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Nested Networks

Urs Primas[1]

[1] Institute for Urban Landscape, Department of Architecture, Design and Civil Engineering, Zurich University of Applied Sciences, Switzerland

Abstract

The concept of Nested Networks is proposed to address the interplay between different levels of scale in the analysis of urban form. Focusing on processes of tissue formation, the internal configurations of buildings or building compounds are considered as local, spatial networks nested within a global host network of urban space. Two case studies within the historical core of Zurich investigate how such configurations of local, spatial networks have been affected by shifts in centrality within the superordinate host network, and how the reshuffling of local configurations has in turn allowed adaptations of the superordinate network. The proposed approach draws on a combination of Process typology and Space Syntax. In view of the results, the potential of a more thorough cross-fertilization of these two strands of urban morphology is discussed.

Keywords: *Spatial Networks, Tissue formation, Process typology, Space Syntax*

1. Introduction

The evolution of urban form is studied on different levels of resolution, ranging from territorial patterns to the internal structure of individual buildings (Kropf 2017: 54). Each level of resolution – territory, city, tissue, building – addresses a specific set of problems and calls for appropriate methods. Meanwhile, a major challenge resides in the need to understand how these levels interact. How are growth processes of a city as a whole related to properties of its sub-units and their characteristic tissue patterns? In what way is local tissue formation affected by modifications of the superordinate system of urban space? How is typological innovation on the building level influenced by the location of an individual site? As it has been expressed through the metaphor of the urban "organism" (Caniggia and Maffei 1979: 165), such relationships point in two ways: On the one hand, "top-down" – processes on a larger scale may constrain and sometimes initiate change on a local scale. On the other hand, incremental change on the local level can add up to create a new set of "bottom up" – conditions for superordinate transformations. Therefore, an appropriate understanding of the big necessitates knowledge of the small, and vice versa.

This paper focuses on the relationship between the evolution of building types and the way in which buildings are embedded in superordinate systems of urban space. The concept of nested, spatial networks is proposed as an appropriate bridge, capable of capturing essential properties on different levels of resolution. Both the internal structure of buildings and the superordinate structure of urban space can be described as networks of bounded spaces. On a conceptual level, the notion of a network leads to a description of the structuration of urban space through a set of boundaries and a set of connections. By offering specific degrees of permeability, boundaries allow for various types of flows: people, other living organisms, matter, energy or information. In this sense, boundaries are always interfaces. Urban and architectural space is understood as a continuum, structured by the hard boundaries of rooms or buildings, but also by other, less pronounced types of boundaries such as plot limitations or the visual margins of “convex spaces”.

The proposed approach is based on a combination of conceptual frameworks stemming from complementary strands of urban morphology: Process typology and Space Syntax. Section 2 highlights the potential for cross-fertilization and lists a couple of overlapping notions. The concept of nested networks is then applied to the study of exemplary transformations that occurred within the city core of Zurich in the course of the nineteenth and twentieth centuries, when the removal of fortifications and other intra-urban boundaries combined with outward growth engendered a major upgrading of the street network. Section 3 describes the methods that have been applied to map and investigate the conditions and effects of those transformations, both on the level of the global network and on the local level of individual plots and buildings. Section 4 discusses the results of the case studies and introduces the notion of polarity reversal to describe transformations on individual plots and on specialized compounds that emerged following major shifts of centrality distributions within the spatial network hosting them. Additionally, the resources for network upgrading residing in such compounds are pointed out. Section 4 summarizes conclusions and gives an outlook on further research.

2. Combining Process typology with Space syntax

Table 1. Some overlapping concepts and notions in process typology and space syntax

Overlapping area	Process typology	Space syntax
Global centrality (e.g. closeness / betweenness)	Polarity (Caniggia and Maffei 1979: 131)	Global integration / choice (Hillier 1996: 160)
Local centrality (e.g. closeness / betweenness)	Nodality (Caniggia and Maffei 1979: 131)	Local integration / choice (Hillier 1996: 160)
Low centrality values	Anti-polarity (Caniggia and Maffei 1979: 172)	Segregation (Hillier 1996: 175)
Major connecting routes	Matrix routes Restructuration routes (Caniggia and Maffei 1979: 133)	Hub-and-spoke structure Long lines with obtuse angles (Hillier 1999: 171)
Local access networks	Implementation routes Connecting routes (Caniggia and Maffei 1979: 133)	Deformed grids Short lines with near-right angles (Hillier 1999: 171)

Process typology and Space syntax have originated from rather different cultural, scientific and linguistic backgrounds. On closer examination, we nevertheless find overlapping concepts and notions that are of particular interest when it comes to the role of network effects for the emergence of structured urban form (Primas 2021).

2.1. Process typology

An account of urban form in terms of nested hierarchies corresponds to basic tenets of process typology. Interrelations are identified between typological change on the level of buildings or building compounds, and processes of tissue adaptation related to modifications of global street patterns. Regarding networks, the notion of "nodality" is crucial: "*When ten houses are built in San Frediano, all similar because built at the same time, and a time span passes*", we will find them no longer similar - due to many factors, but certainly "*due to their reciprocal position and to their being near to or far from a node*" (Caniggia and Maffei 2001: 168). These considerations on the scale of individual buildings are extended to formative processes on a larger scale that involve the conversion of "anti-nodal" boundaries into "nodal axes". The essence of this process is generalized in the principle of "successive doubling": The boundary between two modules turns into a central connector once they join to form a new, bipartite structure. (Caniggia and Maffei 1979: 183)

An important extension of the understanding of tissue formation in Process typology is due to Brenda Scheer. Regarding the stability of tissues over time, she differentiates between "static tissue", "campus tissue" and "elastic tissue" (Scheer, 2001). As Scheer has shown, the highly dynamic "elastic tissue" is typically emerging in the vicinity of matrix roads (Scheer, 2004: 109). The question arises, if and in what way the formation of this tissue type is related to the dramatic shifts in centrality values that characterize the development of such roads.

2.2. Space Syntax

Regarding qualitative notions like "polarity" and "nodality", Space syntax provides a complementary approach by formalizing the mapping and analysis of spatial networks. Interestingly, this has been applied both to buildings and to networks of urban open space. But so far, probably following a theoretical distinction between "gamma analysis" of buildings and "alpha analysis" of settlements (Hillier and Hanson 1984: 144), there has been little research on possible interactions between these levels of resolution.

In their analyses of building types, Hillier and Hanson looked for "spatial-functional genotypes" behind the variety of actually realized "phenotypes" (Hillier and Hanson 1984, 42). This was achieved through mappings of the internal, spatial networks of buildings and through the identification of characteristic centrality distributions (Hanson 1998). An analogous approach has proven very successful for the analysis of networks of urban open space. Not to be confused with traditional traffic network analysis, the spatial network analysis proposed by Space Syntax is essentially based on mappings of the human perception of bounded, "convex" spaces (Rashid, 2019: 203).

Under the label of “Place Syntax”, Space Syntax has recently seen extensions facilitating a rich range of morphological studies. The mapping of spatial networks has been related to studies of density, plot patterns and building types (Berghauser Pont et al. 2019). GIS-based tools such as the “Place Syntax Tool” PST (Ståhle 2012) provide bridges between the network representations typical for Space Syntax and boundary representations such as plot patterns or continuous ground floor plans characteristic for process typology.

3. Methodology

Based on an analysis of the evolution of the urban spatial network within the city core of Zurich since 1800, two case studies were selected in areas where shifts in centrality distributions appear to have strongly affected tissue formation. One of them focuses on the transformation of a strip of serial tissue, the other singles out a large compound, situated along a former boundary that turned into a central axis. Furthermore, in an attempt to generalize observations made in the second case, the role of other compounds in similar locations for the upgrading of the network through the opening up of break-through streets was investigated.

To map the evolution of centrality distributions over time, the road centrelines within today’s city boundaries have been vectorized for the time sections of 1800, 1850, 1900, 1950 and 1990, based on georeferenced historical maps and working backwards from the current road centreline (RCL) map. The RCL maps were adjusted for Angular Segment Analysis (Kolovou et al. 2017). Additionally, the plot patterns within today’s city centre were vectorized for 1793, 1850, 1900, 1950 and 1990. Using the PST plugin for QGIS, centrality values (NAIN and NACH) were calculated, and for each origin plot the total plot surface that can be reached through the network was determined for different radii using the “Reach” function in PST. Both analyses were repeated for each time section. A significant change in Reach points to a repositioning of the origin plot within the network and might therefore be related to changes in plot use and building typology.

Two areas that underwent marked shifts in accessibility were selected for further investigation on the level of building configurations. Unfortunately, the data available before the systematic filing of building permits started in 1863 is far from sufficient. An unfinished, continuous floor plan survey of the city centre produced by the ETHZ Chair for the History of Urbanism in 1999 provided a valuable source. Additionally, the survey that had been produced by architecture students of Aldo Rossi and that shows the state of the urban tissue around 1950 (Cantoni et al. 1976) was consulted. Based on available information, the internal distribution networks on the ground floor level were mapped and connected to the road network at the access points of each building. The spaces within buildings were defined as a set of origins, and the plots in the entire city core as a set of destinations. Using the PST “Attraction Reach” function, the total plot surface accessible from each space through the combined local and global networks was calculated at different moments in time and applying different radii and distance metrics. The results allow to assess the relative accessibility of spaces within a building or compound and to identify changes due to the combined effects of the evolution of the global street network and the transformations of local distributive systems.

4. Results and Discussion

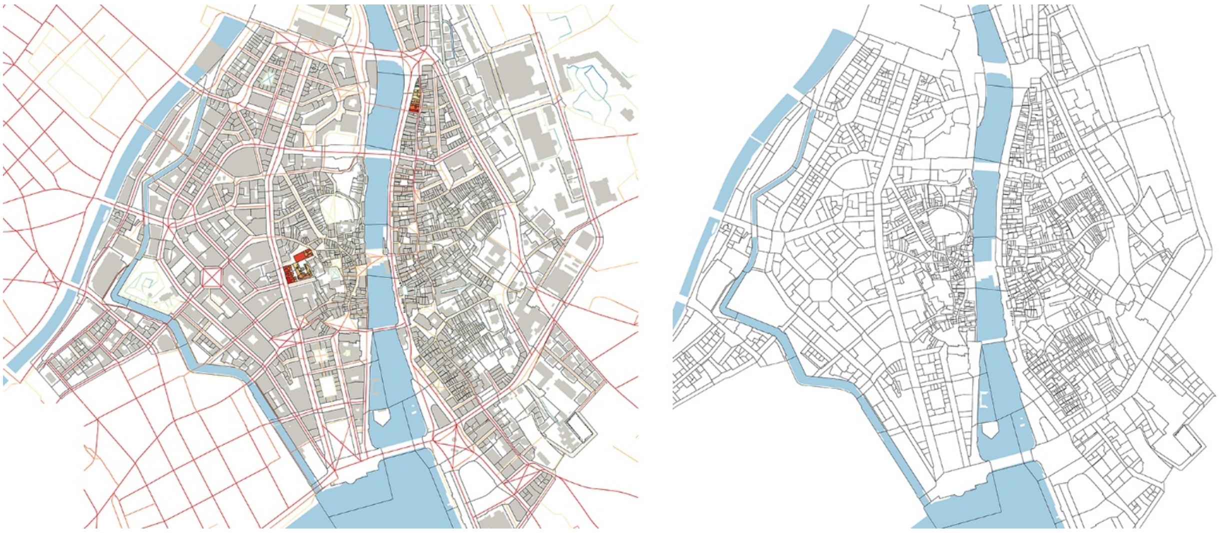

Figure 1. *Zurich around 1990: Location of the two case studies (left) and destination plot pattern (right).*

4.1. Polarity reversal and typological innovation

The first case study investigates the turn-over of a slice of generic, serial tissue along the main artery of the merchant town on the east bank following the construction of a new quayside around 1855 (Abegg et al. 2007: 167-172). The new Limmatquai took over the role of a main north-south throughfare from the former artery, immediately acquiring significantly higher centrality values than the latter. Following subsequent modifications of the global network, the centrality gradient between the two streets increased even further. The fifteen plots in question obtained a second address, providing them with major gains in accessibility. This polarity reversal seems to have initiated a series of transformations affecting both plot pattern and building typology. As a result, the original row of congeneric buildings has given way to a heterogeneous conglomerate, integrating fragments of buildings from various phases in time (Abegg et al. 2007:167).

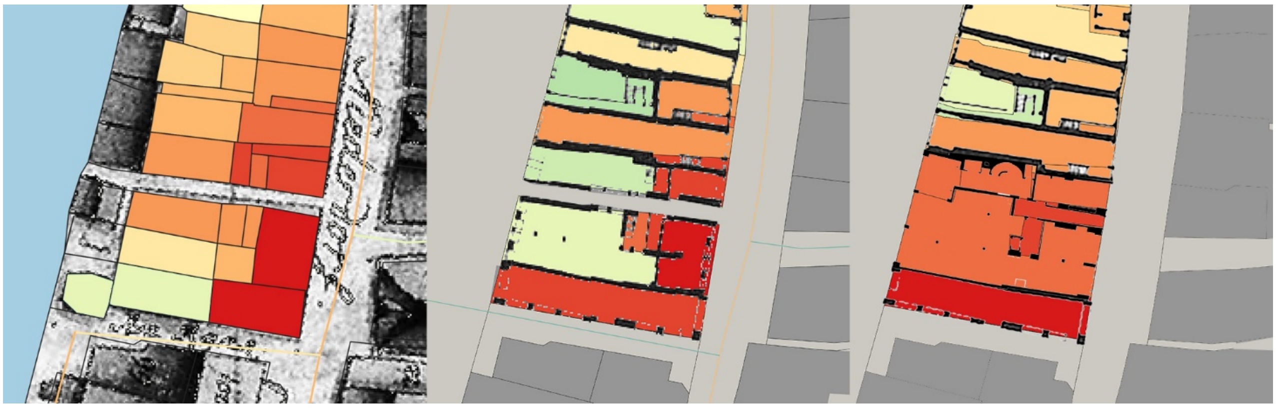

Figure 2. *Detail of reconfigurations between 1793 (left), 1950 (middle) and 1990 (right). The densely partitioned merchant row houses were frequently infused with generous, open ground floor spaces joining the accessibility potential of both addresses. In this case, the fusion of three houses and the integration of an alley led to the emergence of a specific type tailored to the exceptional potential of the location.*

4.2. Polarity reversal of specialized building compounds

On a larger scale, such polarity reversals also occurred in the modifications undergone by the sites of former mendicant friaries during the modernisation of the city centre from 1800 onwards. As M.R.G. Conzen had observed, “urban friaries are common intra-mural fringe-belt features in medieval towns” (Conzen 1968: 122). In Zurich, Dominican friars (Prediger, around 1230), Dominican nuns (Oetenbach 1234), Franciscans (Barfüsser, around 1240) and Augustinians (1270) all obtained large patches of previously unbuilt land that were included within the new town wall then under construction (Gilomen, 1999: 51). After the dissolution of the friaries by the Protestant reformation (1524), these compounds took on various secular functions. For the most part, they remained property of the city and later the canton of Zurich.

Even after the construction of the baroque fortification, the thirteenth-century town wall persisted as an operative, intra-urban boundary (Wild et al. 2004: 47). Up to its demolition from 1806 onwards, the sites of the former friaries retained relatively peripheral positions, turning their backs to the town-wall and their main access points to what was then the city centre. This orientation changed dramatically after the removal of the fortifications and the upgrading of the intraurban street network. In all four compounds, polarity reversals induced by the replacement of the town walls by new thoroughfares and avenues released major structural and functional reshufflings. Nevertheless, the contours of the former friaries remain readable in today’s structural plan. They continue to accommodate large, specialized building complexes and important, public functions.

A case in point is the site of the former Augustinian friary (Abegg and Barraud Wiener 2002: 190). This compound initially turned its back to the western segment of the town wall and was accessed from the east and north. At first, the removal of the wall led to the establishment of new functions and to a series of invasive modifications of existing structures. The internal configurations of both the church and the large, former “back office” building were turned around by the introduction of new entrances in the west, facing Bahnhofstrasse, a newly planned boulevard following the former moat. These initial “capillary adaptations” gave way to more radical transformations later on. Over time, Bahnhofstrasse became the most highly integrated, central line west of the river. Significant gains in centrality followed the break-through linking Bahnhofstrasse to the lake, the establishment of quayside avenues along the lakeshores, the construction of several new bridges and the upgrading of access to Central Station. On the site of the former Augustinian friary this led to a kind of castling move: In front of the compound, representative commercial buildings were erected to exploit the Bahnhofstrasse frontage. Later on, one of their owners, a banking house, gradually expanded by acquiring the other frontage buildings as well as most of the former compound. Eventually, this led to the complete replacement of the remaining compound buildings with the exception of the church and the parish house. Once again, the lion’s share of the former friary is under control of a single owner. The whole complex is accessed through a single, main entrance, now discretely located in the south, while the ground floor frontage facing Bahnhofstrasse is entirely dedicated to retail.

Figure 4. *Relative accessibility in terms of the total plot surface reachable from the ground floor spaces of the former Augustinian friary within a radius of 2000 axialmeters at four moments in time: 1793 (top left), 1850 (top right), 1950 (bottom left) and 1990 (bottom right). Values range from blue (<8000m2) to red (>79500m2). Axialmeters is a hybrid distance measure proposed in PST to combine metric walking distance with the number of axial or angular segment steps. It is calculated as the product of the two measures (m*steps).*

4.3. Specialized building compounds as resources for network upgrading

Throughout the nineteenth and twentieth centuries, the inner configurations of Zurich's former friary compounds have been influenced by major shifts in centrality within the urban spatial network in which they are nested. Meanwhile, these compounds have themselves provided crucial resources for the establishment of new, superordinate connections. Between 1865 and 1910, a total of seven projects for break-through streets were considered, four of which were eventually realized. Together with the quaysides, the additional bridges and the boulevards following former fortifications, these streets now form the integration core of the contemporary centre. While all of the non-realized projects required cutting through intricate patterns of small, privately owned plots, the majority of the surface of the effectively realized break-through streets lies within the boundaries of former friaries.

One reason for this is obviously ownership. Since city and canton were still under control of most of the compound areas, it was relatively straightforward to achieve major reconfigurations there. However, the peculiar shifts in centrality that the compounds underwent after the removal of the fortifications suggest an additional, less obvious reason: Initially occupying peripheral interstices between matrix roads with their associated tissues, they now lay in areas where the establishment of new connections would yield the most significant gains in overall centrality. The expropriation and demolition of small-scale tissue has certainly never been easy. But it was absolutely feasible at the time – provided the expected gains in network performance outweighed social, procedural and financial resistance. The break-through projects that were abandoned or left unfinished did not promise centrality gains of the same order of magnitude, as they mainly linked up to established, narrower throughfares where they might only have increased congestion rather than opening up new capacities.

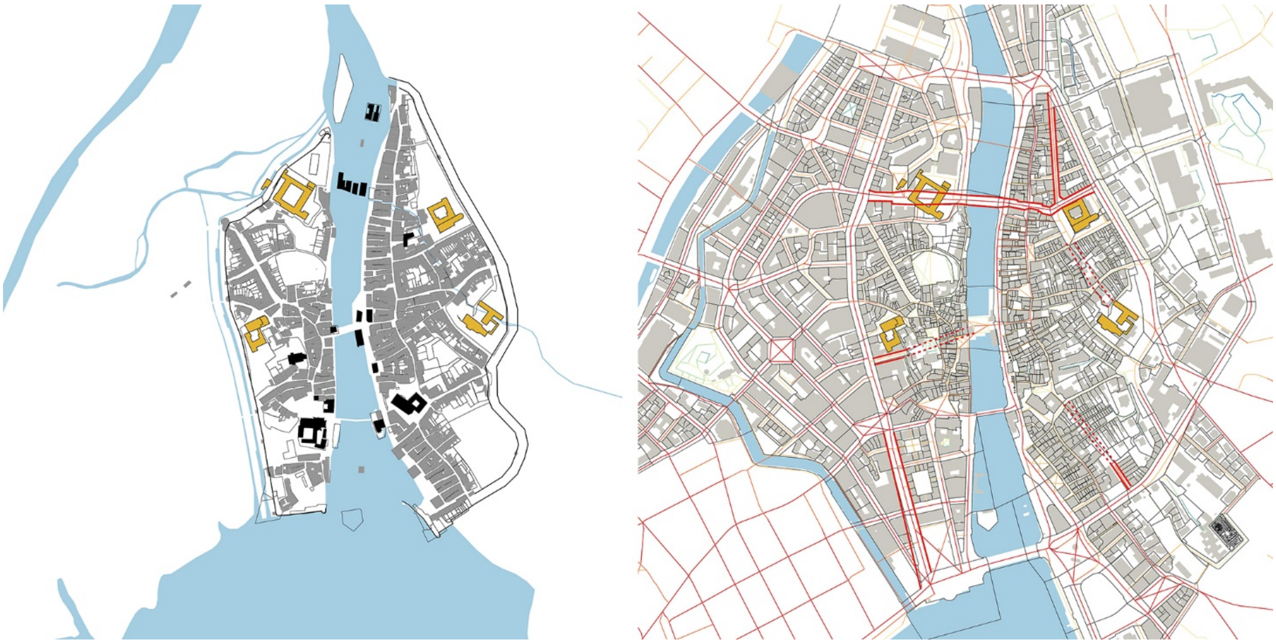

Figure 5. *The left map shows Zurich around 1330 with the mendicant friaries in yellow. They were initially located peripherally along the town wall. The right map shows the break-through streets opened up between 1870 and 1915 (bold red lines) and the planned, but not realized break-throughs (dashed red lines).*

4. Conclusions and Outlook

The results of the case studies suggest three hypotheses:

(1) Tissue adaptation is correlated with fluctuations in centrality. Plots, buildings and building complexes that are addressed from urban spaces undergoing significant shifts in centrality, or that acquire new address points with substantially different centrality values are likely to undergo change in the form of plot reconfiguration, capillary adaptations within existing buildings or replacement of buildings.

(2) Large, specialized compounds act as "change drivers" while small-scale and serial patterns of plots or buildings provide stability. On the one hand, large compounds are particularly affected by the transformations of former boundaries into connectors. On the other hand, they themselves allow for the introduction of new network connections through the possibility of a radical reconfiguration of their internal structure.

(3) Substantial network adaptations such as break-through streets are more likely to occur where they achieve an optimal balance ("rendimento") between the number of plots involved (minimum) and potential gains in centrality (maximum).

So far, the evidence collected in the case studies only allows to hint at such correlations. To discuss possible causal relationships between shifting centralities and tissue adaptation, typological innovation or other transformative processes, it will be necessary to systematically examine the frequency of change over time in larger areas and to compare it with the evolution of centralities in the corresponding regions of the network. Furthermore, the effects of shifts in local centrality values should be differentiated from the effects of shifts in values on large, global radii. A promising line of inquiry might include a further investigation of the formative processes of "elastic tissues" (Scheer, 2004). Possibly, the degree of "elasticity" of a tissue can be related to the degree of stability of centrality distributions in the network serving it.

Regarding methods and tools, the mapping of local subgraphs of buildings or building complexes into the graph of the superordinate, spatial network needs further development. This is not as straightforward as it may seem. Some edges might have to be weighted differently in either direction (everybody can leave a building, but only a selected group of inhabitants / visitors can enter it), and different types of boundaries perform very differently depending on the type of flows considered, for example regarding inter-visibility (flow of information) as opposed to accessibility (flow of people / goods).

Last, but not least, a "Nested Networks" approach could be further developed in the light of the Conzenian strand of urban morphology. What comes to mind first is the study of the role of shifting centralities in fringe formation. Furthermore, the question of the identification of plan units (Oliveira et al. 2015) might be considered, possibly in combination with the notion of the "pertinent strip" proposed by process typology to describe a series of plots and buildings hosted by a common carrier.

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