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MEASURES OF THE FIT BETWEEN STREET NETWORK, URBAN BLOCKS AND BUILDING FOOTPRINTS

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THEME: Urban Structure and Spatial Distribution

Abstract

Which block sizes, shapes and configurations can most flexibly accommodate a variety of building footprints? This question is fundamental to urban design and planning because it decides whether the network of streets and blocks can act as the stable framework for the growth and change of land uses over time. This paper proposes measure of good fit between streets and blocks as well as blocks and footprints. The question is raised as to what the role of built form is in bringing forth both amalgamation and fragmentation. To address this question, the second part of the paper builds profiles of Atlanta and Savannah in terms of the size and shape properties of blocks in relation to present building footprints. The efficiency of both cities is tested by implementing the building footprints stock of one to the blocks stock of the other. The balance between how much the block is built and how much variety of building footprints it can accommodate leads to a measure of block performance. The broader purpose of the work is to assess the possibility of more compact urban forms that can accommodate a wide range and statistical distribution of building footprints.

Within the last decades, the space syntax community has been reevaluating the role of metric in understanding the behavior of cities locally and globally. In a recent article Hillier was underlining the difference between global topo-geometric properties and potential local metricity (Hillier, Turner et al. 2007). The aim of this paper is to look at two regular grids to understand the relationship between dimensions of urban elements and their impact on performance which encompasses syntactic properties. Performance can be evaluated in terms of flexibility of block, or set of blocks, to allow changes in land use and in terms of stability to respond to connectivity and intelligibility of a city as a whole.

The changes that occur over time within the urban fabric to accommodate different types of building footprints should be look at to see their role on affecting global or local properties of the grid. An efficient block will provide stability at its edge to give a sense of urban community and identity, therefore locally integrated. In parallel it should allow flexibility in its internal structure to accommodate the evolution of the built form.

[Figure 1] Relationship of Blocks, Streets and Buildings

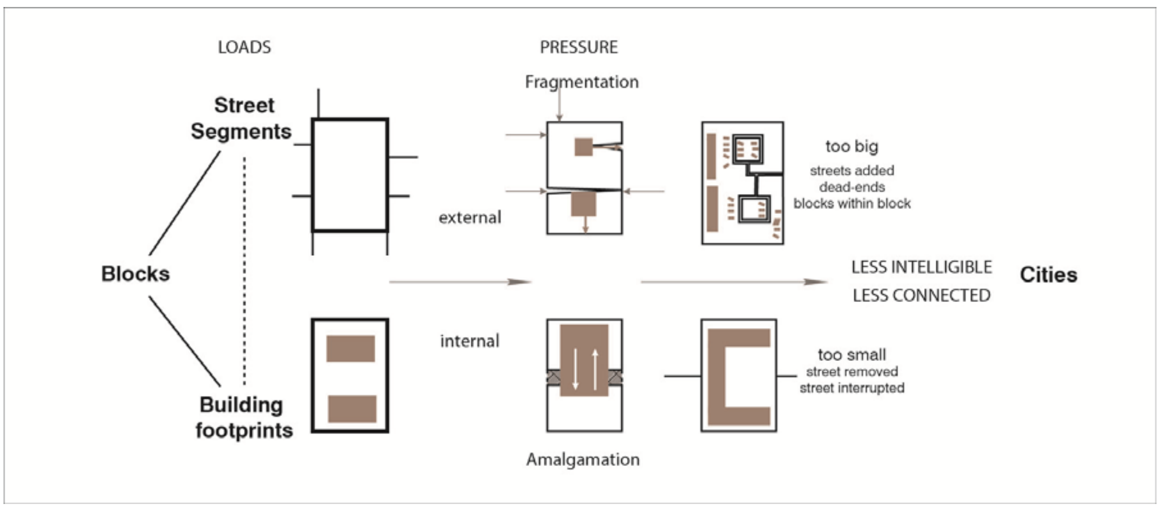


Figure 1 is showing the problematic of the block boundary. The boundary of the block is under the pressure of two types of load: an external load related to the street connectivity, and an internal load linked to building configuration. Any deformation or transformation of the urban block shape and size is captured when looking at amalgamation and fragmentation of blocks. A previous study of Australian and North American cities, looking at both phenomena, has shown that size and shape influence the performance of urban block on the development of buildings and circulation pattern (Siksna 1997).

The first section of this paper confirms and refines these conclusions. Fragmentation and amalgamation are further studied to define the role of the street structure in the stabilization of block changes. Two types of grid are chosen as a pilot study: the historical district of Savannah and one of the grids in downtown Atlanta, both cities located in Georgia. The former is selected for its uniquely designed grid which defines an intrinsic hierarchical system while the latter is composed of a relatively neutral and homogeneous street grid. They are representative of both amalgamation and fragmentation phenomena. Here it is argued that their comparison shows to which extent cities include the seeds of their transformation. It shows how the layout of a street network can affect or not the location of changes. Therefore it highlights which grid type is more efficient. It raises then the question of the role of built form in both amalgamation and fragmentation.

To address this question, the second part of the paper builds profiles of Atlanta and Savannah in terms of the size and shape properties of blocks in relation to present building footprints. The efficiency of both cities is tested by implementing the building footprint stock of one to the block stock of the other. The swap of blocks and building footprints demonstrates that amalgamation occurs when building footprint shapes, larger than a given threshold, are "geometrically incompatible" with available block's shapes. The working hypothesis is that blocks amalgamate when: 1) very large buildings must be accommodated in an environment of small blocks; 2) a building shape is incompatible with a block shape; 3) a complex and large shape of footprint requires a large block. Fragmentation, on the other hand, arises in order to make the interior of large blocks accessible, so that urban land can be more efficiently utilized. The effects of such changes on the stability of the street network is analyzed within a theoretical grid resulting from the swap of both cities, as well as a part of Atlanta to underline the impact of incisions when acting as dead-ends.

The balance between how much the block is built and how many varied building footprints can be accommodated leads to a measure of block performance which is linked to the internal load. Performance of blocks is measured first on the isolated element through its geometric and metric properties, and then as an urban element including a building and a street load. Measure of metric reach (Peponis, Bafna et al. 2008) for GIS data, as well as CityZoom, a visualization tool for assessment of Planning Regulations (Turkienicz, Gonçalves et al. 2008) have been recently developed and allow the link between the dimensions of urban elements and their syntactic measures. The metric reach will serve as the street load and will be used on a theoretical grid to test the stability of the street network under the pressure of changes.

The broader purpose of the work is to assess the possibility of more compact urban forms that can accommodate a wide range and statistical distribution of building footprints in which the street network keeps performing well.

SAVANNAH HISTORICAL DISTRICT AND DOWNTOWN ATLANTA: AMALGAMATION, FRAGMENTATION AND INCISIONS

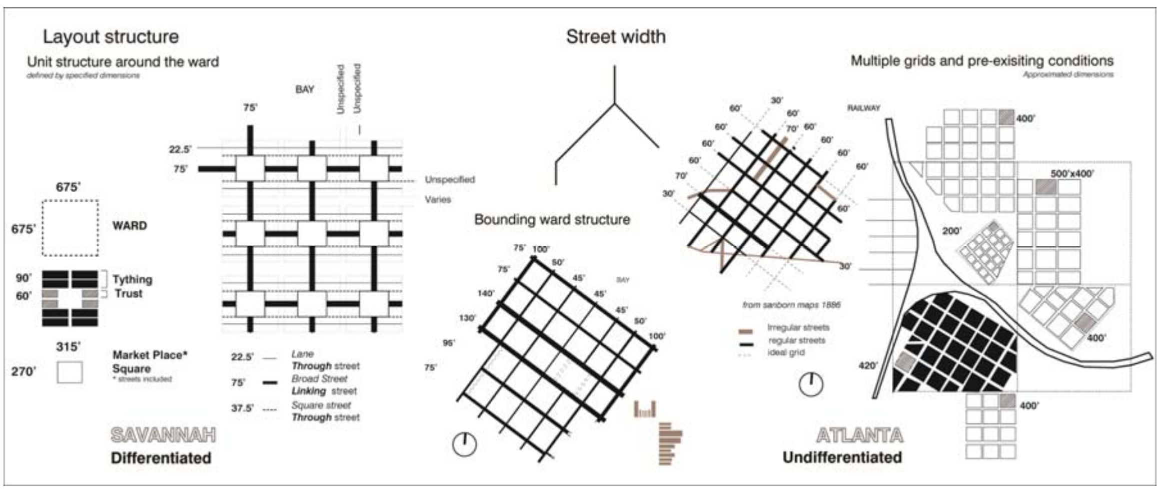
Amalgamation and fragmentation of urban blocks are highlighted within the comparison between an ideal plan, its implementation and its existing state. The ideal grid provides measures and potentials of the grid without constraints: topographical, historical and geographical to name a few. The implemented version removes the accidents that are not part of the evolution but were present in the beginning. And the existing plan illustrates changes.

GRID STRUCTURE(S)

The grid of the historical district of Savannah offers a complex configuration. Its origin is not always agreed upon but the construct of the ward as a unit is not debated. Illustrated on figure 2, a ward approximates a square shape and is composed by 4 Tythings on the upper and lower part – each of them composed of 2 blocks – and 4 Trustee blocks arranged on both side of a central area usually occupied by a park called Square. The split of the grid into two sub-systems respects the ward as a unit: a primary system is composed by the streets bounding the wards and a secondary system is made of streets internal to the wards designed around the central square. The *bounding* system creates a simple gridiron; the more complex secondary system is produced by the *tying* of squares. Both create two logics: one driven by street dimensions and the other by layout properties. A description of Savannah in 1760 by William Gerard de Brahm gives precise dimensions and street widths of the tying system without including any precision for the bounding system.

In the bounding streets system, metric variations of street width bring syntactic variation. Centrality is created in the primary system of streets running north-south by symmetry of street widths – wider streets are located on the edges and street width decreases as street are located towards the center, from 100' to 50' to 45'. Large arteries bound the historical core and create the east and west edges. The location of the Savannah River on the northern part creates a natural edge. The syntactic logic of the street running east-west is the reverse of the north-south logic. Larger arteries are located in the core and width decreases as street are located further away from the center. This dimensional logic differentiates the otherwise uniform grid. Orientation is created and is easily legible.

[Figure 2] Layout structure and street width



Downtown Atlanta is made of several grid systems that vary in size. Each gridiron is developed by land ownership. The land survey is a pre-existing condition that constrains developers to implement their street layout within defined limits. Such pre-existing conditions explain strong variations between a perfect square grid and its implementation. One gridiron is selected to represent generic square grid. Size of block is considered medium sized (Siksna 1997). Figure 2 illustrates the different square grids of downtown Atlanta with dimensions ranging from 200' up to 500'. Square gridirons are very neutral grids that do not provide specific orientation by themselves. Centrality is located at the geometric center but does not correlate with any intensification of incision, fragmentation or amalgamation. In terms of street width, the grid is fairly homogeneous with widths ranging from 58' to 70'. However streets on the edges tend to be narrower, around 30 feet.

[Figure 3] Measures of Savannah's layout

Variations of topologic measures created by Savannah's grid diverge greatly from the logic of street width. The axial map captures the main structure, the bounding system, while the widest streets are establishing the ward system that link central squares. The difference in street hierarchy is shown in the vignettes describing both principles in figure 3. However street width and integration correlate for streets between wards in the east-west direction and central location, and in the north-south direction and edge location. Their combination provides a distinctive highly connected and integrated active zone. Metric reach is a measure of density within the global structure with radius 1mile (1.6km) and within local structure with radius 0.17 (270m) mile. At the local scale it captures the central density of the layout and homogenizes both street dimensions and integration. It underlines local changes related to size of blocks.

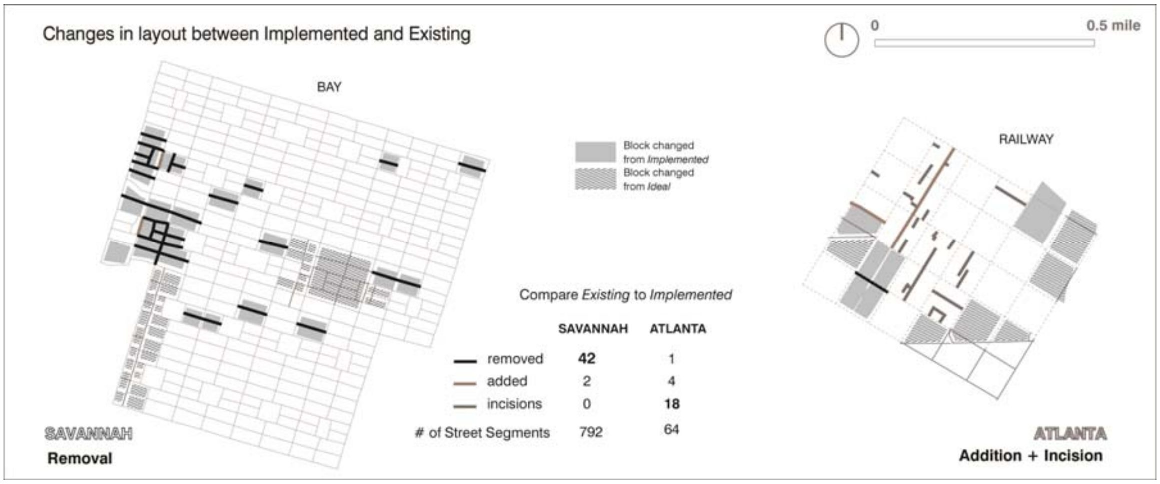
The main consequence of the neutral square grid of Atlanta and the very hierarchical grid of Savannah is the differentiation of global and local structures in the latter. Such differentiation will guide and impact the location of changes.

RECORDING CHANGES

The Savannah Historical District developed through successive phases of construction. First discussed as an *ideal* plan by Oglethorpe and others, four wards and squares were implemented by 1733. Two new wards were added in 1735, 18 more were further implemented based on those 6 original ones of the colonial era (Reps 1984). In this study 26 wards are considered as part of the *implemented* version – 2 are partially implemented. The analysis plan, referred to as *existing*, is based on the 2000 GIS plan of Savannah.

The *existing* plan in figure 4 shows that fragmentation of blocks is almost nonexistent, mainly because blocks are already small. Fragmented blocks exist as left-over of accidents – cemetery, existing land survey, topography. They play a filling role to absorb irregularities and tie them back to the regular grid. It shows that from the *ideal* to the *existing* there are very few streets that are created (3% more) while much more have been removed (8%).

[Figure 4] Changes in street segments from Implemented to Existing



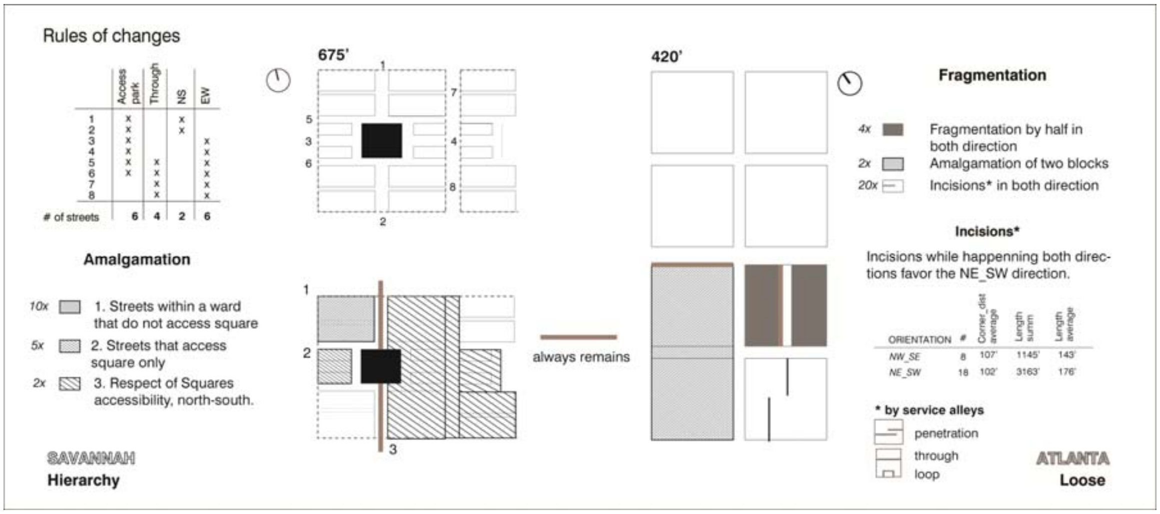
During the implementation phase, street segment creation and removal are balanced (3%). From the *implemented* to the *existing*, only two street segments are created while 42 are removed. Most of the changes happen through amalgamation, fragmentation results when there is a need for reconnecting.

In Atlanta, from the existing plan shown in figure 3, one can observe that both fragmentation and amalgamation of blocks exist simultaneously. A strong difference with Savannah's grid is the simplicity of the grid in its ideal form. However during the implementation phase, numerous changes happen: 9 street segments are created (12%) and 13 are removed (20%). From the implemented to the existing, very few street segments are created (4) or removed (1). The majority of changes are alteration of the block boundaries by incisions: service alleys penetrate towards the interior of the block, loop around or go across. These service alleys differ from a street for they are not legally regulated. Incisions affect a third of the blocks from the original design including fragmented and amalgamated blocks (overall 35%). The following step is to see if a correlation exists between syntactic or metric properties of the grid, and the phenomenon of amalgamation.

RULES OF CHANGES

In Savannah, the global structure is not related to street dimension but to layout properties. The classification table in figure 5 records the street characteristics according to their access to the park, if they are running through the ward without being interrupted, as well as their direction.

[Figure 5] Street configuration rules the location of block amalgamations



The internal configuration of the ward carries a bias in orientation. It is made of 4 "through" streets running east-west and none running north-south. These through streets are differentiated according to their direct access or not to the central square: alleys are through streets that do not access the square. Therefore the primary rule is that linking streets running north-south should be always preserved. This rule also applies to amalgamated blocks in the implementation phase. As the square remains a central element, then the less disruptive amalgamation is within a tything: the disappearance of the alleys. This represents around two third of the amalgamations. The remaining entails the elimination of the street between trust-lots (linking streets running east-west). The two other block amalgamations respect the primary rule of not disrupting the north-south access to the square. The preservation of the central square accessibility and the redundancy of "through" streets create rules and hierarchy for block amalgamation.

If Savannah's hierarchical grid demonstrates a strong control on location and process of changes, a different outcome appears Downtown Atlanta. The square gridiron is less instrumental in the location of changes. There is no bias in orientation to favor one location over another. However, stability is partially embedded in the gridiron. The square blocks, even though transformed by amalgamation or fragmentation, conserve at least one dimension of the original structure: 420 feet. While both fragmentation and amalgamation coexist, they are few compared to the phenomenon where "incisions" are created – which are passages to access the center of the block.

Amalgamation only occurs once as a combination of two original blocks. In two cases (northeast), blocks are bridging over the railroad; in one case (west), the amalgamation results from the left-over of a double fragmentation: original and existing (figure 5). Amalgamation tends to aggregate in one direction (northeast-southwest). While fragmentation occurs in both directions, however the northeast-southwest direction is favored. The fragmentation process splits the square block in half producing similar elongated blocks (420' by 110'). The phenomenon of incision does not follow particular rules neither in terms of location (distance to block corner) nor in length. Some incisions remains dead-end and do not align with others incisions within a block. However the phenomenon of incisions is more intensive in the northeast-southwest direction.

The complexity of the Savannah historical district layout carries a stronger role in locating as well as ruling the process of amalgamation. Studying the location of amalgamated blocks leads to two conclusions. First, amalgamation happens in close proximity of the widest streets that have high integration. The active zone previously described accommodates most of the changes. Topological and metric properties are reinforcing each other increasing accessibility. The width of streets supplements the geometry by easing the access to amalgamated blocks. Second, the structure of the grid is such as to suggest within which block amalgamation can occur without great impact on the overall street system. Based on syntactic properties, the street layout allows local changes without disturbing the overall circulation. Overall there are very little rules provided by the square grid of Atlanta. Square elements are neutral. The main role of the grid is to stabilize block changes by always keeping constant one side of the original square. Atlanta's grid is affected by the phenomenon of incision. It starts to imply the role of internal features present in the block: buildings and their accessibility. The following section looks at the role of building footprints in the process of changes.

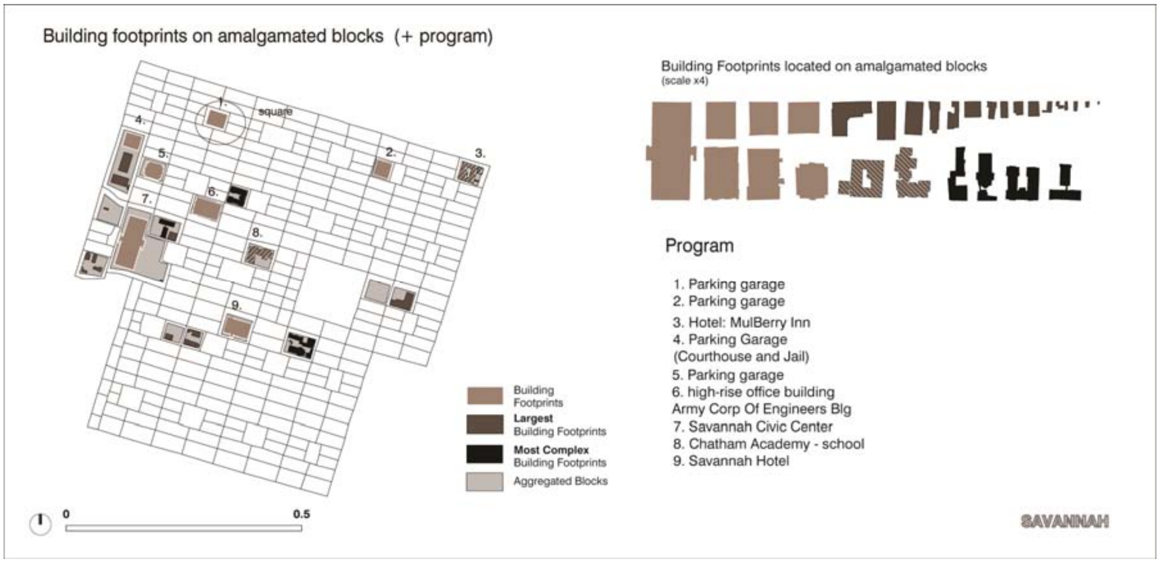
BUILDING SHAPE AND SIZE ON AMALGAMATION OR FRAGMENTATION

The working hypothesis considers amalgamation of blocks as a result of factors related to the morphology of building footprints: the size of the building alone is larger than the block size, the shape of the building is not compatible with the shape of the block or both combined. One of the consequences of block amalgamation is therefore linked to the programmatic requirements of buildings. A final observation is the way blocks behave as they grow larger. The fit between coverage, how much of the block is built, and the configuration of the buildings, which are the number of discrete aggregated footprints, follow a specific pattern. To conclude, the profile of both Savannah and Atlanta are compared to assess their performance. They show the consequences and limitations of both models.

Building shape is defined by two measures: its size [area] and its Square Compactness [SqCpct] which records the complexity of the shape boundary. Square Compactness is the area to perimeter ratio of a shape and how close it is to a square shape. Values ranges from 0 to a little above 1. A square has a value of 1, higher values describes shapes that tends towards a circle. With more elongated shapes, compactness values drop. However, lowest values describe shapes that are both elongated and with a complex contour.

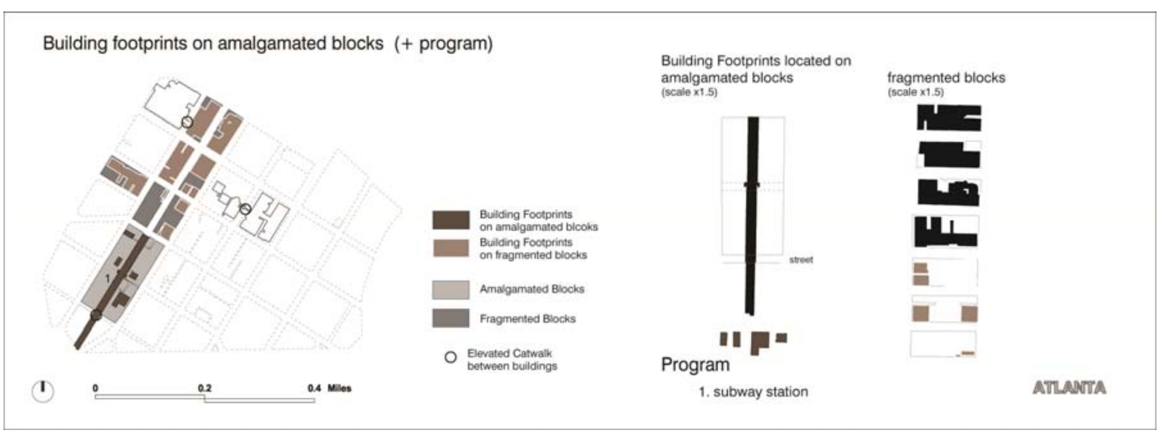
Figure 6 shows that 8 out of the 10 largest building footprints are located on half of Savannah amalgamated blocks (blgft 2-9); one is located on a square (blgft 1). For the 12 more complex building footprints, half occupy amalgamated blocks (blgft 3;8;10-13). From this observation, we can conclude that amalgamation of blocks in Savannah can be explained by the need for larger blocks to accommodate larger footprints but also more irregular footprints.

[Figure 6] Building footprints typologies on amalgamated blocks in Savannah (+ program)



In the case of Atlanta's grid, the amalgamation occurring between two original square blocks is concomitant with the location of a building with a very long and narrow, yet simple, contour (fig.7). It refines the conclusions drawn from the Savannah examples by generalizing the phenomenon of amalgamation. Amalgamation occurs as building footprints' shapes larger than a given threshold are "geometrically incompatible" with available block's shapes. For Savannah, blocks are rectangular and large square buildings cannot be accommodated. In Atlanta, blocks are square and large, very elongated building footprints cannot be accommodated on them.

[Figure 7] Building footprints typologies on amalgamated blocks in Atlanta (+ program)



Over a certain size, building footprints on fragmented blocks tend to occupy the block fully. These observations lead to two further inquiries, the impact of programmatic requirements on building shape and size and the role of incision in relation to building.

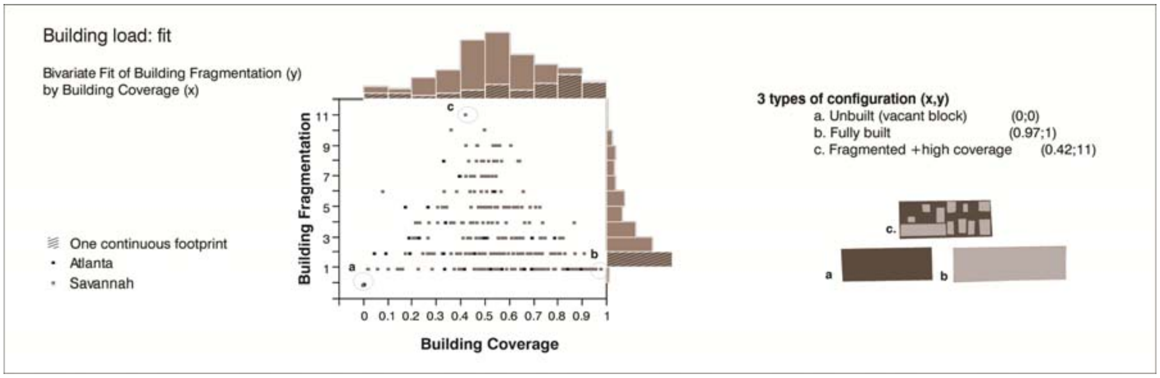
When looking at land use of building footprints located on amalgamated blocks, it appears that shapes are derived from programmatic requirements. In the case of Atlanta the only amalgamation happens to accommodate an above ground subway station: a building that requires a very long and narrow building while blocks in that part of town are square. Looking at the building type on amalgamated blocks in Savannah, 4 out of 9 building footprints are parking garages, 2 hotels, an office building, a civic center and a school. Parking garages require in their design a minimum turning radius for the ramp. The parking distribution on both sides of the ramp and street access usually result in a design that cannot easily be accommodated in the original 60’-90’ wide block of Savannah. The other programs entail large buildings or a complex shape than cannot be accommodated in the standard blocks.

Incisions are often related to block shapes. The Atlanta’s 420’ wide square block requires buildings to be deep, around 200’, to fully cover the block. On average, the depth of aggregated building is 34’ (95’ for the block) in Savannah and 77’ (226’ for the block) in Atlanta. Depth is calculated as the average of distances from the centroid to perimeter (Parent, 2009). Steadman, Evans and Batty are prescribing building plans with a maximal distance of 20-23’ (6-7m) from exposed wall in order to have natural light exposure (Steadman, Evans et al. 2009). Incisions ease accessibility to the interior of the block as well as maintaining a critical distance between buildings for purposes of light and ventilation. Moudon advocates for building the center of the block, which usually remains empty. In order to increase built density, she produces building configurations using alleys cutting through the block (Moudon 1986). The incisions exists as left-over of building form which itself is allowed by block size and shape. Like alleys, incisions allow the densification of the heart of the block otherwise not accessible. The uncontrolled aspect of their formation might lead to underperforming blocks as well as disrupt the stability of the overall street layout.

BLOCK PERFORMANCE WITH BUILDING LOAD

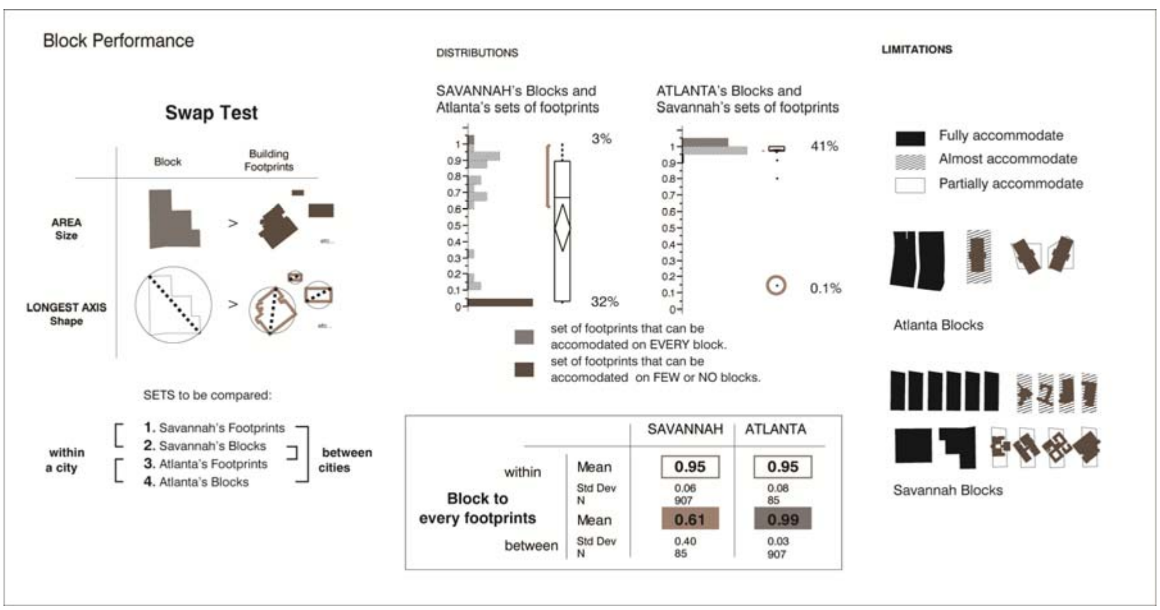
The performance of block can be assessed by two factors: the building coverage as well as building fragmentation (the number of aggregated footprints within a block). The plot of the number of buildings by building coverage in figure 8 shows that as blocks increase their coverage, the number of building varies from few to many. Past a certain threshold, when almost half of the block is built, the number of buildings tends to decrease. The aggregation of buildings into a continuous footprint intensifies. There are very few blocks that have high coverage and many buildings. The plot is showing the same trend for both cities.

[Figure 8] Block configuration taking into account building fragmentation and coverage.



Coverage is more important in Savannah than in Atlanta. The variations in the building layout on a block are also greater in Savannah compared to its smaller size. However the efficiency of a block might be more limited if the building footprints are produced in a different urban setting. So, the performance of each block from each city is tested by implementing the building footprint stock of one to the block stock of the other. The result of this swap is illustrated in figure 9. As a reference, to show the homogeneous nature of each grid, the mean value of each city building stock is tested on every block of that same city (swap within).

[Figure 9] Buildings footprints swap and fit by Area and Range between Savannah and Atlanta



The swap test compares two shapes and gives to each shape the amount of shapes it can accommodate by comparing the size (area) and the range (longest axis) of each. A value is given to each footprint shape according to its potential fit in a set of block shapes. However, range and area alone, while giving a first indication are not solely sufficient; a need for a third should be further developed. For example in the case of building footprints of Atlanta fitting Savannah's blocks, while measures shows that 3 blocks can accommodate all footprints, only 2 can actually fit all of them. The third one cannot accommodate 6 out of the 14 selected (fig 9. Diagrams on the right).

Savannah's blocks can accommodate on average 94.7 and Atlanta 93.8 percent of its own building stock. But the performance of Savannah's blocks decreases when Atlanta's building stock is implemented on each block: the mean value is only 0.61. Only 3 blocks can accommodate all the Atlanta's footprints. Overall all the footprints of Savannah's building stock can be accommodated in Atlanta. One building footprint could only be placed on 5 specific blocks in Atlanta. In average, every block in Atlanta could accommodate most of Savannah footprints (0.995). Savannah while having more variation in building layout is potentially less accommodating to different building types. Atlanta seems to be underperforming in terms of building layout but can accommodate more building types.

ASSESSMENT: CITY PROFILES

The selected area of Savannah covers an area twice as large as the selected area of Atlanta. But the difference between their total surfaces occupied by blocks is less significant. The amount of space taken by the street is higher in Savannah (42%) than in Atlanta (27%)[1]. Larger blocks do reduce the amount of space dedicated to the car. For an average block size 6 times smaller, the occupancy of streets is 1.75 times larger. The ratio of block size and street occupancy is not proportional. The dimension of blocks affects the amount of street frontage as shown in the case of Detroit where smaller blocks are amalgamated to form larger blocks reducing the available frontage (Ryan 2008). A grid with many street segments per area has also the advantage of bringing stability to the global street layout by allowing modification at the local scale. The reverse process of fragmentation can be more difficult to control in terms of location. The example of Atlanta has shown fragmentation which was controlled but it has also shown the phenomenon of incisions which seemed to have occurred randomly. If the incisions over time are transformed into actual streets, there will be a strong impact on the stability of the overall layout. This observation will be later tested on a portion of the city of Atlanta.

[Figure 10] City's profile

City's profile

	SAVANNAH	ATLANTA		S/A
LAYOUT				
Total Grid area (acres)	337	150		2.24
Total Block area (acres)	194	110		1.75
FOOTPRINTS				
# of aggregated footprints	907	85		11
SIZE [Area] (acres - mean)	0.1	0.54		0.19
SHAPE [CpctSq] (mean)	0.81	0.73		
Square compactness [CpctSq] is the area to perimeter ratio of a shape and how close it is to a square (1).				
BLOCKS				
# of Blocks	312	31	35*	10
SIZE [Area] (acres - mean)	0.62	3.61	3.17*	0.17
SHAPE [CpctSq] (mean)	0.82	0.93	0.79*	
STREETS				
# of street segments	952	83		10
SIZE [length]	189'	413'		0.46
SHAPE [Straightness]	0.83	0.46		1.80

	SAVANNAH	ATLANTA		S/A
Performance				
Coverage (% of built parcels)	0.57	0.45	0.45*	1.27
Building Fragmentation	3.14	2.47	2.43*	1.27
Street coverage (% of total area)	42	27		1.57
Metric Reach r=0.17	2.4	1.34		1.80
Metric Reach r=1	57	58		0.97
Swap within	3.14	2.47		1.27
Swap other	42	27		1.57

* includes split blocks and incisions

[1] If the street is scaled to each block, the mean value is 0.27 for Atlanta with a standard deviation of 0.06 (min 0.17 and max 0.4) and is 0.45 with a standard deviation of 0.1 (min 0.22 and max 0.84) in Savannah.

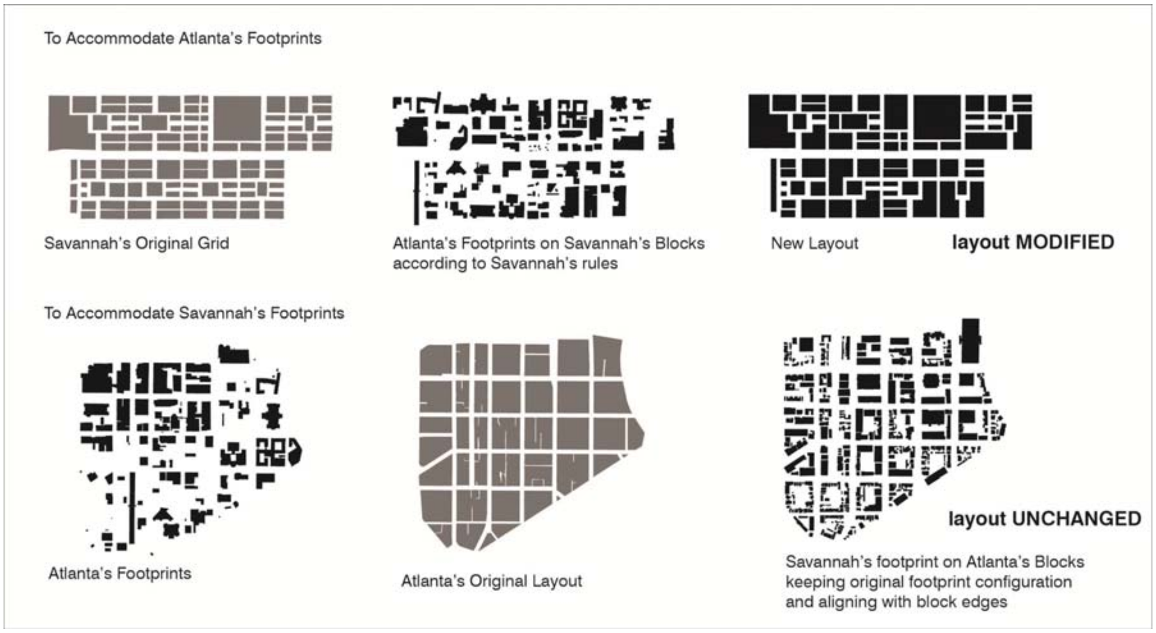
For the compactness of block footprints, a very low standard deviation (0.09) in Savannah indicates a very homogenous grid in terms of shapes that approximate a rectangular and regular one (0.8 values). The Atlanta grid can also be considered as an homogenous square grid, but when incisions are taken into account as part of the block boundary it encompasses more variations: from values approximating 1 for the more regular square blocks to 0.54-0.45 for blocks with incisions.
The phenomenon of incisions is closely linked to building shapes which themselves are allowed by block shape and size. Large square blocks permit more variations in the built form: aggregated footprints in Atlanta have a lower compactness value that is translated by more complex shapes that move away from the square and rectangle. The relationship between footprint shape and block shape is strongly correlated in terms of square compactness. The incisions on the block boundary change the compactness value towards the aggregated building footprint value. Variations in building size are also greater in Atlanta's grid. The grid of Savannah provides a wider range of block shapes but a smaller range of sizes which produce less diversity in terms of buildings shape and size. While the large uniform square block shapes in Atlanta allow variations in both shape and size of building footprints.

If building and block footprints, both behave similarly within a city, the swap test demonstrates the limitations of block shapes and size. Atlanta has produced an aggregated building typology that is difficult to implement in the layout of another city. It can however be partially accommodated.

IMPACT ON STREET CONNECTIVITY

This last section intends to show the potential impact of changes on the street stability. Two phenomena have been previously shown: amalgamation which implies removal of connecting streets, and fragmentation which begins with incisions. At the larger scale, dead-ends streets can be considered as incisions for they have similar behavior, but their impact is more important since they are public. Built on the result of the swap test, figure 11 is an example of how one city layout would need to be transformed to accommodate the building footprints stock of the other. For Savannah the rules of amalgamation were followed as much as possible. In order to minimize modifications of the existing layout, the selected existing section includes the largest blocks. For Atlanta, half of Savannah's building stocks is implemented, which is equivalent to the footprints located on the west part. As much as possible of the footprints pre-existing configuration is preserved and the set of buildings selected is re-oriented along the street and positioned in close proximity of the block boundary.

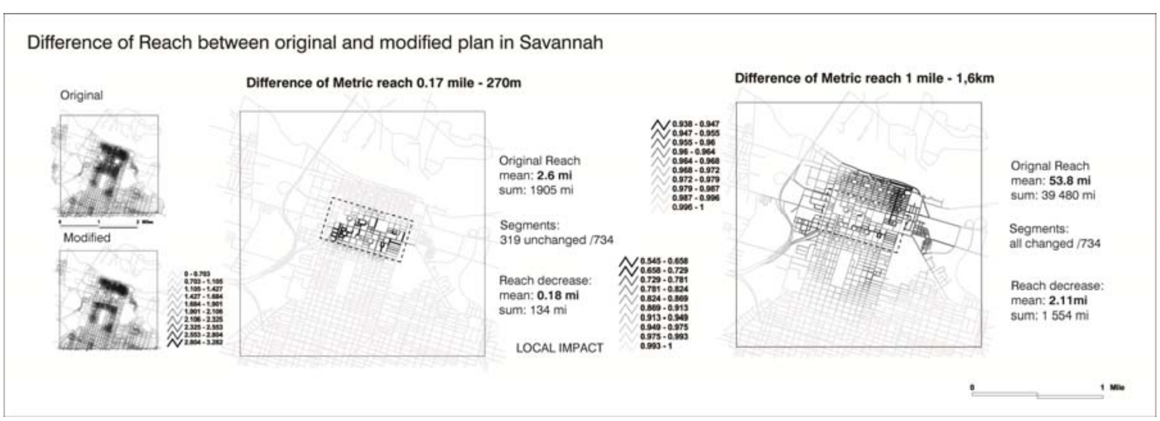
[Figure 11] Footprint swap and layout modification between downtown Savannah and Atlanta



If the incisions are not taken into account, Atlanta's layout remains unchanged, with the exception of a street segment that is reintroduced. Street coverage remains the same. However, there is a slight increase of building coverage (from 0.45 to 0.48) while the block becomes more internally fragmented with an original average of 2.47 footprints per block now up to 9.6.

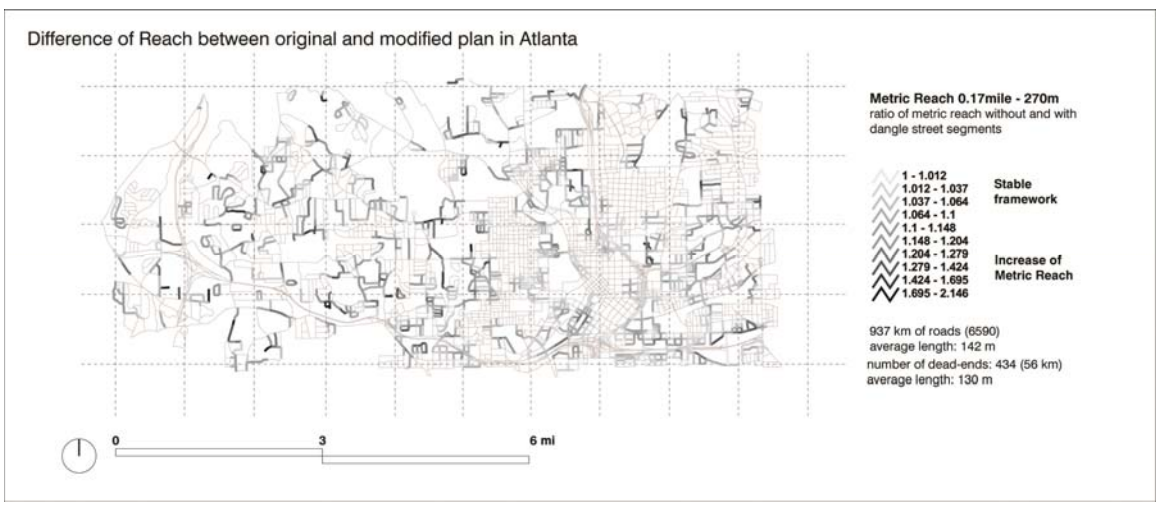
Savannah's layout is largely transformed from 104 blocks to 70 blocks. There is a decrease of 32% of the number of blocks. The impact of such street removals on the global and local structure is measured by the difference in metric reach of the grid.

[Figure 12] Difference of Metric Reach measures before and after modification of Savannah's layout



In figure 12, metric reach is calculated on a modified layout and compared to its original value. The larger maps show the decrease of metric reach for radii 0.17 mile and 1 mile. The values of decrease are obtained by the ratio of the modified reach value of a segment to its original reach value. If the ratio equals 1, it indicates a very stable street segment, and as values come close to 0, it indicates a high transformation of connectivity. In this example, the original reach value and the new value for 0.17 mile are shown in the smaller maps. The modifications of the street layout complete the disconnection between a southern and northern part already existing due to the presence of larger blocks. Looking at the impact, it is locally and exclusively contained within the zone of modification. At metric reach radius 1mile, the average decrease per segment is minimal, only -2.11 for an average total of 53.8 miles per segment. Locally it tends to disconnect the upper north-east part of the historical core. Overall the layout absorbs changes at the local level without any great impact on the global structure. For this argument to be fully effective, the same decrease ratio should be observed on a grid with completely randomized amalgamations. In this particular case, the modifications are following the rules of the grid and as such amalgamations is absorbed by the grid and does not impact the stability of Savannah's street network on the global scale.

[Figure 13] Difference of Metric Reach measures before and after modification of Savannah's layout



In Atlanta the street layout is not modified to accommodate the building stock of Savannah. However it has been shown previously that incisions create pressure on the block boundary. Similar pressure is created by dead-ends streets and lollipops streets on the street segment. Figure 13 shows the difference of metric reach radius 0.17 mile of segments affected by dead-ends streets in a portion of downtown Atlanta and the western section up to the city limits which represent 6% of the total street length. Their length in average is similar to the length of a street segment, around 130-140 meters. Metric reach at 0.17 miles, which corresponds to the double length of a mean street segment, shows that dead-ends exercises local pressure on the street network that remains globally stable. The intelligibility of the street network is locally challenged because the increase in reach is limited to few segments and not long lines, it is only creating internal pressure on the block boundary.

DISCUSSION

Studying the location of amalgamated and fragmented blocks leads to two conclusions: first, depending on the potential of the grid to differentiate global and local structure, location of changes has different types of impact; second, the structure of the grid is such as to suggest which blocks amalgamation can occur without great impact on the overall street system. It shows how certain types of city grid can control and absorb changes without affecting the global scale and minimizing the effect on the surroundings, but the control of geometric properties of block prohibits certain types of buildings, because of their size, form or both.

Programmatic requirements of buildings lead to block transformations as cities evolve and land use changes. The pressure on the block boundary comes from internal pressure exercises by building footprints. Consequently, the internal load pressure translates in the deformation of the boundary into a less intelligible form that affects the stability and connectivity of the street network. The size and shape of blocks can lead to the formation of dead-ends and blocks within block. The intelligibility of the network structure becomes less evident.

The limitation of this paper resides in the choice of relatively small and regular grids that do not represent the reality of actual cities. The definition of block is challenged when it comes to characterize its boundary. Incisions, dead ends, alleys present in blocks are part of the morphology of the city and have an impact on both the built form and the circulation pattern. Another limitation is the choice of aggregated building footprints instead of individual footprints that are not representative of each individual decision. The aim was to develop a structure to serve as a reference for more complex city forms. But also the purpose of this work is to test cities and their capacities for absorbing different building typologies.

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