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Article

Intelligibility of Post-War Reconstruction in French Bombed Cities

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Abstract
In the aftermath of the WWII, many French cities faced a great need for reconstruction in response to the heavy destruction caused by the bombardments. Reconstruction plans were developed and implemented at relatively short notice in response to a critical and urgent situation. However, not all cities adopted the same approach: (a) some proposed and implemented a new layout; (b) others tried to recreate the old street layout but with some updates such as widening and alignment; and finally, (c) some have preferred to resort to more targeted interventions. The choice of approach was motivated by various factors associated with the level of destruction, the futuristic vision of the architect or urbanist in charge, or the historic value of the place destroyed. This article assesses the impact of these approaches on the urban tissue by measuring changes in the overall morphology and intelligibility of multiple city centres before and after the reconstruction based on their cadastral maps. Intelligibility is first measured as a configurational property of the street layout and then as a result of public participation in a navigation task using these maps and digital technology that records the speed of movement and trajectories. This allows a comparison between the original street layout and the new one, as well as across the different cities. Drawing on indicators of spatial cognition, this interdisciplinary research approach provides a means to measure and better understand the impact of the reconstruction on the intelligibility of urban environments.

Keywords
bombed cities; intelligibility; skeleton; spatial cognition

Issue
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1. Introduction

The destruction of cities due to conflicts and wars generates the question of how to rebuild them. Any reconstruction of an urban space must position itself in the face of its past, think about the history of the place that is no longer and how to respond to its destruction. Faced with destruction, several choices are possible: (a) to rebuild identically, (b) to preserve the ruins, (c) to restore the traditional character, or (d) to use this opportunity to innovate (Bullock & Verpoest, 2011). In France, in the wake of the WWII, the level of destruction resulting from the bombardments wiped out large parts of town centres—some were destroyed by up to 80%. Once the rubble was removed, this large-scale destruction produced vast areas of empty land where once had been dense urban fabric, contrasting with the remaining surroundings. These large voids within the urban fabric were seen at the time to present the perfect conditions for implementing Tabula Rasa planning, as advocated by some modernists. They presented opportunities to build a new future liberated from the constraints of the past. This view conflicted with the notion of continuity and identity found in the familiarity of the inhabitants with the structure of their streets. Part of the debate was focused on the importance given to the preservation and reinstatement of the character of the past city to ensure continuity for its inhabitants, and to which extent this opportunity could be used to implement the long-awaited upgrades of the urban fabric with a more airy, rational, and hygienic urbanism, already a primary concern of the first reconstruction. This dual concern

is reflected in a letter addressed to the architects of the reconstruction plan of Orléans by its mayor Pierre Chevallier on January 16, 1945:

> Modern installations should be built, some public buildings should be modernised; existing roads should be upgraded and ventilated and open spaces should be provided, etc.…At the same time, the historical character of the city, of which we are rightly proud, should be preserved. (Chevallier, 1945, para. 2–3)

Part of the character of a town is related to the way it is experienced and by where people tend to naturally congregate, which forms the identity core of a town. From an experiential perspective, an urban grid with its clear orthogonal structure engages its visitors very differently compared to the irregular streets of a medieval town. The former has a clarity built into its geometry that provides a Cartesian structure in which to navigate, while the latter, with its less predictable layout, is more conducive to exploratory behaviour or Flânerie (Sansot, 1973). The morphological character of the medieval or historical fabric which results from micro-adaptations over time (Noizet & Clémençon, 2020) cannot be easily replicated or emulated in a planned proposal due to their incremental nature. Although they can also evolve over time, the geometry of grid layouts can be more easily reproduced by comparison. As such, all destroyed cities are not equal in their reconstruction and their ability to be replicated to provide continuity. Preservation of character is partially embedded and expressed in the physical characteristics of the urban tissue that includes street, plot, and building patterns (Kropf, 1996). Changes in the relationships of these three elements impact the character of a city through the configurations of buildings on the urban blocks and the pattern of urban blocks that forms the street structure.

The relationship between the morphological and structural characteristics of cities and how they are experienced is embedded in what Lynch (1960) calls mental maps and their legibility. The legibility of complex urban environments is based on the identification of their different parts and the ability to structure them into a coherent pattern. The work of Hillier et al. (1987) goes further and proposes the notion of intelligibility mainly embedded in the structure of the street network and arising from their configuration. A street network is syntactically intelligible when it is possible to get a sense of the whole network based on local information (Hillier et al., 1987). Levels of syntactic intelligibility are measured by the relationship between local connectivity, how many spaces are directly available, and global integration—how each space is positioned concerning all the other spaces of the system. Syntactic intelligibility supports two types of navigation with different purposes: exploration and wayfinding (Peponis, 2016). Exploration is associated with the ability of the street network to offer opportunities without necessarily having a particular destination in mind, while wayfinding requires finding a route to reach a specific destination. Intelligible cities should be able to support both types.

The decision-making during the navigation process is associated with cognitive abilities linked to the formation of mental spatial representations and how they guide motor decisions. Cognitive mapping, a map-like mental representation of space (Tolman, 1948), is one of the processes used to store and interpret spatial information in the mind (Kitchin, 1994; O'Keefe & Nadel, 1978). Cognitive maps, by organising spatial information found in the environment, imply a hierarchy of spatial knowledge (Hirtle, 2003). This map-based strategy is associated with exploratory behaviour. The other type of cognitive strategy involved in the navigation process is the route-based strategy linked to motor function. It is linked to sequential information such as speed, direction, and turns and relates more to goal-oriented navigation and wayfinding (Lafon et al., 2009). It has been suggested that cognitive maps concur with the production of a cognitive "skeleton" formed by the major paths identified by an individual, which serves as a spatial reference to guide decisions (Kuipers et al., 2003). This skeleton includes the preferred routes that tend to correspond to the primary street network. The primary network, in turn, tends to include the most syntactically integrated streets (Peponis, 2016). The relationship between the exploration of city maps and motor skills has shown that different street configurations are associated with different decision times, with shorter time for street layouts that have longer and straighter streets (Christova et al., 2012; Sakellaridi et al., 2015), highlighting a lower degree of cognitive effort. Using a goal-oriented task and recording hand movement, previous research has shown that Haussmannian urban transformations have greatly increased the syntactic intelligibility of French towns by bringing more hierarchy in the historical fabric with the implementation of wider and straighter streets (Vialard, 2022). Furthermore, Yaski et al. (2011) found that grid-like layouts are more permeable and tend to be easier to cognitively navigate than more irregular patterns.

Building on this work and within the context of bombed cities, this research looks at the impact of design decisions on the syntactic intelligibility of the street structure and wayfinding. It asks to what extent the reconstruction plans changed how the city is experienced through the assessment of their intelligibility as a configurational property of the street layout, impacting the ease of their navigation. The comparison between pre- and post-WWII urban layouts shows the impact of the changes on the intelligibility of public space. The intelligibility of the urban form is assessed from two points of view: as defined by the geometrical properties presented by the reconstruction plans but also as a function of navigating map-like representations of urban environments. The first part highlights the role of maps and plans

in shaping the reconstruction of the bombed cities as a key tool to rethink cities for the architects and state officials. It discusses the different approaches taken and how the pre-WWII original layouts influenced the proposed new layouts. The methodology section presents the setting of the experiment and the different measures associated with the morphological properties of the maps and the cognitive and motor functions of the participants when tracing routes on these maps. To reflect the two types of measures, the results section is organised in two parts looking first at the morphological changes of the public space of the maps and their impact on configurational intelligibility, and second, at the routes selected by the participants with their associated motor and cognitive metrics and their impact on the skeleton of the urban structures. Finally, the skeletons of primary drawn routes are compared between the pre- and post-war maps to identify the continuities and changes in their structure.

2. Context

2.1. Map, A Tool for Change

In 19th-century France, maps became a means for the state to control and shape public space, as well as for planning changes. The systematic survey of France to produce the Napoleonic cadastre, started in 1806, consolidated the importance of plot boundaries and solidified its distinction from public space. In the same year, the required production of alignment plans for cities above 2,000 inhabitants aimed at bringing some rationalisation to the public space by identifying possible street alignments, and widening, the creation of new streets, and squares. Building on these precedents, the use of plans in the two World Wars became a complementary tool to laws and policies that tended to be directed to the individual and helped to shift the approach to a more global vision. This shift from an individual to a collective approach is what distinguishes the two periods of reconstruction. While both post-war periods are accompanied by a set of laws that recommends establishing reconstruction plans, they have had very different impacts. The destruction at the end of WWI was for the most part in the countryside. Fewer cities were destroyed and to a lesser extent than after WWII. On March 14, 1919, Cornudet's law established the Development, Embellishment and Extension Plan (PAEE—Plan d'Aménagement, d'Embellissement et d'Extension) first aimed at cities with more than 10,000 inhabitants destroyed during the war. They intended to adapt these cities to the industrial era by improving aesthetics, hygiene, and circulation (Renaud, 2016). However, they had a limited impact with only 10% implemented by the start of WWII. One of the reasons was the lack of connection with the law of April 17, 1919, establishing the grounds for war compensation which was paid to individuals without any constraints on how to use the money (Voldman, 2011), making a collective vision difficult.

For WWII, the reconstruction process started before the end of the war, during the Vichy government, with the creation in November 1944 of the Ministry of Reconstruction and Urbanism (MRU) by Raoul Dautry (Voldman, 1989). This was followed by the establishment of Development and Reconstruction Plans (PAR—Plan d'Aménagement et de Reconstruction) by the Ordinance of April 21, 1945, which required the approval of the newly created MRU. The compensation law of October 28, 1946, was more tuned towards the public interest rather than individuals (Vayssière, 2009). Owners were required to join a state-managed or independent reconstruction association or cooperative to benefit from the compensation (Clout, 1999). This was a more state-driven and collective approach, which brought the possibility to think more holistically. One of the main tools was land or plot consolidation (*remembrement urbain*). Land consolidation helped in reducing the number of plots and allowed for the creation of larger plots and consequently larger building footprints (Chabrol, 2010; Clout, 1999). With their medieval fabric, both Amiens and Caen saw their number of plots divided by three. The process of land consolidation involved a zone whose perimeter included both the space of the street and the individual plots. The amalgamation into a single space erased boundaries allowing for easier changes in the perimeters of urban blocks and the definition of new street configurations (Chabrol, 2010). It meant that more space, therefore, could be allocated to public space. This increase facilitated the widening and alignment started in the past century and the creation of public squares and new streets. In exchange for their lost individual property, owners were offered a co-ownership share of a larger building or a spatial transfer of the cadastral base. The decisions were made during meetings of the reconstruction associations. The presence of the architects of the reconstruction plan (Table 1) played an essential role in these negotiations and the application of their plan (George, 1960).

The reconstruction plans for the future street layout tended to show the outline of urban blocks (*plan masse*). There were no directives or specifications for what should be included in such a plan. Some showed the new street layout with the boundaries of the urban blocks, some the building footprints, and other, more abstract, zones. Their scale ranged from 1–500 to 1–50,000 but the high-level plans at 1–2,000 and 1–5,000 were mostly used (Table 1). Although these plans were only two-dimensional representations of space, they were essential in the discussion between the different stakeholders (MRU, inhabitants, council and architects) to communicate the broader vision for the city. This justifies to some extent the use of figure-ground plans to understand the impact of change, as they play an important role in driving changes and in shaping public space.

Table 1. Dates and authors for the PAEE, the PAR, and the scale of the plans.

Cities	Type	PAEE *	Architect	PAR	Architect/Urbanist	Scale 1 **
Amiens	Historical	1919	Duthoit	1942	Dufau	2,000; 5,000
Caen	Historical	1938	Danger	1947	Brillaud de Laujardière	2,000; 10,000
Dunkirk	Historical/17thC	1911	Agache	1949	Leveau & Niermans	2,000
Le Havre	16thC/18–19thC	*1786*	Lamandé	1945	Perret	2,000; 50,000
Lisieux	Historical	*1898*	Bailleul	1946	Camelot	5,000
Lorient	18thC	1929	Parenty	1943	Danger & Toury	2,000
Orléans	Historical/18–19thC	*1751*	Hupeau	1945	Royer & Abraham	500; 2,000; 10,000
St-Nazaire	19thC	*1858*	Leferme	1947	Le Maresquier & Guillou	5,000
Tours	Historical	1933	Agache & Saunier	1946	Lefèvre & Patout	5,000

Notes: * and other significant plans in the absence of PAEE, in italics; ** as listed in the repertory of the national archives by the Direction de l'aménagement foncier et de l'urbanisme (1990).

2.2. Bombed Cities: Before and After

Bombed cities have in common the disappearance of their urban fabric, however, the size of the area affected by the destruction and their past urbanism play an important role in the mode of rebuilding undertaken. The nine cities selected represent different types of urban forms and are located in the northern and western regions of France, which were the most affected. They range from historic towns with a predominant medieval fabric (Lisieux, Amiens, and Caen), to established cities restructured around new major axes (*percées*) implemented during the 18th century (Orléans and Tours), or by a new grid extension in the 17th century (Dunkirk), to relatively new ports that emerged during the 18th and 19th century (Lorient) following a grid plan (Saint-Nazaire and Le Havre). The overlay of pre- and post-war block boundaries in Figure 1 illustrates the different levels of destruction for each city and the subsequent modifications: where street boundaries were aligned or widened, where new streets and squares were created, and where block consolidation or subdivision occurred. Figure 1 also helps visualise any orientation changes.

The reconstruction plans shared a common aim which was to update the cities to higher hygienic standards. In the historical towns, the new plans proposed a more open city centre and wider circulation axes with a rationalisation of spatial structure. This was achieved by the introduction of a new major axis (Caen and Amiens) or public square (Orléans and Tours), alignment and widening of existing major axes (Orléans, Tours, Dunkirk, Amiens, Caen, and Lisieux). The historical cities tended to have vernacular fabric made of a very dense system of small plots which were systematically re-modelled by the post-war proposals. In Caen, the street grid was realigned to connect more directly with the docks, wide streets were created in both directions, and elongated east-west blocks were subdivided to create more accessibility north-south (Clout, 1999). It is important to note that Orléans and Tours were only partially destroyed and are examples of targeted and contained intervention. In more recent cities planned on grids, the aims are similar, the widening of streets is also systematically applied but the tendency is towards the aggregation of blocks. In Lorient and Saint-Nazaire, the centre was moved away from the docks (Dieudonné, 2001). In Lorient, based on the PAEE, the radial plan was adjusted to become more rectilinear, preserving the main central square. The adjustment of the grid in Saint-Nazaire was made through the consolidation of urban blocks into larger ones (Sicard, 1994) while the main orientation was preserved. Le Havre also consolidated its smaller blocks into larger ones but the previous colliding grids—inherited from successive extensions—were consolidated into a single grid with wide streets and larger blocks. One historical street was preserved due to pressure from the inhabitants (Jacono & Arnould, 2000).

3. Methodology

The methodology for testing degrees of syntactic intelligibility is centred on the properties of maps as they relate to the plans used by the architects and urbanists of the reconstruction to convey the new street layout. The proposed method combines the configurational properties of maps and some of the motor functions associated with map navigation to assess the impact of post-war reconstruction in bombed cities. A wayfinding task is implemented that links the role of maps with the experience related to their navigation. It makes it possible to link the measures associated with the geometric properties of maps to the metrics associated with the cognitive and motor efforts of the participants when selecting and drawing a path between two locations.

3.1. Setup

Twenty participants were asked to draw what they perceived to be the shortest path between two pairs of diametrically opposed points on a circular map. Asking

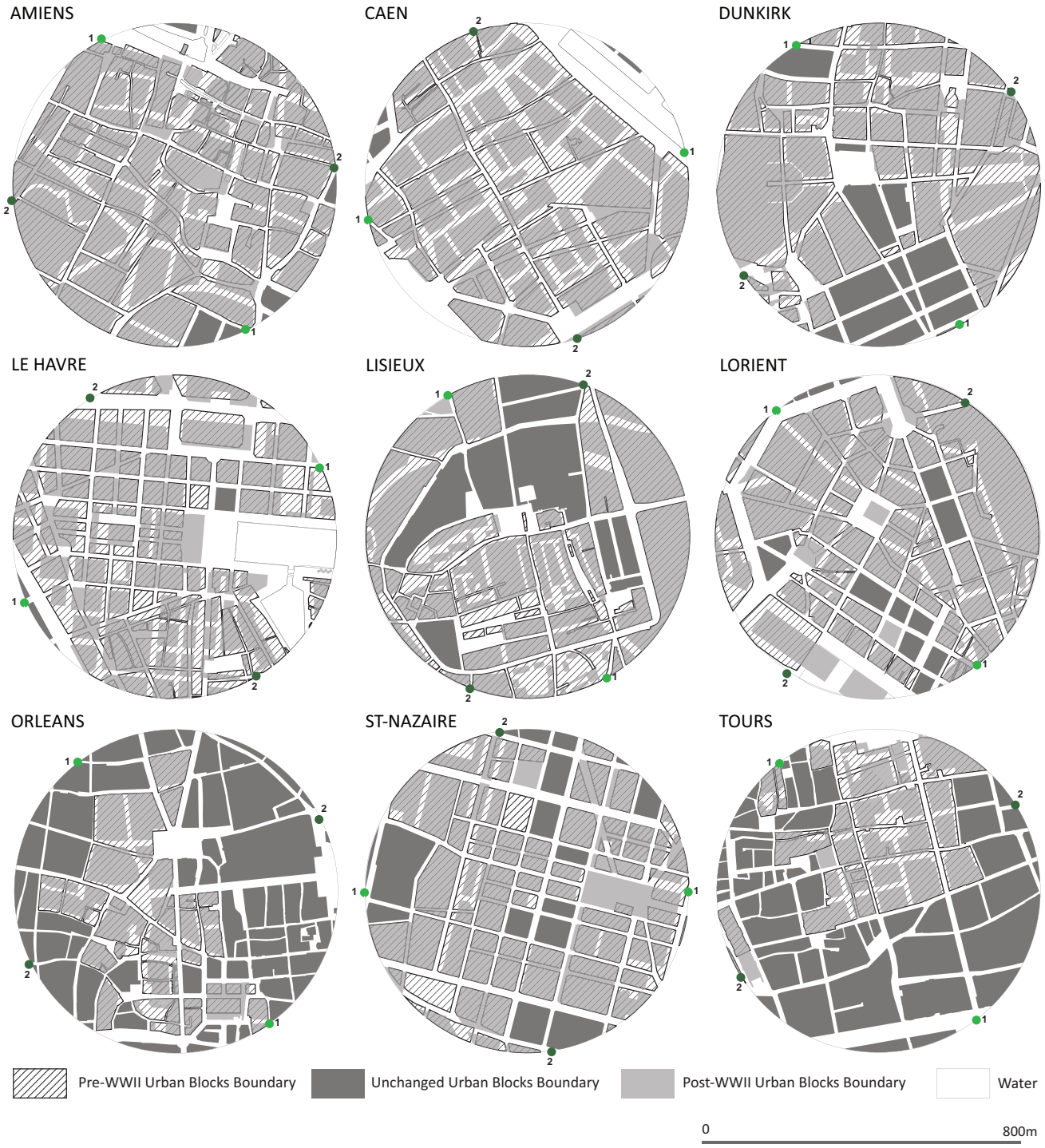

Figure 1. Maps showing the urban blocks boundaries of the nine cities highlighting urban blocks only present in the pre-WWII (hatch) layout, the unchanged blocks (dark grey), and the new urban blocks (light grey).

about the shortest path entails a goal-oriented task which may differ from an exploratory attitude—it suggests efficiency. For each of the nine cities, the circular map covered most of the urban zone destroyed by the bombs within a quarter-mile radius, which is roughly equivalent to a five-minute walk. The base maps used the current cadastral maps, which were then updated manually using the reconstruction plans to reflect the situation pre-WWII. The navigation task used two map representations: a city block map (Figure 2a) and a building footprint map (Figure 2b). The first one focuses on the public space as the space that is not contained within plots and therefore uses a figure-ground representation differentiating the urban blocks from the public space. The notion of public space in this case encompasses everything that is not contained within plot boundaries, which includes for example the space of the street. Block maps were used to compare pre-WWII and post-WWII street layouts.

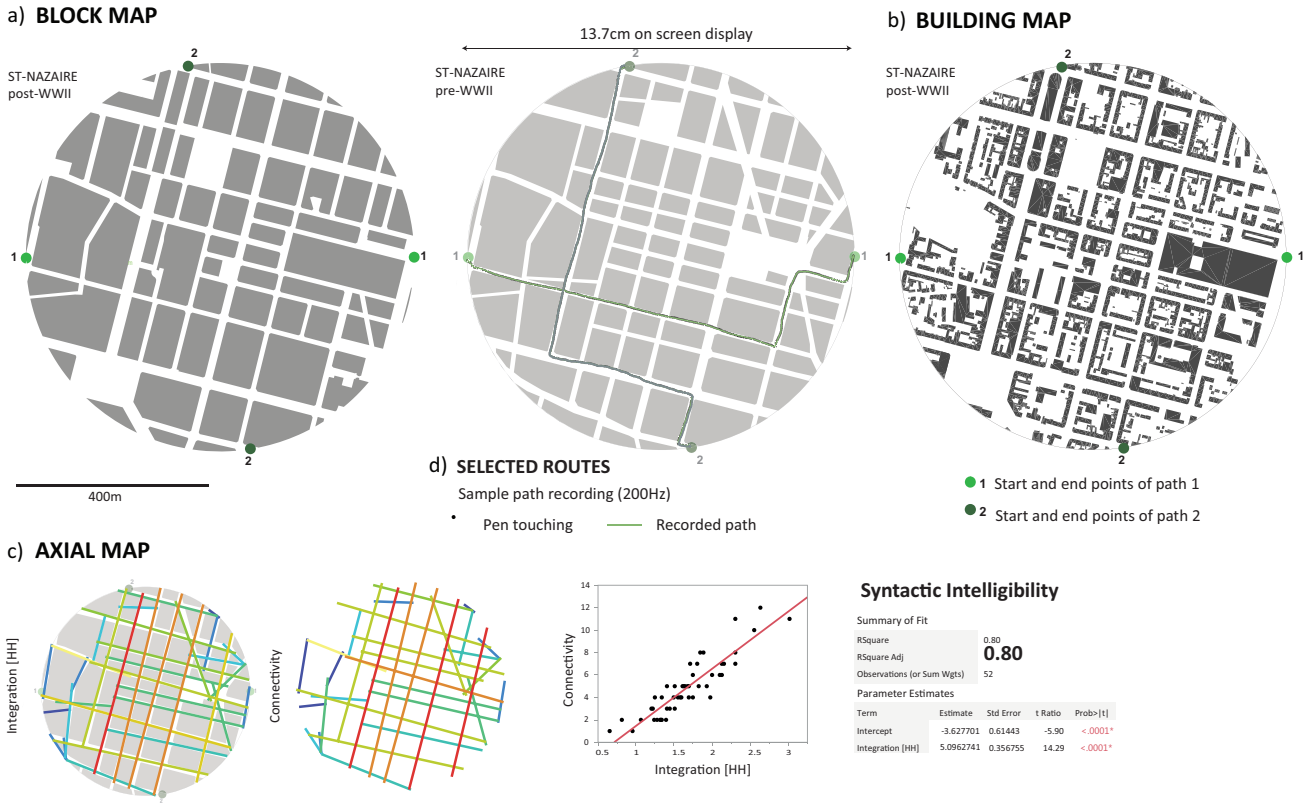

Figure 2. Different types of maps—Block map a) and Building map b)—were used for the cognitive task, and for measuring some of the configurational properties—Axial map c)—such as syntactic intelligibility, and an example of two recorded paths d).

Another set of maps showing the footprints of buildings rather than blocks was used to assess the impact of building configuration on the legibility of the open space in post-WWII layouts. Overall, each participant was asked to draw a total of 54 routes: two routes for 27 maps representing nine cities before and after.

The routes are recorded using a digital tablet and the NeuroMotor pen, a biomedical device used primarily to detect tremor patterns while performing graphical tasks (Tolonen et al., 2015). The NeuroMotor system measures fine motor skills, capturing minute changes in motions through the recording of x-y positions of the pen at a sampling rate of 200Hz.

3.2. Data

The intelligibility of the urban fabric is measured as the configurational properties of the urban form and participates to some extent in the constitution of the cognitive map. Intelligibility is also assessed through the choice of routes and their characteristics, which are more related to motor function, measured by the speed of tracing. The set of data reflects this dual approach by providing measures linked to the urban form and street configuration represented in the map, and measures linked to the choice of routes by the participants.

3.2.1. Morphological Measures: Map Properties

From the figure-ground maps, some morphological features are extracted such as the number of blocks as a measure of density, their area and perimeter. The perimeter of the urban blocks gives an overview of the amount of frontage available. The percentage of public space in the block map is based on the area not included within the plot boundaries, while in the building map, it is based on all the space that is accessible between building footprints regardless of plot boundaries.

Syntactic intelligibility is a topological property of the street configuration measured through axial representation (Hillier et al., 1987). An axial map translates the open spaces of figure-ground maps into a series of axial lines representing all convex spaces and can be likened to lines of sight (Bafna, 2003). It implies that the spaces traversed by the axial line are visually connected. Long axial lines, therefore, tend to represent wider or longer straight streets, which are often more recognisable as they tend to structure the street network (Peponis, 2016). In turn, axial maps are converted into graphs, where each node of the graph represents an axial line. Two values are computed for each axial line: integration, how far that line is from all the other lines of the system; and connectivity, how many other lines are directly connected to it. These are computed using the specialised software Depthmap

(Turner, 2001). Axial intelligibility represents the relationship between the local connectivity of a line and its global integration (Figure 2c). A strong correlation between the two properties suggests that it is easier to infer the position of a space globally based on its local connections (Peponis, 2016). Cities with a high degree of correlation between the two measures are found to be cognitively easier to understand and, therefore, easier to navigate.

3.2.2. Cognitive and Motor Metrics: Route Properties

The navigation is recorded through a series of drawn routes which provide information regarding the ability of participants to process spatial information. Completion time in graphical tasks is a traditional measure of cognitive and motor function—it encompasses the time taken by a participant to solve a task. In this instance, it entails finding the shortest route between two given points on a map. Velocity, or speed of tracing, considers completion time concerning distance and also reflects the cognitive and motor skills of participants in terms of making sense of and drawing on figure-ground maps of unfamiliar cities.

The overlapping of drawn routes from all the participants on each map is used to show the emergence of a skeleton made of the primary choice of routes. The degree of overlaps reveals the presence, or absence, of a core structure that can be made of the main axis and centrality. If the same routes are selected by the participants, the presence of a clear skeleton will suggest a street layout with an established core structure. If routes are multiple, it will suggest a layout with a less defined central core that may, however, offer alternative routes. The changes in the skeleton between the two periods provide information on how the reconstruction has preserved, or not, the continuity of the urban form by conserving a similar structure, changing it, clarifying it, or weakening it.

4. Results

4.1. Properties of Maps

4.1.1. Morphologic Change

One of the main morphological changes taking place in post-war layouts is the increase in the surface area of towns given over to public space (Figure 3a) which confirms the systematic use of land consolidation to liberate public space. While on average, before the war, public space represented a little more than a quarter of the total area (27.5%), it amounts to just over a third today (34.6%). The increase in public space is not necessarily due solely to an increase in the length of streets. The overall linear frontage remains relatively unchanged, even slightly reduced (Figure 3b). Rather, it is through the systematic widening of streets and the creation of large public squares to accommodate a more generous and therefore more hygienic public space already promoted in the PAEE extension plans.

4.1.2. Syntactic Intelligibility of Street Configurations

The surface given to public space transforms the syntactic intelligibility of their layout. Based on its configuration, each layout has been assigned an intelligibility value that represents the strength of the relationship between the local connections of a street with its surrounding, and

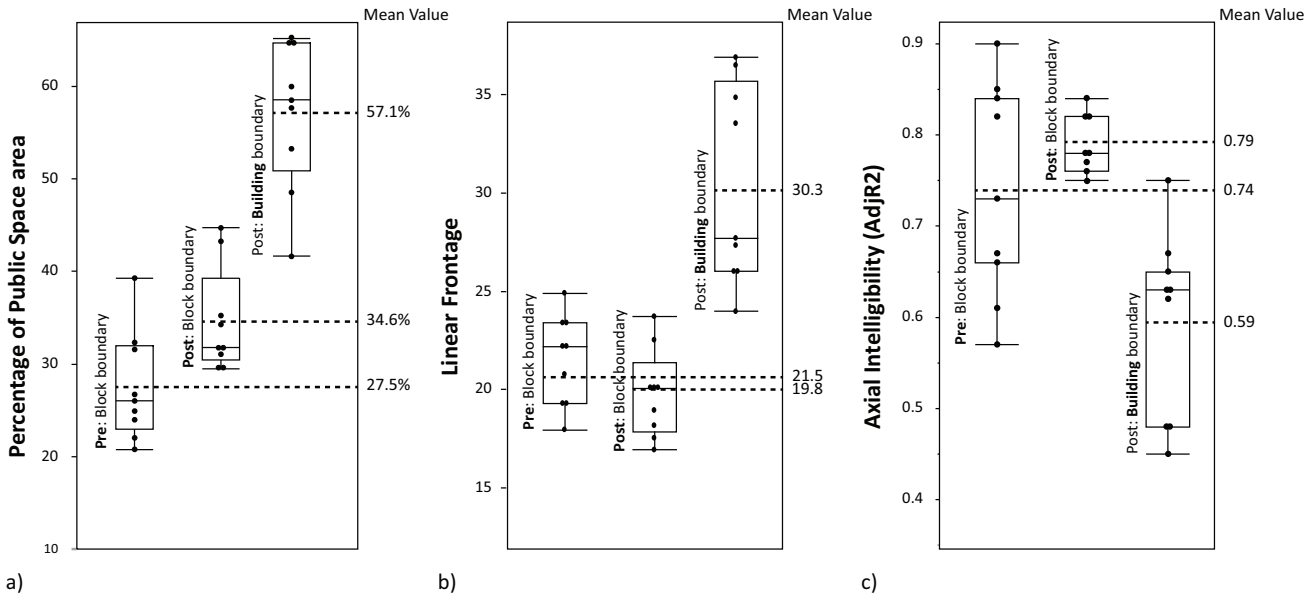

Figure 3. Graphs show the distribution of mean values of each town in the three different maps (pre-war and post-war urban block layouts and post-war building layout) for the percentage of public space a), street linear frontage b), and axial intelligibility c).

how that street is centrally located and globally accessible from all the other spaces. Layouts with high syntactic intelligibility values tend to be layouts that support more efficient navigation (Barton et al., 2014). They are usually supported by the presence of long straight streets that provide continuity. Based on these values, pre-war layouts can be categorised into three types: the highly intelligible grids (Saint-Nazaire: 0.9, Le Havre: 0.85, and Lorient: 0.84), cities that went through 19th-century transformation (Dunkirk: 0.82, Lisieux: 0.71, Tours: 0.67, and Orléans: 0.66) and layouts which retain some of their medieval fabric with the lowest syntactic intelligibility (Caen: 0.61 and Amiens: 0.57). This seems to confirm the role played by long and straight streets present in the grid-like layout and less in the medieval fabric.

Pre-war layouts represent a wide range of levels of intelligibility (0.57–0.9). It suggests that, before the reconstruction, cities carried different characters and would offer different experiences based on the variation in their street structures, potentially allowing efficient or looser navigation. The reconstruction plans seem to homogenise the layouts with values comprised within a much smaller range but higher overall (0.75–0.84; Figure 3c). When comparing the pre- and post-war intelligibility values for each city, the layouts with the highest intelligibility values tend to lose intelligibility while the opposite happens for layouts with previously lower intelligibility. Saint-Nazaire has a layout that loses the most intelligibility but remains still high (0.76). In this case, a grid layout is replaced by another grid layout, accompanied by a change of scale in the street width or block size. Amiens (0.75) and Caen (0.84) are the two layouts that gain the most in terms of intelligibility due to the complete re-modelling of their medieval fabric into a rational layout. Overall, the impact of the reconstruction brings more intelligibility to the street structure and seems to be more beneficial to the updating of historical fabric towards a more efficient structure. The question then is to what extent the character of these medieval towns is preserved and whether the new layout provides any continuity for its inhabitants. Looking at the intelligibility values of the building maps, this homogenisation effect is counterbalanced by the choice of building configurations, which reduces the intelligibility of the layouts overall but re-introduces stronger variations in values, possibly indicating different characters for the cities.

The relationship between the increased amount of space given to the public space and the overall increase of intelligibility values in post-war layouts is confirmed by the statistical correlation between the two sets of values (Figure 4a). In block maps, the relationship shows that as more public space is provided, the intelligibility of a place is increased (AdjR^2 = 0.34, n = 18, 0.0066). In building maps (Figure 4b), the intelligibility values decrease as the space is more fragmented by a higher number of aggregated building footprints (AdjR^2 = 0.38, n = 9, 0.0448). From an urban design perspective, the intelligibility of a street layout can be impacted by the type of building configurations within urban blocks. Orléans and Lisieux are both cities that have implemented very different building configurations: one remains quite historical and opted for a more traditional building configuration, while Lisieux opted for more freestanding building patterns. As a result, the intelligibility of the building map in Lisieux drops drastically compared to the block map but only lower slightly in Orléans.

4.2. Routes

4.2.1. Intelligibility and Ease of Navigation

The following set of results concerns the intelligibility characterised by the configurational properties of the map and how they impact the speed of tracing and the

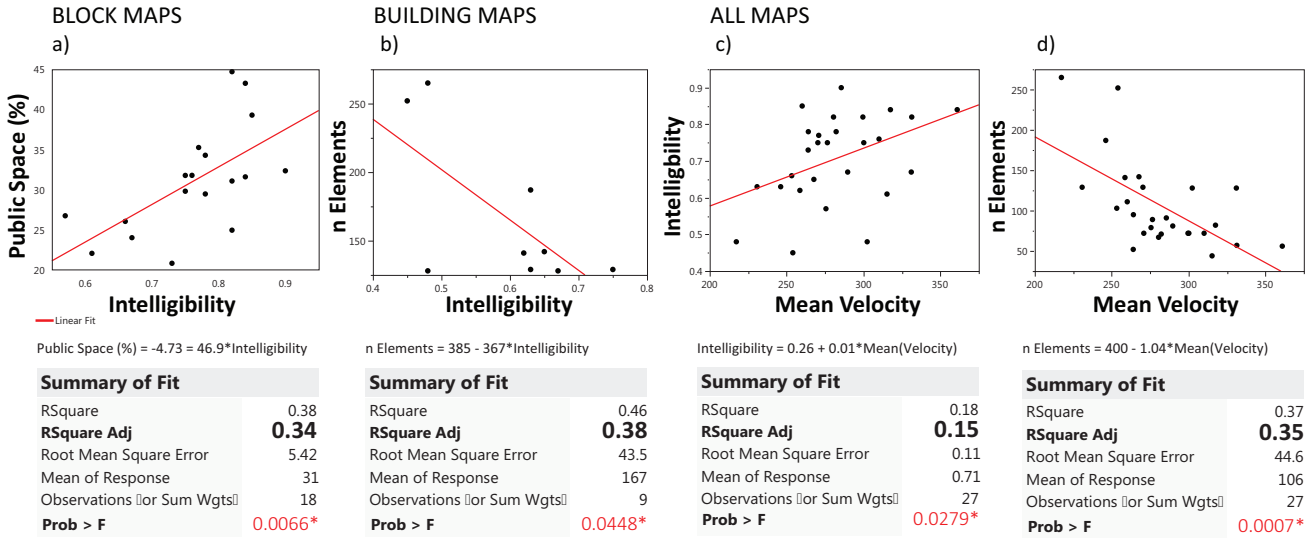

Figure 4. Linear regression between intelligibility, percentage of public space, number of elements (blocks and buildings), and mean velocity for different sets of maps.

ease to navigate them. A low but statistically significant link exists between the level of intelligibility of the urban form and the speed of tracing ($AdjR^2$ = 0.15, n = 27, 0.0279; Figure 4c). It indicates that the more intelligible the layout, the easier is it to find a route and complete it. That relationship exists to a lesser extent than previously found in historical French towns (Vialard, 2022), which is explained by the greater variety of street layouts included in this study, particularly the grid-like plans. Navigation speed is also highly correlated to the number of elements present in the maps ($AdjR^2$ = 0.35, n = 27, 0.0007; Figure 4d). The elements are either the urban blocks or the aggregated building footprints depending on the types of maps. Finer-grain urban fabrics do not necessarily impact the level of intelligibility (no significant association) but slow down the process of navigating their layout. As mentioned previously, the level of fragmentation of building configurations—increased for example by the use of open block configurations—impacts intelligibility. More fragmentation lowers intelligibility and slows down the speed of navigation.

4.2.2. "Cognitive" Structures: Skeletons

As participants select similar or different routes, the preferred routes form a skeleton of pre- and post-war block map navigation (Figure 5). First, the level of definition of these skeletons provides information on the structure of towns. It indicates whether layouts are leading to consolidate routes—similar behaviour from all participants—or offering multiple routes—absent of clear choice. Second, the skeletons depending on their alignment or misalignment with existing and new central squares and main streets clarify the importance of their presence from a cognitive and motor perspective. The superposition of the two skeletons, pre- and post-war, highlights the continuity of the urban form or the changes that occurred in the way space is navigated. Continuity and rupture can be seen in terms of full, partial, or absence of retention of the shape of the skeleton. It can then be compared and related to changes in cognitive and motor functions as measured by the gain or loss of intelligibility and speed of navigation.

Comparing the velocity in the pre-war and post-war block maps, the latter is overall easier to navigate with an average increase of velocity by 7%. Loss of velocity is generally observed when the new layout provides a finer-grain fabric than previously. The subdivision of large blocks to produce a finer grain fabric increases its permeability and therefore offers more choices, which slows down the decision-making process, which translates into slower navigation. In Lorient, this translates into the loss of a clear skeleton in the new layout, while Tours preserves most of its primary structure. Conversely, this multiplication of routes can enrich navigation by creating more opportunities.

Continuity or rupture can be seen in the preservation of the main routes and public squares. They are central elements that can challenge or reinforce the sense of continuity or rupture with the past form. They are often part of the most integrated core structure, strengthening their role as the active centre. This can be challenged by the creation of a new thoroughfare (Amiens) or the doubling of an existing one (Caen and Orléans) that can lessen the role of the historical main street by making it less cognitively present. Similarly, the creation of a new square (Orléans, Amiens, Lisieux, and Caen) can shift the centrality of the layout or lessen its presence, creating a rupture with the past. In one instance (Tours), the new square is placed on a nested grid rather than in alignment with major streets, which lessens its presence and fails to bring some centrality to the layout.

Table 2 summarises the changes that occur between the pre- and post-war skeletons to assess the level of continuity or rupture, highlighting the new, retention, or loss of centrality and main axis. Continuity, the resilience of the pre-war skeleton, is achieved in three cities. Tours was only partially destroyed and retains most of its skeleton. Dunkirk and Le Havre, despite their high level of destruction, retain both their centrality and skeleton with a slight alteration of the main routes. Dunkirk has a more consolidated skeleton. On the opposite spectrum, Lorient and Amiens are both cities that show the biggest changes of their past structure. In Amiens, both centrality and the main street are changed and moved towards the south. In Lorient, while the centrality remains, the change in the orientation of the grid multiplies the routes and weakens the new skeleton.

5. Conclusions

In a study of the reconstruction of Caen written in 1960, the author ponders on the uncertainty that remains on how the new street layout will function and potentially modify the character of the city and its uses: "The reconstruction is not complete yet….We don't know yet which will be the most important commercial axis and the crystallization points of urban life" (Bruté de Rémur, 1960, p. 160). This highlights the challenges associated with the scale of changes and their implications, and how these new layouts will function. The main question was whether the reconstruction plans preserved continuity or created a rupture with the lost urban form and structure. This question has been approached from a planning, morphological, and cognitive perspective to understand how the post-war reconstruction impacted the character of the pre-war cities.

From the planning perspective, two related aspects played an essential role in shaping post-war cities. The role during the reconstruction period of associations of war victims, architects, and their teams on the one hand, and reconstruction plans and land consolidation on the other cannot be understated. The use of plans for implementing changes alongside legislation has allowed the actors of the reconstruction to think more holistically and implement a collective vision. This approach

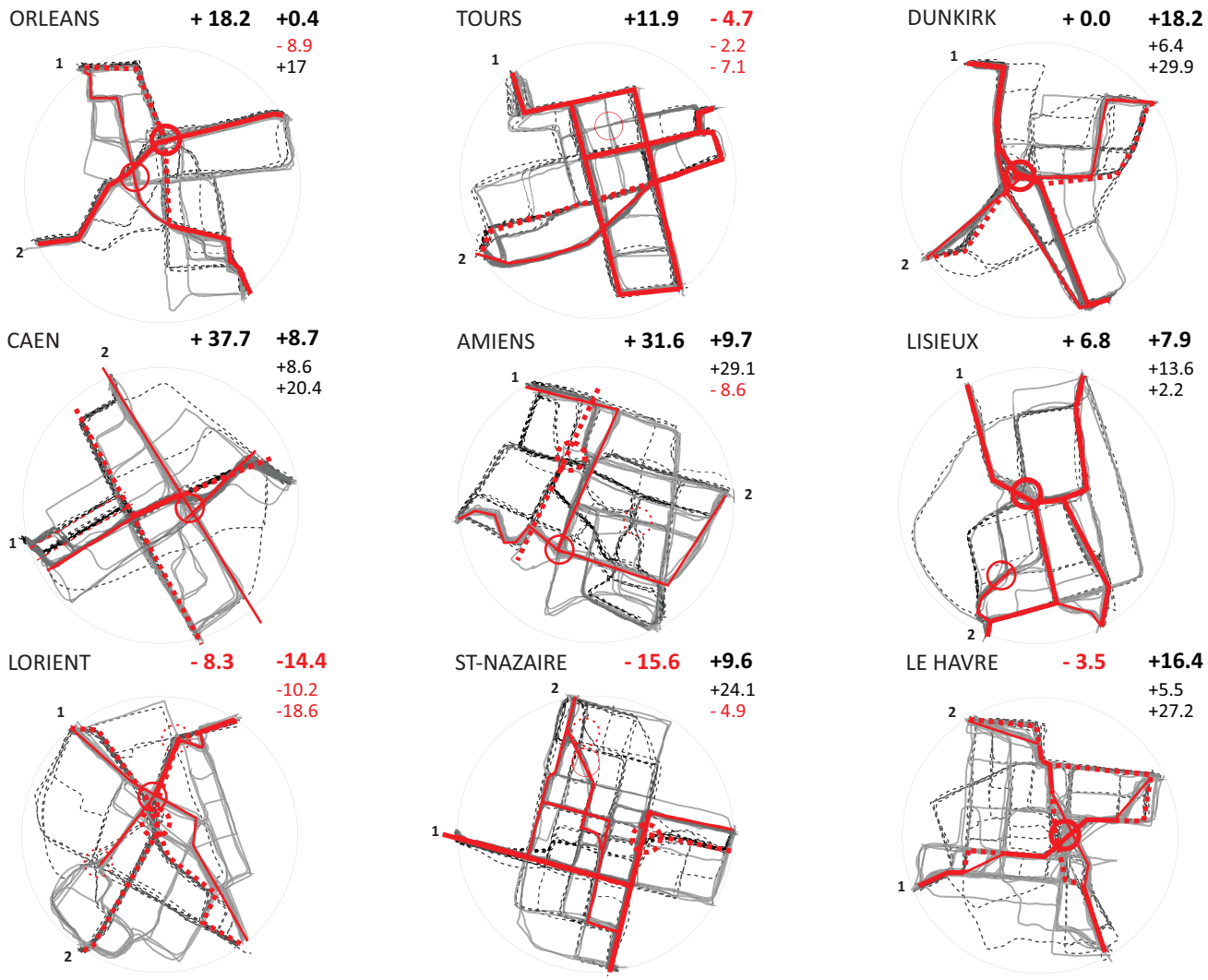

Figure 5. All selected routes per city and map type: Mean velocity values and the percentage of increase of mean velocity values between the pre-war and post-war maps. The skeleton formed by the most navigated routes is highlighted in red.

Table 2. Skeleton classified in terms of continuity or rupture, and in terms of retention or loss of centrality and main axis.

	Continuity			Centrality			Main Axis		
Cities	Strong	Partial	Little	New	Retained	Lost	New	Retained	Lost
Amiens			x	x		x	x		x
Caen		x		x			x		x
Dunkirk	x				x		x	x	
Le Havre	x				x			x	
Lisieux		x		x	x			x	
Lorient		x	x		x		x		x
Orléans		x		x	x		x	x	x
St-Nazaire		x				x		x	
Tours	x						x	x	

has produced overall more intelligible street layouts to varying degrees, however, depending on the type of urban form. What was the aspiration that could not be fully achieved in the first reconstruction is finally implemented during the second reconstruction. While the PAEE were not necessarily implemented, it served as a basis for the more systematic implementation of the PAR which was more strongly supported, with better supervision from the state and their architects.

The creation of cooperatives and associations and land consolidation have been the key to this collective approach. Land consolidation by erasing individual ownerships embedded in the boundaries of plots and by consolidating them into a single space made it possible to fully rethink these boundaries and gave more flexibility to the architect. Full or partial re-orientation is made possible as well as consolidation or fragmentation of blocks. The creation of new streets, the alignment and widening of existing ones, and the creation of new squares are more easily achievable. They can be thought of holistically and carried out in a compressed time frame. Through the associations, the inhabitants have also sometimes been able to push back and fight to preserve a certain continuity by preserving a main street or by minimising the extent of land consolidation.

From a morphological and configurational perspective, the main changes in the layout from pre- to post-war plans are a general increase of open space and syntactic intelligibility. A statistical relationship exists between the two that shows that the proportion of space in these cities is associated with a certain level of intelligibility: The more space is dedicated to the public, the higher the intelligibility. By unpacking where the increase of intelligibility occurs, it has been shown that the organic fabrics were the ones that had the largest increase. The introduction of new long and straight streets, already present in the grid-like layouts, creates clear thoroughfares and long vistas, making the layout cognitively more intelligible and facilitating navigation.

These new vistas result either from the alignment and widening of a series of existing streets or the creation of a new connection. While they syntactically increase intelligibility and facilitate navigation, they have a very different impact on the sense of continuity. In the first instance, widening and alignment reinforce and consolidate the presence of formerly familiar streets, while the creation of new connections has sometimes shifted the centrality of a layout and created a disconnect from the past. Although different strategies are chosen and applied, overall, the tendency has been towards the homogenisation of city fabrics. More diversity of urban forms existed in pre-war layouts. Regardless of the amount of destruction, either partial or complete, the new layout of historical towns has brought more Cartesian order, as shown by the reduced gaps between the values of syntactic intelligibility. If the rationalisation process that occurred during the reconstruction had a greater impact on the historical fabrics and brought more efficiency to their circulation, it is important to question the potential loss of character of a city carried by its irregular streets.

The reaction to this new Cartesian order and the loss of organicity in cities need to be acknowledged and discussed, however briefly. A parallel and comparison can be drawn with the transformations of French towns in the 19th century, exemplified in the work of Haussmann in Paris, driven by similar hygienic concerns. They transformed the landscape by introducing wide and long streets imposed on an organic existing fabric that changed the structure of towns and their character. While some, like Giedion (1967), have admired the efficiency of Haussmann's cuts through the urban fabric, others, like Benjamin, have deplored the disappearance of the character of "picturesque" and "old Paris" documented by the photographs of Atget (ca. 1900–1910) and the loss of identity linked to the introduction of new rational boulevards and avenues:

> The quartiers of Paris in this way lose their distinctive physiognomy….Meanwhile, he [Haussmann] estranges the Parisians from their city. They no longer feel at home there, and start to become conscious of the inhumane character of the metropolis. (Benjamin & Tiedemann, 1999, p. 12)

The experience of the city promoted by Benjamin is that of the flâneur and the labyrinth, which contrasts with the public space offered by the efficient boulevards. Following Benjamin's footsteps, the situationists reacted to the rational order of the cities of the reconstruction and criticised these new "sterile" cities. They criticised the loss of playfulness that can be associated with the pleasure of getting lost in the city and proposed the *dérive* as a means of re-introducing meaning into this rational urban environment. The emphasis of the reconstruction plan has been indeed on facilitating wayfinding to the detriment of exploration. However, the presence of multiple routes in some layouts could be an indication of possible *dérive* and it would be beneficial to study them further. Some of the answers could be found in approaching the city as supporting both wayfinding and exploration.

Finally, some limitations exist, mainly linked to the use of two-dimensional abstract maps which cannot recreate the actual experience of navigating these environments and all the elements that contribute to the character of a city, such as landmarks and land use, which can influence the choice of one route over another. It is acknowledged that tracing a route on a map is not equivalent to walking the streets of a city. Furthermore, the cropping of the area on the maps might not necessarily represent the true structure of the city centre, and the locations of destination points bring biased choices for some routes. However, while limited in the amount of urban space analysed and its two-dimensionality, this research can provide some insights into the geometry of

the street layout, which is often how new developments are designed, through the means of plans. It offers potentially new ways to bring together the design decisions as represented in maps and their potential impact on how the city is structurally experienced. It can help to clarify the intelligibility of an urban environment by linking the configurational properties of maps and the cognitive skeleton of the routes.

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Conflict of Interests

The author declares no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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