The spatial signature of convergence and divergence in two cities

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TOWARDS MODELLING SPATIAL DYNAMICS IN URBAN SYSTEMS

UNDERSTANDING

1980

Generative experiments (Hillier and Hanson, 1984)

Integration is static and choice is dynamic (Hillier et. al., 1987)

Cellular automaton with agent modelling (Batty, 1991)

Changes in the shape of cities (Hillier & Hanson, 1993)

Demand and supply agent model (Krafta, 1994)

Centrality as a process (Hillier, 1999)

Self-Organization and the City (Portugali, 2000)

Centrality and extension (Hillier, 2002)

Multi-layer agent model (Krafta et. al., 2003)

Self–organisation in organic grid (Hillier, 2004)

Add hoc models in architecture and urban design

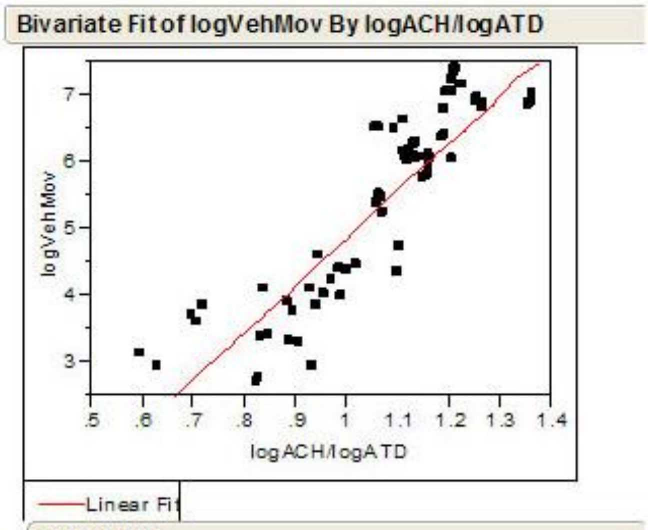
2011

MODELLING

MODELLING SPATIAL DYNAMICS IN URBAN SYSTEMS

HYPOTHESIS

Cities are Simple!



Linear Fit

logVehMov = -2.191075 + 7.0512462 logACH/logATD

Summary of Fit

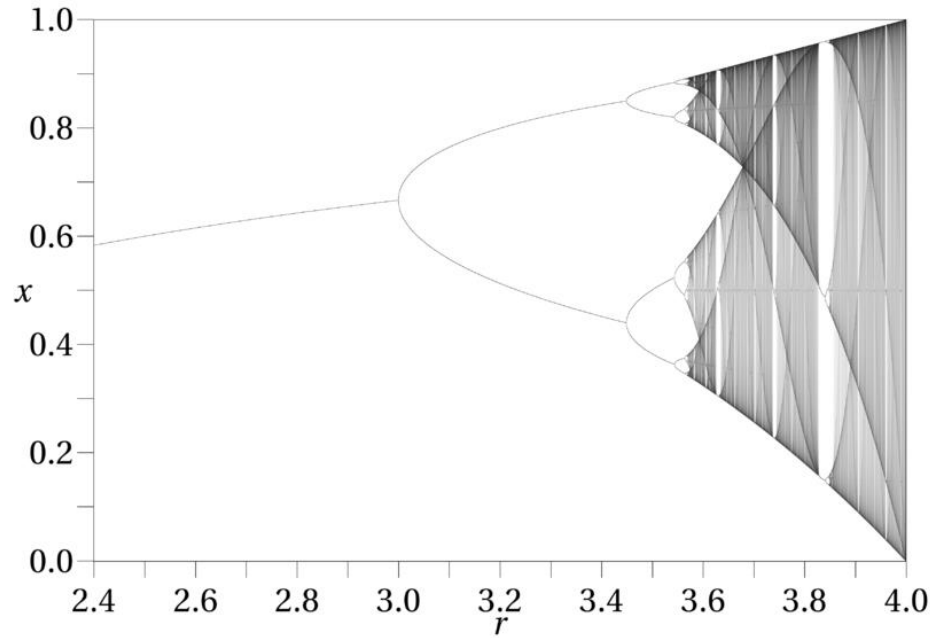
RSquare	0.754288
RSquare Adj	0.751178
Root Mean Square Error	0.688669
Mean of Response	5.42242
Observations (or Sum Wgts)	81

A city is “a network of linked centres at all scales set into a background network of residential space. We then show that this universal pattern comes about in two interlinked but conceptually separable phases: a spatial process through which simple spatial laws govern the emergence of characteristically urban patterns of space from the aggregations of buildings; and a functional process through which equally simple spatio-functional laws govern the way in which aggregates of buildings becomes living cities. It is this dual process that is suggested can lead us in the direction of a ‘genetic’ code for cities.” (Hillier, 2009)

http://otp.spacesyntax.net/methods/urban-methods-2/interpretive-models/

Hillier, B. (2009). The genetic code for cities–is it simpler than we thought?. in proceedings of complexity theories of cities have come of age at tu delft september 2009

Cities are Complex!



“The tension between chaos and order often keeps cities on the edge of chaos _ a situation that enables cities to be adaptive complex systems and withstand environmental changes.” (Portugali, 2012)

"Chaos is aperiodic long-term behaviour in a deterministic system that exhibits sensitive dependence on initial conditions" (Strogatz: 323).

Let V be a set. The mapping f: V → V is said to be chaotic on V if:

1. f has sensitive dependence on initial conditions,
2. f is topologically transitive (all open sets in V within the range of f interact under f),
3. periodic points are dense in V. (Devaney 50)

"A chaotic map possesses three ingredients: unpredictability, indecomposability, and an element of regularity "(Devaney: 50).

http://en.wikipedia.org/wiki/File:Logistic_Bifurcation_map_High_Resolution.png

Strogatz, Steven H. Nonlinear Dynamics and Chaos. Cambridge MA: Perseus, 1994.
Devaney, Robert L. *An Introduction to Chaotic Dynamical Systems.* Menlo Park, CA: Benjamin/Cummings, 1986.

Quoting Jane Jacobs!

“Cities [are] problems in organized complexity”

Jane Jacobs (b. 1916), U.S. urban analyst. The Death and Life of Great American Cities, ch. 19 (1961).

To understanding cities we need:

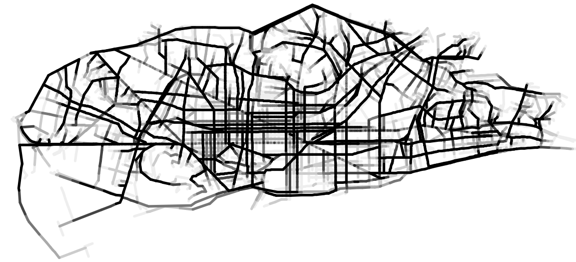
1. To think about processes;

2. To work inductively, reasoning from particulars to the general, rather than the reverse;

3. To seek for "unaverage" clues involving very small quantities, which reveal the way larger and more "average" quantities are operating.

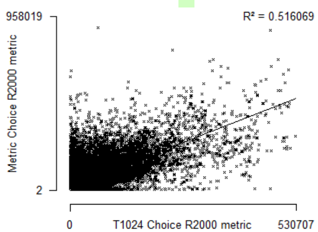
Cities show an autonomous behaviour in their growth and differentiation mechanisms. These mechanisms reinforce a self-organised parts-whole structural unity by which planned grid structures are deformed and adapted to match natural growth patterns.

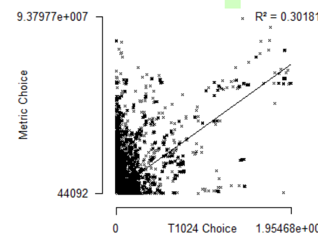
We start from Space *looking for regularities in the geometry of street networks*

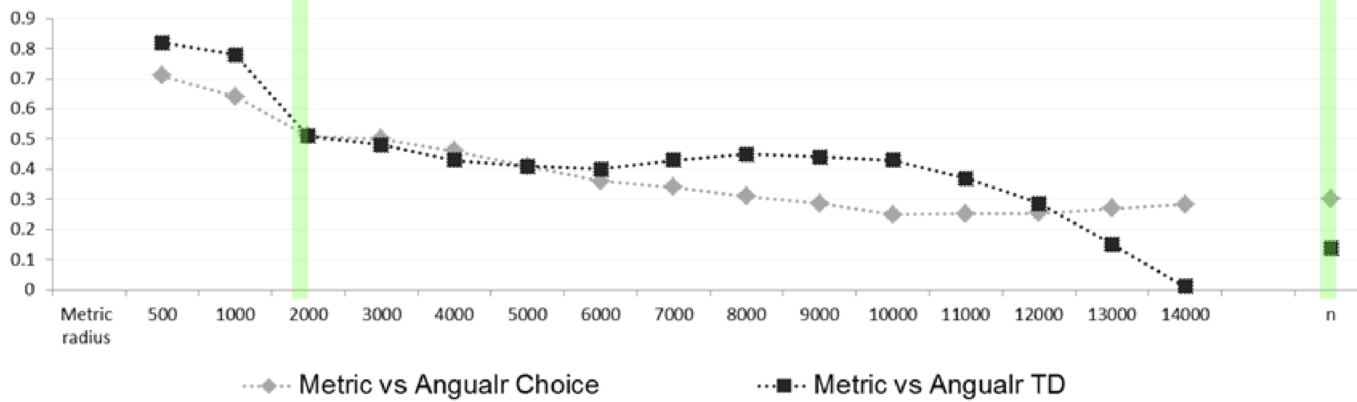


Angular choice

Metric choice

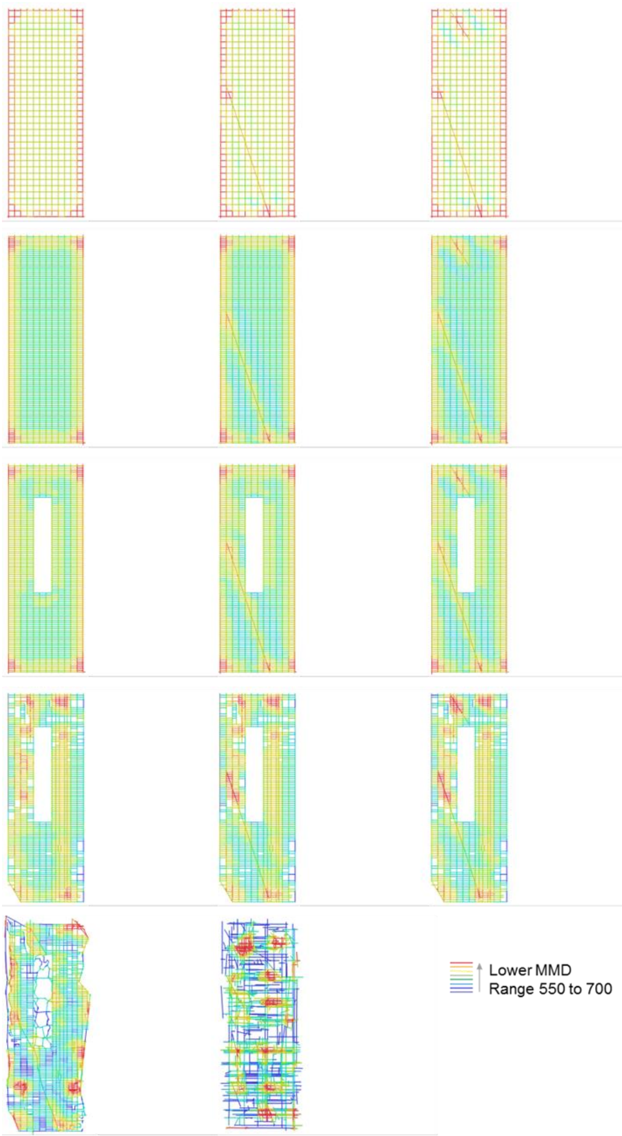




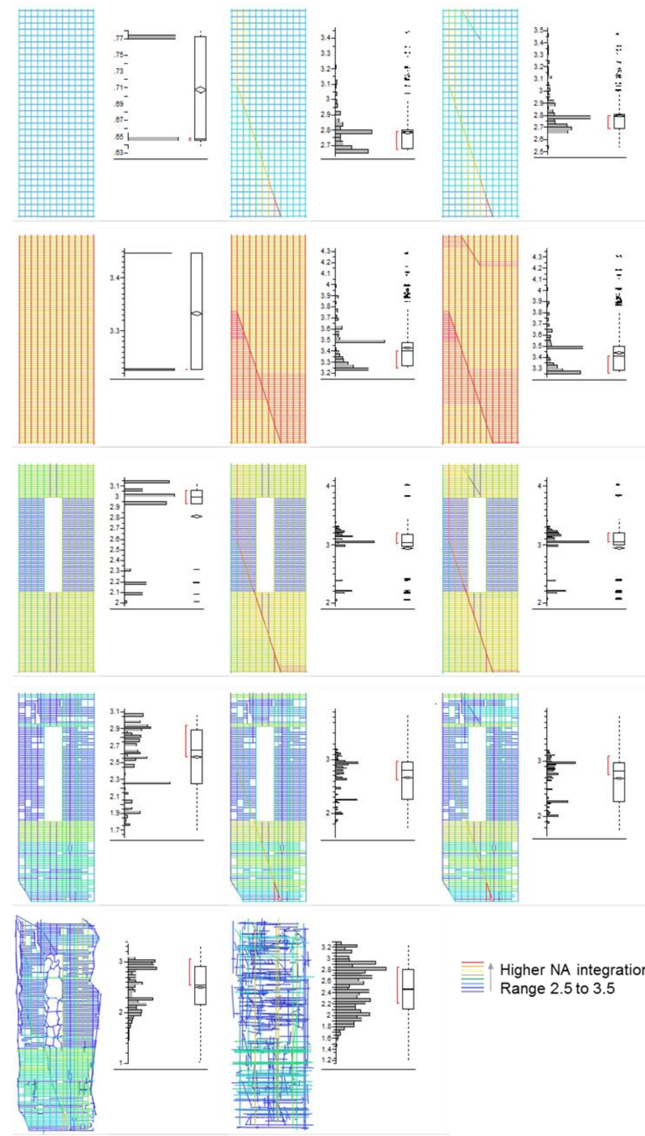


Al_Sayed K. (2013). The signature of self-organisation in cities: Temporal patterns of clustering and growth in street networks, International Journal of Geomatics and Spatial Analysis (IJGSA), Special Issue on Selected Developments in Spatio-temporal Modelling, In M. Jackson & D. Vandenbroucke (ed), 23 (3-4): 379-406

On order, structure and randomness: *where do urban systems fall?*



Metric Mean Depth MMD Radius 1000metric



Normalised Angular integration Radius n

Searching for clues in the historical growth patterns of Barcelona and Manhattan

Goal/purpose/rule

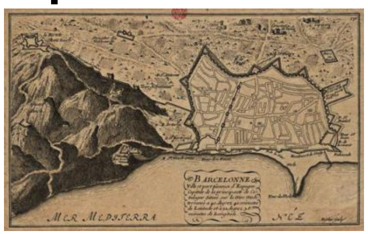
Assumption

$$Y = 99.877e^{0.1622x}$$

$$R^2 = 0.9657$$

A model can be outlined from the process of growth and structural differentiation in cities

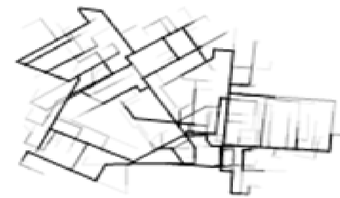
Input



Mapping and externalising growth dynamics in historical growth patterns

spatial system

Output



simulations and short term predictions

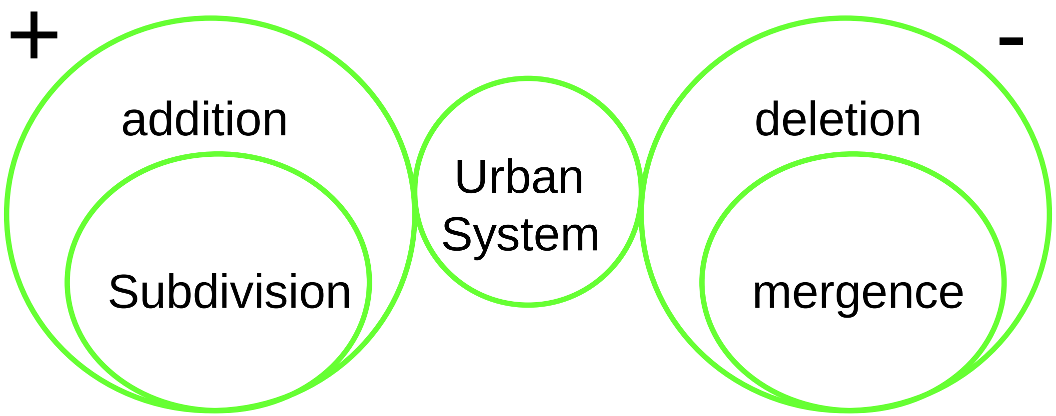
Condition

Expansion affordances Space to expand people to occupy
Will determine whether positive or negative dynamic changes

PRINCIPLES OF THE SYSTEM

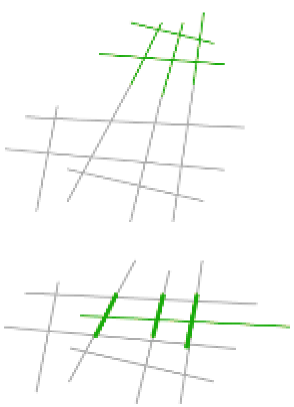
Positive feedback

Reinforcing feedback

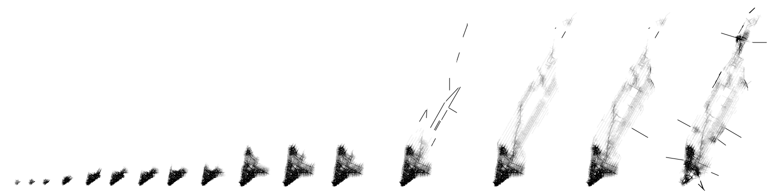


edges

middle

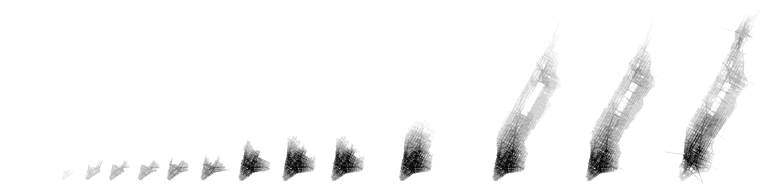


Looking for generic trends in the historical growth of urban street networks



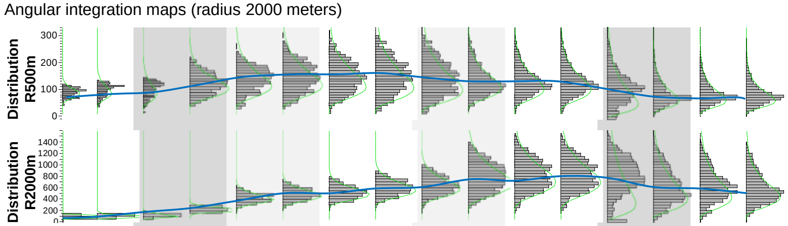
1642 →

Angular integration maps (radius 500 meters)



1642 →

Angular integration maps (radius 2000 meters)



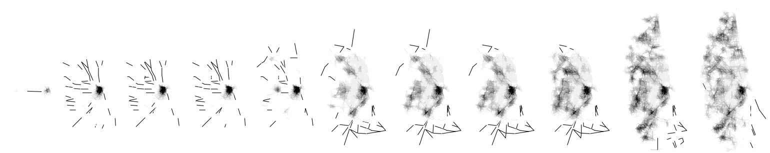
year	1642	1661	1695	1728	1755	1767	1789	1797	1808	1817	1836	1842	1850	1880	1920	2008
Intel	0.77	0.84	0.87	0.69	0.68	0.56	0.58	0.61	0.63	0.72	0.73	0.74	0.70	0.50	0.62	0.66
Syn	0.77	0.84	0.89	0.69	0.70	0.88	0.87	0.86	0.86	0.84	0.85	0.85	0.79	058	0.71	0.71

Severity of transition from one synchronic state to another given structural and distribution indicators

Higher angular integration values

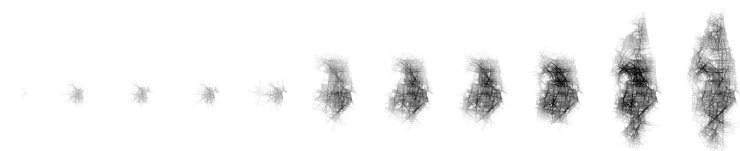
Log normal distribution curve

Mean/median values



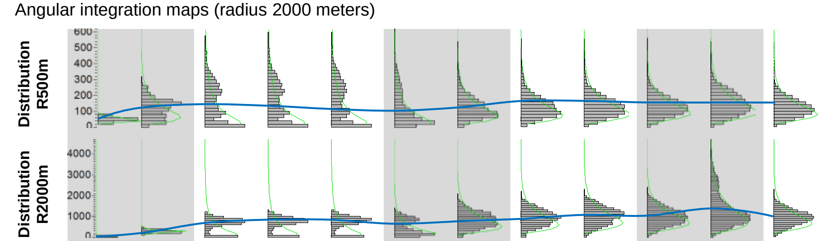
1290 →

Angular integration maps (radius 500 meters)



1290 →

Angular integration maps (radius 2000 meters)



year	1260	1290	1698	1714	1806	1855	1891	1901	1920	1943	1970	2008
Intel	0.90	0.62	0.57	0.58	0.58	0.52	0.68	0.67	0.67	0.62	0.47	0.40
Syn	0.90	0.71	0.64	0.65	0.64	0.64	0.71	0.72	0.71	0.69	0.63	0.59

Severity of transition from one synchronic state to another given structural and distribution indicators

Higher angular integration values

Log normal distribution curve

Mean/median values

Looking for generic trends in the historical growth of urban street networks

Manhattan

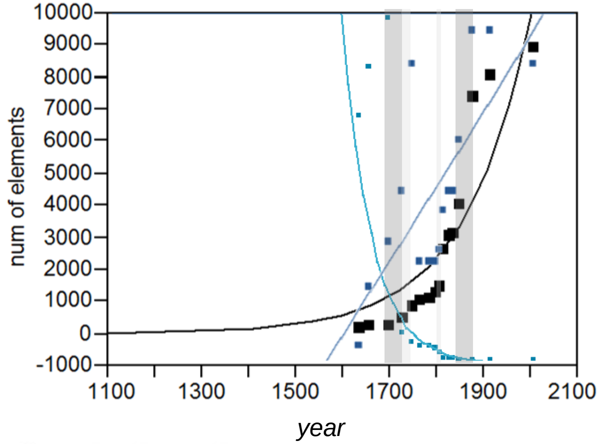
Linear and nonlinear fit solutions

Deformity R^2 = 0.80 Natural logarithm fit
Fractal D R^2 = 0.53 Linear fit

Nonlinear fit solution

SSE	DFE	MSE	RMSE
27692661.637	14	1978047.3	1406.4307

Parameter	Estimate	ApproxStdErr
b1	0.007164405	0.00106851
b0	733.0202662	237.867098
b1	0.013	0
b0	159	0

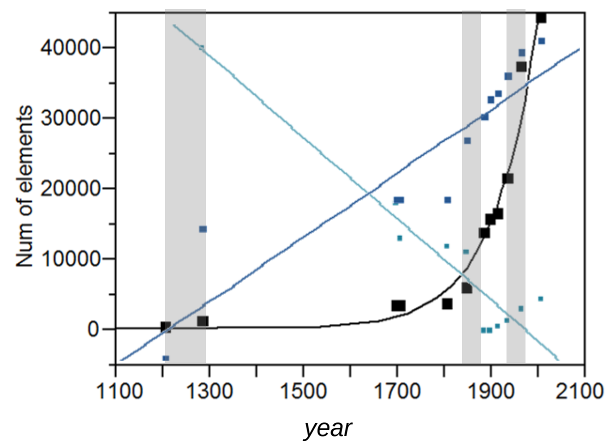


Barcelona

Deformity R^2 = 0.95 Linear fit
Fractal D R^2 = 0.83 Linear fit

SSE	DFE	MSE	RMSE
72703917.749	10	7270391.8	2696.3664

Parameter	Estimate	ApproxStdErr
b1	0.0105310111	0.00088276
b0	10.25766467	6.91634685
b1	0.006	0
b0	90	0



■ number of elements
— Expon. (number of elements)
— Deformity trend
— Fractal Dimension trend
▬ Transitional states in the growth trend

$$f(x) = X_0 * \mathrm{Exp}(X_1 * (year - year_0))$$

where the parameters initial values are;

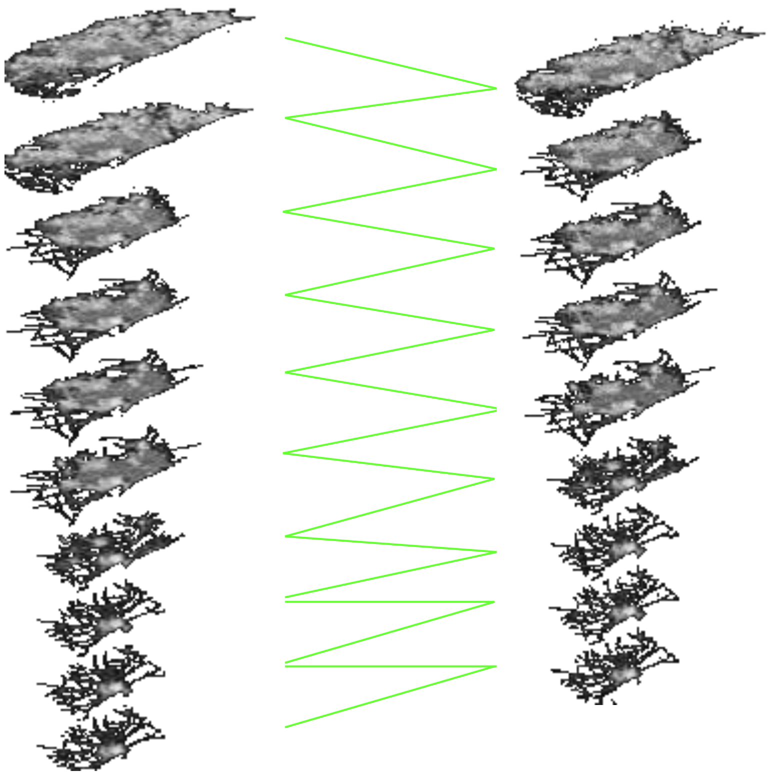
X_1 = 0.013, X_0 = 159 for Manhattan

X_1 = 0.006, X_0 = 90 for Barcelona

Method/Product

Asynchronising structures

Mapping transformations in-between
synchronic states of the growing system



A dynamic model

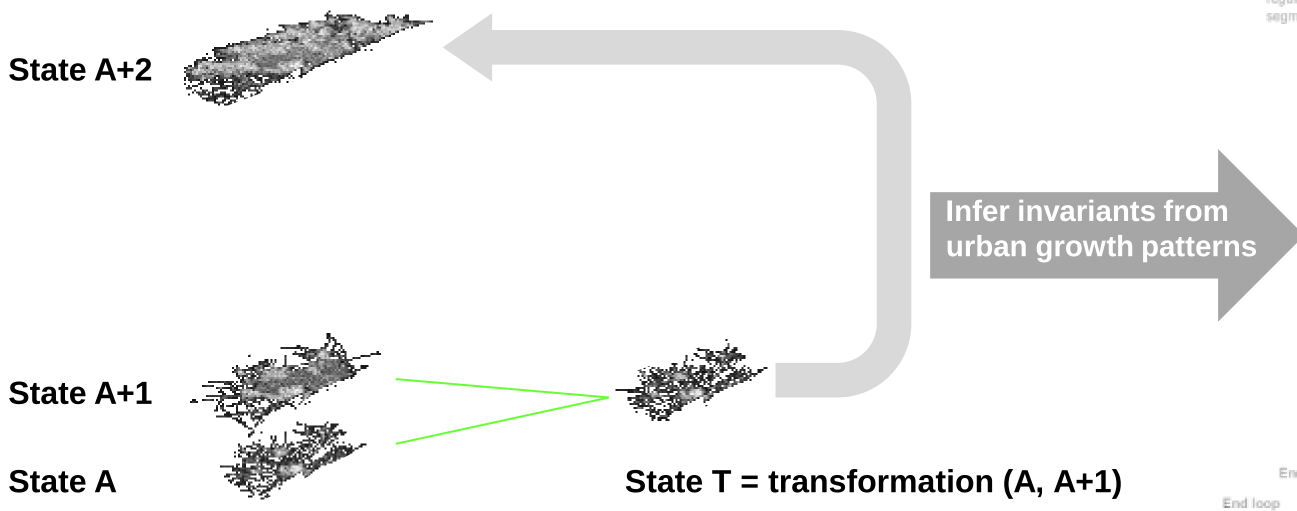
That implements generative rules

Method/Product

Asynchronising structures

Mapping transformations in-between synchronic states of the growing system

Extract an invariant that marks growth patterns



While aggregate integration values of elements in the system do not approximate a log normal distribution locally and a normal distribution globally

While system has not reached its maximum boundary and complexity is penalised by regulator (*if* connectivity value of a certain element raises above10, *then* no more segments are attached to this particular segment)

// preferential attachment

If peripheral patches exhibit high changes in local integration ***then*** increase *attachmentProbability*

If routes of high angular choice *Rn* are on the edges ***and*** these routes have previously witnessed high changes in angular choice, ***then*** increase *attachmentProbability* at the intersection of these routes to add new elements and form patches.

If patches are above a certain number of elements ***and*** size of patches goes beyond certain proportions ***then*** increase *attachmentProbability* to distribute within a Gaussian that covers patches.

If a gain of centrality is at its utmost in sparsely spread structures ***then*** increase *attachmentProbability* to add new elements following a Gaussian distribution within a certain metric radius.

Add new elements of length *segmentLength* (short) and angle *segmentAngle* (near right angle) to the neighbouring edges with greatest *attachmentProbability*

If centres have high local integration compared to the whole system, ***then*** increase *attachmentProbability* to connect centres

Add new elements of length *segmentLength* (long) and angle *segmentAngle* (small) to the neighbouring edges with greatest *attachmentProbability*

// pruning

If the area within the constrained boundaries is filled, ***remove*** elements with lowest local integration values.

End loop

End loop

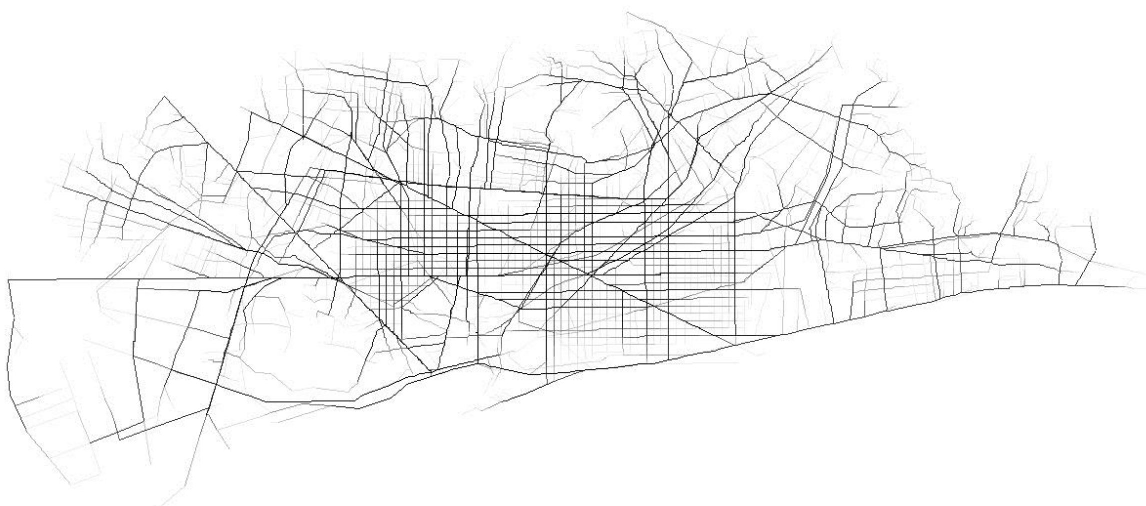
Make assumptions on how they contribute to urban growth

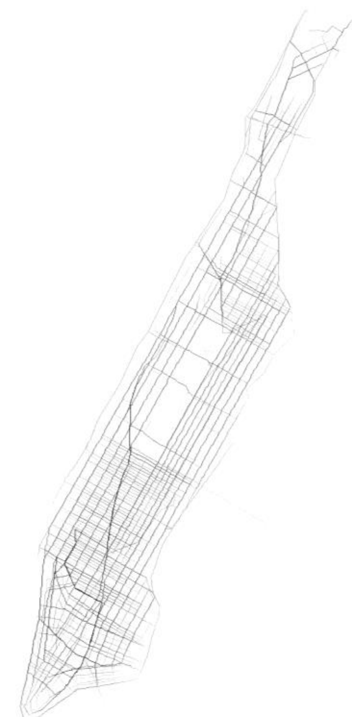
Emergence

Generative growth is a bottom up activity. Given the condition of spatio-temporal configurations in the street network, a generative mechanism operates to allow for the emergence of new elements and patches.

CHOICE IS THE GENERATOR

The superstructure marked by cumulative changes in choice is the generative structure of growth (The origin of cities)





Cumulative changes in choice

recorded between 1260 and 2000

Barcelona

recorded between 1642 and 2000

Manhattan

high changes in choice SLW recorded between states (a and a+1) of the growing system

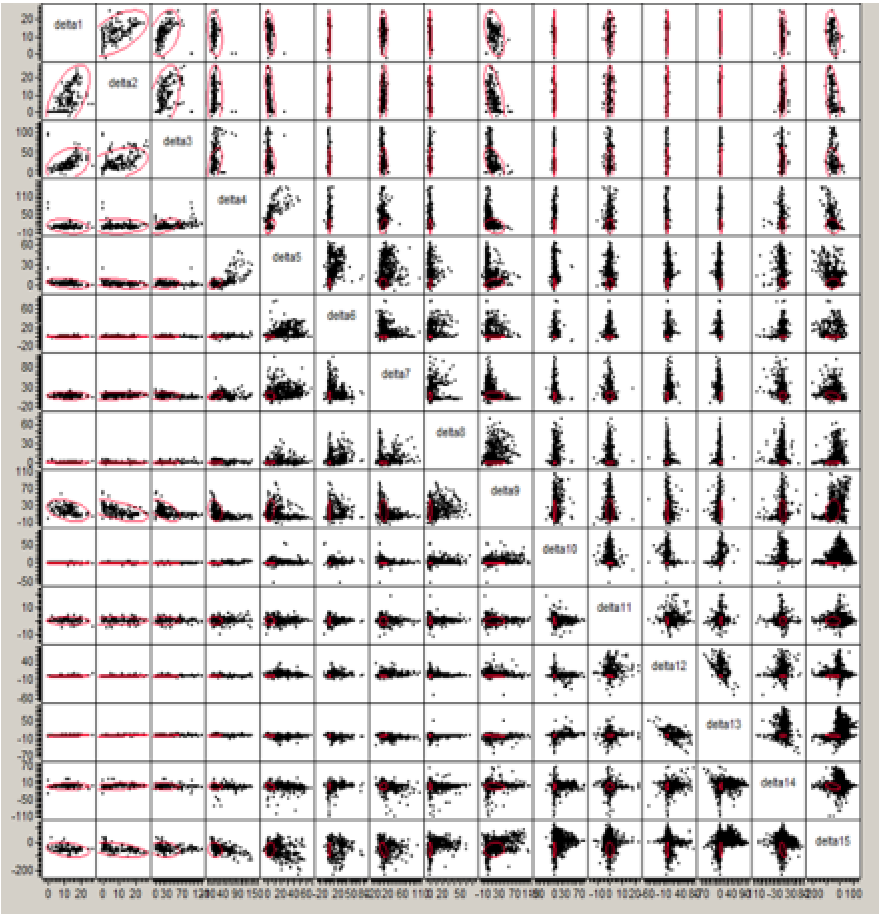
Divergent Cities Cor

Al_Sayed, K., Turner, A. (2012) [Emergence and self-organization in urban structures], In Proceedings of the AGILE'2012 International Conference on Geographic Information Science, in J. Gensel, D. Josselin and D. Vandenbroucke (eds), Avignon, France.

PREFERENTIAL ATTACHMENT

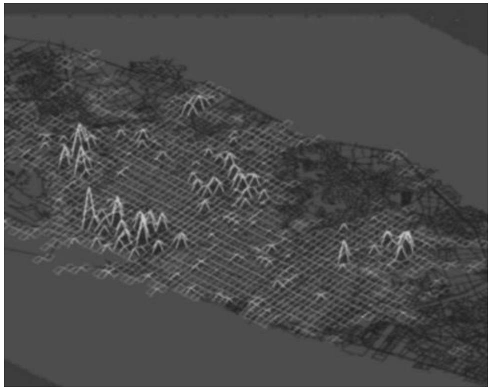
where configurational changes are more likely to occur, elements tend to attach to new spatial structures

CHANGE WILL NOT LEAD TO CHANGE

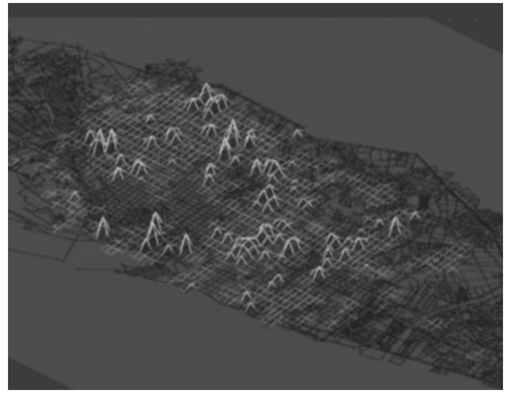


A matrix of maps plotting changes in integration (radius 500m) over time

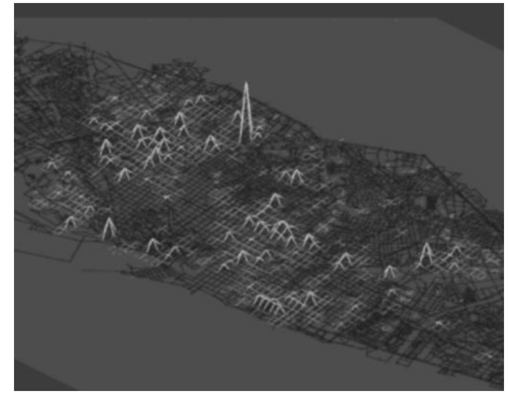
CHANGE TRANSFERS



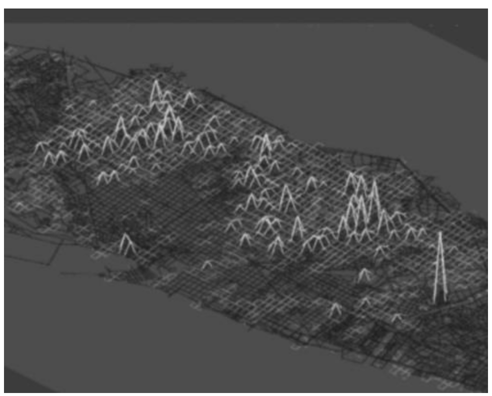
1806-1855



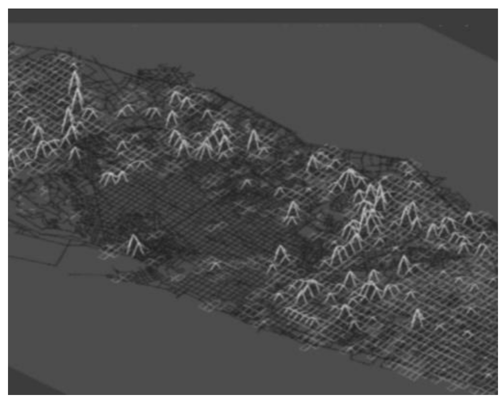
1855-1891



1891-1920



1920-1970



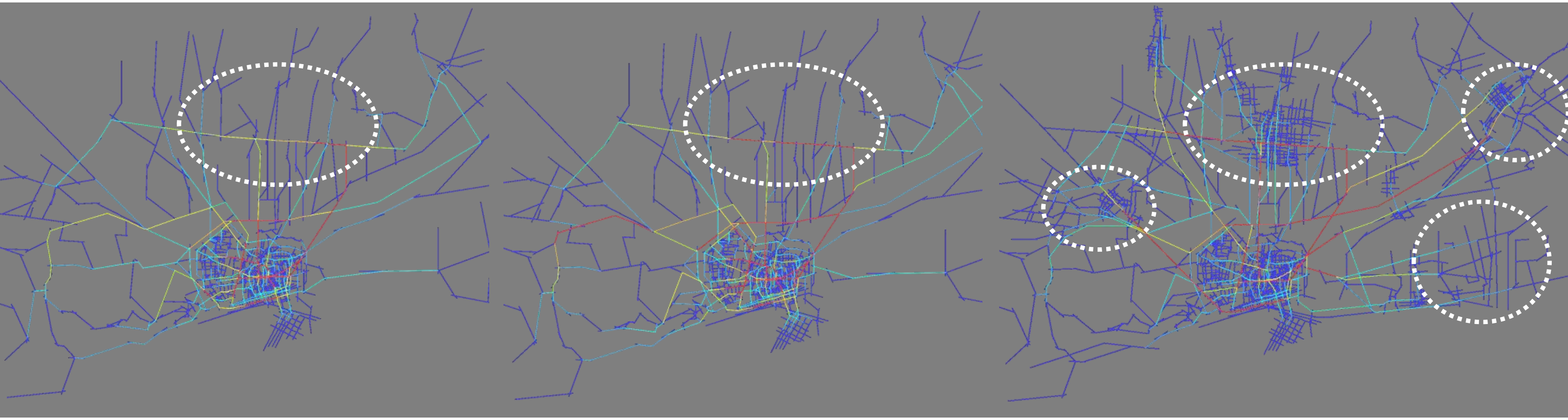
1970-2010

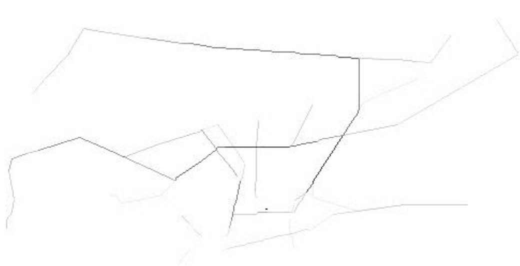
Waves of change in integration values transferring from the core of Barcelona towards the edges

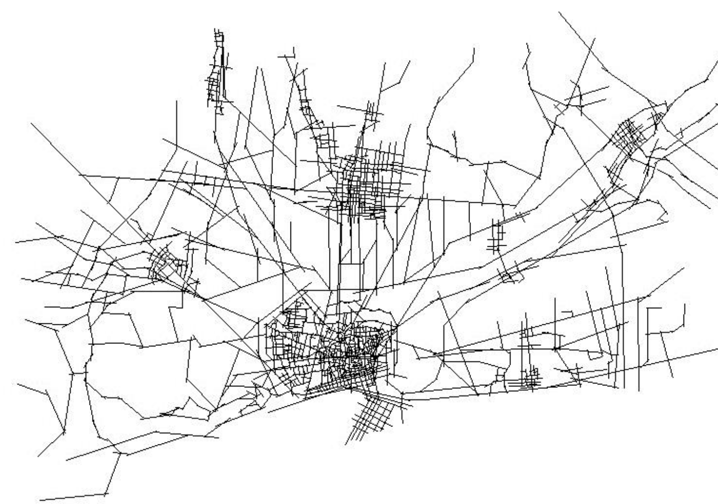
Al_Sayed K. (2013). The signature of self-organisation in cities: Temporal patterns of clustering and growth in street networks, International Journal of Geomatics and Spatial Analysis (IJGSA), Special Issue on Selected Developments in Spatio-temporal Modelling, In M. Jackson & D. Vandenbroucke (ed), 23 (3-4): 379-406

Preferential attachment

Angular choice is generative globally







Al_Sayed K., Turner A., Hanna S. (2012). Generative structures in cities, In Proceedings of the 8th International Space Syntax Symposium, Edited by M Greene, J. Reyes, A. Castro, Santiago de Chile: PUC, 2012.

PRUNING

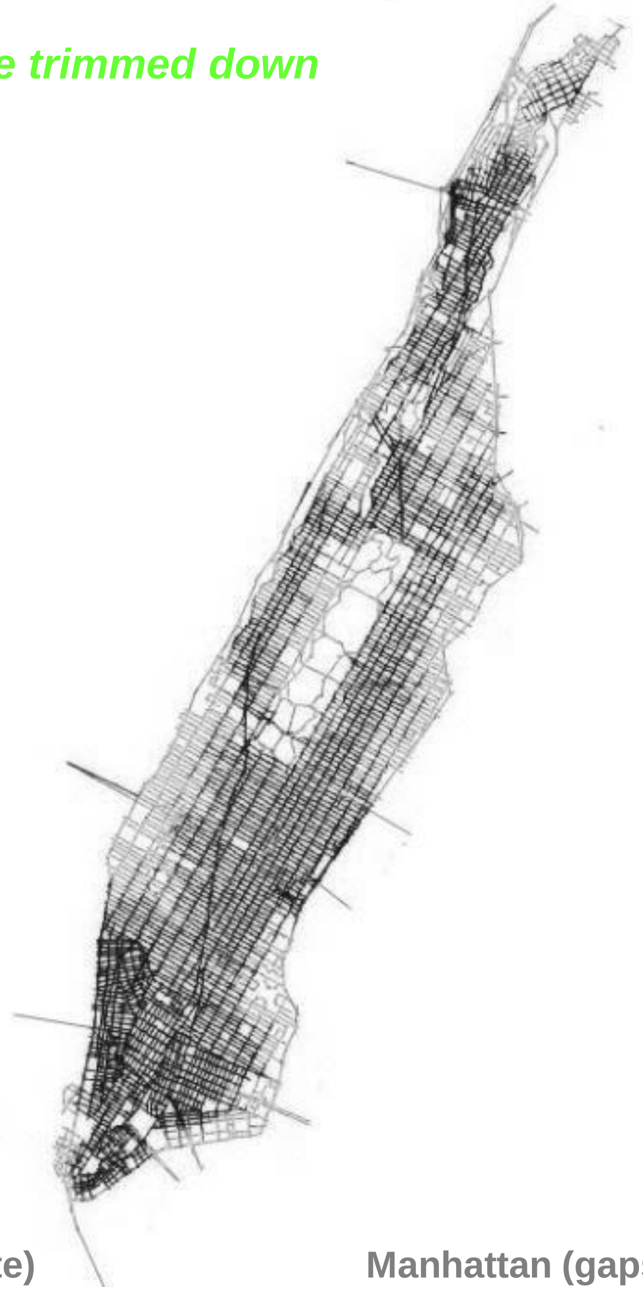
Once the growing structure reaches its maximum boundaries, patches with low local integration will tend to disappear

PRUNING

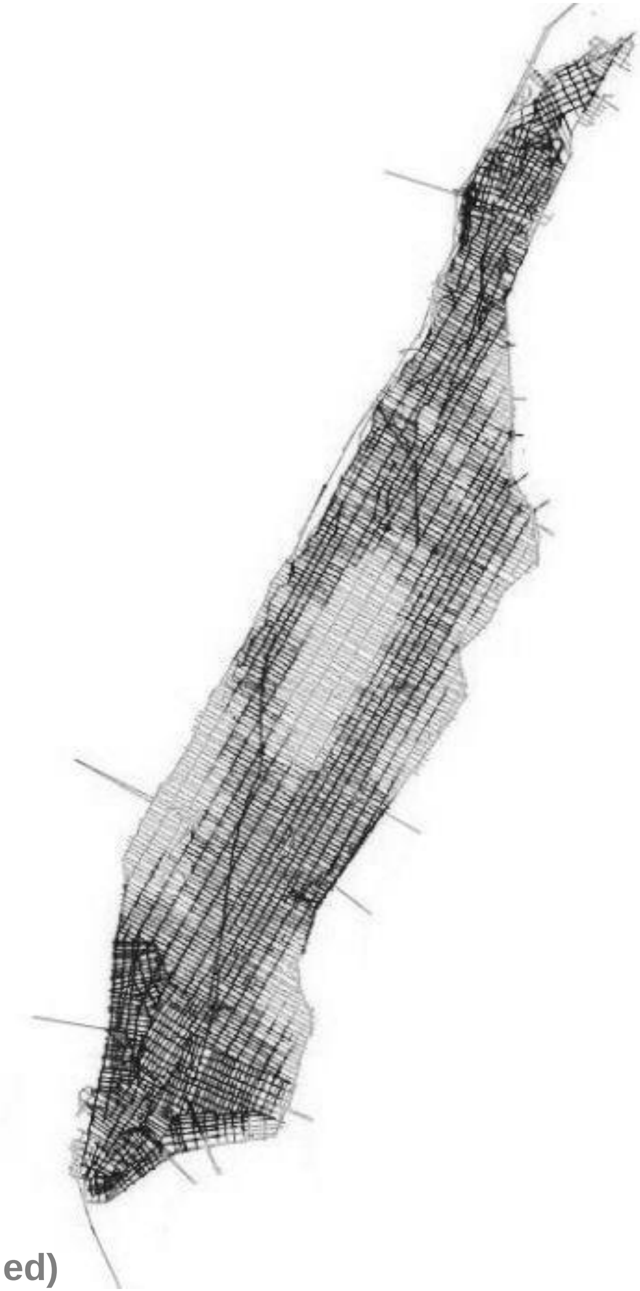
Weak local structures are trimmed down

Higher values mean high integration
radius 800

Colour range 3colours at 130



Manhattan (current state)



Manhattan (gaps filled)

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Al_Sayed K., Turner A., Hanna S. (2009). Cities as emergent models: The morphological logic of Manhattan and Barcelona, Proceedings of the 7th International Space Syntax Symposium, Edited by Daniel Koch, Lars Marcus and Jesper Steen, Stockholm: KTH, 2009.

Self-organisation

There is a top-down process which ensures through a mechanism of self-organisation the maintenance of a part-whole structural unity. This process repeats a fractal structure that has certain metric proximity within itself and between its parts. the overall distance between patches approximates one and half the radius that defines them.

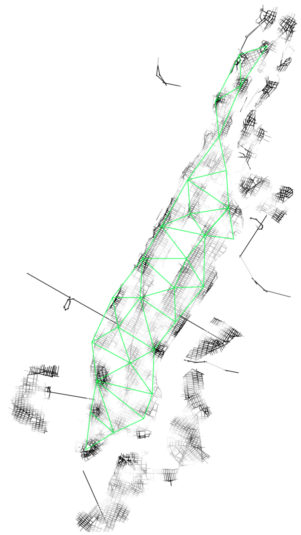
DISTANCE CONSERVATION BETWEEN PATCHES

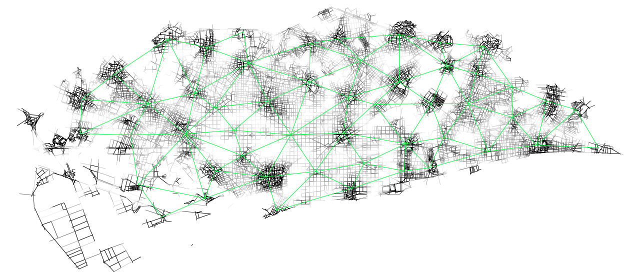
Clusters were derived directly from MMD radius 1000 metric

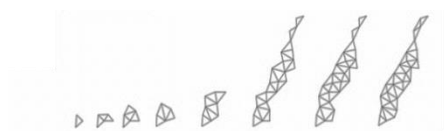
Manhattan **Barcelona**

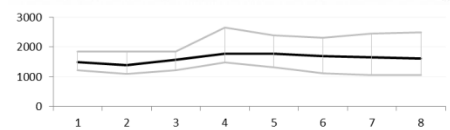
Distances between each two neigbouring patches linking their peaks

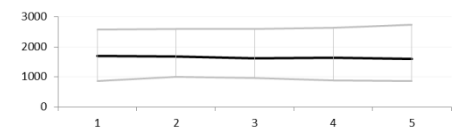
higher MMD R 1000 values marking patchwork patterns in the physical street network



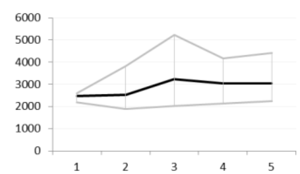


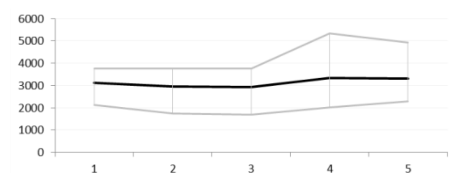






MMD Radius 1000





MMD Radius 2000

Max distance
Average distance
Min distance

1780 → 2000   1780 → 2000

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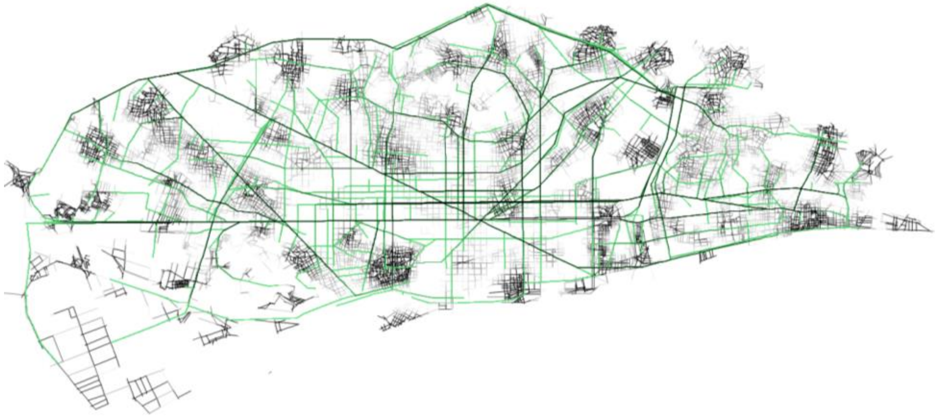
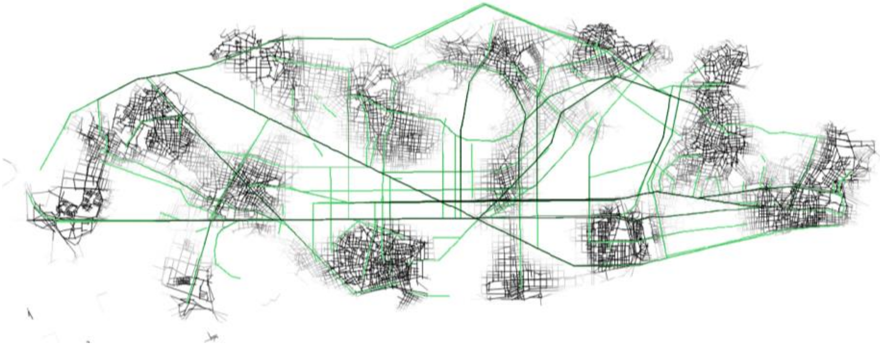
SPATIAL BEHAVIOUR IN CITIES

- Cities grow naturally wherever an emergent bottom-up activity is possible
- Cities deform to differentiate the uniform grid either by intensifying the grid where more through-movement is expected or by pruning weak local structures.
- In a process of preferential attachment, city structure records a certain memory wherever integration change takes place and recalls this memory to attach to new elements.
- This process is continuously updated once the system reconfigures its local settings.
- The system is apt to to fit within a certain distribution and tends to conserve metric distance between patches.
- Structural differentiation aims to adapt the grid to match organic city structures.
- Spatial structures in cities can be considered as independent systems that are self-generative and self-organised.

Angular choice R 6000 metres against MMD R 500



Angular choice Rn metres against MMD R 1000



Angular choice Rn metres against MMD R 2000

Distinguishing two layers in the spatial structure: a background & a foreground

Overlaying two maps; Angular choice map R 6000 metres and Patchwork map, metric mean depth within radius 1000

Barcelona

Other Variables of Complexity

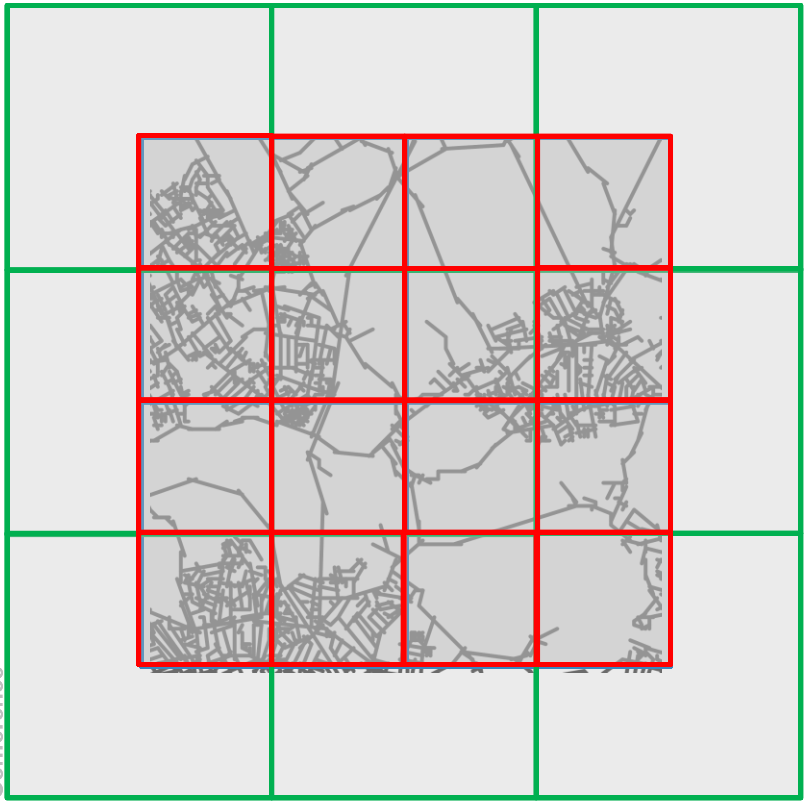
Is space predictive of urban form and function?

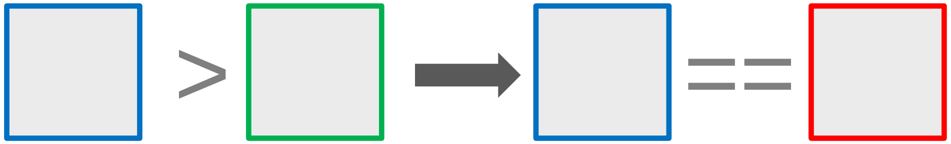
Or

Is space the materialised product of urban form and function?

Mapping space-form-function

Pixelmapper* binning spatial and urban data



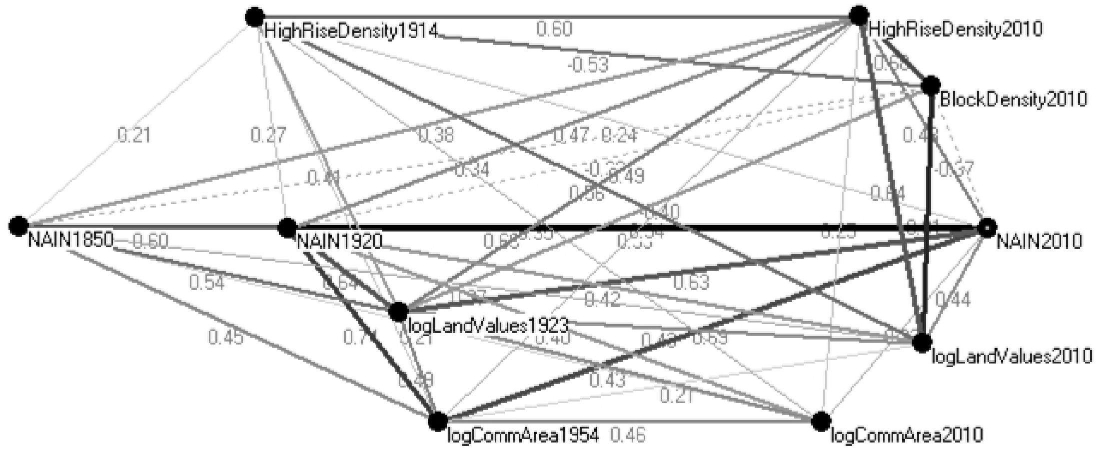


For the second filter we define latent variables that capture the relationship between spatial structure and form-function parameters

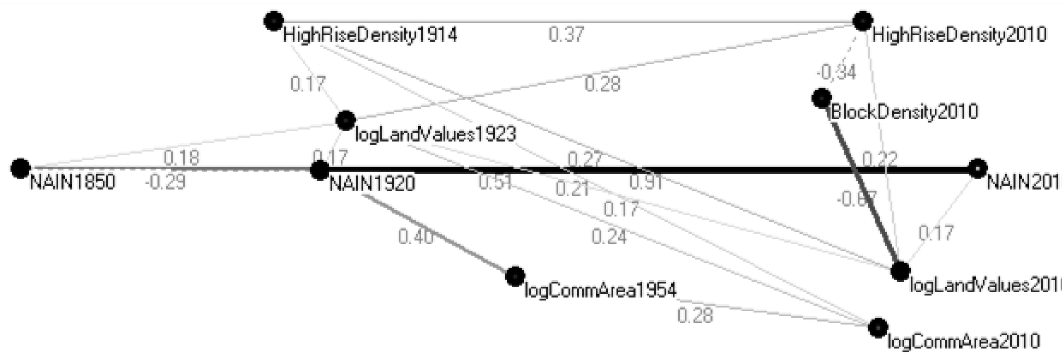
* Al_Sayed K. (2012) Space Syntax as a parametric model, Proceedings of the Fall 2011 PUARL International Conference, Oregon, Portland.

Does street accessibility come first in the process of urban development?

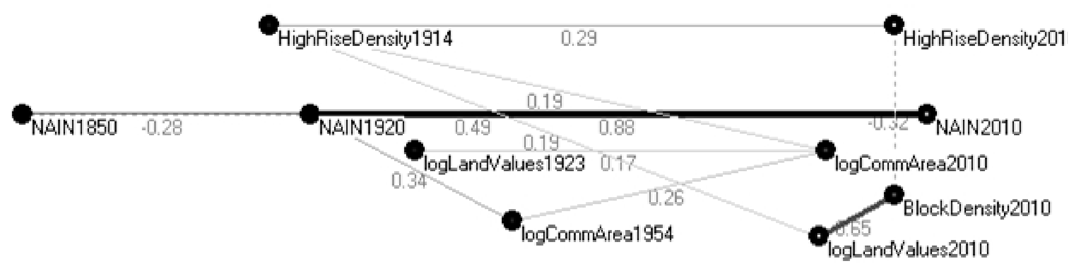
Modelling dependency networks



Zeroth order Pearson correlation coefficient



1st order Pearson correlation coefficient



2nd order Pearson correlation coefficient

Does street accessibility come first in the process of urban development?

Modelling dependency networks

In Manhattan, there was a clear pattern of dependencies, where street accessibility in 1920 was found to relate well to commercial land uses and land values. Land values were found to mediate the relationship between accessibility 1920 on the one hand and high-rise development, block density, and area of commercial activity in 2010. High-rise development in 1914 was also found to correspond to land values 2010, which in turn rendered high correlations with block density.

This research is part of Kinda Al_sayed PhD thesis (2007 -2014) supervised by Alasdair Turner, Sean Hanna, and Alan Penn

Al-Sayed, K; (2014) Urban morphogenesis; how form-function complexity coupled temporal changes on street configurations in Manhattan and Barcelona over the past centuries. Doctoral thesis, UCL (University College London).