a mask increased by a buffer zone of 3 meters. To reduce some defects detected at higher altitudes, the interval from 1 to 20 m from the ground has been considered (the white parts of the trees refer to volumes above 20 m).

the availability of solar energy as well as on the availability of water and nutrients. Useful information on the geometric configuration of the trees can be mapped through the use of lidar surveys. Mapping of solar radiation on the ground and the roofs can support the choice of herbaceous or tree species to be cultivated and the effective possibility of absorbing CO_2 based on the available energy. The mapping of solar radiation conducted starting from these surveys also allows for identifying possible areas suitable for urban agricultural production, from planting fruit trees, installing productive green walls, rooftop agriculture devices, and other urban agriculture interventions that can favor the start-up of local productive activities.

Maps on local availability of rainwater and useful wastewater

The amount of rainwater incident monthly on roofs and open spaces represents important information in the choice of low energy-consuming strategies oriented not to use drinking water from the aqueduct. Making this information available requires associating information relating to the quantity of rain incident monthly and annually on the roofs and to the geometric data made available by the aerial photogrammetric survey relating to buildings and open spaces. This climatic data is made available by the local municipality and ARPA (Regional Environment Protection Agency) and refers to data representative of the annual average and data relating to extreme events (representative of the possibility that an extreme event occurs in a multi-year interval of time usually 20, 50 or 100 years). In the case of the data referring to the

Figure 14: Amount of organic waste emitted from each census block each year.

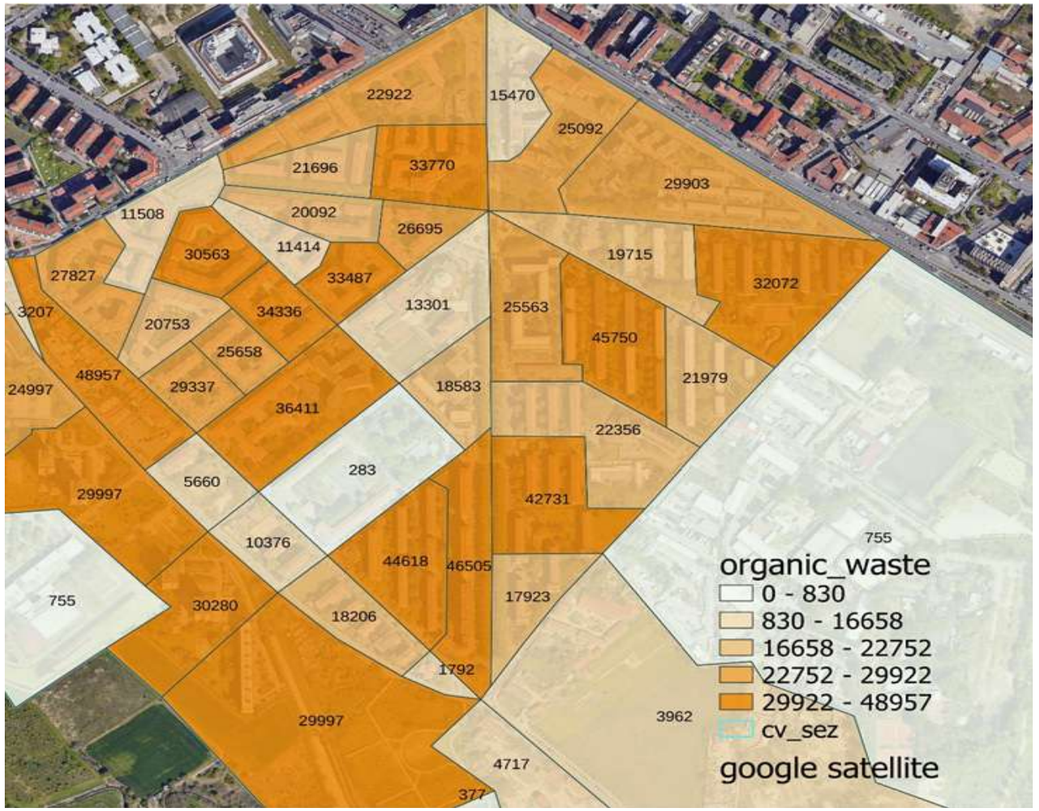
monthly average, the open data portal of the municipality of Milan reports the monthly average of the atmospheric precipitation values (Comune di Milano, 2021). The data show an average annual quantity equal to 1006 mm, with monthly average values that fluctuate depending on the month from 50mm in August to 100mm in April, except for November where values around 170 mm are recorded.

Maps on the amount of carbon and nitrogen emitted through organic waste

Another aspect in which a systemic approach to design favors the implementation of carbon-neutral strategies is related to the possibility of locally producing nutrients. Buildings regularly export nutrients in the form of metabolic waste and organic waste. In the second case, the local treatment of the green component of organic waste would provide a contribution to the ability of local ecosystems to absorb CO_2, both in the soil and in the metabolic activity of plants (Chrisoulakis, 2015). Starting from the number of inhabitants associated with the census block, it is possible to map the potentially emitted flows of organic waste and therefore of the relative nutrients (starting from carbon and nitrogen flows).

Tools to support the applications of technologies to reduce water consumption and for the reuse of rainwater

In the specific case of the rules underlying the accounting of carbon flows associated with the PGT of the municipality of Milan, the CO_2 emissions include the emissions associated



with energy consumption for water supply and wastewater disposal. Mapping rainwater availability makes it possible to use these flows not only for irrigation but also to reduce the consumption of drinking water from the aqueduct. To

Figure 15: Quantity of water captured annually by the roof divided by the number of inhabitants present in the census section (unit of measurement, cubic meters/ person per year).

understand the precise effectiveness of this solution it is important to compare the capture capacities of roofs and waterproof open spaces with the mapping of water consumption per building. These types of maps can be elaborated starting from the number and characteristics of the inhabitants associated with each census block.

About Locally available rainwater, making this information available, requires associating information relating to the quantity of rain incident monthly and annually on the roofs to the geometric data provided in the aerial photogrammetric survey relating to buildings and open spaces. This information refers to data representative of the annual average and data relating to extreme events not representative of the average but representative of the possibility that an extreme event occurs in a multi-year interval of time usually 20, 50, or 100 years. In the case of the data referring to the monthly average, the open data website of the municipality of Milan reports the monthly average of the atmospheric precipitation values (Comune di Milano, 2022). Rainfall was measured in the urban area of Milan between 2008 and 2014, with values ranging from January 2008 to December 2014.

The mapping of rainwater availability makes it possible to use rainwater not only for irrigation but also to reduce the water consumption from the aqueduct. To understand the precise effectiveness of this solution it is important to compare the capture capacities of roofs and waterproof open spaces with the mapping of water consumption per building. As in the

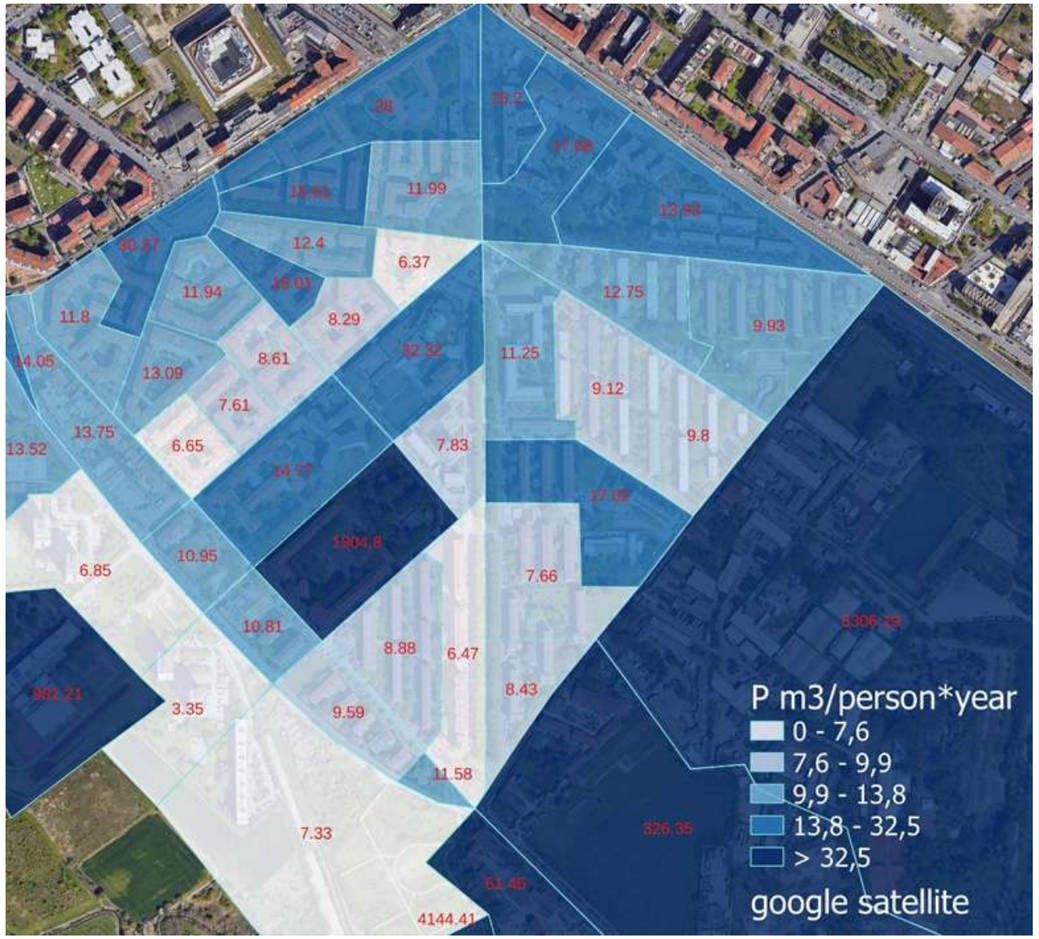


Figure 16: Maps of annual flows of polymeric waste from dwellings by census blocks.

case of solar energy mapping, starting from data concerning the climatic variables (in this case the pluviometry in the different months of the year), it is possible to enrich the database with information to support the design process. In particular maps about the amount of rainwater incident monthly and yearly on roofs and open spaces.

Tools to support the use of sustainable or recycled materials
The possibility of locally producing sustainable or recycled materials presupposes the mapping of possible emission flows of waste material from local production and residential activities. This availability of information could give rise to local collection and processing workshops. Among municipal solid waste, paper and textile waste could find use as building insulating material together with straw produced by peri-urban agricultural activities. Polymeric materials would find an interesting use in the construction of support devices for urban agriculture (for example tanks for cultivation and water storage).

Tools to support strategies for sustainable mobility
The thematic maps to support the application of these strategies at the current level of development include the availability of open spaces per person in the different census blocks (for bike parking and mobility). The reduction of CO_2 emissions is correlated to the per capita reduction of daily impacts and quantified in terms of avoided kilometers, a significant data is the availability of parking spaces per person. If these spaces coincide with those most affected by

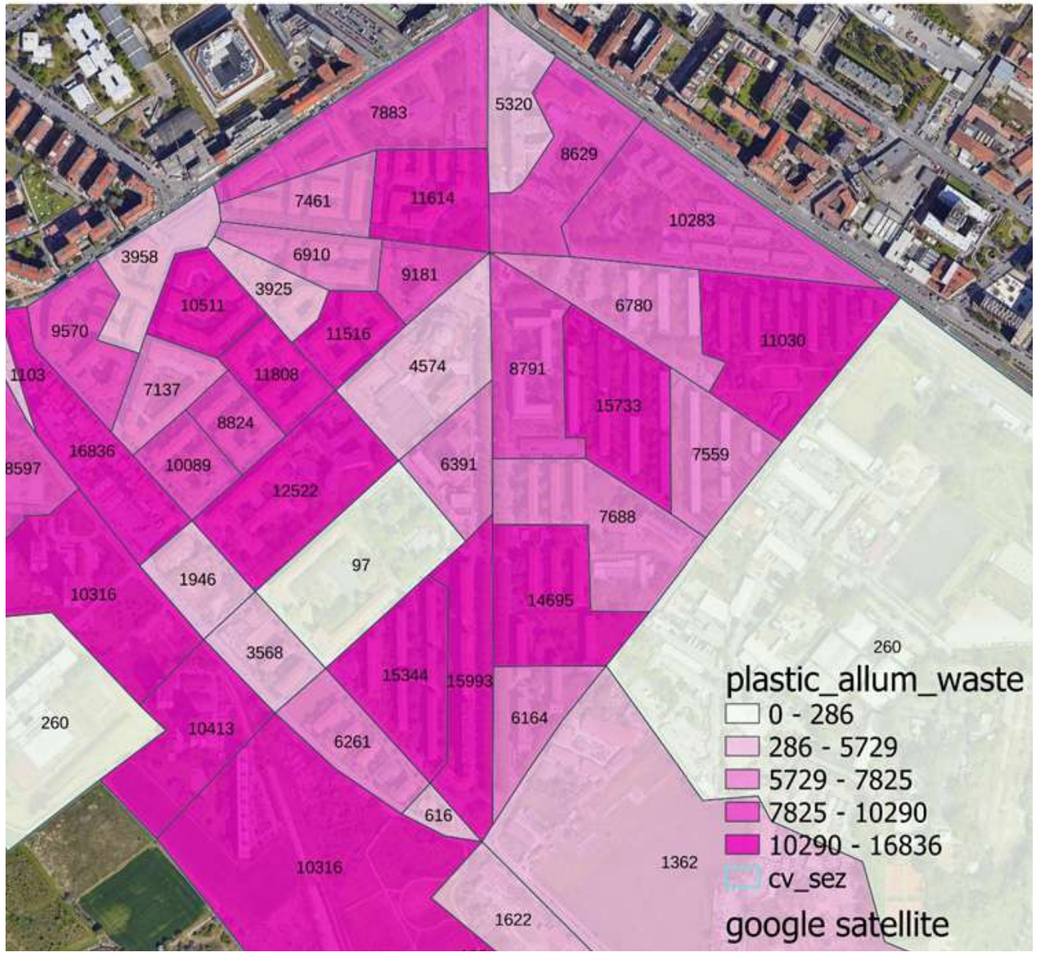


Figure 17: Maps of annual flows of paper waste from dwellings by census blocks

solar radiation then they could be suitable for the installation of photovoltaic canopies or photovoltaic pergolas suitable for generating shade and at the same time producing electricity for mobility.

Conclusions

The coexistence on the same GIS of different types of information, through the thematic maps developed to date and under development, has revealed the usefulness of associating to census blocks data relating to the local territorial metabolism. The information on local supply of energy and matter and on the local demand finds in the quantification per person a functional unit of reference capable of carrying out trans-scalar balances, both at the block scale, represented by the boundaries of the census blocks, and at a larger scale through the aggregation of the data associated with each block. The provision of this data on the same gis support allows for the development of scenarios relating to the possible activation of local circular micro-economies. A fundamental condition for local micro-economies to be activated is the possibility of intercepting existing spending flows, these dynamics are activated in the first place by the daily life of the established community, for example by the expenses for winter heating, together with the expenses for transport and food supply. The intention to intercept local spending flows further opens up the possibilities of intervention to reduce CO_2 emissions linked to lifestyle, giving the possibility to act on buildings and open spaces to reduce the energy consumption of buildings but at

the same time reduce the impacts of mobility and nutrition. In the latter case, the design of the vegetated spaces plays a multiple role, on the one hand, it favors the absorption of CO_2, on the other it lends itself to the activation of local production/consumption flows that can be promoted by local cooperatives, oriented towards the local management of nutrients and local food production.

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Social Acceptability of Technical Solutions and Role of Human's Behavior

Alessandro Rogora

Technology is important to reduce human impact on the planet, but changing in personal behavior is necessary and much more effective. People hardly accept to modify their lifestyle and the difficult to evaluate the impact of personal behavior is used as an excuse not to change anything.
The research TRACES was focused on the idea was that there is no chance to arrive at sustainability if people do not deeply change personal behavior.
The research TRACES is based on a game-based learning approach in which collaborative approaches and digital technologies support the performance response of design actions in building carbon neutral housing scenarios. TRACES can be played both at the Urban (or Community) level and at the Building (Personal) level referring to a building or a group of buildings in which a limited number of people can play in person. It is structured into six 'impact sections', with some subsections: **clothing**, **mobility**, **food**, **home** *(heating and cooling, electricity, domestic hot water, cooking),* **leisure** *and* **communication**, **others** *(education, health, and services), for each section impact values are given in terms of* m^2 *of surface area used and amount of* CO_2 *emitted.*
In these years the research project TRACES has revealed a great deal of growing potential even if the attempt to simulate the entire impact of our behaviors requires a significant work to reduce the complexity in analysis and communication.

Urban settlements are constantly increasing, and we are approaching a point where over half the human population will live in cities. This human concentration gives rise to complex problems, ranging from pollution to difficulties providing resources to sustain the inhabitants' lives. This situation results in low resilience of urban settlements to events that may affect the territory and the settled society. The complexity of consumption patterns and the flows of energy and matter in transit (inflows and outflows) require a profound rethinking compared to the past, as these flows differ in magnitude and complexity. This book, New Energies for the City, represents an initial attempt to reflect on the complexity and specificity of urban metabolism, as well as on potential solutions to address and transform the identified critical issues into possible elements for mitigating problems. New Energies for Cities explores the challenges and opportunities related to the transition towards more sustainable and resilient cities, with particular reference to Milan.

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