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Resilience, space syntax and spatial interfaces: The case of river cities

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Abstract

Resilience defined as the capacity of a system to manage impacts, keep its efficiency and continue its development has been scrutinized by researchers from different points of view over the past decades. Due to the prominence of resilience in urban planning, this paper intends to find out how the spatial structure of cities deals with disturbances, and if geographical phenomena such as rivers affect the resilience in cities. Using the space syntax methods syntactically analyze the resilience in cities, we innovatively introduce two measures; similarity and sameness. These measures are in relation with the syntactical properties of cities and compare the degree of resilience between different groups. Similarity measures the degree to which each city retains the relative magnitude of its foreground network after a disturbance and sameness is the degree to which each city retains the same segments as its foreground network after a disturbance. Likewise to network resilience studies, we apply different disturbances on cities and explore the reaction of cities to disturbances in terms of size of the foreground network and which segments are parts thereof. We then compare different groups based on these measurements as a method to analyze sameness and similarity. The results show that the resilience, in the way we define it, is different in different cities depending on in which view and based on which parameters we are discussing the resilience. Additionally morphological phenomena such as rivers have a great impact on the structure of cities and in turn on their resilience.

Keywords
River-cities, Resilience, Space syntax, Spatial analysis, Disturbances.

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1. Introduction

The rate of urbanization and the dynamic development of cities has been rapidly increasing over the past century, with half of the world's population now living in cities (United Nations, 2014). As a result, urban resilience is becoming an increasingly important issue. The frequently uninhibited patterns of urban sprawl make cities and the people living there vulnerable to multiple stresses, and increase the need for sustainable planning (TERI, 2009). A resilient city not only facilitates interaction with nature, and improves response to natural disasters; it also helps increase sustainability, mitigating some of the undesired consequences stemming from human activity (Reid and Demarin, 2013). It has also become clear that as a result of climate change and the consequent increased risk of flooding or droughts, rising sea levels, and more extreme weather conditions, geographical conditions are increasingly factors that must be considered in studies of urban resilience (Carter et al., Leichenko, 2011; Pickett, Cadenasso, and Grove, 2004).

In relation to this broad set of issues, in this paper we investigate how a single property of urban space—the morphological configuration of public space into networks—relates to a single geographical feature—the presence or absence of a river—and how this relates to questions of urban resilience. This research is designed to increase our knowledge of a focused subset of urban resilience, "resilience in spatial morphology" (Marcus and Colding, 2014). In particular, we will study how spatial configurations, specifically as studied in space syntax research, may be more or less resilient to alterations to their systems. Further, the inclusion of rivers allows us to offer some initial findings on whether vulnerabilities can be generically linked to a city's geographical features.

Degrees of network continuity and network fragmentation are commonly investigated and important features of network resilience in terms of robustness. In this study, we investigate different aspects of networks from the perspective of resilience. Our focus will not be on network continuity issues per se, but rather on how the configurational and systemic characteristics of networks and nodes are changed by disturbances. A novel method using sameness and similarity measures (Koch & Miranda, 2013) was created for analyzing urban resilience through investigating the effects of disturbances on the city network. This paper focuses on developing these two concepts within the context of the spatial configuration of cities, and using them to examine whether the presence or absence of rivers has a significant impact on how cities react to disturbances. As such, this is not a comprehensive investigation of resilience, but rather an attempt to add additional perspectives on what constitutes resilience in urban settlements, as well as an understanding of the structural effect of rivers and the role of bridges in city configurations. A full investigation would include studies of complete system breaks, changes to global trip lengths, changes in specific accessibilities and distances, and many other issues.

Finally, with this research we aim to increase knowledge within the field of space syntax on aspects of systemic change, which arguably is still in need of development. In order to do this, both resilience and space syntax as they pertain to the content of this paper require further discussion, as does the translation of the concepts of sameness and similarity into the methodology that is this paper's primary contribution. This includes testing the developed concepts on larger empirical samples.

2. Resilience

While ostensibly a clearly defined term, the concept of resilience has become ambiguous due to the way it is used in different fields. It is a regular part of the vocabulary employed in fields such as ecology, engineering, social network and network theory, the material sciences, economics, and architecture, and has lately become a nearly interchangeable substitute for the term sustainability in urban planning. Concerns have recently been raised that the proliferation in its use may lead to it becoming a catch-all term, similar to what has arguably happened with "sustainability" (Rose, 2007; Grünewald and Warner, 2012; Galderisi, 2014). Reviewing how resilience is defined in different fields, therefore, is important in order to clarify the set of properties of a resilient system that will be employed in this study.

Resilience was given its contemporary definition in the field of ecology by

Holling (1973, p. 14) as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables." This definition is similar to what United Nations International Strategy for Disaster Reduction (UNISDR, 2009, p. 24, p. 31) offers as "the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions." Similarly, in network theory resilience is defined as the degree to which a network's efficiency remains functional, changes or is damaged when vertices are removed in a random or targeted fashion from the system (Iyer et al., 2013). In urban planning, resilience is defined as the "capability to prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to public safety and health, the economy, and national security" (Wilbanks, 2007, p. 2). A summary of the concept of resilience, then, would seem to concern the ability of a system to survive or be maintained in the face of disturbance. Holling himself, however, later noted (1996) that two dominant types of resilience definitions have emerged, which he calls ecology resilience and engineering resilience. In short, the former is characterized by a system's ability to "bounce back" after a disturbance, and the latter by a system's ability to continue working unaffected by a disturbance. The research in this paper addresses both of these kinds of resilience to an extent, although through the specific interpretation of each as sameness and similarity factors.

3. Space syntax and resilience

In this paper we therefore aim to develop a method for measuring resilience in different cities interpreted through space syntax models, and measured from different points of view. We seek to establish a link between the spatial properties of a city network and resilience on the one hand, and between resilience and the morphology of a city on the other hand. The usefulness of space syntax as a set of theories and tools for spatial and configurational analysis has been demonstrated not only in the interpretation of morphological space, but also in linking geometrical and syntactical measures and analysis of the city's spatial configuration. Research that directly addresses the relationship between space syntax and resilience problems is uncommon, although a few recent cases can be found. Researchers like Hillier (1996) and Shpuza (2005, 2006, 2007, 2011, and 2013) have implicitly pointed to resilience in some of their studies, but without using the same term. In his thesis, for example, Shpuza (2006) examined the relationship between floor plate shapes and layout integration. He showed that removing unit cells in different ways from building floor plates in different shapes affects the mean depth and integration values differently. He stated that this effect depends on the position of the cell in relation to the presence of underlying regions in a floor plate shape. This, however, does not directly address resilience, and centers on small-scale spaces like floor plate shapes, rather than comparatively large-scale spaces such as street networks and cities.

Esposito and De Pinto (2015) investigated the influence of flood risk on the city of Turin and syntactically measured flood resilience. They calculated different syntactical properties, such as angular segment integration and angular segment choice values in global and local radii for the conditions before and after the flood. Conducting a principal component analysis and clustering, they compared the spatial configuration of the city both pre- and post-flood. Since they found limited changes in spatial properties, they concluded that Turin's network retained the same functional structure before and after the flood, and could be considered resilient in the wake of the flood disaster.

Cutini and Di Pinto (2015) examined the actual effects of the Vesuvius volcano on the configuration of the self-organized urban area on its slopes to try to find out how space syntax may be involved in measuring the resilience of the city in relation to the volcano. Introducing different syntactical parameters, including mean connectivity, synergy (correlation between radius 3 and radius n integration), and frequency index (the ratio between the highest choice value and the value for the maximum frequency of use for a given line), they posited that a system is more resilient if the first two parameters mentioned above increase, while the third decreases. They concluded that the new development in the city, from this point of view, has made it more vulnerable to an eruption, and has decreased the area's resilience.

Carpenter (2013) investigated disaster resilience in the coastal Mississippi area of the U.S. that was hit by Hurricane Katrina in 2005. Using temporal data from before and after the hurricane, Carpenter studied the effect of syntactical and built environmental measures on community resilience. The syntactical parameters used in this research to evaluate the connectivity of streets were metric and angular reach (Peponis, Bafna and Zhang 2008), which are calculated based on distance and direction changes, respectively. Several other variables were also added to the model. Carpenter found that some specific syntactical and environmental parameters had positive influences on the city's resilience, such as metric reach, the density of social networking organizations, historic site density, and land use mix. Other variables, such as the presence of parks, actually had a negative impact on resilience. The paper concluded by highlighting the role of the built environment and syntactical parameters on social networks and resilience.

In another recent work that forms part of the basis for the methodology used in this paper, Koch and Miranda (2013) sought to conceptually discuss resilience in relation to space syntax theory, and offered methodological parameters for measuring resilience in buildings, which other notable earlier work has also addressed albeit for other purposes (e.g., Unlu et al, 2005). To do so, they used existing space syntax measures, such as integration and connectivity, to suggest measures relating to sensitivity such as sameness and similarity factors, which are discussed in the next section. Through these concepts of resilience they were able to measure a building's adaptability, as well as identify vulnerable locations inside buildings. It should be noted that Koch and Miranda use sameness and similarity as broader concepts with a range of specific individual measures, allowing a qualitative discussion, whereas we, in this paper, will be making use of specific individual measures as indicators of these concepts. The authors mention, however, that this definition of resilience does not uniquely relate to morphology. What they present concretely is a framework by which buildings can be understood as resilient in different ways according to their spatial configuration. Resilience is then measurable depending on the answers given to the question "resilience of what and for what?" This question almost paraphrases what Weichselgartner and Kelman (2014, p. 21) propose as the critical question for any resilience study. Koch and Miranda finally conclude that syntactic resilience specifically means the degree to which a spatial configuration formulates a similar spatial interface (e.g. Hillier and Hanson, 1984) before and after a disturbance—or as Cutini and Di Pinto (2015, p. 66:5) put it, the measures investigate "the impact of change on inhabitancy and cultural identity." We chose this position in part because it reaches beyond the generic observation that a more distributed system is more resilient to failures, acknowledging that, for social and cultural reasons, simply increasing the distributedness of a system may be problematic. In this paper we will further expand upon Koch and Miranda's work in approaching resilience from the point of view of configuration as socio-spatial interface. A wide range of resilience issues—including, for example, emergency egress or access to emergency shelters (Sari and Kubat, 2011; Dou and Zhan, 2011)—can reasonably be much better understood using other models, measures, and methods.

A secondary aim of this paper is to elucidate the properties of a syntactical view of resilience by means of quantitative comparison of resilience between river cities and non-river cities. For this reason, while the main body of empirical material concerns river cities, a control sample of non-river cities has been added. The paper shows how investigation of a large sample of cities morphologically divided into two groups allows patterns corresponding to each group of cities to be uncovered. The main hypothesis of our research is that resilience is affected by the form of cities, which in turn is affected by morphological phenomena on a geographic scale. In this study the presence or absence of rivers streaming through the cities plays the role of morphology which influences resilience in river cities in comparison to non-river cities. To enhance the strength and accuracy of the results, a large sample of cities of different sizes from a variety of locations was chosen.

This means that the research in this paper constitutes a dual investigation of how spatial configuration, as studied in space syntax research, can be understood from a resilience perspective, on the one hand, and how an understanding of network configuration and characteristics, as developed in space syntax, can contribute to a broader understanding of the resilience of city systems on the other hand. We therefore introduce ways of measuring resilience related to syntax theory, and ways of understanding resilience based on the relationships between space and society explored in syntax research. This paper thus contributes to resilience research by investigating how concepts of resilience can be studied using the strengths of syntactic analysis, rather than looking at habitual methods of analyzing resilience, but implementing them using a syntactical model or syntactical measures.

4. How should resilience be measured?

Due to embracing a wide range of aspects and definitions over time, there is no flawless, uniform method for measuring a system's resilience. Depending on the system observed, and the point of view from which resilience is defined, the methods and models might be different. One of the established perspectives for resilience investigation is the study of resilience in complex networks, including city networks (Holme et al., 2002). In spite of dissimilarities in technique, the basis of all methods is similar, due to the ability to graphically represent a network as a collection of nodes and edges (referring to the objects and connections, or interactions between objects in a network, respectively) (Albert et al., 2000; Latora and Marchiori, 2003; Hu and Verma, 2011; Ghedini and Riberio, 2001; Iyer et al., 2013). The method used in this paper conforms to the targeted failure and attack approach, but focuses on changes in syntactic properties, rather than on network continuity or network breaks.

While the terms resilience and robustness are used nearly interchangeably in research, in this paper we will in practice primarily investigate robustness, which is often used in research focusing on the efficiency and stability of a network. As Bankes (2010, p. 148) notes, "the resource base of methodology and software for robustness analysis provides a solid foundation for establishing a practice of resiliency analysis." The difference between resilience and robustness, however, is that robustness concerns the strength and durability of a system to withstand internal and external disturbance without critical changes to the original system, while resilience refers to the flexibility and adaptability of a system to recover or bounce back from internal or external disruption and revert to the original system, or a stable state based on new requirements (Read, 2005; Folke, 2006; Haan et al., 2011). Robustness, from the point of view of this paper, forms a specific aspect of resilience clearly related to Holling's (1996) discussion of types of resilience above.

As mentioned previously, the connection between resilience and space syntax in research is limited compared to the potential. What we expect from this integration is: first, to develop a general framework for integrating spatial configuration in terms of space syntax and the resilience of a system; and second, to use this framework to quantitatively compute syntactical resilience, and compare these measurements between cities.

To investigate resilience in different cities based on syntactical properties, the integration and choice values of the cities are extracted. These measures are the two main properties used today in space syntax research (Hillier et al., 2012, Hillier and Iida, 2005), and it has been repeatedly established (Hillier and Iida, 2005; Turner, 2007; Hillier et al., 2012) that they show positive and significant correlations to pedestrian movement flow in cities. Furthermore, we have earlier shown that choice value offers a good metric for the study of the interaction between morphology and street networks (Abshirini and Koch 2016). For the purposes of this paper integration and choice value can be explained as corresponding to closeness centrality (Bavelas, 1950) and betweenness centrality (Freeman, 1977), in graph theory and complex network analysis, respectively. Integration measures the accessibility of a network, defined as the number of turns that each segment has to make to reach all other street segments in the network (Hillier et al., 2012, Hillier and Iida, 2005), compared to a standardized growth pattern for normalization. Choice is defined as the number of shortest paths that pass through each segment of all shortest

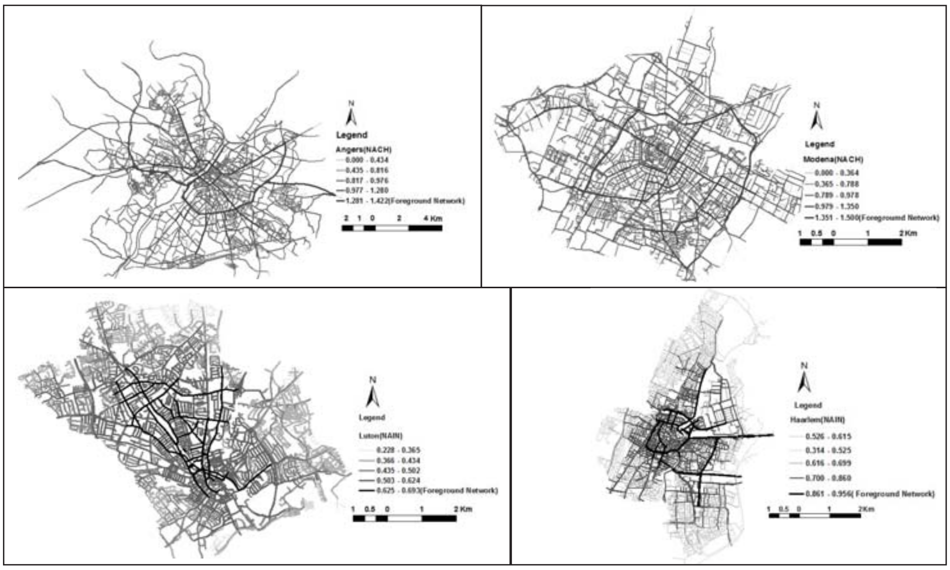


Figure 1. *Illustration of NACH and NAIN values for a subsample of River-cities and Non-river-cities; a) NACH for Angers (river-city), b) NACH for Modena (non-river-city), c) NAIN for Haarlem (river-city), and d) NAIN for Luton; In all figures the color range varies from light gray lines to dark gray representing the lowest and the highest values respectively.*

paths between all pairs of segments in a system (Hillier, 2009; Hillier and Iida 2005). In order to keep the calculations free of excessive dispersion, as well as to be able to compare cities of different sizes, this paper uses a method introduced by Hillier et al., (2012) to normalize angular choice (NACH) and angular integration (NAIN) values (Figure 1).

Two factors must be taken into consideration for this analysis. The first is the method for applying a disturbance to the system, and the second is the method of measuring the effect of this disturbance on the system. The latter concerns the method for measuring the resilience of the city according to its syntactical properties, comparing pre- and post-disturbance states (cf. Cutini, 2013). Two different methods were used to simulate disturbances in the street network. The first, applied exclusively in river cities, was grounded on the importance of these bodies of water to the space, and involved simply cutting bridges from the street networks. The resulting city was thereafter referred to as river-cut (Figure 2a). The second method involved applying a targeted attack to both river cities and non-river cities, by removing the segments with the highest choice value measures from the network. This was done since, as Hillier (2009) explains conceptually, the foreground network can be understood as the portion of the network that binds the city together globally. From certain perspectives, these segments thus perform a role that is conceptually similar to that of bridges, even if their precise function is different. While this is the conceptual interpretation of the foreground network, the way it is literally defined is as the subset of segments with the highest choice values, usually the highest 10% (cf. Hillier, 2009, Hillier, 2016). Hillier finds that to a large extent, this picks up a mostly interconnected global network of lines extending large distances through the system, while picking out a relatively small number of segments that tend to be interlinked. This is why binding the city together is suggested as a way to conceptually understand the foreground network, even though the precise definition does not require the system to be interconnected. This measure can be compared to Hillier and Hanson's integration core measure (1984), which is the 10% of axial lines with the highest integration values. In both cases, the percentage can and has been altered (cf. Shpuza 2013), but 10% is the most commonly used figure. In both cases, it is common for—counter to the conceptual idea—the "foreground network" and "integration core" to form internally disconnected systems. Usually they appear as one larger interconnected system, and additional smaller parts that are disconnected from the larger core or foreground. This is especially true when the measures are applied to local radii. To ensure comparability, and to further inform the research, this method was

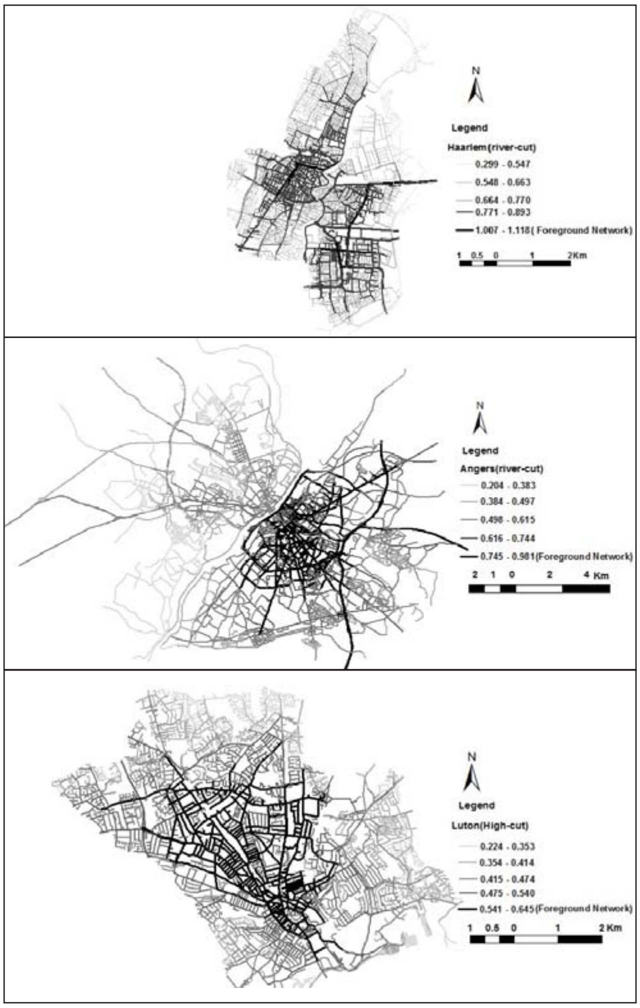


Figure 2. *Illustration of NAIN values; a) River-cut (Haarlem), b) River-high-cut (Angers), and c) Non-river-high-cut (Luton).In all figures the color range varies from light gray lines to dark gray representing the lowest and the highest values respectively.*

applied to both river and non-river cities. The number of segments cut in this way in a river city was the same as the number of segments forming bridges in that city. For a non-river city, it was equal to the number of segments cut in a river city of the same size. Size was defined based on the total number of segments forming a city's network. In this way, two new types of cities, river-high-cut (Figure 2b) and non-river-high-cut (Figure 2c), were produced.

To measure the effect of disturbances on the city network, a method inspired by Koch and Miranda's work (2013) is introduced here. The method is developed and adapted for the networks on the scale of cities instead of on the scale of buildings, and specified to allow comparison over a large number of cases. Thus, while Koch and Miranda (2013) discuss sameness as the extent to which a configuration is the same before and after a disturbance, and similarity as whether it has a similar character before and after a disturbance, these concepts require more precision in how they are measured. They also need to be adapted for the purposes of this paper. For Koch and Miranda, the purpose of sameness is to understand whether specific spaces retain their role in a configuration, whereas the purpose of similarity is to evaluate whether the configuration as a whole can be considered to have the same character from the point of view of spatial configuration as a social interface, regardless of whether or not the specific spaces have the same role. For similarity, this means investigating the degrees of distributedness in the system: in effect, whether the system before and after the disturbance becomes deeper or shallower, and whether the differentiation between deep and shallow changes—that is, are there more or fewer spaces in shallow or deep parts of the system. This can be characterized as analyzing how the system distributes centrality. Our overall approach thereby echoes that of Cutini (2013), in that it concerns itself with how the global network reacts to disruptions, but differs in how we specifically test and measure this. Cutini's (2013, p. 102:5) work is based on "the assumption that resilience, roughly speaking, is a matter of diffused richness in alternative paths from any origin to any destination" and that "its value could be somehow reproduced by the level of distribution of the shortest paths." Cutini suggests adding bridges to river cities as a means of increasing resilience, which makes our study a comparative parallel, since we remove bridges. Additionally, we investigate a larger sample compared to Cutini's two hypothetical cases and one real disaster case. In order to operationalize these concepts for the analysis of large samples of cities, we have developed two specific parameters as indicators. For sameness, we ask the extent to which the foreground network is defined by the same segments before and after a disturbance, and for similarity, we ask whether centrality is distributed to fewer segments (becoming more structured according to the works of Hillier et al.,) or to more segments (becoming more distributed according to the works of Hillier et al.,).

These approaches to measuring the similarity and sameness factors are then analyzed using choice and inte-

__Table 1.__ Calculation of similarity (difference in size) for a subsample of cities; Angers is a river city and Luton is a non-river-city. Size of foreground network is number of segments with the highest 10 percent value for choice and integration property. Difference in size is calculated based on equation 1. "Original" refers to before disturbance and "bridge-cut" and "high-cut" refer to after disturbance.

Size of foreground network				Difference in size	
city	original	bridge-cut	high-cut	Bridge-cut	high-cut
Angers (Choice)	887	988	792	0.114	0.107
Luton (Integration)	627		697		0.112

gration values. To clarify this method, in Figure 3, a river-city (Angers), and a non-river-city (Luton), are shown in different states: the current city with all specifications; the city with its bridges cut (labeled river-cut city); and the city with the segments with the highest choice values cut (labeled river-high-cut city). As seen in Figure 3, the highest 10% of the choice value in each circumstance is considered to be the size of foreground network.

Similarity is intended to measure change in global network character. This concept echoes the work of Dalton and Kirsan (2005) on graph isomorphism, but is measured differently here. Table 1 illustrates the difference between the size of the foreground network before and after the disturbance. This is calculated based on Equation 1:

$$\Delta x = |(A-B)|/A \quad (1)$$

In which Δx represents the change in the size of the foreground network, and A and B represent the size of the foreground network before (referred to as "original" in Table 1) and after the disturbance (referred to as "bridge-cut" and "high-cut" in Table 1), respectively. The size of the foreground network is simply equal to the number of segments forming it. It should be noted that what Equation 1 calculates is not how many times bigger or smaller the size of foreground network A is than the size of network B (this is why the absolute value is used in the equation), but rather the ratio of changes in the foreground networks before and after the disturbance.

Since the whole networks do not increase or decrease in total size, this measure can be used to understand whether the distribution of centrality becomes more focused (as in a structured system) or more dispersed (as in a distributed system). From this point of view, the structure of a city is judged to be more similar if the difference in the size of the foreground network before and after a disturbance tend towards zero .

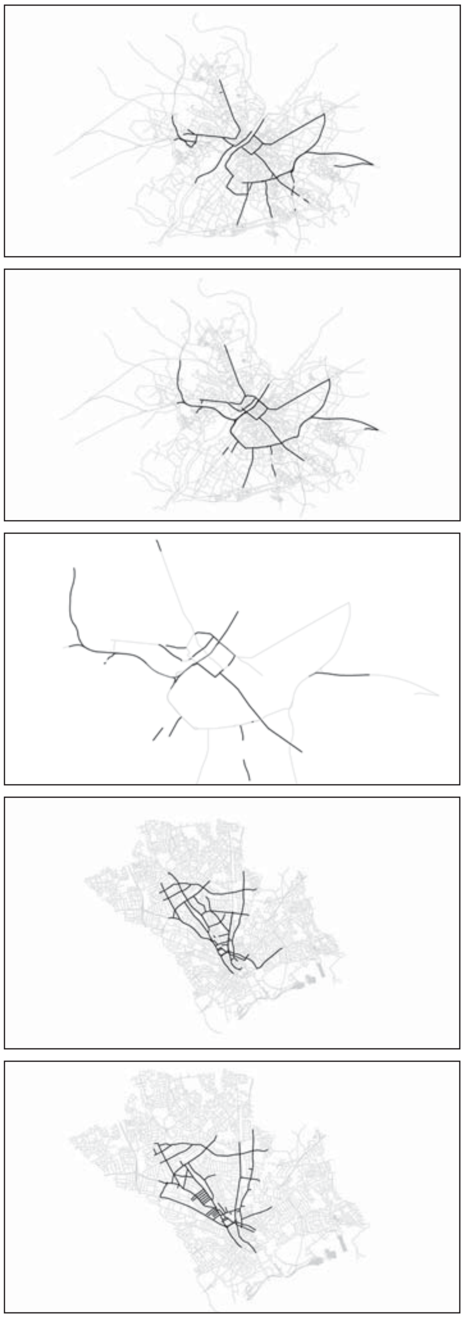


***Figure 3.** Illustration of the foreground network; The highest top 10 percent of choice value (black lines) is considered as foreground network; Angers: a)river city, b) river-cut, c) river-high-cut. Luton: d) non-river-city, and e) non-river-high-cut.*

__Table 2.__ Calculation of sameness for a subsample of cities; Angers and Haarlem are river cities and the others are non-river cities. In each situation the number of same segments is compared to that for the original(before the disturbance).

	No. of same segments		Sameness	
city	bridge-cut	high-cut	Bridge-cut	high-cut
Angers (Choice)	638	465	0.719	0.524
Haarlem (Integration)	166	698	0.198	0.832
Modena (Choice)		681		0.816
Luton (Integration)		473		0.754

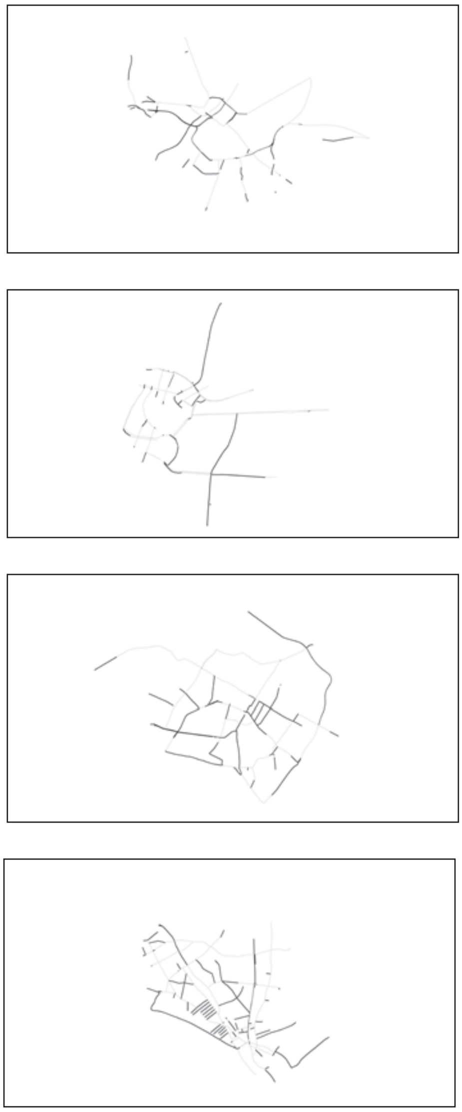


__Figure 4.__ Segments of foreground network changed (dark) and retain unchanged (light gray) after a disturbance; a) Angers (river-cut compared to origin for choice value), b) Haarlem (river-high-cut compared to origin for integration value), c) Modena (non-river-high-cut compared to origin for choice value), and d) Luton (non-river-high-cut compared to origin for integration value) ; origin: city before a disturbance.

Similarity is calculated in the same way for the integration value, as well.

Sameness is the value showing the degree to which each city is able to retain and keep its functionality in the same way and in the same place as before. To calculate this measure, Koch and Miranda (2013) correlated the values of all vertices in a visibility graph analysis (VGA) of a building before and after a disturbance, with a higher correlation suggesting a higher degree of sameness. Sameness therefore reflects Cutini's idea that a network is less resilient if a disturbance moves centrality to other nodes (2013, 102:5-102:8). Koch and Miranda additionally discuss whether the differences between states can be found locally or globally through how the differences appear in the scatter plots. In our analysis, we focus specifically on centrality as an indicator of sameness. Therefore, the segments forming the foreground network in each city are compared before and after each disturbance to determine whether each segment that previously formed part of the foreground network is still part of this network post-disturbance. Specifically, we use a geometrical analysis in order to compare the location of segments before and after a disturbance on the foreground networks. As illustrated in Figure 4 , segments highlighted in light gray are located in the same places in both scenarios, and are therefore categorized as same in the foreground network. Conversely, segments highlighted in dark colors are not the same—they either disappeared from or were added to a foreground network after a disturbance—and are therefore categorized as changes in the foreground network. For clarity, we wish to stress here that the analysis of sameness is not about location per se, but about identifying which segments form part of the foreground network in order to be able to analyze the ratio of segments remaining in the foreground

Table 3. *Collection of River cities and Non-river cities studied in this paper.*

River City	Country	No. Of Segments	River City	Country	No. Of Segments	Non- River City	Country	No. Of Segments
Amiens	France	8910	Lohr Am Main	Germany	8823	Aix -En-Provence	France	27666
Angers	France	25058	Maghull	UK	1618	Basingstoke	UK	19825
Aschaffenburg	Germany	24108	Montlucon	France	7771	Beaun	France	4130
Auxerre	France	4526	Leicester	UK	30559	Beauvais	France	5486
Bergerac	France	6998	Oberhausen	Germany	26349	Böblingen	Germany	9971
Blackburn	UK	6854	Örebru	Sweden	18013	Braga	Portugal	23529
České Budějovice	Czeck Republic	7057	Orleans	France	7410	Châteaubriant	France	3608
Český Krumlov	Czeck Republic	1953	Prerov	Czeck Republic	2430	Colmar	France	10237
Charleroi	belgium	29397	Saintes	France	4428	Coventry	UK	46253
Châtellerault	Franceance	5078	Saint-Quentin	France	9999	Gloucester	UK	16098
Cluj-Napoca	Romania	8789	Schweinfurt	Germany	22085	Harrogate	UK	8500
Criel-Sur-Mer	Franceance	2938	Tours	France	20561	Issoudun	France	2605
Dax	France	5100	Umeå	Sweden	33895	Les Herbiers	France	4575
Dresden	Germany	86828	Valenciennes	France	4304	Luton	UK	14688
Fontenay-Sous-Bois	France	4434	Venlo	Netherlands	15779	Mansfield	UK	7757
Haarlem	Netherlands	17254	Villeneuve	France	6112	Modena	Italy	25396
Helmond	Netherlands	24550	Vilnius	Lithuania	43366	Mönchengladbach	Germany	50565
Laval	France	7592	Wolfsburg	Germany	38617	Saint-Étienne	France	13438
Le Mans	France	21737	Würzburg	Germany	19956	Sindelfingen	Germany	15806
Lille	France	15431	York	UK	13179	Soest	Germany	4738
Limoges	France	21854	Zlin	Czeck Republic	15984	Wiesbaden	Germany	42675

network; that is, how much of the foreground network is constituted by the same segments as before. In a more detailed study using axial lines as the basis for segment generation, removal of individual segments could change the geometry and location of specific remaining segments that would still represent the same spatial unit, and the question we are investigating regards the spatial units of which the segments are abstract representations. Since we make use of road center line maps to generate segments, however, this is not the case. Thus, while the geometrical analysis is in principle a method for pinpointing which segments are the same before and after (by identifying segments with the same location), in this specific study, geometrical location and segment identity correspond. This is then used to test how many segments retain their role as part of the foreground network, and how many newly appear or disappear from the same.

The ratio between the number of same segments and total segments in the foreground network gives us the sameness measure for the city (Table 2). This value can vary between zero and one, with a lower value pointing to lower resilience in that city in terms of sameness. A higher value, conversely, suggests that the city could preserve its functionality as before, indicating a structure with higher resilience.

Sameness and similarity thus test two different morphological properties of the street network related to the overall idea of urban space as a social interface. Here, sameness answers how much of the interface remains the same, and similarity measures the extent to which the city retains its configurational character.

4.1. The sample: Data training and area of research

Collection of spatial data for the purposes of comparative research is usually a time-consuming, onerous and costly process. In this paper, a large sample of cities is used with the intention of showing sufficient diversity in size, location and morphology, while maintaining some similarities. The sample is formed by two different groups of cities: those with rivers, and those without. To create the sample, we took advantage of freely distributed and editable geographic maps called open street map (OSM) data (Haklay and Weber, 2008). Data acquired from this source typically requires some preparation to be ready for subsequent analyses. This data is furthermore subject to the quality of the user-generated content. Because we are working with a large sample size, however, we believe that the quality and accuracy of the data after preparation is adequate. A sample of 42 river cities ranging from small (1,618 segments) to medium (86,828 segments) in size, from different European countries was collected (Table 3) and labeled river cities. To be able to examine resilience in river cities specifically, a control sample of 21 cities without rivers was gathered and labeled non-river cities. This sample was carefully compiled, taking the distribution of sizes and geographical locations into account in order to make the samples comparable (Table 3).

5. Results and discussion

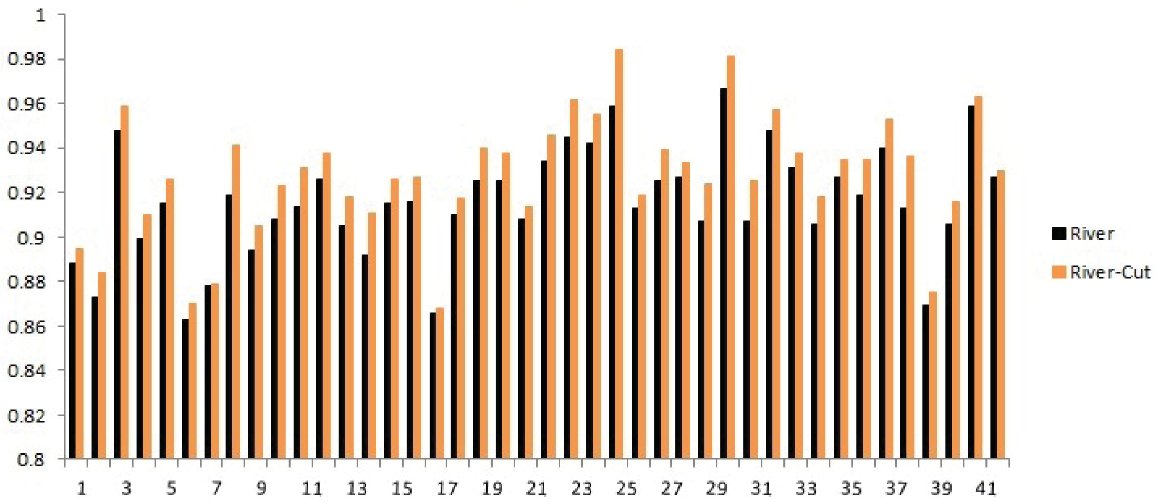


Figure 5. *Dramatic increase in mean choice value of the river-cut cities in comparison to river-cities. All the river-cut cities show increased mean choice values, as demonstrated in diagram.*

This section begins with statistical analysis, including correlation and anova (analysis of variance) tests. Correlation will show if there are significant correlations between different syntactical properties in different groups of cities, and the anova test will show if there are significant differences among the mean values of different groups of cities. This ensures that the main and control samples are reasonably different from each other, as well as sufficiently similar internally to be compared to one another as groups. After first establishing that the samples are relevant and statistically comparable, we will then proceed to investigate similarity based on the size of the foreground network, and sameness based on the methodology explained above. Based on these analyses, potential patterns in each main group of cities will be discussed.

As background to the anova test and the correlation, the key properties of space syntax for different groups are presented in Table 4. As a general pattern, we can see that the values for each property show a reduction after the disturbance, as would be expected. The only unexpected change is in the river-cut group, which shows a dramatic increase in all properties in comparison to the other groups that is consistent throughout most of the sample. For example, all of the river-cut cities show increased mean choice values, as demonstrated in Figure 5, whereas maximum choice increased in 75% of the cases (31/42). In terms of integration, there is an increase in mean integration in 57% (24/42) of the cases, and in maximum integration of 64% (27/42). A table showing all value changes is provided as an appendix (Appendix Table 1). This is more closely examined and analyzed in Abshirini and Koch (2016).

This may seem surprising, but it is logical given the specific kind of system information provided by the syntactic analyses. The bridges, while being important connectors in the city, are few in number, and as normalized network entities form comparatively segregated sub-systems, with a limited amount of connections to other segments. The standard deviation shows the minimum dispersion for the mean choice value (0.012), while the maximum integration value shows the maximum dispersion (0.117).

Table 4. *Choice and integration values calculated for different groups.*

Category	Number of samples	Mean-Choice	Max-Choice	Mean-integration	Max-integration
River cities	42	0.916	1.482	0.637	0.979
River-cut group	42	0.927	1.501	0.65	1.095
River-high-cut group	42	0.91	1.474	0.584	0.878
Non-river cities	21	0.91	1.48	0.613	0.94
Non-river-high-cut group	21	0.894	1.444	0.532	0.781
Standard deviation	5 Groups (168 individuals)	0.012	0.021	0.047	0.117

5.1 Correlation and Anova Test

In order to establish the relevance of the statistics and our correlation research, an anova test was conducted on the syntactical properties of all groups to show if the mean of samples in the groups are different. The null hypothesis assumes that the samples come from populations that are not significantly differentiated by their mean values. Since differences in the mean value are critical for the rest of the comparative analyses (Abshirini & Koch, 2016), the null hypothesis needs to be rejected.

Table 5. *ANOVA test conducted on the samples for all properties in different groups. "df" is degree of freedom calculated based on number of groups(5) and number of all individuals(168) and F is the statistic ratio calculated by "df(between groups)/df(within groups)". The results are rounded to 3 decimal places by SPSS.*

		Sum of Squares	df	Mean Square	F	P-value
Mean-Choice	Between Groups	0.016	4	0.004	5.422	0.000
	Within Groups	0.124	163	0.001		
	Total	0.140	167			
Max-Choice	Between Groups	0.047	4	0.012	8.427	0.000
	Within Groups	0.229	163	0.001		
	Total	0.277	167			
Mean-Integration	Between Groups	0.255	4	0.064	6.326	0.000
	Within Groups	1.644	163	0.010		
	Total	1.899	167			
Max-Integration	Between Groups	1.728	4	0.432	14.585	0.000
	Within Groups	4.828	163	0.030		
	Total	6.557	167			

Table 6. *Correlations (R-value) between disturbed groups of cities and their originals.*

Correlations	Mean Choice	Max Choice	Mean Integration	Max integration
River city/River-Cut	0.962	0.464	0.797	0.58
River city/River-High-Cut	0.961	0.534	0.883	0.835
River-Cut/River-High-Cut	0.905	0.175	0.668	0.421
Non-River city/Non-River-High-Cut	0.499	0.42	0.58	0.506

Table 5 shows the results of the anova test for all properties in all different samples, including river cities, non-river cities, and all variations of these (5 groups). As illustrated in Table 5, the anova test determined significant differences between groups at the $p<.001$ level for the three conditions: [$F(4, 163) = 5.422$, $p = 0.000$] for mean choice value; [$F(4, 163) = 8.427$, $p = 0.000$] for maximum choice value; [$F(4, 163) = 6.326$, $p = 0.000$] for mean integration value; and [$F(4, 163) = 14.585$, $p = 0.000$] for maximum integration value. This validates the separation of the samples into two different groups for further analysis.

Following the anova test we made correlations between each pair (disturbed groups and their original groups) to see how the different disturbances in the cities affected the correlations between spatial configuration properties in these cities. The average value for each property (mean choice, maximum choice, mean integration and maximum integration) is compared. Based on the results collected in Table 6, it is evident that the correlation between river-high-cut and river cities is the highest of all.

In contrast, the correlation between the non-river-high-cut group and its group of origin, non-river cities, is the lowest. It is also evident that the correlation between river-cut and river-high-cut (two different derivations of river cities based on two different types of disturbances) is relatively lower than the correlations between these groups and their group of origin (river cities). This means that bridges and foreground networks have different effects on river cities. Additionally, the mean choice values show the highest correlations for almost all pairs (the only exception is the correlation value (0.499) between non-river and non-river-high-cut). Maximum choice values show the lowest correlation.

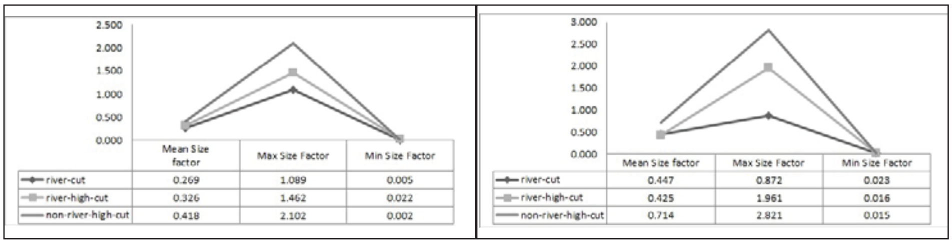


Figure 6. *Average, minimum, and maximum similarity calculated for different groups of cities; a) Choice value, b) Integration value*

5.2. Similarity

Based on the definition of similarity in this paper, if a city's similarity shows a uniform change before and after the disturbance, it might suggest that the city is more stable or more resilient. This is used as an indicator of how the spatial system operates as an "interface logic" from a socio-structural point of view—that is, the extent to which the system is arranged in a distributed or structured manner, as understood through how large portions of the system participate in forming the foreground network. From this point of view, the specific streets forming the foreground are not the issue, but rather the structural properties of the network considered as a whole.

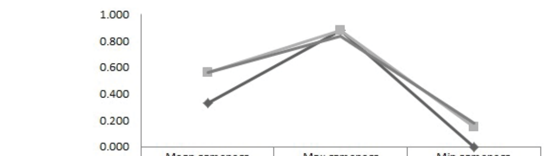
Figures 6a and 6b demonstrate that the river-cut group shows relatively superior similarity in comparison to the other groups in terms of the choice property (except for minimum size factor). Similarity for the integration value, however, is more sporadic, and cannot be said to characterize any group. While river-high-cut shows 0.425 for the mean size factor, which is the highest of all, river-cut and non-river-high-cut groups show 0.872 and 0.015 for the maximum and minimum size factors, respectively. This, however, generally follows the same trend as the choice value. As an interesting finding, non-river-high-cut shows the best size factor for both minimum choice (0.002) and minimum integration (0.015) values.

As a general conclusion to this section, we can state that the river cities overall showed superior similarity compared to non-river cities, although minimum similarity for the choice and integration properties is better in non-river cities than in river cities.

It can be noted here that while the magnitude of change is considered in absolute values, cutting the bridges generally had a decreasing effect on the size of the foreground network in river cities as calculated via the integration value (35.7% showed an increased value, whereas the rest showed a decreased value). Cutting the highest value segments, on the other hand, had a less consistent effect on river cities (50% increase and 50% decrease), and there was a tendency for sizes to increase in the non-river cities (76.2% increase). This becomes increasingly clear looking at the choice values, with the portion of cities with increased network sizes reaching 30.9%, 57.1% and 76.2%, respectively. It thus appears that the general reaction of non-river cities to the disturbance was to involve more segments in the foreground network as a response, whereas the picture for river cities was different, even taking into account the shrinking effect of cutting the bridges. Thus, while the change is generally smaller for river cities than for non-river cities, the response in non-river cities seems to be more predictable. This consistently increased spread of the foreground network in the latter may have implications for other aspects of resilience, or on the effects of consecutive disturbances. It also seems that as a social interface, there was a clear tendency for non-river cities to become less structured by disturbances to the foreground network, whereas a noticeable portion of the river cities became more structured—that is, dependent on fewer segments to form the global city interface structure. This suggests the existence of additional research opportunities in order to determine which morphological properties lead to an increased foreground network size, and which lead to a decreased size in response to disturbances, where the sampling of river cities and non-river cities has implications for this. Conclusive results, however, are not within the scope of the present study.

5.3. Sameness

As defined in the methodology section, sameness concerns the degree to which a city retains the same segments forming the foreground network before and after a disturbance. Figures 7a and 7b show that the results for sameness factor do not show a significant variation from the results for similarity. For the choice property, the river-cut group has the highest sameness value. The river-high-cut group follows the same pattern closely, except in mean value (0.585), for which non-river cities come out ahead (0.611). It is worth noting that while this supports Cutini's (2013) reasoning that highly central segments are important for resilience, it indicates that bridges, specifically, are not as crucial as they may seem for global network properties, even if they are crucial from other resilience points of view. It becomes important to differentiate between the bridge as an architectural object, the role played by bridges in systems, through binding cities together across rivers, and the system role of organizing centrality. Like similarity, sameness demonstrates an irregular pattern for the integration properties, and varies from measure to measure. In Figure 7b, non-river cities show the highest sameness for the mean (0.562) and minimum values (0.179). River-high-cut keeps its place in between for each individual sameness value; this is almost identical to sameness for the choice value.



	Mean sameness	Max sameness	Min sameness
river cut	0.334	0.882	0.000
river high cut	0.560	0.880	0.153
non-river-high- cut	0.562	0.834	0.179

Figure 7. Average, minimum, and maximum sameness calculated for different groups of cities; a) Choice value, b) Integration value

6. Conclusion

Cities are susceptible to any disturbances to their structures, especially to their foreground networks. This is demonstrated by perceptible changes to the syntactical properties of their foreground networks before and after disturbances. These reactions can affect their sameness before and after a disturbance, and their similarity before and after a disturbance respectively, where the former comes close to engineering resilience and the latter, arguably, closer to ecological resilience as discussed by Holling (1996). The reactions of cities to disturbances, however, are different, due to their different structures and morphologies. The results of this paper may suggest that a river as a morphological phenomenon plays a significant role in the stability and resilience of river cities, albeit in a way that may seem counter-intuitive. This is because the correlation values show that the river-high-cut group is more connected to its group of origin than the river-cut group, which in turn is more connected than the non-river-high-cut group. The way river cities respond to disturbances in their foreground network (measured by their statistical mean) is more regular and more resilient than how they respond to cutting their connecting bridges, and more resilient than non-river cities in their performance as spatial syntactic structures for social interface. This both confirms and challenges Cutini's (2013) work. Studying effects on centrality patterns before and after change is informative, but the particular use of bridges as key actors in the system is refined when it comes to understanding the global properties of the network. Our work also statistically tests some of Cutini's and Koch's and Miranda's ideas on a large sample. The regularity found in this study, however, does not by itself signify a higher generic resilience in river cities, since a generic measurement of resilience would need to take into account additional properties.

It should be noted that while we found here that the syntactic structure of public space systems seemed to be more resilient in river cities, our research did not supply enough evidence to confirm that this was due to the presence of a river. At this point, this remains an observation of an existing correlation rather than a conclusion of causation. Having noted this important distinction as to what conclusions can be drawn from the research, however, the results do indicate that as socio-spatial interfaces (cf. Hillier and Hanson 1984, Markus 1993, Koch 2013), river cities are generally more resilient than non-river cities. This means that they have the capacity to maintain more similar interface logic after a disturbance is introduced, whereas the interface logic changes more in non-river cities. Maintained interface logic is understood here to mean that the system remains structured or distributed to a similar degree in river cities, but grows more structured or distributed in non-river cities as a result of disturbance.

The results for sameness factor, which is the degree to which a city maintains the same foreground segments after a disturbance, are almost the same as for similarity. This means that river cities show a higher capability for maintaining a configuration in which the segments of the foreground network are the same as before the disturbance. A simpler way to state this is that it examines if the main street remains the main street, syntactically, after the disturbance is introduced. If the role of being main streets shifts to other segments, the city may need to adapt its program over time. Maximum and minimum values can help reveal the general trend of syntactic resilience in different groups. From the perspective of this paper's methodology, the river-cut group demonstrated the highest resilience. This goes for all values except sameness for the integration value, which suggests there are nuances elucidated by the methodology that can be investigated further in research to come. A finding of interest is that non-river cities tend to respond to disturbances by distributing the foreground network onto more segments. Which morphological properties lead to which kind of responses needs to be further investigated, as this may have significant implications for how a society would need to respond to disturbances both immediately, and over time. At the same time, the non-river-high-cut group shows the lowest values for all calculations, the sole exception being the integration value for sameness. The river-high-cut group's resilience falls somewhere in between the two other groups, with the exception of the integration value for sameness.

The main purpose of this paper, however, has been to present an initial demonstration of the potential of methodological advances for analyzing syntactic resilience, further developing the work of Koch and Miranda (2013) and adapting it to an urban scale, since, as Esposito and Pinto (2015) point out, the work of Koch and Miranda is methodologically not directly applicable to urban-scale analysis. The developed method provides important information that pertains to urban resilience, while specific implications require further research.

It must be recognized in this discussion that the measures used here do not take into account "complete network break" of the system (cf. Wang, 2015) (such as when one part of a city becomes inaccessible from another), the effects of disturbances on global or specific trip lengths, or specific programmatic connections between land uses, all of which would reasonably form part of a more complete review of a city system's resilience. In addition, the results are not uniform within the different groups, and the focus in this paper has been on general trends regarding the effects of rivers on city resilience from a morphological system point of view. The focus on syntactical properties, however, highlights some specifically morphological resilience characteristics that are important to consider. Resilience is a multifaceted and fuzzy concept, and as complex networks, cities show complex reactions to disturbances in their structure that vary from one city to another. To compare or evaluate the resilience of different cities we acknowledge that, as has been noted repeatedly in resilience research (e.g. Galderisi, 2014; Rose, 2007), the use of a bundle of parameters is necessary. This paper proposes two such parameters as a contribution to this bundle: syntactic sameness, and syntactic similarity.

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