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Proposals for the use of graphical models in urban climatic maps

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Martha Evonuk

We propose applying the chorematic methodology to the processes and issues addressed by the urban climatic mapping framework, i.e., the interdisciplinary discussion and analysis of thematic data, the production of analytic maps, and the creation of recommendation maps to advise urban planners. After introducing the method, its theoretical basis, and its process, we discuss its fitness and present the possibility of its application in this thematic context. We then propose a first series of applications, for diurnal heat stress and nocturnal urban heat island analysis, as an example and basis for further discussions, based on recent work in the Toulouse agglomeration. We also propose graphical models to express recommendations concerning urban climate issues in Toulouse. The process used the choremes table expanded with dynamic models, according to the multi-step method proposed by H. Théry (1988). The produced models are now entering a test phase to discuss the method with urban planners.

Nous proposons d'appliquer la méthode chorématique au processus et aux questions traitées par la cartographie climatique urbaine, c'est-à-dire dans le cadre de la discussion et de l'analyse des données thématiques et de la création de cartes de recommandations pour l'aide à la décision des acteurs de la planification urbaine. Après une introduction qui présente la méthode, ses bases théoriques et sa procédure, nous discutons de son adaptation et de la possibilité de son application dans ce contexte thématique. Ensuite, nous proposons une première série d'application, pour l'analyse du stress thermique diurne et de l'ilot de chaleur urbain nocturne, en tant qu'exemple et base de discussion, en s'appuyant sur nos travaux récents à l'échelle de l'agglomération toulousaine. Nous proposons aussi des modèles

graphiques pour exprimer les recommandations concernant les enjeux de climat urbain à Toulouse. La procédure a utilisé une table des chorèmes étendue de modèles dynamiques, en suivant la méthode proposée par H. Théry (1988). Les modèles graphiques produits entrent désormais dans une phase de test, pour en discuter la méthode et l'intérêt avec les acteurs de la planification urbaine.

climat, chorématique, modélisation graphique, carte, planification urbaine

climate, chorematic method, graphical modeling, map, urban planning

Introduction

After several research projects on urban climatology in Toulouse (see Dumas, 2021 for a comprehensive summary), several challenges have arisen concerning the cartographic representation of the urban climate in Toulouse for urban planning purposes.

Concerning urban climate mapping, there is a whole line of international work initiated by German researchers and disseminated throughout the world (Ng and Chao, 2015). This dissemination process was greatly pushed by the dynamism of the Asian research teams, especially in Japan and then in China. As part of the french ANR-MApUCE (2014-2019) and ADEME-PAENDORA (2017-2019) projects, we have tested different cartographic approaches. First of all, an approach which consists in characterizing the urban surface from the microclimatic point of view (inspired by the German and Asian approaches) based on climatopes (Xi *et al.* 2022). Then, through an approach that takes advantage of the strong skills we have in France in microclimate modeling, and which makes it possible to identify the areas at stake by crossing data on the one hand and urban expertise on the other (Hidalgo *et al.* 2022).

Complex spatial data were represented for different uses: analyses, group reflection, and communication with urban planners and city representatives. Several interdisciplinary discussions led to numerous exchanges concerning data generation and processing, as well as data analysis, visualization, and communication. Many diverse types of graphical representations were used, evoking different and sometimes unfamiliar techniques and disciplinary habits in urban climatology. These discussions, concerning complex and interacting spatial phenomena, needed to be based on shared definitions, methods, and effective representation tools that were easily understandable within the entire interdisciplinary team.

As Hidalgo *et al.* (2022) shows, one of the solutions used for the final representation of urban climate issues, aimed at local urban planners, was the schematic form, that is, sketches or graphical

simplifications. This solution was the result, in particular, of discussions initiated during the “Climate Geo-Visu” workshops, which focused on a discussion and review of possibilities for graphical representations. In this paper, we explore one of the ideas that emerged: the possibility to use the chorematic method, with graphical models (Brunet, 1980).

Indeed, graphical models, as per the chorematic method, have an advantage in that they can be used both as discussion and analytic tools and as a means of communication. First, they constitute a combinatorial assembly of simple models, with a graphical representation. Second, they deliberately deviate from a faithful, scaled representation of the spatial reality. This method allows issues to be considered at different scales, in terms of both physical scales and complexity, by distinguishing and comparing individual issues before combining them into a progressively more complex and interactive model. Finally, being models, they can be used to construct predictions based on different scenarios, which is particularly useful in the context of urban climatology. Note that this method is considered as a process and not solely for its resulting graphic form.

This paper presents how the chorematic method can be applied to the context and issues classically addressed using the urban climatic map framework (Ng and Ren, 2015) and proposes a first series of applications, as an example and a basis for further discussion.

Graphical models, choremes, and urban climate cartography

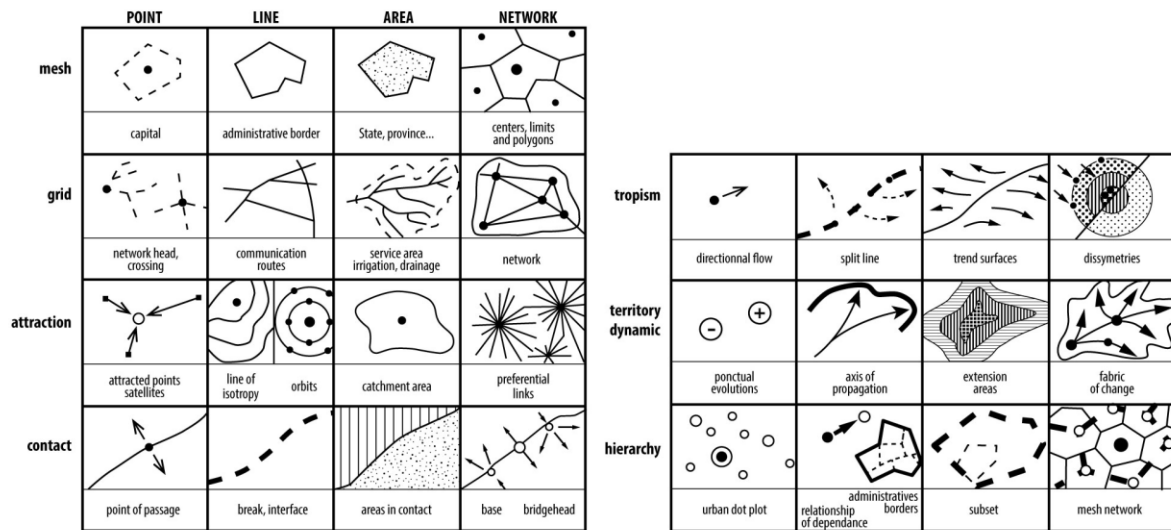
The chorematic method, based on graphical models called choremes, marked a milestone in geography and cartographical representation in France at the start of the 1980s, as a result of its contributions and the controversy it triggered (cf. the 76th issue of the *Hérodote* journal, published in 1995). Nevertheless, as a method and process of thinking about spatial phenomena, its interest has not been challenged and it constitutes the basis of research in several domains (cf. Lardon and Houdart, 2017; Casanova Enault and Chatel, 2017; Garbolino and Voiron-Canicio, 2020). Before presenting how the chorematic method can be used in urban climate studies, a short introduction is required.

The chorematic method: a graphical spatial modeling tool

Chorematics is a spatial analysis method, that is, the “formalized study of the configuration and properties of the space of societies” (from the Dictionnaire de la géographie by Lévy and Lussault, 2013). These configurations, patterns, structures, or recurrent spatial forms can be integrated with theories and models of the functioning and evolution of systems (from D. Pumain for the Hypergéographie online dictionary, 2004). Originally developed in the framework of regional and modeling geography, the chorematic method expanded into other fields linked with geography, such as urban and land use planning, territorial foresight, and geopolitics.

In a seminal paper in 1980, Roger Brunet proposed a graphical representation of individual spatial configurations based on simple forms, or choremes. With these choremes, one can model complex situations by combination and assembly, in a progressive manner, step by step. This process is the chorematic method. Brunet constructed the first choremes table (Figure 1) and proposed several examples of use to produce models of different territories. Over the years, some complements have been added to this first table, by Brunet and other authors, to develop new choremes and new patterns, including dynamic patterns. The choremes table is often regarded as an alphabet of forms that can be combined as a grammar of graphics to describe territorial patterns.

Figure 1: The first choremes table developed by Brunet (1986)



Source : R. Brunet, Mappemonde 86/4, 1986

Following different applications and experimentations, Brunet published a new synthetic paper on choremetics in 1986 to better describe and structure the method within spatial analyses. Modeling a territory with choremes begins with a search to identify its fundamental structures and dynamics by defining hypotheses about the concepts involved. These hypotheses can be translated into simple graphical forms chosen from the choremes table. Then, these hypotheses can be tested by verifying if the basic models are expressing the fundamental structures, that is, if the produced patterns resemble the observed spatial processes, by adjusting and swapping them into various combinations. It is therefore necessary to go back and forth between the model and reality, combining induction and deduction. Elementary models are combined to produce progressively more complex spatial configurations, which should increasingly mimic the observed reality and, consequently, allow better possibilities for descriptions and explanations. Note that this method is, from the beginning, based upon a graphical representation and visual approach to phenomena, with a strong link to cartography. The creation of a chorematic model is not the simple production of a summary or generalization of a territory, which could result in an oversimplifying schema. This is often the case in examples of simplistic or incomplete applications of the method, cf. Brunet (2004).

A multi-step method based on two hypotheses

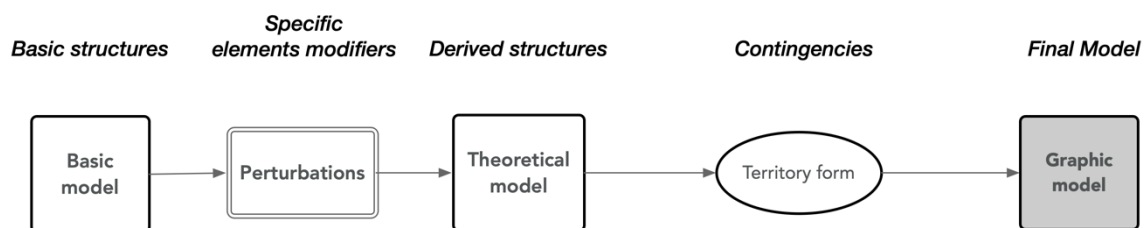
As an example, we can refer to the very enlightening methodological papers of Hervé Théry on Brazil in 1988 and Sébastien Velut on Argentina in 2001. Here, we describe the method using the example of Brazil. According to Théry (1988), two hypotheses underlie the chorematic method.

“... [T]he basic assumption is that each point of space is situated in a series of fields which structure space and whose local interference forms a system, that each situation is defined in relation to flows, thus in relation to centers, directions, gradients, limits.”

“Another strong hypothesis is that these structures and their combinations can be accounted for by models. These models are a simplification of reality, reductive and provisional. They constitute a simple approach to complexity, a tool to be used provisionally until a better one can be constructed.”

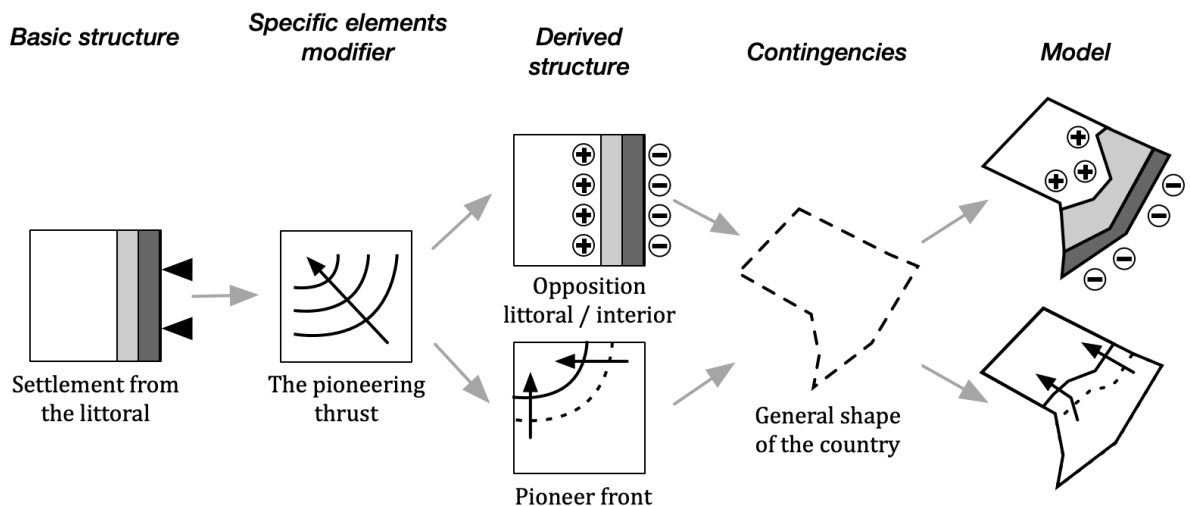
The method proposed by Théry is summarized by the diagram in Figure 2.

Figure 2: Diagram of the graphical modeling process using choremes



The application of this method to the “basic structure” of the progressive settlement of Brazil by Théry is illustrated in Figure 3.

Figure 3: Basic structure example of the progressive settlement of Brazil



Adapted from Théry, 1988

Adapted from Théry, 1988

The analysis of the spatial distribution of the phenomena, coupled with knowledge of the territory, allows a hypothesis to be formulated about the basic structures, i.e., the individual choremes, that are suitable to model the territory. These choremes are picked from a generic table, either the seminal one of Brunet (1986) or from variants developed since by several authors. The assembly of these choremes produces a basic model. Then, it is necessary to identify and model the modifying elements, which are specific to the territory and will transform or disrupt the basic structures. Examples used by Théry (1988) include the pioneer front toward the Amazon and the presence of a climatic anomaly, which gives the Nordeste region in Brazil its distinct semi-arid climate. Similarly, we incorporate smaller-scale spatial structures, such as the presence of secondary centers, local dynamics, and/or an active subdivision of the territory. In this way, we obtain derived structures that complicate the model and refine it. However, at this step, the model is still composed of simplified geometric choremes. It is then necessary to consider the contingencies caused by the form of the territory, the general delineation of the borders, and the presence of irregularities or fine transitions to transform the model so that its simplified form looks like that of the territory. Square models are deformed toward a polygonal model whose extension, indentations, projections, or stretching better represent reality.

As the method describes, this process is based on the selection and the simplification of spatial structures, by experts of the domain via a progressive discussion. It goes without saying that the results are eminently of a qualitative kind, the original spatial indicators are simplified and summarized to help model a situation. The value of the results lies in the quality of the analysis by the experts, their discussion and in the quality of the selection and combination of the graphical basic and intermediate models into final models.

This final polygonal model is not the only result of the method: the production process itself involves

several significant operations that require exchanges, the stabilization of definitions and discussion points, the development of hypotheses, the analysis of elementary phenomena, and a reflection on their combination. The process itself is therefore also an important result of the method. Moreover, this represents a working method that encourages discussion and produces communication tools that are efficient and adapted because they are simple and shared among the team. To quote Théry (1988): “The synthetic and attractive form that is the graphic model - if it is successful at least - makes it a convenient and quick communication support.”

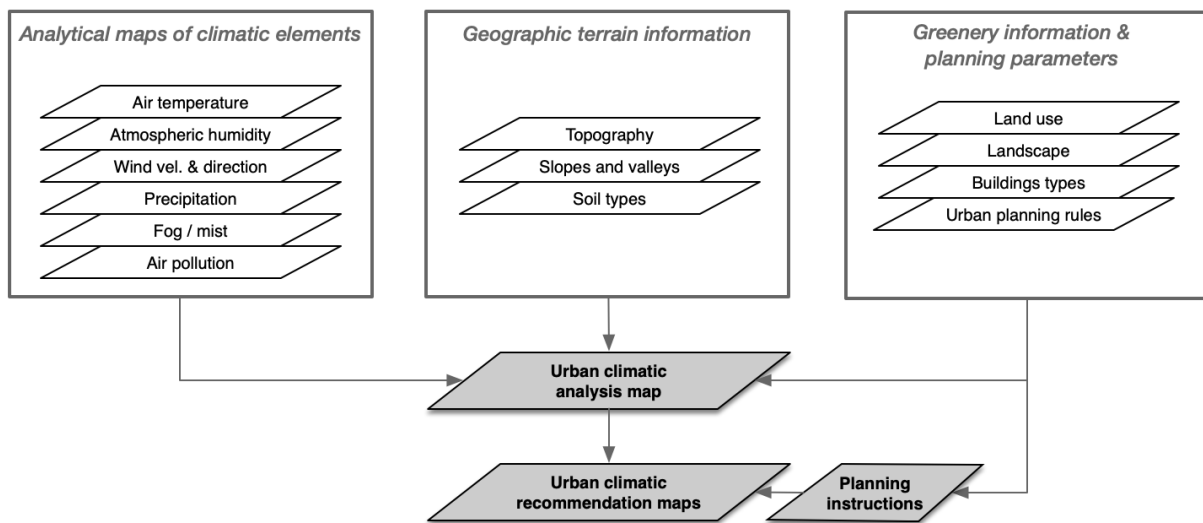
In the framework of interdisciplinary urban climate research between atmospheric physics, climatology, urban geography, urban planning, and cartography and complex spatial phenomena and issues, the chorematic method constitutes an interesting possibility for both the analysis of spatial phenomena and interdisciplinary communication. Before exploring the application possibilities using a local example, it is necessary to quickly present the types of analyses and representations used in the field.

Urban climate cartography: different representations for distinct objectives

Cartographic representations are often used in the field of urban climatology. This type of representation takes several forms depending on the type of analysis, the stage reached in the methodological process, the objectives, and the target audience. The objective here is not to replace effective and validated cartographic representations but to see how the chorematic method can help to complement these approaches to make them more accessible in an interdisciplinary framework and to accompany a complex process.

A grouping of the different types of spatial data and associated representations was proposed by Ng et al. (2015), as shown in Figure 4.

Figure 4: Structure of urban climatic maps (adapted from Ng et al., 2015)



Adapted from Ng et al., 2015

Adapted from Ng et al., 2015

In the 1980s, the introduction of spatial data information and geographic information system tools facilitated the communication of meteorological and climatic information, which are important assets for urban climatic maps. These maps are the result of microclimatic analyses and were found to be a good translation tool for environmental issues. This technique is widely used in Germany, Asian countries, and above all Japan. Many climatic maps have been produced for several cities, such as Kobe and Osaka in Japan (Ashie et al., 2009), Hong Kong (Ng et al., 2012), and Singapore.¹

Within this approach, the concept of urban climatic maps (UCMaps) is defined via two types of maps: the Urban Climatic Analysis Map (UC-AnMap) and the Urban Climatic Planning Recommendation Map (UC-ReMap).

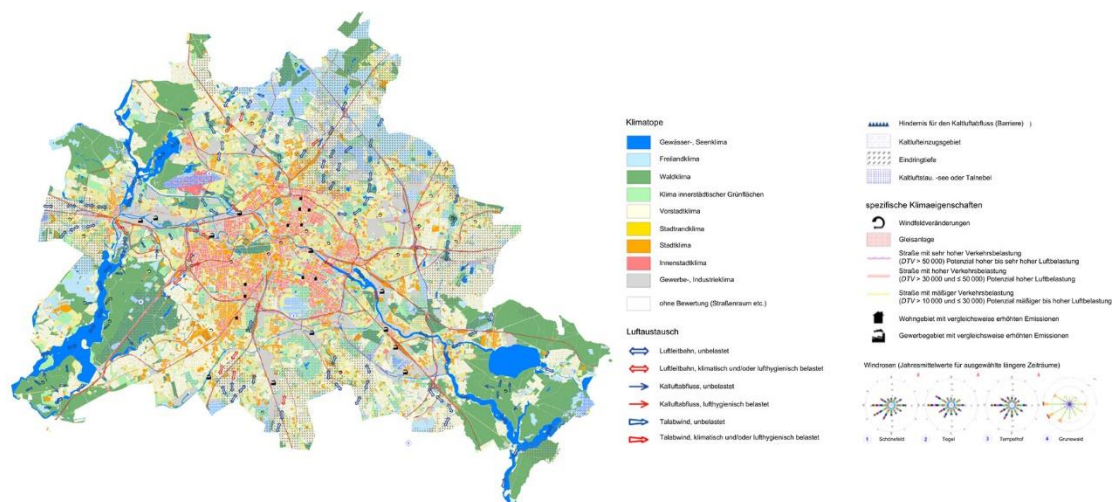
Urban Climate Maps

A UC-AnMap combines climatic situations and simulations with other urban factors, including land use, topography, and urban geometry. A UC-ReMap, based on the UC-AnMap analysis, proposes orientations for urban planning. Recommendations are defined for different areas and are based on adaptations to strongly exposed climate zones. In Europe, Germany initiated similar microclimatic analyses in several cities (e.g., in the Ruhr region, Berlin, and Stuttgart) and became the leader in UCMap studies in Europe with the construction of synthetic climatic function maps to guide their urban planning.

¹ <https://www.coolingsingapore.sg/journal-papers>

In Germany, the method developed is the result of work starting in the 1970s and has contributed to the international dissemination of climatic maps in terms of methodology and standards. The VDI 3787 directives published by the Association of German Engineers (VDI) in 1997 and updated in 2015 (Figure 5), have become an international benchmark in the field of urban climatic maps that has inspired many other cities and researchers around the world (Ng and Ren, 2015).

Figure 5: Climate analysis of the city of Berlin



General view, original scale 1:265,000, [link](#) for the full quality map.

Senate Department for Urban Development and the Environment, Environmental Atlas, 2016

In recent years, inspired by examples in Japan and Germany, other countries have proposed their own climatic maps, notably in Hong Kong (Ng et al., 2012, Urban Climatic Map and Standards for Wind Environment - Feasibility Study, 2006), cities in the Netherlands (Arnhem; Burghardt et al., 2010), in Spain (Bilbao; Acero, 2012), and in many other geographic contexts (e.g., in Iran, Sweden, Switzerland, Norway, Greece, Poland, Brazil, and Thailand).

UC-AnMaps often reveal a mapping conception closely related to the disciplinary field of the researcher. The German and Hong Kong maps are influenced, in their spatial representation and semiology choices (symbolic representations), by the visions of their urban space-oriented architects and urban planners. The scale and the cartographic legend used also contribute to this pattern. This indicates that climatic maps are designed in a close partnership between town planners (and their internal structures) and researchers. The resulting UC-ReMaps are characterized by a direct approach to the recommendations, indicating precisely what should be done at a fine scale in the city and what actions are required to preserve and/or to improve the climatic conditions (Figure 6).

This pedagogical aspect of choremes was well used in the context of geography textbooks in France in the 1990s, even though they were received at times with criticism and taken as oversimplified models of reality. However, the chorematic method is a process, not just its (graphical) results, as we explain here. A chorematic map model cannot be disseminated alone, its progressive legend and commentary are essential.

This is even more important for the UC-ReMap, which is a description of recommendations for urban planners. This map is the result of the interpretation of the UC-AnMap in terms of advice for the evolution of the urbanization of a city, with an emphasis on several key points, such as patterns to preserve or, inversely, to counter. Destined for urban planners, these maps show concrete ideas translated into actions and instructions, e.g., zones that should be preserved or improved. In this case, the chorematic mapping process can play the role of an introduction and an explanation of the instructions to emphasize the proposed actions at the city scale. Here, we are considering the capacity of choremes to model patterns and dynamics at play at the global scale of a city; then, planners can look at the finer details of the instructions, zone by zone or city block by city block.

To illustrate these propositions, we use the example of the UCMaps for the Toulouse Metropole agglomeration in the south of France (cf., Hidalgo *et al.*, 2022). In the continuation of this work, we will test their pertinence and effectiveness with urban planners and local elected officials by the way of workshops.

Application to the case of Toulouse

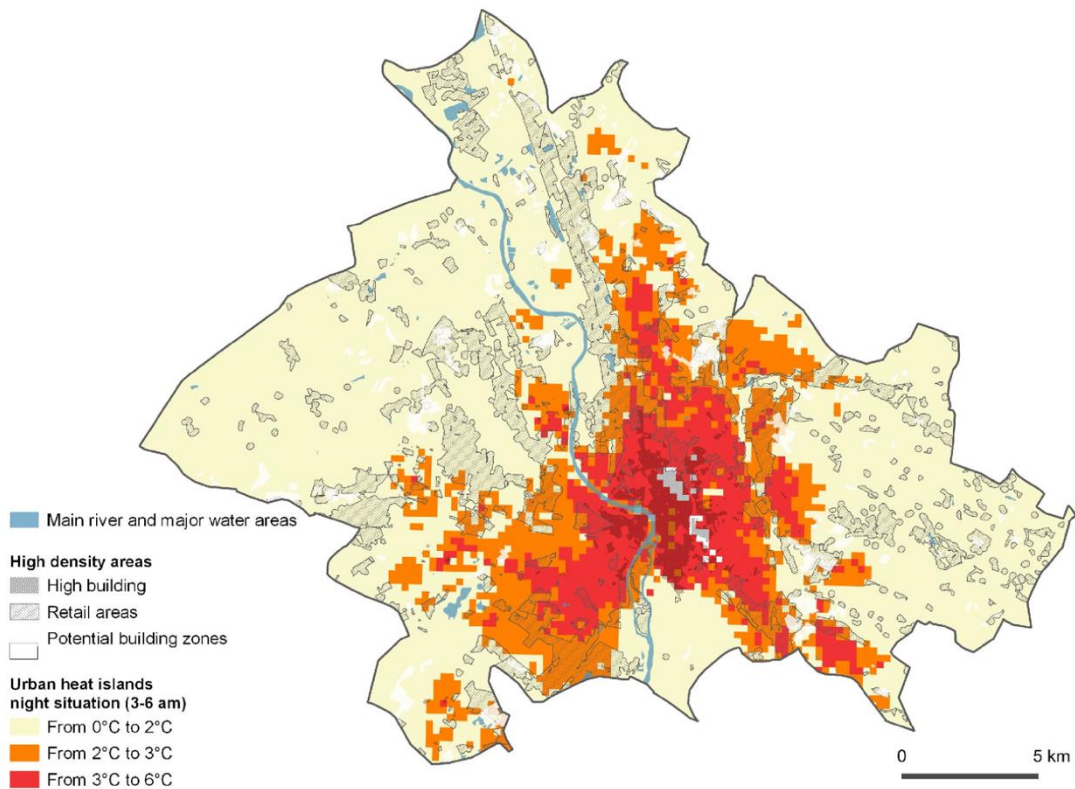
The work in Toulouse, in the context of two successive research programs and seminars, served as an opportunity to test the potential of the chorematic approach. Here, we present the processes leading to a UC-AnMap concerning the urban heat island and diurnal heat stress issues and UC-ReMaps adapted to the current urban planning policies.

A graphical model of night-time Toulouse's urban heat island

The Toulouse Metropole worked on its last Urban Master Plan, from 2015 to 2019, incorporating several ongoing scientific studies characterizing its main environmental and social issues. As part of this work, the urban heat island (UHI) at night, the thermal comfort during the day, and the wind conditions were investigated using a meteorological model (Kwok *et al.*, 2019) to define their spatial structures. A typical summertime meteorological situation with high daytime temperatures and a strong nocturnal UHI was selected using the local weather type approach developed by Hidalgo and

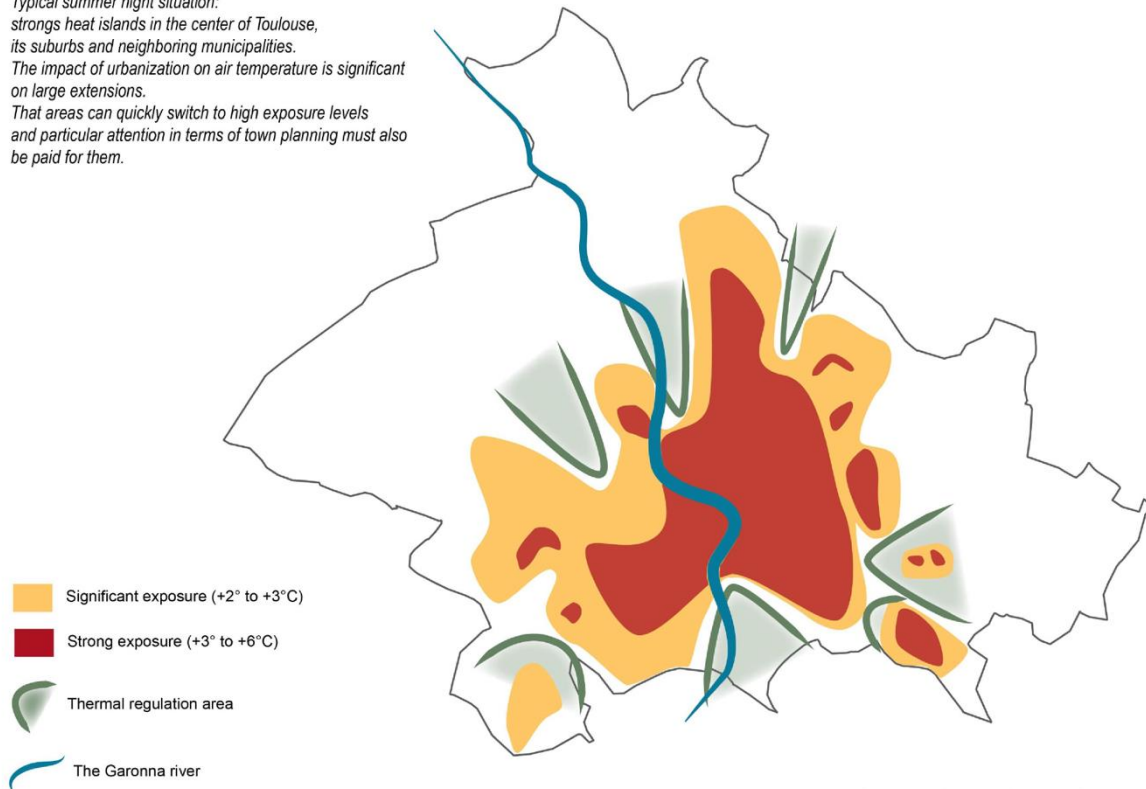
Jouglà (2018). Climatic analysis and recommendation maps (the terminology used in French was “strategic maps”) were developed for the diurnal heat stress levels, nocturnal UHI, and wind (Figure 7).

Figure 7a: Examples of Urban Climatic Planning Recommendation Maps for Toulouse, nighttime



Sources : DB-Mapuce (2015), climatic data (CNRM, LISST, 2018), IGN ©, Toulouse Métropole (20

*Typical summer night situation:
 strong heat islands in the center of Toulouse,
 its suburbs and neighboring municipalities.
 The impact of urbanization on air temperature is significant
 on large extensions.
 That areas can quickly switch to high exposure levels
 and particular attention in terms of town planning must also
 be paid for them.*

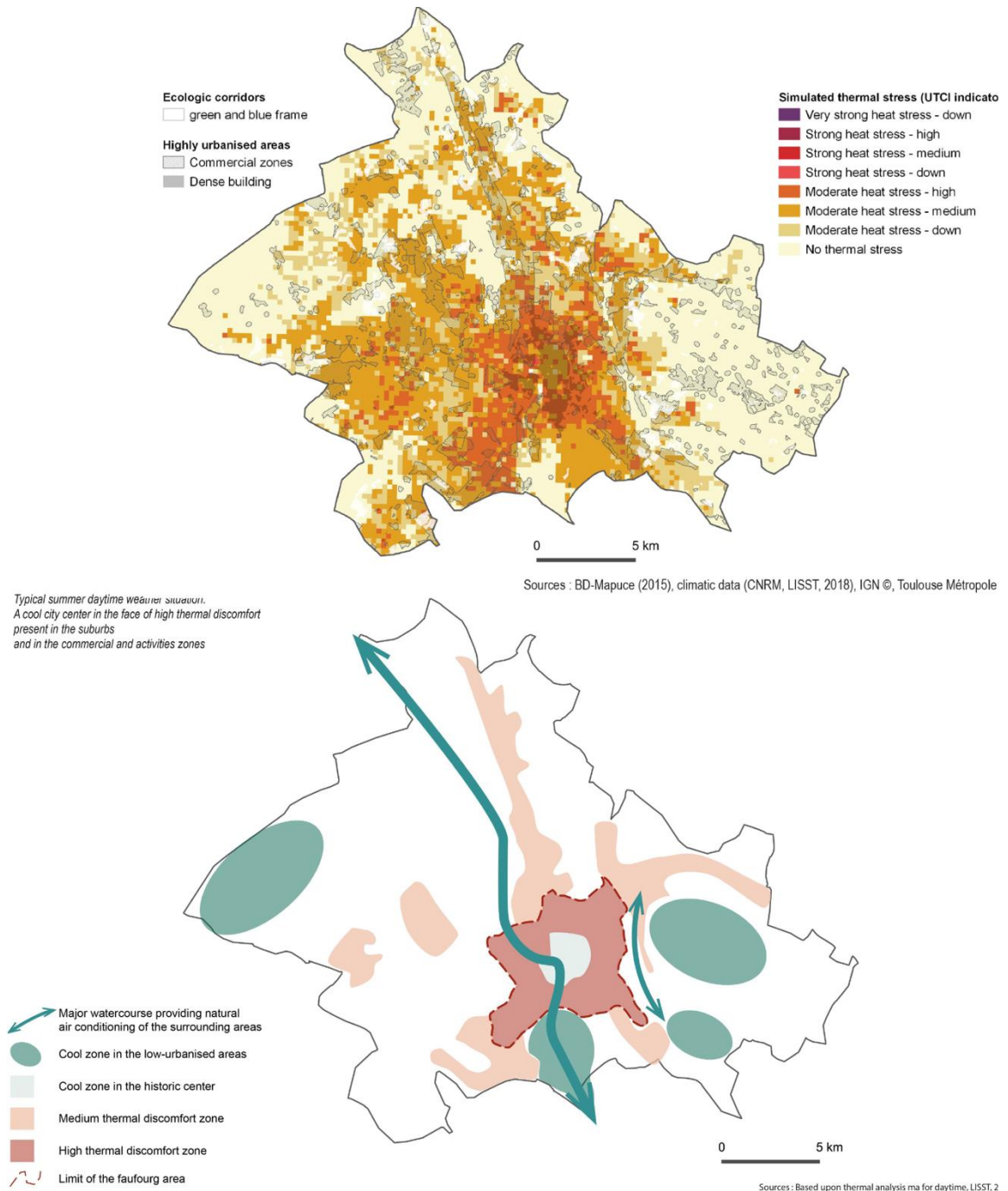


Sources : from map analysis for typical summer night situation,

Examples of Urban Climatic Planning Recommendation Maps (UC-ReMaps) (top) and strategic maps (bottom) for nighttime thermal conditions in Toulouse

Hidalgo *et al.*, 2022

Figure 7b: Examples of Urban Climatic Planning Recommendation Maps for Toulouse, daytime



Examples of Urban Climatic Planning Recommendation Maps (UC-ReMaps) (top) and strategic maps (bottom) for daytime (right) thermal conditions in Toulouse

Hidalgo *et al.*, 2022

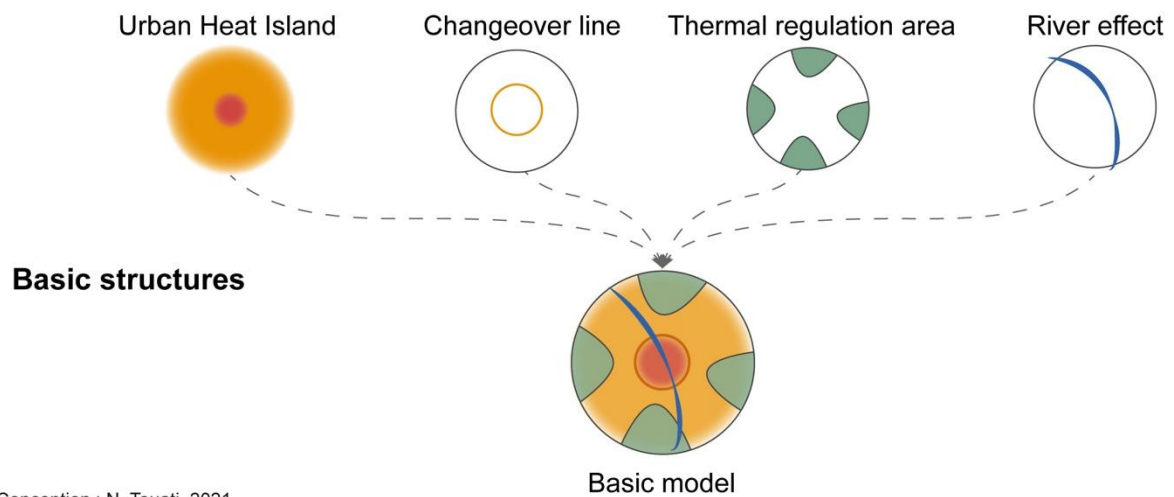
The maps produced (Figure 7) are the result of the analysis of several indicators: air temperature for the nocturnal UHI and a synthetic indicator of diurnal heat stress (the Universal Thermal Climate Index, UTCI²) that involves air humidity, wind speed, and solar radiation. These indicators are themselves synthetic, the result of a statistical analysis, from a numerical simulation that produce continuous spatial values.

The maps show multiple spatial structures. The spatial extension of the exposure to the UHI is not the only feature shown on the maps; several spatial co-occurrence and geographical issues are implied for the urban planner, e.g., types of land use and zoning, natural cooling areas.

A first attempt to produce simplified forms resulted in sketches and schematic maps, as shown in Figure 7 (bottom). To better explain and represent the spatial structures found in the analysis and discuss them with the diverse team members, a chorematic method was engaged. Following the method described earlier in Section 2, several individual basic models were selected to start the process. The UHI illustration presents a classic concentric spatial structure, with a central part showing high exposure and a peripheral zone with a lesser but worrying level of exposure. These classes (and their spatial limits) were defined by the experts of urban climate. To these researchers, the crucial issues were the spatial extents of these areas, as well as their evolution (changeover line), constraints, impacts and their relationship with the geographical terrain (the thermal regulation zones and the river). To take this into account, different basic graphical models were selected and tested. They formed the starting point of the chorematic method and the resulting illustration legend.

Figure 8: Urban heat island (UHI) model step 1: the basic structures

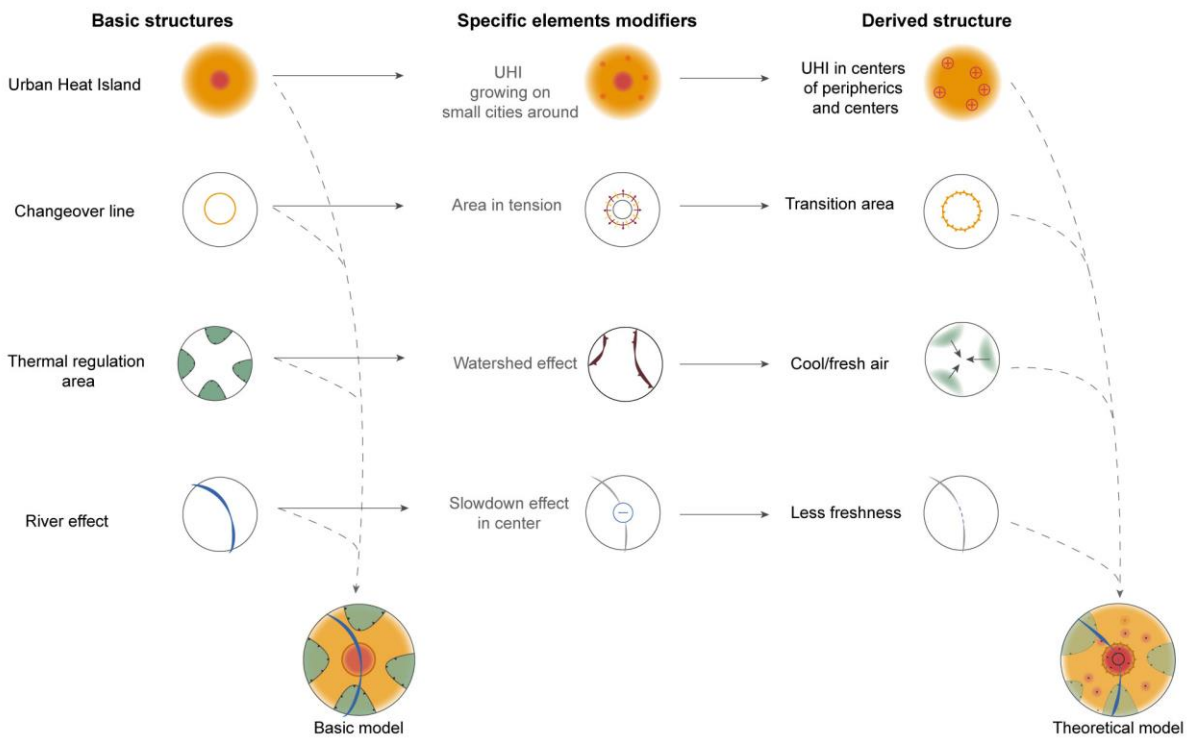
² <http://www.utci.org/>



The models were selected from the choremes table, with the addition of color and dithering to express the dynamics. The resulting basic model was very simple (Figure 8), a starting point for discussions about the involved phenomena.

The second step, as per the method, was to determine the modifiers to the basic structures and to express them graphically using variants of the choremes. The UHI is in fact complicated by the existing suburbs and suburban cities. The contact area between the different exposure-level zones, the changeover line, is central to the representation, and this contact area is dynamic. The thermal regulation areas (the green and blue zones) are distorted by the relief and the watershed effect. The river effect has a large impact on the city center. These modifications were graphically modeled, producing the graphical models in the middle column of Figure 9. Then, these modifiers were applied to the basic structures to produce more pertinent models of the situation, models that more efficiently represent the interpretation of the indicators: the UHI with peripheral zones, a transition area, dynamic cooling patterns, and a subdued river effect in the city center.

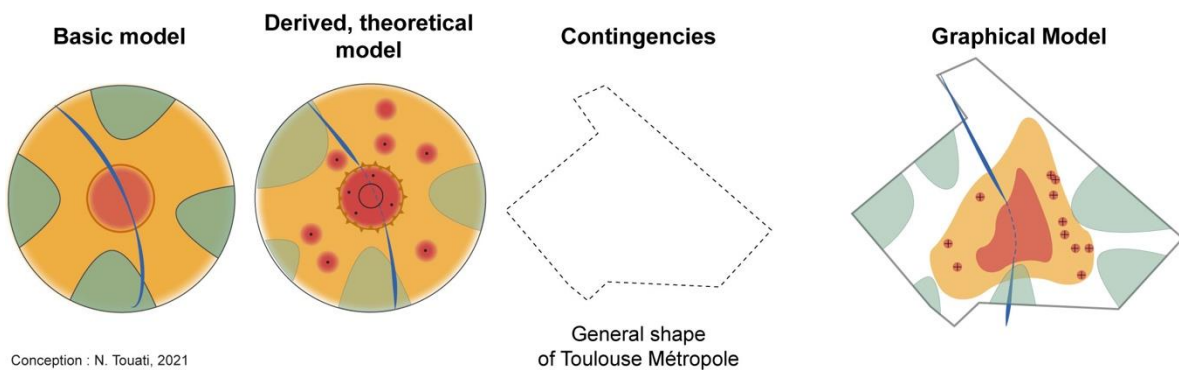
Figure 9: UHI model steps 2 and 3: modifiers and derived structures



N. Touati, 2021

The theoretical model obtained after this third step (Figure 10) represents the situation more closely. Its general form remains circular and abstract; therefore, the final step was to refine it to look more like the form and disposition of the agglomeration.

Figure 10: UHI model final step: adaptation to the general form of the Toulouse agglomeration



Conception : N. Touati, 2021

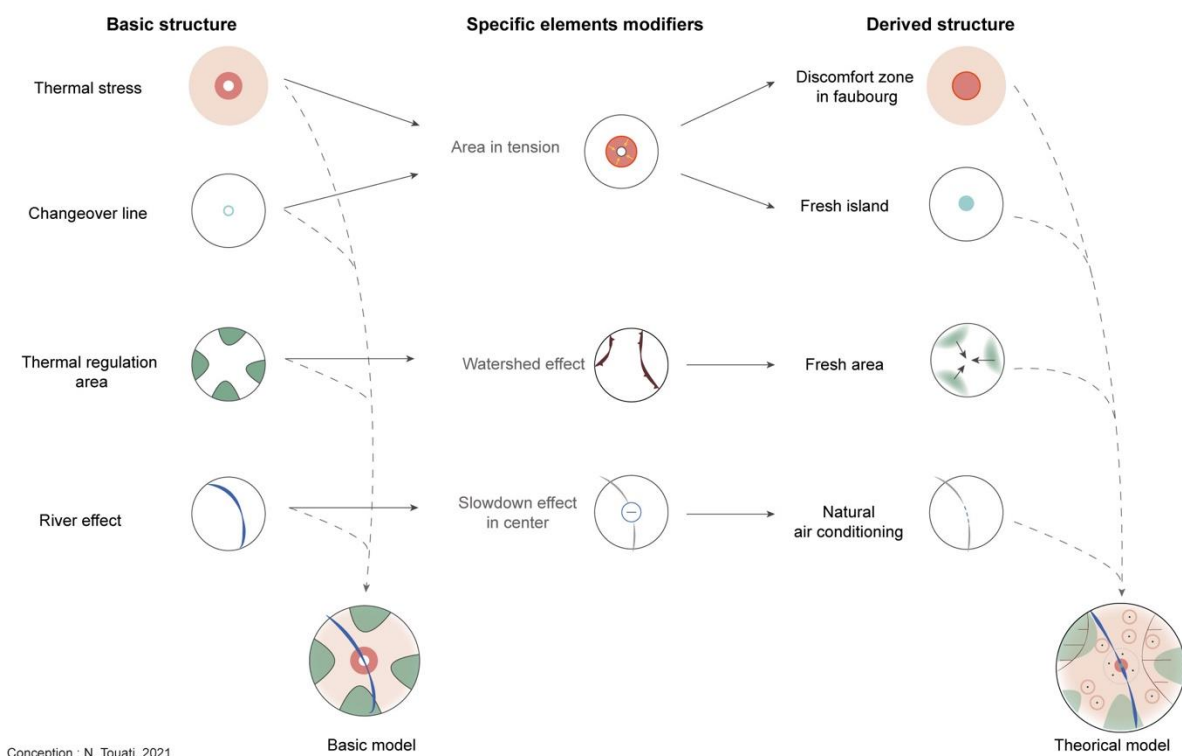
N. Touati, 2021

The final model was then ready to be shown to local partners and discussed, in relation to urban-planning policies, at the agglomeration scale. This model expresses, in a synthetic and spatial manner, the main issues of the UHI in Toulouse and offers a basis for discussions between researchers, urban planners, and representatives of inhabitants.

A graphical model of diurnal thermal comfort in Toulouse

A thermal comfort analysis was conducted using the UTCI, following the recommendations of the International Society of Biometeorology,³ considering several factors and indicators. The results show a complex situation for the Toulouse agglomeration, again with several spatial patterns that we have attempted to graphically model using choremes.

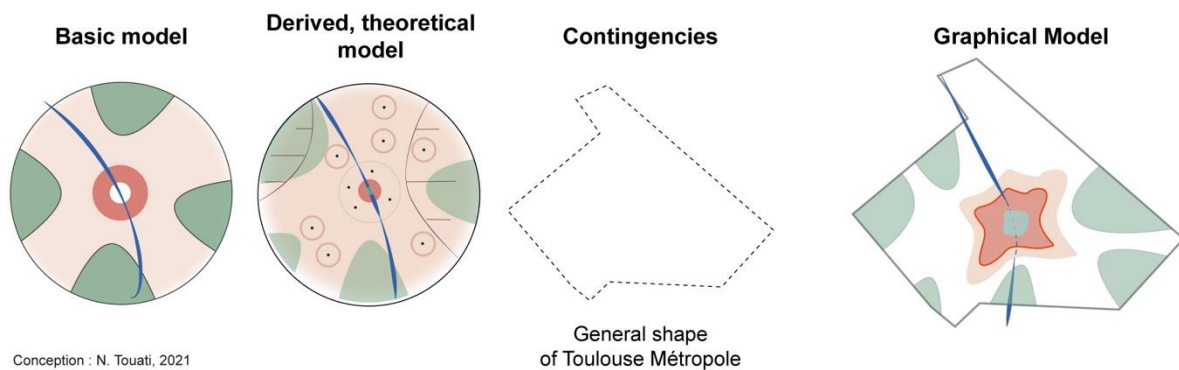
Figure 11: Universal Thermal Climate Index (UTCI) model steps 2 and 3: modifiers and derived structures



³ <http://www.utci.org/>

The basic choremes used (Figure 11) for the modeling process were approximately the same as those used for the UHI; the implicated spatial structures revolved round the same patterns: center-periphery, punctual evolutions, axes of propagation, contacts, and catchment areas.

Figure 12: UTCI final modeling step



N. Touati, 2021

The final graphical model shows (Figure 12) the expert's interpretation that the peripheral municipalities are less intensely impacted by diurnal heat stress than nocturnal UHI and that the thermal discomfort tension is higher between the center fresh island (in white) and the first ring of suburbs (in red).

As mentioned in the introduction, the chorematic method can also be used to communicate recommendations derived from analyses of urban climate issues.

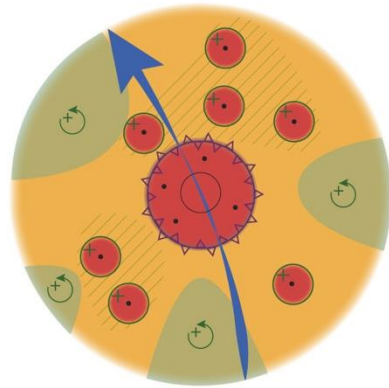
Graphical models to express recommendations to planners

Tentative models of recommendation choremes were produced (Figure 13), building on analyses of the UHI and the thermal comfort. These graphical models complement each other to express advice and the means to alleviate climatic issues occurring by day (thermal comfort) and night (UHI) at the scale of the agglomeration.

Figure 13: Graphical recommendation models for the Toulouse UHI (night) and UTCI (day) issues

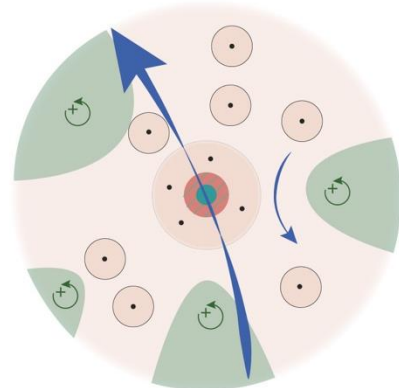
Recommendations to take into account the micro-climatic issues in urban planning policy for Toulouse

UHI recommendations

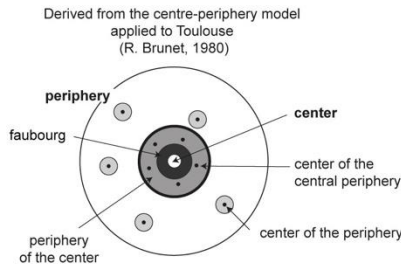


- Urban heat island**
- Not insignificant exposition
- Transition area : limit of the strong exposure zone which to contain**
- Strong exposition
- Center of the 1st ring communes**
- + Preserve the fresh areas and reduce soil sealing by revegetation
- Economic activities and commercial zones**
- Limit soil sealing and climate control use
Increase the vegetation presence

UTCI recommendations



- Thermal regulation**
- Ventilation corridor (narrower in the center)
- + Attractive area, thermal regulation
Freshening spaces preserved
- Thermal regulation area (hillsides, woods, etc.)



- Hypercentre**
- Fresh island to preserve in the day
Creation of shading
Reduction of anthropic heat input
- Faubourgs of 1st ring**
- High thermal discomfort
- Moderate thermal discomfort
- Increase the vegetation presence

Conception : N. Touati, 2021

N. Touati, 2021

The UC-ReMap models used the same graphical modeling process following the chorematic method; however, the recipients, the urban planners, and the local representatives working on the master plans, were less available for long and progressive work on basic models, modifiers, and derivative structures. Therefore, we plan to organize workshops, perhaps as serious games, to present these results, the chorematic urban climate analysis and recommendation models and discuss their adequation, usefulness and communication efficiency, allowing the possibility of their modification.

A sort of executive summary was designed by providing a single image with an expansive legend. This design must be supported by a descriptive text or a presentation of the basic choremes, their combination, and the resulting recommendations, highlighting the progressive process. To alleviate the cognitive difference between a classic map and a simplified form model, a comparison chart should also be provided.

Conclusions

This work contributes to international studies of urban climatic mapping by presenting how the

chorematic method can be applied to the process of producing maps to analyze the urban climate and to advise urban planners. From a theoretical point of view, the chorematic method is based on graphical models called choremes. Choremes can be treated as an alphabet of forms, which can be combined as a grammar of graphics to describe territorial patterns. This approach, historically used in other fields linked with geography, such as urban and land use planning, territorial foresight, and geopolitics, is proposed here as a method and a process of thinking about climatic spatial phenomena.

After an introduction to the theoretical basis of graphical models and its potential use in urban climatic maps, a proposed application in Toulouse was presented as an extension of previous urban climatic mapping research using more classical representations based on grids and sketches. The proposed models are the result of a long process of interdisciplinary discussion, analysis, and thematic reflection on the UHI (nocturnal) and heat stress (diurnal) issues. The represented spatial objects, or choremes, are the result of a decomposition of the elements of the thematic map into selected basic structures, influenced by specific modifiers and recomposed as graphical models. This method moves away from the original complexity of quantitative indicators to propose a simplified but, we hope, an effective modelling vision of the issues and solutions.

The example of Toulouse demonstrates that graphical models are good communication tools that can enrich exchanges between disciplines. For our team, the process provided a very interesting context in which to define concepts, spatial patterns and interactions between researchers from various disciplines. This experience provides a reminder that our cities, as opposed to being just microclimatic study objects, are, first and foremost, organized geographical and social spaces impacted by environmental issues. It will be interesting to see if a more general and systemic model can emerge through the study of a larger corpus of cities; this idea is currently being explored. Graphical modeling therefore allows us to prioritize our knowledge through its role of synthesis while remaining close to a thematic map (Lardon, 2017). It can then be presented as a tool to help in decision-making and to facilitate the expression of ideas, contributing to a collaborative approach in the implementation of diagnoses and recommendations. Collaboration with the urban planners and local elected officials in Toulouse is ongoing to test the effectiveness of the models and the process.

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Acero, J. A., Arrizabalaga, J., Kupski, S., Fernandez, J. G., Katschner, L., 2012,, "Analyzing urban heat island in Bilbao (Spain), a coastal region." In *8th International Conference on Urban Climate and 10th Symposium on the Urban Environment. International Association for Urban Climate and American Meteorological Society, Dublin, Ireland.*(189) (pp. 1-4).

- Ashie Y., Tanaka T., Sadohara S., Inachi S., 2015, "Urban climatic map studies in Japan: Tokyo and Yokohama", in Ng, E. and Chao, R. 2015, *The Urban Climatic Map: A Methodology for Sustainable Urban Planning*. Routledge.
- Brunet, R., 1980, "La composition des modèles dans l'analyse spatiale." *L'Espace géographique*. 4:253-265.
- Brunet, R., 1986, "La carte-modèle et les chorèmes." *Mappemonde*. 86 (4):2-6.
- Brunet, R., 2004, "D'une erreur commune à propos de cartes et de modèles. Commentaire sur « Quel fond de carte pour l'Australie ? » de Patrick Poncet" *Mappemonde*. 74 (2-2004).
- Burghardt, R., Katzschner, L., Kupski, S., Chao, R., Spit, T., 2010, Urban climatic map of Arnhem city. *Future Cities, urban networks to face climate change. Interreg IV.*(www.future-cities.eu).
- Casanova Enault, L and Chatel, C., 2017, " La modélisation graphique de phénomènes émergents pour répondre aux besoins de la prospective ", *Mappemonde* (119).
- Dumas G., 2021, " Mise en place de services climatiques au sein de la métropole toulousaine à base d'un réseau d'observation pour le monitoring de l'îlot de chaleur urbain ", thèse de doctorat, CRNM, Toulouse.
- Hidalgo, J. et Jouglà, R., 2018, On the use of local weather types classification to improve climate understanding: An application on the urban climate of Toulouse. *PLoS ONE*, 13 (12).
- Hidalgo, J., Touati, N., Haouès-Jouve, S., Jégou, L., Bretagne, G., Bocher, E., Masson, V., Mayis, A., Jouglà, R., Petit, G., Schoetter, R., collectif Géovisu, 2022, "Mapping the urban climate for summer comfort management in urban planning: climate analysis and semiology of graphics", *Cybergeo*, accepted.
- Garbolino, E. and Voiron-Canicio, C., 2020, *Ecosystem and territorial resilience: a geopropective approach*. Elsevier.
- Kwok Y.-T., R. Schoetter, K. Lau, J. Hidalgo, C. Ren, G. Pigeon, V. Masson, 2019, "How well does the Local Climate Zone scheme discern the thermal environment of Toulouse (France) ? An analysis using numerical simulation data", *International Journal of Climatology*, 39, 5292–5315.
- Lardon, S., Houdart, M., 2017, "Les Chorèmes face à l'évolution des thématiques et pratiques de recherche, en agronomie et aménagement des territoires." *Mappemonde*. (122).
- Lévy, J., Lussault, M., 2013, *Dictionnaire de la géographie*, Belin.
- Ng, E., Chao, R., 2015, *The urban climatic map: a methodology for sustainable urban planning*. Routledge.
- Ng, E., Yau, R., Wong, K, Ren, C. and Katzschner, L., 2012, *Final Report of Hong Kong Urban Climatic Map and Standards for Wind Environment- Feasibility Study*.
- Pumain, D., 2004, *Analyse spatiale. Dictionnaire Hypergéogé*, en ligne, <http://www.hypergeo.eu/spip.php?Article38>

Théry, H., 1988, "Modélisation graphique et analyse régionale. Une méthode et un exemple." *Cahiers de géographie du Québec*. 32 (86):135-150.

Velut, S., 2001, "Argentine, modèle à monter." *L'Espace Géographique*. 30 (3):231-244.

Wong, N, Kardinal Jusuf, S., Katschner L a, Ng, E., 2015, "Urban climatic map studies in Singapore", in Ng, E. and Chao, R. 2015. *The urban climatic map: a methodology for sustainable urban planning*. Routledge.

Yin, S., Ren, C., Zhang, X., Hidalgo, J., Schoetter, R., Ting Kwok, Y., Ka-Lun, K., Lau, 2022, "Potential of Synthetizing Climatopes and Local Climate Zones for Urban Climatic Planning Recommendations: A Case Study in Toulouse, France", Cybergegeo, accepted.