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Mapping the city's trajectories to cool the city and better resist heat waves

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Abstract: During the months of July and August 2021 and 2022, numerous climatic disturbances such as heat domes in Canada, floods and landslides in Belgium, Germany, Turkey, China as well as giant fires in Russia and Greece have marked the news and people's minds. Climate inertia and the complexity of changing the world's energy model make it necessary to adapt territories to limit the impacts of the changes that are underway. However, if the speeches on the urgency to act to cool the cities have become omnipresent, the implementations of solutions seem limited, and some territories even seem to be going in the opposite direction by massively artificializing the edges of urban areas. The objective of the FreshWay research project is to identify and analyse planning and implementation on the ground to combat summer heat waves and to represent the adaptation trajectories of cities. The first information that is questioned is the evolution of urban vegetation insofar as plants provide shade and allow cooling through the process of evapotranspiration. The paper presents the required information and the data model, cases study, the process to integrate data, the choice of indicators and the construction of trajectories from different perspectives for the municipality of Castelnau-le-lez, Sarcelles and Pontault-Combault, and at different level of details.

Keywords: trajectories, adaptation, heat waves, semiology, design

1. Introduction

During the months of July and August 2021 and 2022, numerous climatic disturbances such as heat domes in Canada, floods and landslides in Belgium, Germany, Turkey, China as well as giant fires in Russia and Greece have marked the news and people's minds. Climate inertia and the complexity of changing the world's energy model make it necessary to adapt territories to limit the impacts of the changes that are underway. Adaptation of territories, combined with imperative efforts on mitigation, is therefore an essential strategy to maintain the quality of life of living beings (humans, fauna and flora) and limit the costs linked to the disorders caused by these events. This requires improving alert and crisis management systems (fires, heat waves, floods, hurricanes, health crises), but also urban, peri-urban and rural developments which should make it possible to reduce the effects of these repetitive crises and to adapt the territories to the climates of the future. Well aware of these challenges, the states are establishing laws, regulations, labels and standards to steer the transition. The regulations evolve over time and in the end the action is taken at the local level, in the local communities and by a set of actors, including private actors through the implementation of development projects. However, if the speeches on the urgency to act to cool the cities have become omnipresent, the implementations of solutions seem limited, and some territories even seem to be going in the opposite direction by massively artificializing the edges of urban areas.

The objective of the FreshWay research project (https://www.laburba.com/recherches/freshway/) is to identify and analyse planning and implementation on the ground to combat summer heat waves and to represent the adaptation trajectories of cities. Municipalities were chosen to the east of Paris and in the south of France, in Occitanie, to study the evolutions of city planning and implementations over the last 20 years.

At the digital level, the aim of the project is to spatially represent the cooling solutions of the urban space and their evolution over time. The first information that is questioned is the evolution of urban vegetation insofar as plants provide shade and allow cooling through the process of evapotranspiration. The evolution of urban vegetation is particularly important because it is the result of a desire for revegetation and destruction for housing and economic development needs. Other small-scale implementations such as shade structures, fountains, water features, Oasis courtyards (vegetated schoolyards) or cooling networks are also studied and mapped because they contribute to the creation of cooling islands.

Beyond the constitution of the geographic data support from existing data bases - sometimes below the selection threshold of the databases in the case of isolated trees - we propose urban cooling indicators and their standardization in order to be able to compare cities of different sizes. We also propose a data model to represent planning and achievements by integrating the indicators that will be used to represent the adaptation trajectories of the studied municipalities.

The paper presents the required information and the data model, our cases study, the process to integrate data, the choice of indicators and the construction of trajectories from different perspectives for the municipality of Castelnau-le-Lez, Pontault-Combault and Sarcelles.

2. From characterisation to data model

The objective of the project is to study the trajectories of cities in terms of urban cooling. This includes two aspects: the planning of cooling measures and the evolution of the capacities of the territory, that is to say what in the territory makes it possible to fight against urban heat. The notion of territorial capacity makes it possible "to take into account the ecological potential of the territory, the capabilities being linked to the resources that should be activated within the territory" (Buclet and Donsimoni, 2021). The study of trajectories therefore aims to analyse the evolution over 15 years of urban planning and the capacities of territories in favour of the fight against summer heat.

In this paper we focus on planning and capacity elements that have a spatial footprint, so we will not represent, for example, planned budgets, studies, training, communication, which also participate in the fight against urban heat.

Many studies identify the types of cooling solutions (Santamouris, 2014); (Bernard et al., 2020). They are often classified as green or grey solutions. In our project we are studying vegetation, water bodies, shade structures, choice of high albedo coatings as well as fresh benches and cooling networks.

Urban climate models such as TEB (Lemonsu et al., 2012) model the space in the form of meshes in which the percentages of vegetal soil, buildings, impermeable soil, permeable soil and water surface are described, to which the tree canopy surfaces are added. Indeed, in the computation of heat balances, the more mineral a city is, the warmer it is. We will therefore calculate the evolution on the vegetation ground surfaces, water surfaces, permeable soils, all of which are favourable to urban cooling, compared to the evolution of mineral surfaces - built and impermeable – which are unfavourable to urban cooling. We also calculate the evolution of the canopy surface of trees.

At the planning level, we look at what, in the local urban plan, protects green and blue spaces compared to the proportion of spaces dedicated to housing and activity zones. We also look in these areas, dedicated to housing and activities, the minimum percentages of surface 1/ unbuilt and 2/ in open ground. The evolution of these quantities will be relevant of the planning trajectories for fighting against summer heat.

The data model we propose (Figure 1), composed of planification part and an urban space part, allows us to describe this information which will allow us to calculate and represent trajectories when we have these data at different temporalities.

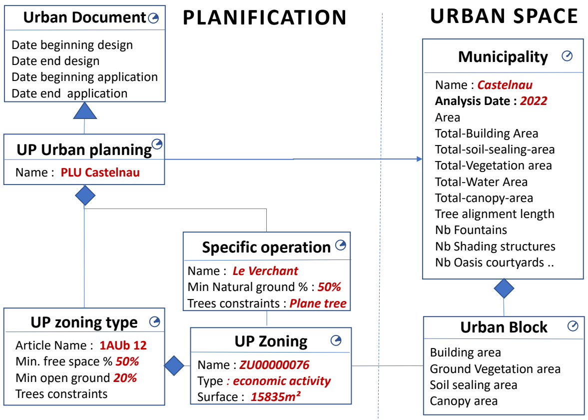

Figure 1 Data model to describe the planification and the urban cooling capacity over time.

3. The case study

In the FreshWay research project we plan to work on different cities. In this paper, we limit ourselves to presenting, as an illustration and as first results, some neighbourhoods of three cities: Castelnau-le-Lez in the south of France, Pontault-Combault in the east of Paris and Sarcelles in the north of Paris.

3.1 Castelnau-le-Lez

Castelnau-le-Lez is a medium size city at the border of Montpellier in south of France with approximately 20 000 inhabitants. In the past very focused on agriculture, Castelnau-le-Lez is now a land reserve for Montpellier, even if some vineyards have been preserved. The construction of a tram line in 2006 linking Castelnau-le-Lez to the centre of Montpellier has transformed the city, which has become very dense. We choose as an illustration a district along the construction of the tram (figure 2).

Figure 2. A district of Castelnau before the tram (2005) and 15 years after the tram (2021). © IGN Géoportail

In the space illustrated in figure 2, the urban plan (PLU) has been modified along the tram line authorizing the construction of 3-storey buildings. Fifteen years after the change of PLU, the space has changed almost completely without any constraints being imposed.

3.2 Pontault-Combault

Pontault-Combault is a town 20 kilometres east of Paris with approximately 39,000 inhabitants. It is located at the edge of the Parisian peri-urban area, it is still surrounded by many fields. Its study is interesting because it is in the process of urbanization and is gradually encroaching on its surrounding agricultural reserve (figure 3).

Figure 3. A district of Pontault-Combault 2008 – 2022 © IGN

3.3 Sarcelles

Sarcelles is a town 16 kilometres north of Paris with around 60,000 inhabitants. Sarcelles is characterized by large ensembles, but still has some natural spaces. Sarcelles has the reputation of being a green city, even a city-park. We will see how the situation has evolved in recent years.

Figure 4. A district of Sarcelles 2008 – 2021 © IGN

4. The data source and the data acquisition

4.1 Urban planning data

The local urban plan (PLU) is available in the form of a set of descriptive documents in each town as well as maps. An urban planning geoportal was created in 2015 (www.geoportail-urbanisme.gouv.fr). This portal lists urban planning areas with links to associated planning documents. The outline of the zones is compatible with the IGN topographic reference data, the BDTopo, which facilitates its use. For our project we load the urban planning data and calculate the protected surfaces over time.

4.2 Topographic data to describe the cooling capacity of cities

As described above, we wish to account for the evolution of the mineral and non-mineral parts of each territory studied. More specifically, we seek to count the quantity of built surfaces, paved or soil sealed surfaces, hydrographic surface, surface of ground vegetation and canopy surface. We use the IGN's BDTopo, which is the French reference for topographic data and which also provides vintage data, which makes it possible to study the evolution of the territory. We can therefore have the BDTopo on the two dates studied.

The figure 5 of the BDTopo compare to figure 2 illustrates the fact that if the BDTopo is perfect for the description of buildings and roads, on the other hand the description of the vegetation, whether on the ground or in the canopy, is very insufficient for climate studies (Bétou et al., 2022). This is due to the data base specification thresholds which do not make it possible to retain small surfaces, even if they are perfectly visible on the aerial images (figure 2).

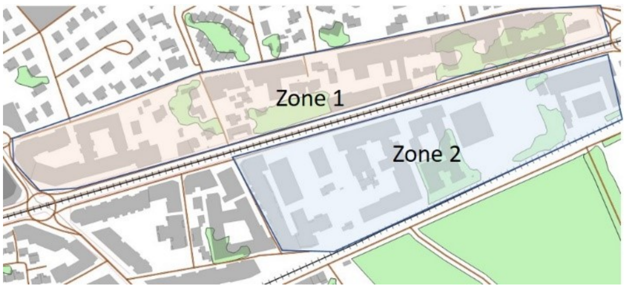

Figure 5. Extract from BDTopo 2021 on Castelnau-le-Lez © IGN

We have therefore chosen to identify the main areas of change for each city and to digitize the ground vegetation and the canopy surface for each of the cities studied. This work is easily done thanks to the BDTopo and the images of the geoportal but remains time-consuming. In the following we compare the information given from the BDTopo on the entire city with the information, more accurate, acquired for the most changed districts in terms of land use.

4.3 Other data

In the project we intend to compare the specific cooling solutions emerging between 2005 and 2020 such as shading structures, fountains, oasis schools or cooling network. This step requires information gathering work in

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the field which is not yet complete so we do not present it in the paper, but it will also constitute important indicators for our project.

5. The result

We present below the first results of our project at three levels of granularity. We use data from Castelnau-le-Lez to illustrate the results at the scale of two zones (two urban block) of change, data from Pontault-Combault to illustrate the aggregation of changes from the seven zones studied at the scale of the municipality, and data from Sarcelles to illustrate the changes at the planning level.

5.1 Castelnau-le-Lez : focus on two zones along the tram

For Castelnau-le-Lez we have chosen two neighboring areas, along the tram, which have been disrupted by the impact of the construction of the tram and the modification of town planning rules. The two zones, illustrated in figure 2, took 15 years to be modified: the tram was built in 2006 and the PLU written in 2006, authorized the construction of 3-storey buildings in the zones connected to the tram with a mandatory percentage of open space of at least 20% of the area and at least half of it (10%) in open ground. No sale obligation existed, but the profit from the sale encouraged the owners to gradually sell their land and real estate developers built the buildings within the authorized construction limits. 15 years later, the metamorphosis has taken place as shown in figures 6. The ground vegetation has gone from 76.3% to 46.4% in zone 1 and from 59.7 to 13.7% in zone 2. The impermeable/soil sealing surface that remains in zone 2 is a construction zone which is being replaced by new buildings (built in 2022-2023).

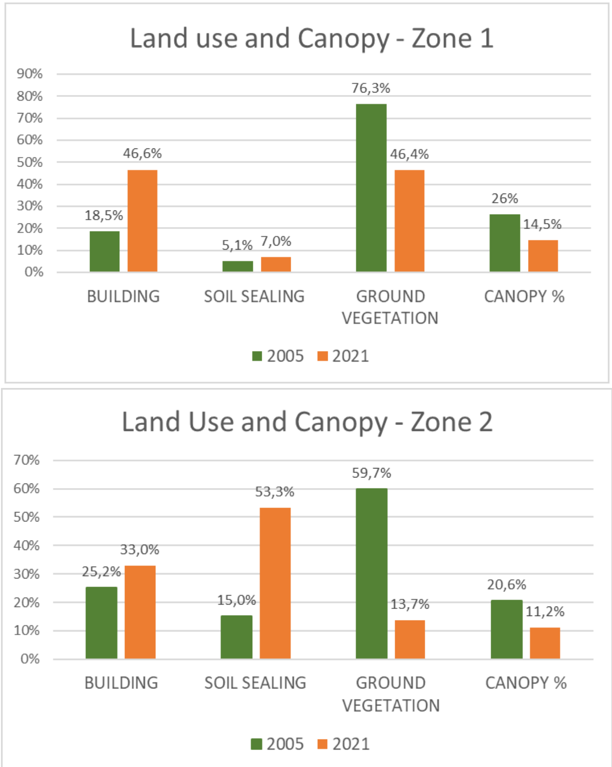

Figure 6. Trajectory of areas along the tram in Castelnau-le-Lez

On these two areas, the city has lost 33300 m² (3.33 ha) of ground vegetation and 9200 m² (0.92ha) of canopy, which is not nothing.

5.2 Pontault-Combault: the analysis of main changes

On Pontault-Combault, we have decided to compare two methods. The first consist to identify the areas that changed a lot during the period form aerial photography, to use IGN BDTopo for buildings, hydro areas and roads and to complete with soil sealing (impermeable data), ground vegetation and tree canopy digitalisation. We consider that the sum of the area of building, soil sealing, hydro and ground vegetation covers 100% of the area, and that canopy is another cover. As canopy tree cover the ground on aerial photography, we estimate with the context if the non-visible soil is a ground vegetation or a soil sealing. For Pontault-Combault, we identifier 7 areas, one is illustrated in figure 3. After digitizing the missing information, we made statistics (figure 7).

These 7 areas were massively mineralized, and plant surfaces were lost on the ground (from 39.1 to 29.6) ha and (from 6.8 to 4.4) ha in canopy.

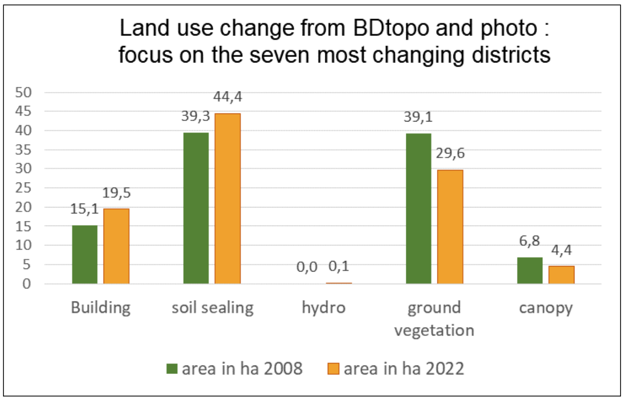

Figure 7 Vegetation loss between 2008 and 2022 from image analysis in 7 areas of Pontault-Combault.

When we use the BDtopo (figure 8) we can also see that the city is more mineral in 2022 than in 2008 since the built surface and the road surface have increased. We can see that the vegetation has slightly receded but less than can be detected when the data is captured more precisely. The theme 'other' represents agricultural areas as well as all surfaces that are not represented by objects in the BDTopo.

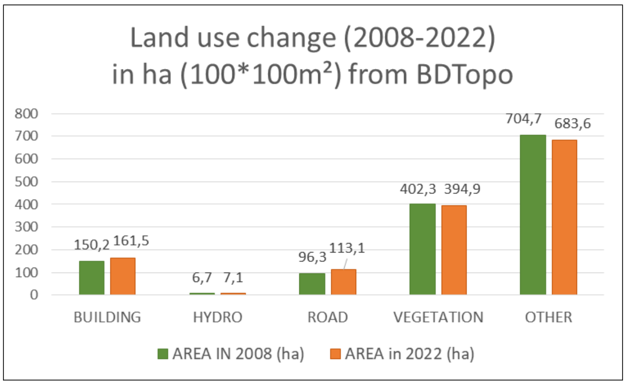

Figure 8 Main evolution of land use changed between 2008 and 2022 from the BDTopo in Pontault-Combault

If we compare the changes in built, hydrographic surfaces, and paved surfaces and vegetation surfaces according to the two methods (limited to the areas that have changed the most from the BDTopo and a photointerpretation of the aerial photos (figure 7) or from the BDTopo over the whole municipality (figure 8)) we can see that, necessarily, we do not obtain the same result since the municipality has changed everywhere, and not only in the 7 selected zones. Nevertheless we also noticed that the evolution of the ground vegetation in the 7 zones is greater than the evolution of the vegetation described in the BDTopo, which clearly confirms the fact that the thresholds used in the BDTopo for the description of the vegetation do not make it possible to compute the loss of vegetation. Indeed in the BDTopo, hedges are selected if they are more than 25m long and less than 20m wide, woods are digitized if they are larger than 500m² are digitized, and between 80 and 500m² it depends on the appreciation of the data collector. Thus our study confirmed that a certain number of wooded areas of less than 500m² are missing from the database. None the less, BDTopo gives the good tendency but minimises the vegetation loss (or gain).

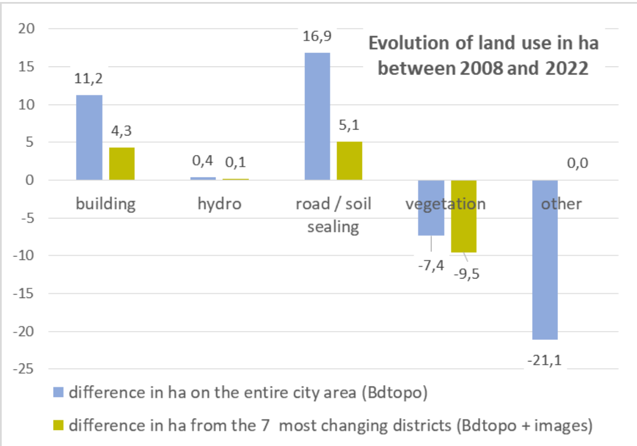

Figure 9 Evolution of land use on the entire city of Pontault-Combault and on the most changing areas.

5.3 Sarcelles: analysis of the evolution of planning

In France, the ground is regulated by planning tools including the PLU, structured by types of land use. Each type has its own regulations that authorize or constrain land use changes and new constructions. Figure 10 illustrates the regulated area for each type for the municipality of Sarcelles. We see that in 2008 the building permit in new available natural or agricultural land is 3.2% of the territory while in 2020, it is 1.7%. There is therefore greater protection of natural and agricultural areas in 2020 than in 2008. On the other hand, we can see that the area of natural and agricultural spaces has decreased from 26% to 23.2% of the territory, i.e. a loss of 24km² (i.e. 2400ha), which is actually a very important loss between 2008 and 2020.

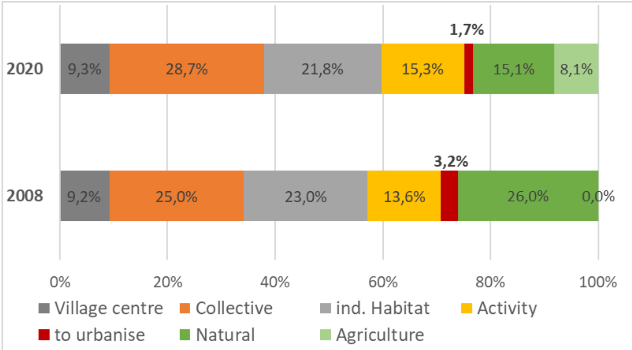

Figure 10. Trajectory of planned areas by type in Sarcelles

Another important component in planning document is the preservation of natural spaces in the municipality, as well as the minimum percentage required in free space and open ground space during new constructions. This percentage is very important because when it is low, the space might be occupied by buildings and impermeable areas. Figure 11 illustrates the transformation of a house into a building in the area of Castelnau-le-Lez (figure 2) with a minimum constraint of free space of 20% and 10% minimum in open ground. The accurate calculation shows that the rule is respected at the minimum: the free space and open ground are reduced to the minimum required by the law. In these configurations, the old trees were all destroyed.

Figure 11 A new building respecting the constraint of 20% free space, the half on open ground.

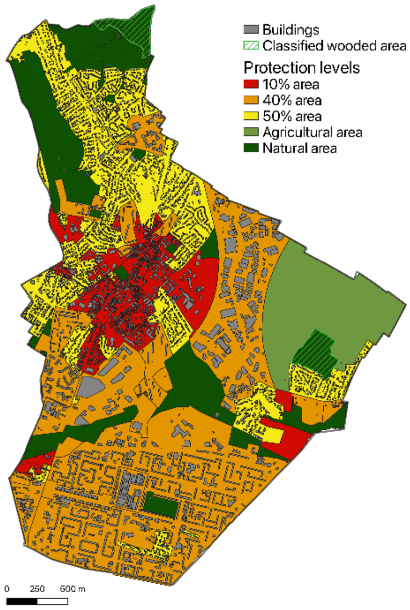

Figure 12 Protected areas and constraint of minimum free space in the PLU-2020 of Sarcelles.

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It is therefore interesting to examine in the PLU the part of the territory protected in terms of open space and open ground. Figure 12 shows the protected surfaces and the minimum percentages of free space and in the ground (open ground area) for the city of Sarcelles. We can see that the current PLU (2020) does not protected much the preservation of free space and open space, even if the head of planning department we met complained about the number of 40 and 50% which – from his view point – limit the development of the city. Another interesting point we still have to study is to compare the mineral density of each area to this percentage of free and open space during time.

6. Conclusion

Climate change is now threatening our societies and it is urgent to join forces to reduce greenhouse gas emissions but also to adapt our territories to the effects of these changes. The world, and in particular Europe, is facing an increase in the duration and intensity of heat waves. The use of intensive air conditioning, if unavoidable, should be avoided as much as possible so as not to accelerate warming. One of the urban adaptation is to find solutions to limit urban heat, to offer islands of freshness. Vegetation is identified as a practical solution, without regret, because it offers a set of services including that of creating shade and cooling by evapotranspiration. Other solutions are identified as the addition of shading structures or the installation of energy-efficient fresh network.

The objective of the FreshWay project is to understand and map the trajectories of cities in their consideration of the needs to combat summer heat. From the analysis of several territories, we propose to analyse, on the one hand, the local planning but also to count concretely on the ground the implementations of refreshing solutions and the evolution of the mineral part, which participates in the warming of the city and the quantity of permeable, hydrographic and vegetal soils which participate in evaporation, evapotranspiration and water flow. We also count the tree canopy which contributes to shade and evapotranspiration.

In this paper, we present the first methods that we test and that we apply on different territories from topographic data and urban planning rules. We supplement our analyses with interviews with the services of the municipality and field surveys of small-size cooling solutions that are not included in our databases.

Our first conclusions are that none of the cities we study are taking the right trajectory and that in 15 years the mineral has progressed. This is not surprising, as urban sprawl process is very active in France (Desrousseaux et al, 2018).

The other conclusion is that the French reference database, the BDTopo, is currently unsuitable for the description of vegetation in cities, while the IGN has data (aerial photography) and skills that would allow it to capture this information. However, the use of such data base is already very useful because it makes it possible to identify the progression of mineral surfaces thanks to these vintage database versions.

On-going research work consists of completing the collection of data on the different municipalities and proposing representations of the trajectories, making it possible to show the overall evolutions but also all the implementations which make it possible to go in the right direction.

6.1 Acknowledgements

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