Intelligibility of French historical towns: assessing the impact of 19th century urban interventions.

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Abstract

During the 19th century, French cities underwent great transformations in response to insalubrity. Many new streets were created and changed the overall intelligibility of the street network with the creation of boulevards where the defensive town wall used to stand, as well as large avenues to provide better accessibility to the centre of towns.

This study aims to assess the impact of these transformations on the urban tissue by measuring the intelligibility of the urban form before and after the transformations. It compares the Napoleonic cadastral maps of Agen, Amiens, Avignon, Dijon, Clermont and Tourcoing with the current cadastre. Intelligibility is measured by the ease of navigation towards the centre of an urban environment and the ease of traversing it as one traces a path between two given points on the map. The choice of paths is examined, highlighting the role of the new streets.

This research brings together the cognitive mechanisms that underpin the exploration and decision-making process when navigating urban maps with their syntactic and morphological properties. It examines the motor aspect of decision-making during the navigation process. Motor reactions are recorded using technology developed for the quantification of neuromotor impairments. This interdisciplinary approach provides a means to measure and better understand the intelligibility of urban environments.

Keyword: *intelligibility, cognitive morphology, spatial cognition, route selection*

Introduction

Urban environments have different morphologies and levels of complexity in terms of street structures, which can impact their intelligibility. When exploring new environments, the configuration of streets can facilitate wayfinding with the presence of primary streets such as main thoroughfares, that contrast with the denser and irregular local infill of street patterns. The urban transformations at the turn of the 19th century in France exemplify the desire of cities to bring legibility to their overall street network by offering more direct routes between selected locations with the creation of large avenues and boulevards through the urban fabric.

In the case of historic French towns, the transformations have been documented in cadastres, atlases and maps, which have also served as planning tools. The establishment of the Napoleonic 'cadastre' by the law of September 15, 1807 surveys and fixes officially the limits of private and public properties. On the following day, to control planning decisions at that time, another law requires a 'general alignment plan' for any municipality with more than 2,000 inhabitants. This plan is mainly intended to govern, list and record all the creations of new streets as well as the alignments and widening of old streets to be undertaken as a cohesive whole rather than in a piecemeal fashion (Laisney, 2002). This highlights the importance of maps for recording and planning urban changes and their potential for assessing their impact. By comparing the Napoleonic cadastre established prior the major transformations with the current cadastre (cadastre.gouv.fr, 2010), it is possible to see how the morphology of the urban blocks and the configurations of streets have changed (Vialard, 2015).

This study goes one step further by measuring the impact of such transformations on the legibility of public space. It assesses the intelligibility of the urban form as a function of both its configurational properties and its level of ease of navigation from a cognitive perspective. Using cadastral maps from both periods, a navigation task is designed asking participants to find the shortest routes between two locations. The cognitive mechanisms involved in the completion of the task are used to assess the level of intelligibility of the selected French towns and whether the interventions have had the desired impact on the legibility of their public space.

The first part of the study clarifies the relationship between the morphological properties and intelligibility of urban environments, and their link to cognitive mechanisms involved in the navigation of urban environments. It aims to establish and verify whether intelligibility, measured as a configurational property of the public space, is linked to a measure of cognitive effort during the navigation task. The second part of the analysis compares the differences in outcomes between the two periods. The proposition is that while urban transformations have in general increased the legibility of the street network, this should translate into a more intelligible city, thus offering easier, and therefore faster, access to its centre and more direct traversing routes.

Intelligibility, path selection and cognitive process

The process of navigation and finding one's way requires multiple steps: orienting yourself, recognising the destination and deciding which route to select (Golledge, 2003). A fourth aspect is spatial updating during locomotion that can occur at decision points such as at an intersection (Brush & Calkins, 2008). These involve cognitive abilities to process spatial information. One of the processes is the use of a 'cognitive map' which is the way humans store and interpret spatial information in their mind (O'Keefe and Nadel, 1978; Kitchin, 1994). Cognitive mechanisms that involve map-like knowledge and representation of space are also referred as survey strategy in path navigation (Lafon, Vidal et al., 2009). There is an agreement that cognitive maps are involved in the decision process while navigating an urban environment. They are associated with people's behaviour in the environment, through decision making and its subsequent behaviour (Downs and Stea, 1973; MacEachren, 1992).

Selecting a route depends on our understanding of the environment, and its legibility. The legibility of an urban environment is "the ease with which its parts can be recognized and organized into a coherent pattern" (Lynch, 1960). Transposed in terms of street configurations, the level of intelligibility is determined by the relationship between the level of integration of the system as a whole - how accessible each space is from all the others - and the degree of connectivity it provides - the number of spaces directly available (Hillier, Burdett et al.,1987). An intelligible street network is when it is possible to get a sense of the system as a whole based on local information. It is argued that high correlation between the two properties indicates street systems that are cognitively easier to understand, and therefore to navigate (figure 1).

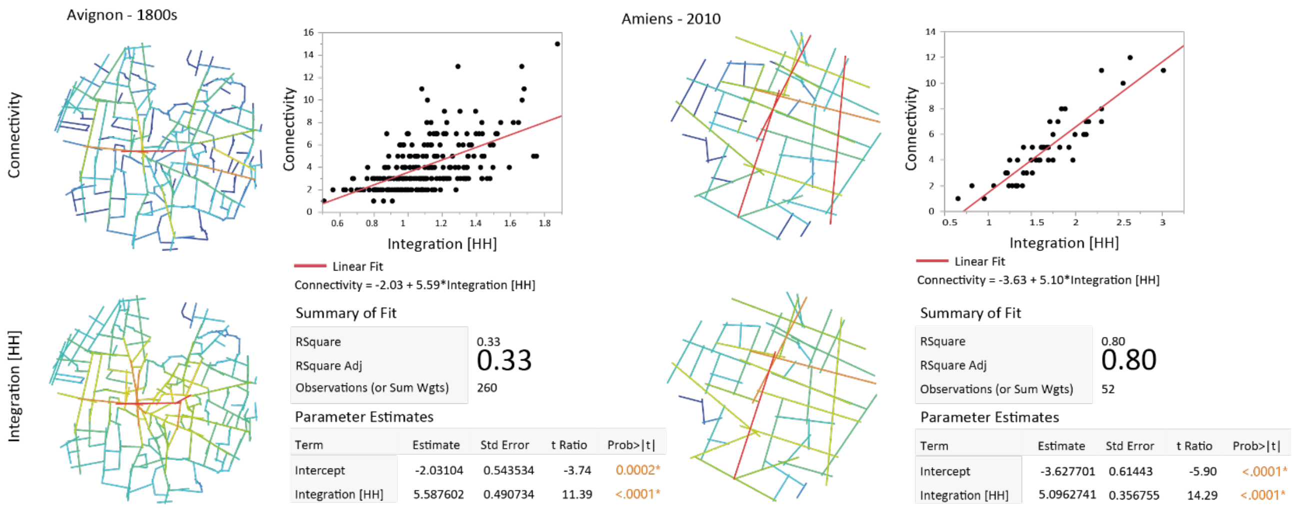


Figure 1. *Configurational intelligibility as the adjusted R squared value of the correlation between measures of integration and connectivity of an axial map in Depthmap representing Avignon in 1800s and Amiens in 2010.*

The cognitive effort required to navigate a novel environment is often measure by the time taken by an individual to complete the task (completion time) and the speed of tracing (velocity). Previous research has shown that different street layouts have an impact on the decision time when navigating maps (Sakellaridi, Christova et al., 2015). Completion time (CT) is a well-used measure of cognitive abilities to assess both motor skills and cognitive functions.

Methodology

Six cities with different levels of urban transformations have been selected. Urban transformations of the public space occur through two main types of intervention: the creation of new street, creating a new connection, or widening and aligning the boundaries of existing streets, creating straighter and more continuous frontages as shown in figure 1 (Vialard, 2015). The level of changes between the two periods is indicated as the percentage of new street frontage compared to the total length of street frontage: Amiens (76%), Tourcoing (47%), Agen (36%), Clermont (25%), Avignon (20%) and Dijon (12%). Their *morphologic* *properties* include the size and number of urban blocks, number of intersections and street width. Street width results from the total area of public space divided by the total of street segment length. The assumption is that having fewer large urban blocks will be easier to navigate than many smaller ones as it reduces the number of decision points at their intersections.

Figure 2. *Map of Agen showing the creation, alignment and widening of street between 1800s and 2010. It also shows the selected part of the map for the 2 tasks based on the locations of the 'edges'.*

The maps represent a circular area based on the current (2010) and Napoleonian cadastre (1800s). It is half a mile wide, equivalent to a 10-minute walk. When possible, the area selected includes at least two edges of the city centre, such as the town wall or peripheric boulevards (figure 2). The starting points are located on the circle to maintain a consistent distance, as the crow flies, throughout the sample. Origins and destinations are selected so they exist in both versions of the 1800s and 2010 maps. In the first task, the destination is the centre of the circle, in the second task, it is located diametrically opposite to the origin (Vialard & Zietsma, 2020).

Six participants are presented a total of 12 maps representing the six cities during both periods on a digital support (tablet). They are asked to draw what they perceived as the shortest path between two points using of a digital pen. Minute changes in motion patterns when performing the task are recorded by the NeuroMotor pen, a biomedical device designed primarily to detect tremors by measuring fine motor skills during graphical tasks (Tolonen, Cluitmans et al., 2015). The Neuropen system records the x-y position of the pen sampled at 200 Hz (sampling time) and when the pen is touching (execution time). From these recordings, path length, cumulative changes of direction along the path, completion time and mean velocity can be inferred and computed for each path. *Motor skills and cognitive functions* are measured by completion time and speed of tracing, or velocity. Completion time and velocity are two collinear measures of cognitive abilities to process spatial information when navigating.

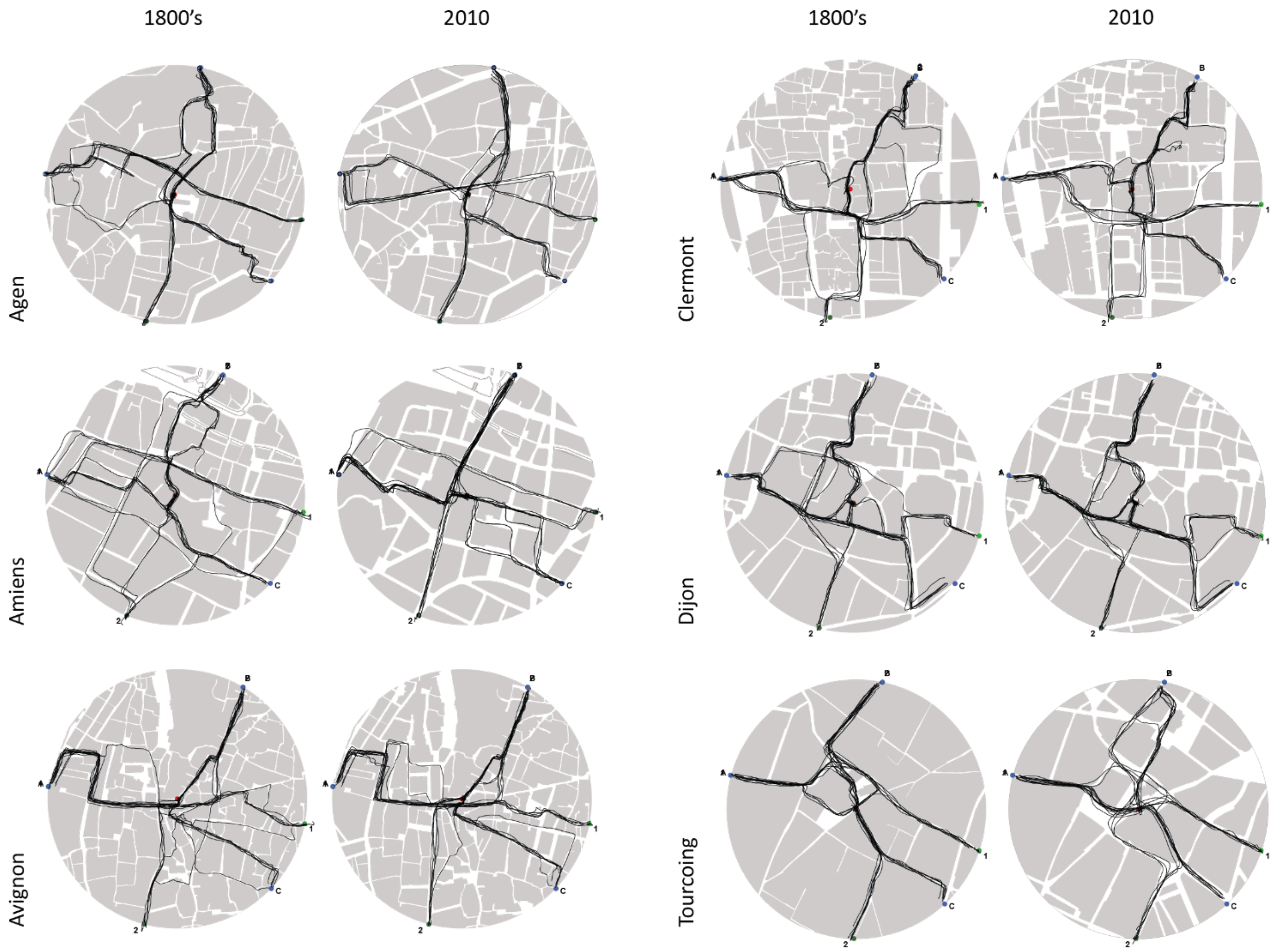


Figure 3. *Maps of the 6 cities based on the Napoleonic cadastre and the current one in 2010 showing all the selected routes (30 paths per map).*

A total of 360 paths makes the set of data to assess cognitive functions (figure 3). The motor skills and cognitive ability of each participant are evaluated through their selection of 30 routes. The trajectories between given origin and destination locations are examined as well as the range of route choices. Route choices is measured by the number of different paths selected by the participants: it can range from 5, all participants select the same path, to 30, all participants select a different path. In this study, the range is contained between 9 and 16.

Results and Discussions

Urban Properties facilitating navigation

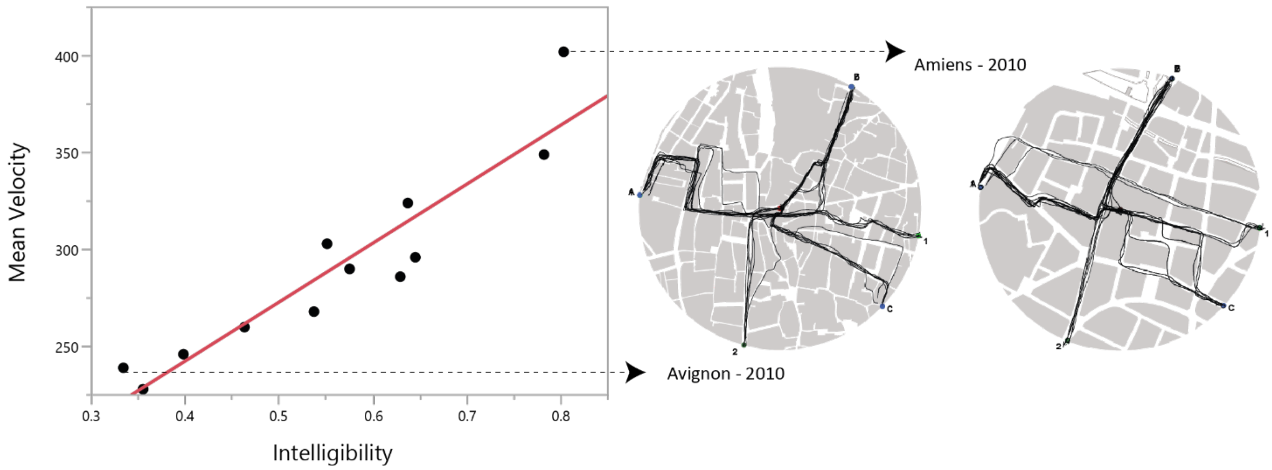
This section establishes and clarifies the relationships between configurational intelligibility of cities, their morphological properties, and the cognitive abilities of participants. It presents the factors that contribute to ease navigation, route selection and completion. Table 1 shows the results of bivariate of cognitive measures with morphological properties and intelligibility based on 12 maps accounting for 30 paths each.

Table 1. Table showing the correlation between morphological and configurational measures, intelligibility, with fine cognitive and motor function. (n=12) The adjusted R square (R^2), the significance (p) and the coefficient (B) are reported.

Cognitive and motor function		Morphological and configurational properties by maps					Selected routes by map		
		n Blocks	Mean Block area	Mean Street width	n Intersections	**Intelligibility**	Mean cumulative angles	Mean Length	n Route choices
Velocity	R^2	0.44	0.14	0.54	0.51	**0.86**	0.91	0.53	0.36
	p	0.0112*	*0.1227*	0.0041*	0.0056*	**<.0001***	<.0001*	0.0043*	0.0237*
	B	-0.50	*+37*	+0.05	-1.78	**+0.03**	-26.8	-0.80	-0.03
CT	R^2	0.50	0.23	0.40	0.59	**0.79**	0.97	0.71	0.21
	p	0.0063*	*0.0677*	0.0165*	0.0022*	**<.0001***	<.0001*	0.0003*	*0.0759*
	B	+32.4	*-2641*	-2.53	+117	-0.17	+1706	+56.4	*+1.58*

Note: * denotes p <.05

From a morphological perspective, the presence of a smaller number of urban blocks will shorten the navigation time. By reducing the number of intersections, it removes decision points along the path, which shorten the time required to complete the task. The width of the street also has an impact on the speed of tracing. Wider streets tend to be easier to navigate. However, the size of the urban blocks does not have a significant impact on the speed of tracing, or the completion time.



Linear Fit

Mean Velocity = 121 + 304*Intelligibility

Summary of Fit

RSquare	0.87
RSquare Adj	**0.86**
Root Mean Square Error	18.6
Mean of Response	291
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	23683.680	23683.7	68.1891
Error	10	3473.236	347.3	**Prob > F**
C. Total	11	27156.917		<.0001*

Figure 4. *Linear fit between the measure of mean velocity (30 paths) and intelligibility per city and period (12 maps). The maps of Avignon and Amiens in 2010 illustrate a respectively low and high intelligible structure.*

There exits a strong and highly significant correlation between velocity and completion time with the measure of intelligibility (figure 4), while there is no significant correlation with the configurational measures of mean integration and mean connectivity. It suggests that highly intelligible urban patterns, by having both an accessible global structure and high local connectivity, allow for the selection of routes that are faster to navigate, being either more direct or at least more identifiable.

The high correlation with cumulative sum of angles along the route and completion time suggests that straighter routes are faster to navigate. It confirms previous finding on the angularity of the route but also what is perceived as turns or changes of directions impacting the choice of route (Montello, 1991; Crowe, Averbeck et al., 2000; Jansen-Osman and Wiedenbauer,2004). However, as the sampling frequency records very fine motor skills, some of the direction changes are due to minute tremors while drawing rather than actual changes of direction on the map. Further work is needed to differentiate between the two types of changes of direction and resulting angles produced.

Impact of transformations

Table 2 reports the relative change of morphological, configurational and cognitive measures between the two periods, using the state of 1800s as reference.

Table 2. Table showing the increase or decrease of morphological and configurational measures, intelligibility and fine motor skills: completion time, velocity.

	Morphological and Configurational properties (maps)						Cognitive and motor functions (paths)				
City	Inc. Public space	Inc. n Blocks	Inc. Block size	Inc. Street width	Inc. n Intersections	**Inc. Intelligibility**	Inc. Completion time	Inc. Cumulative Angles	Inc. Distance	**Inc. Velocity**	**Inc. n Route choices**
Agen	53.8	41.0	-36.5	31.3	16.1	**38.4**	-23.1	-32.9	-4.0	**23.2**	**0**
Amiens	35.5	-16.5	6.5	50.0	-34.5	**39.7**	-36.8	-50.5	-7.6	**38.6**	**-40.0**
Avignon	26.2	5.9	0.6	-21.3	13.5	**6.3**	0.7	6.4	0.1	**-4.6**	**15.4**
Clermont	13.7	-1.0	-4.8	17.0	30.1	**16.0**	0.4	2.3	-0.4	**3.1**	**-37.5**
Dijon	8.7	10.1	-11.2	7.3	0	**-2.5**	2.8	3.4	-2.0	**-2.5**	**7.14**
Tourcoing	15.9	35.7	-39.0	105.3	25.0	**22.8**	-1.2	-3.9	-2.8	**7.7**	**-23.1**
Mean Increase	**23.0**	**12.6**	**-14.0**	**31.6**	**4.2**	**20.1**	**-9.5**	**-12.6**	**-2.8**	**10.8**	**-9.2**

Morphological changes

The main morphological change between the two periods concerns the systematic growth of public space which results in an increase in number of urban blocks but of smaller size. A phenomenon linked to this growth is the size of the streets, which take up more space and become wider. These observations are consistent with the urban transformations of the 19th century, mainly comprising the creation of new streets, public squares as well as the alignment and widening of streets.

It is worth noting some variations within this trend. In the case of Amiens, it is expressed through both fewer and larger urban blocks, which implies a strong increase of public space, as evidenced by the much wider streets. The urban blocks in Avignon are both more numerous and larger which translates in narrower streets, while the public space in Clermont gains wider streets with a decrease in the number of urban blocks which are also smaller.

Intelligibility

A consequence of these morphological changes is a variation in the intelligibility of the public space. Overall, they have a positive effect on the legibility of the street structure (+20%), with both Agen and Amiens improving the most (approx. +40%). However, the transformations in Dijon seem to have slightly reduced the intelligibility of the public space, it can be explained by an already high intelligibility value prior transformation combined with a lower level of transformation between the two periods. By opposition, Avignon starting with an already low intelligibility keeps a relatively low one despite the interventions (+6.3%).

Motor function and Cognition

Variations in intelligibility have implications in the selection of a route in both configurations, before or after the transformations. The selection of what is perceived as the shortest route is part of the decision-making process. A reduction in completion time indicates configurations that are easier to navigate after the transformations. Tasks on the 2010 maps generally take overall 10 percent less time to complete than on the 1800's ones. This is partly explained by the selections of routes with a reduced sum of cumulative angles (-12%) and slightly shorter metrically (-3%). A decrease in the cumulative angles implies the selection of a more direct and straighter path. However, the selected paths in Avignon, Clermont and Dijon take more time to complete and have a higher sum of cumulative angles.

Velocity relies less on the length of the path than completion time. Variations of intelligibility between the two periods is significantly and highly correlated to variations of velocity (R^2=0.81, n=6, p=0.088*, B= 0.92): a gain in intelligibility causes an increase of velocity when selecting a route. While the loss of mean velocity in Dijon is expected because the new configuration loses overall in intelligibility, it is on the other hand more unexpected for Avignon. But there again, the paths which are selected in Avignon, after the transformations, are on average a little longer and less direct, which can explain more motor effort during the task.

Conclusions

From a historical perspective, it is possible to assess and quantify the impact of urban transformations on the intelligibility of the overall system. Some cities have benefited more than others from the urban transformations. Morphological changes linked to the growth of public space with more blocks but smaller in size, wider streets, and fewer intersections contribute to the increase in the intelligibility of the street structure. It results in shorter completion times and higher velocity during navigation by allowing the selection of shorter and straighter paths, reducing overall motor and cognitive efforts.

This study suggests that there is a relationship between the morphological properties of cities and the intelligibility of the public space, which has an impact on spatial cognition and how people select their routes on a map, indicating that similar impact might apply to real environments. It confirms that the existing measure of intelligibility based on configurational properties of the public space are associated with cognitive mechanisms used in our understanding of the urban environment.

However, this is a limited study in that it only applies block representations. Street centerline representation might require different visuo-construction abilities. For example, street centerline representations do not account for the width of the street in the velocity measure. Furthermore, it is limited to historical French urban form which tends to be hierarchical systems. More research is needed to see if these findings will be still relevant for grid-like urban structure where choices of route are less differentiated (Mohsenin and

Sevtsuk, 2013; Coutrot et al, 2020). A more detailed analysis of the properties of the selected routes will also provide further understanding in the decision-making process (Sevtsuk and Kalvo, 2021).

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APPENDIX 1

Table 3. Table showing morphological and configurational measures and intelligibility by city and period.

		Morphology & Configuration (12 maps)					Cognition & Motor functions (360 selected paths)				
City	Period	n BLK	Mean BLK area	Mean Street width	n intersections	Intelligibility R^2 BLK	Mean CT (s)	Mean cumulative angles	Mean Distance	Mean Velocity	n route choices
Agen	1800	83	5,132	6.4	143	0.398	4.76	6837	1010	246	15
	2010	117	3,261	8.4	166	0.551	3.66	4585	970	303	15
Amiens	1800	79	4,916	9.8	119	0.575	4.43	6025	1020	290	15
	2010	66	5,238	14.7	78	0.803	2.80	2982	942	402	9
Avignon	1800	135	2,858	7.5	340	0.334	5.41	7250	1085	239	13
	2010	143	2,876	5.9	386	0.355	5.45	7711	1086	228	15
Clermont	1800	104	3,457	10.0	236	0.463	4.49	5887	1008	260	16
	2010	103	3,292	11.7	307	0.537	4.51	6021	1004	268	10
Dijon	1800	69	5,899	9.6	94	0.645	4.25	5143	1076	296	14
	2010	76	5,240	10.3	94	0.629	4.37	5316	1055	286	15
Tourcoing	1800	28	16,397	7.6	36	0.637	3.43	4262	968	324	13
	2010	38	10,010	15.6	45	0.782	3.39	4097	941	349	10