Investigative Modeling and Spatial Analysis
A commentary on directions

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Introduction
I take the subtitle of the workshop as the main title of my presentation and take the opportunity to make comments on three topics: computation, modeling and normative theory, aware that we are now thirty years after the publication of *Architectural Morphology* (Steadman, 1983). I will do so with an emphasis on questions not typically pursued in journal publications. While publications present substantive hypotheses and studies, here I will speak more of underlying assessments and motivations. I will do this in the comfort of an increasing resonance between the cultures of research teams at KTH and Georgia Tech, at a time when KTH is confirming itself as a major center of spatial analysis and architectural morphology internationally. We, at Georgia Tech, track with great interest the work pursued at KTH and our work is often inspired by it.

Space syntax and the computation of measures of built form
Since the early 1980s space-syntax has been marked by an effort to carve measures of layouts that are used to: model the human performance of buildings; benchmark building types and compositional types; and evaluate design proposals. Within this trajectory, three intellectual trends are significant with respect to computation.

First, graph theoretic measures such as closeness and betweenness centrality have become established in the study of networks, including streets and social-organizational interactions, across a range of disciplines from sociology and management to interior design and architecture. Thus, the definition of space syntax in terms of the pioneering use of graph analysis for the purposes of architectural research is no longer compelling.

Second, the derivation of syntactic representations of layouts based on standard orthographic projection drawings has become as important to space syntax as the application of graph based measures. Thus, space syntax is an integral branch of architectural geometry; it is also increasingly able to contribute to representtations of built space that support not only design decisions (a circumscribed ambition) but also design intuition and design thinking (an expansive ambition).

Third, measures of metric distance, angular distance, turns distance and geometric visibility polygons have become as common in space syntax as measures describing transitions through boundaries. Thus, space syntax measures are increasingly comparable to other measures of architectural and urban form and often synergistic with them.

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These trends reinforce the early programmatic aim of space syntax, to enrich the description of built form in ways that express aspects of performance and function and bring them within the purview of systematic design intention. Such description brings added value to the fundamental architectural expertise, the representation of buildings not yet present in order to instruct the process of building them.

Three technological trends merit at least as much attention as the intellectual ones listed above.

First, computational representations of space and form have become ubiquitous; parametric design tools of varying degrees of sophistication allow architects to explore the connection between rules and formal outcomes and to study variations; GIS platforms incorporate increasingly flexible tools for network analysis. By implication, the unique strength of space syntax has to be sought in substantive theoretical claims. Increasingly, the questions "what is interesting" and "why is it interesting" will take due precedence over more open ended exploratory descriptions.

Second, data is increasingly available and massive data availability is likely to both enhance and to drive the development of models of the human performance of built space in the near future. Sources of data will range from data bases, such as the GIS data bases compiled by government, to data provided by various kinds of sensing, or built from tracking various geo-coded devices. The labor intensive and contextually constrained case study approach that has enabled space syntax researchers to formulate hypotheses about the human functions of built space is likely to recede in significance as compared to data mining and processing with an eye to generalization.

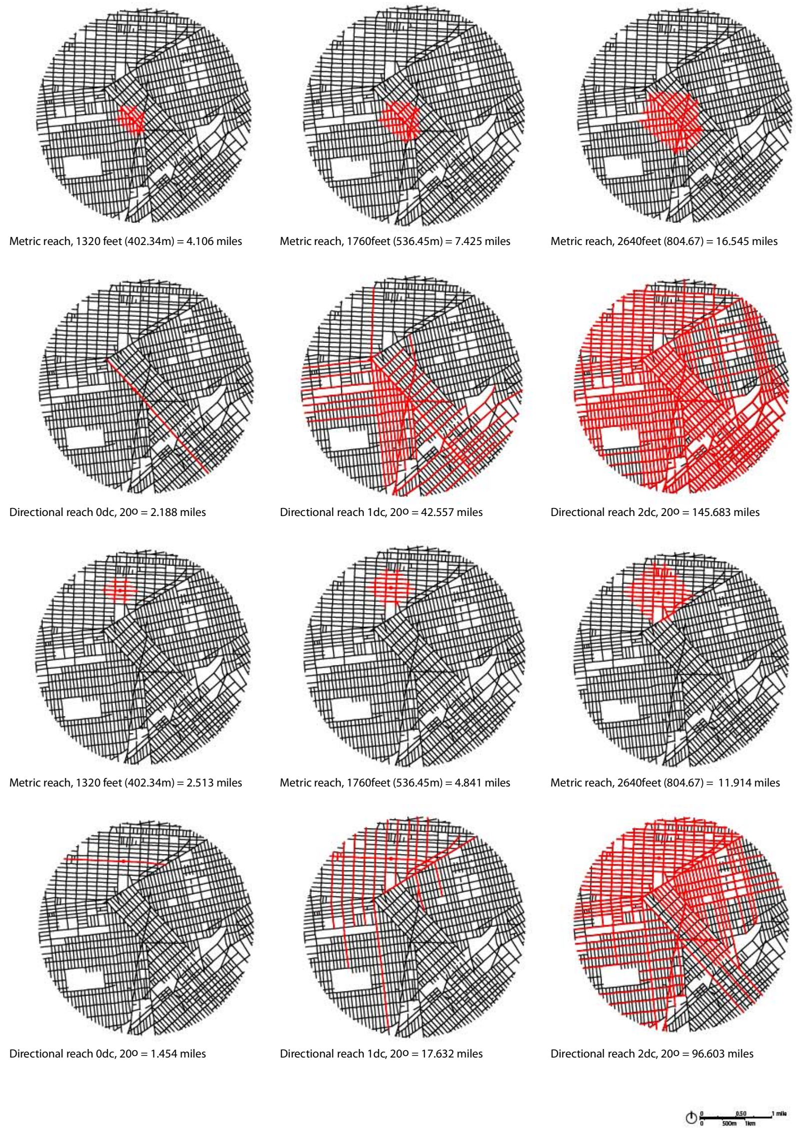
Third, computational power continues to increase and richer building information models become the norm. Analyzing built space in its three physical dimensions will soon become more feasible than it has been in the past, both from the point of view of computation and from the point of view of data availability. This is likely to focus attention on new theoretical and methodological problems. For example, 3-D analysis is likely to bring into sharper focus the distinction between patterns of access and patterns of view. It is also likely to introduce directionality into the discussion: more occupiable space becomes exposed as one looks down a courtyard or atrium than as one looks up.

In short, as the development of measures and representations of spatial organization and spatial form accelerates within architecture, and also across other disciplines that study space, so space syntax will be defined more by its substantive theoretical contributions and less by any particular set of analytical tools – this does not mean that DepthMap will not continue to serve many of us as a familiar and useful tool suitable for many purposes. At the same time, as space syntax looks afresh at its fundamental theoretical ambitions, so it is likely to become more sophisticated in the analytical techniques and richer in the data inputs used.

Measures and representations: more deliberate, simpler, and more precise

In the light of the above general trends, the thrust of computational efforts at Georgia Tech has been two-fold: to develop measures that are analytically more discriminating and distinct; to develop representations that are theoretically more deliberate. I will provide examples.

The first example is from spatial analysis at the urban scale. The measure of integration in standard axial analysis has been associated with fundamental statistical results regarding the behavioral, cultural and cognitive human functions of street networks: integration is associated with the distribution of movement, the creation of patterns of co-presence, co-awareness and potential exchange, and the inclusion of streets in cognitive maps. From an analytical point of view, however, axial integration is a fairly complex variable. It incorporates the effects of multiple more primitive variables including the length of a street compared to others, its sinuosity or linearity compared to others, the density of intersections along the street and also in the surrounding environment. These more primitive variables affect integration implicitly through the way in which they affect the construction of the axial map representation of the street network under study. In addition, integration expresses the ratio between a standardized closeness-centrality graph-theoretic measure and the extrapolated value that corresponds to a theoretical graph whose number of nodes is equal to the number of lines in the axial map. As a consequence, it is next to impossible to intuit the meaning of the integration value of an individual line independent of its rank in the order of values of all lines in the street network under study. Integration is a convenient and powerful measure that begs a lot of questions.



Figue 1: Example of colliding grids: New York. Total street length = 191.363 miles = 307.97 km; area = 7.0686 sq miles = 4523.89 acres = 1830.75 hectares. Street density = 223.347 feet per acre = 168.46 meters per hectare. Mean distance between intersections = 397.63 feet = 121.2 meters. Note: directional reach computed with 20° threshold angle.

The study of street networks in terms of metric and directional reach unpacks some of the variables implicit in axial integration (Peponis, Bafna and Zhang, 2008). In addition, the measures are associated with units of length. Metric reach measures the total street length which is accessible from the mid-point of a street segment within a network distance threshold. Metric reach increases in proportion to the density of intersections. Directional reach measures the total street length which is accessible within a threshold of changes of direction, where the minimum angle that defines a change of direction is defined at the outset. Directional reach increases in proportion to the linear alignment of street segments even as it is sensitive to the density of intersections when the threshold of direction changes is set to a value greater than zero – when in fact directional reach measures the linear extension of streets within a threshold of sinuosity, very much along the principles of Figueiredo's (2005) continuity lines but without having to construct axial lines first. Given the metric or directional reach of a street segment it is the mean number of direction changes per unit length can be calculated. As shown in figure 1, metric reach tends to grow evenly around a street segment as one increases the threshold distance, while directional reach grows unevenly as one increases the threshold of allowable direction changes. The different sub-shapes picked by metric and directional reach express a fundamental fact: the syntax of street networks creates a relational hierarchy. Accordingly, not all parts of en environment which are equally accessible based on metric distance are equally easy to find based on direction changes.

The second example is from spatial analysis at the scale of buildings. Once a building layout is processed, say in DepthMap, the results of the analysis are typically represented back onto the plan by coloring occupiable space according to the variability of a measure of interest. Coloring is usually based on the division of a the set of values assumed by the measure into a specified number of groups by setting the intervals such that the variation of the values within groups is as small as possible and the variation of the values between groups is as large as possible. Different groups have few or many members according to the distribution of the original numbers. The idea is that positions with the same color have comparable properties relative to the measure of interest and positions with different colors have different properties. On ArcGIS this is referenced as coloring by "natural breaks" based on the Jenks-Fisher algorithm (Coulson, 1987; Jenks and Coulson, 1963; Fisher, 1958). A similar approach is adopted in DepthMap. One problem with this approach is that typically the number of intervals has to be specified in advance. In ArcGIS the number of intervals is chosen by the analyst. In the case of DepthMap the process is invisibly embedded in the computation and results in 10 intervals. The question arises as to whether the number of intervals chosen, deliberately or by default, provides a reasonable visual representation of the underlying spatial structure of the plan.

Recently I studied a sample of 67 buildings from the point of view of the geometric visibility connections between the tiles of a 0.7m x 0.7m tessellation flood-fill (Peponis, 2012). I was interested to explore the distribution of positions with panoramic purview (the positions affording a greater number of direct connections, such as those along corridors) relative to other positions (the positions with a more restricted number of connections, such as those inside rooms). For the purposes of the analysis all connections were simultaneously of view and access, never of view alone. The theses I advanced were as follows: first, building plans are kept simple thanks to the presence of prominent spaces (such as corridors, courtyards, atria and halls) that afford greater purview over some part of the premises; second, these prominent spaces are so distributed that the distance of other locations from the nearest prominent space is quite small, whether measured according to path length or according to visual turns; third, I argued that the mean visual turns between any two positions with a building layout as a whole is kept relatively low (at a 2.5 turns for the sample as a whole) thanks to the distribution of panoramic tiles.

In conclusion, I speculated that a "building skeleton" can be defined by linking panoramic tiles into a network – a task still being pursued. Any space not yet visited or cognitively registered would be mentally linked to this skeleton. While the cognitively registered links would thus increase over time, the skeleton itself would be fairly stable and would be recognized early on. The advantage of this approach to the definition of a building skeleton is that it does not presuppose the more complex computations involved in analyzing the relationship of every space to every other space – the exact presupposition made in "integration analysis" in space syntax. The hypothesis is that integration analysis captures the consequences of much simpler and more fundamental relationships that are critical to the design of buildings.

One weakness of my approach was the arbitrary yardstick I used in order to determine which tiles count as panoramic purview tiles – I simply took the 10% of all tiles in a layout that are associated with the largest number of direct geometric inter-visibility connections. This leaves the argument open to questioning based on the possibility that the choice of a different arbitrary yardstick might have led to different results. As a response, I have revisited the way in which we represent the structure of plans according to a measure we choose – in my case inter-tile connectivity based on geometric visibility. Working with Peka Christova, of the University of Minnesota, and Matthew Swarts at Georgia Tech, we implemented silhouette analysis (Rousseeuw , 1987) to decide how many clusters are optimal if k-means cluster analysis is used to place the values associated with all tiles in a layout into groups. A MatLab script allowed us to split the values into 2, 3, 4, … 20 k-means clusters, and silhouette analysis allowed us to choose the number of clusters which creates the greatest similarity of values within clusters compared to the dissimilarity of values across clusters. Quite fascinatingly, for 70 percent of the buildings the optimum number of clusters was 2. By implication, the representation of visual interconnectivity values by forcing colors to represent 10 intervals might be over-discriminating.

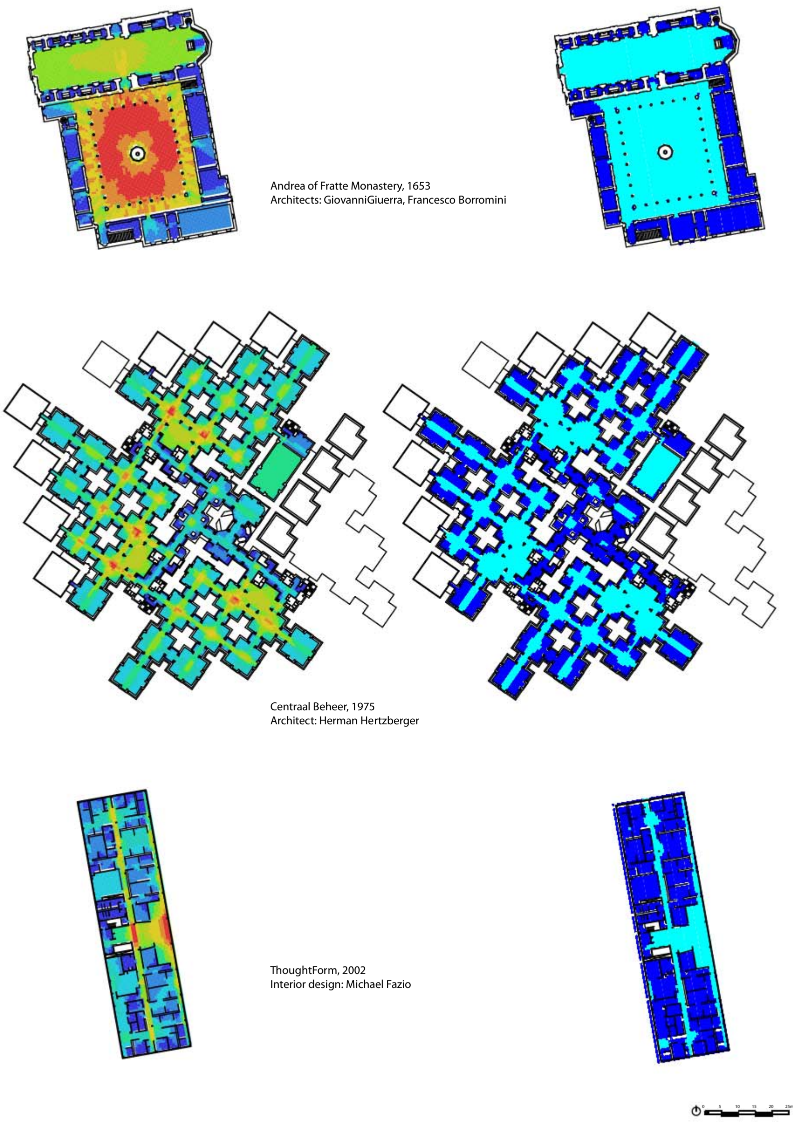


Figure 2: Three buildings analyzed for inter-tile geometric visibility. On the left: plans colored according to 10 natural break intervals imposed on connectivity values (red indicates highest connectivity; blue indicates lowest). On the right: plans colored according to 2 k-means clusters of connectivity values (light blue indicates higher connectivity; dark blue indicates lower).

Figure 2 compares the representation of interconnectivity according to 10 (the DepthMap default) and 2 intervals for three buildings, chosen to help me make my point rhetorically. The representation according to 2 intervals results from more complicated secondary computations, but looks much simpler, indeed intuitive.

The representation according to 10 intervals gives a nuanced rendering which may appear a little excessive: Do we really care that connectivity varies inside the courtyard at Andrea of Fratte? Do we really think that some module centers stand out in Centraal Beheer? Is the distinction between slightly more densely and slightly more sparsely subdivided areas significant in ThoughtForm? These questions may appear a little contrived. However, the comparison between the 10 and 2 intervals representations points to a rather significant theoretical consideration. The rendering of the three buildings according to 2 intervals captures their essential syntactic-typological structure: a set of smaller spaces arranged around two major spaces at Andrea of Fratte, a courtyard and a church nave; a set of spaces off a circulation grid with open nodes in Centraal Beheer; a set of spaces off a major and a minor corridor linked by a central meeting area at ThoughtForm. These fundamental generative principles, or syntaxes, are then enriched by the variations of connectivity better rendered by the use of 10 intervals. The enrichment is a significant fact; it speaks to aspects of immersed in-situ experience. However, we should not confuse the rendering of a field of experiential and perhaps even functional variation with the underlying syntax that gives rise to them.

The two examples I provided, from the analysis of street networks and buildings, serve to indicate the kinds of precision we are striving towards, as we better understand what is at stake with the original analytical techniques of space syntax; techniques that surely have proved very fruitful in the past. As we gain in precision and as we become more deliberate, so we gain in insight or renewed intuition.

From the discovery of simple regularities to rich models, in search of causality

Enhanced data availability and computational capability allow us to build increasingly complex models of the association between measures of layout and measures of function. I will, again, argue by example. Figure 3 shows that commercial frontage in the City of Buenos Aires, measured as the proportion of street segment length that is fronted by commercial parcels, is negatively associated with increasing distance from the City center (Plaza de Mayo) and positively associated with the 2 direction changes reach of street segments. The associations appear very clear because data is averaged by ten quantiles for both axes thus taking out much of inter-segment variation.

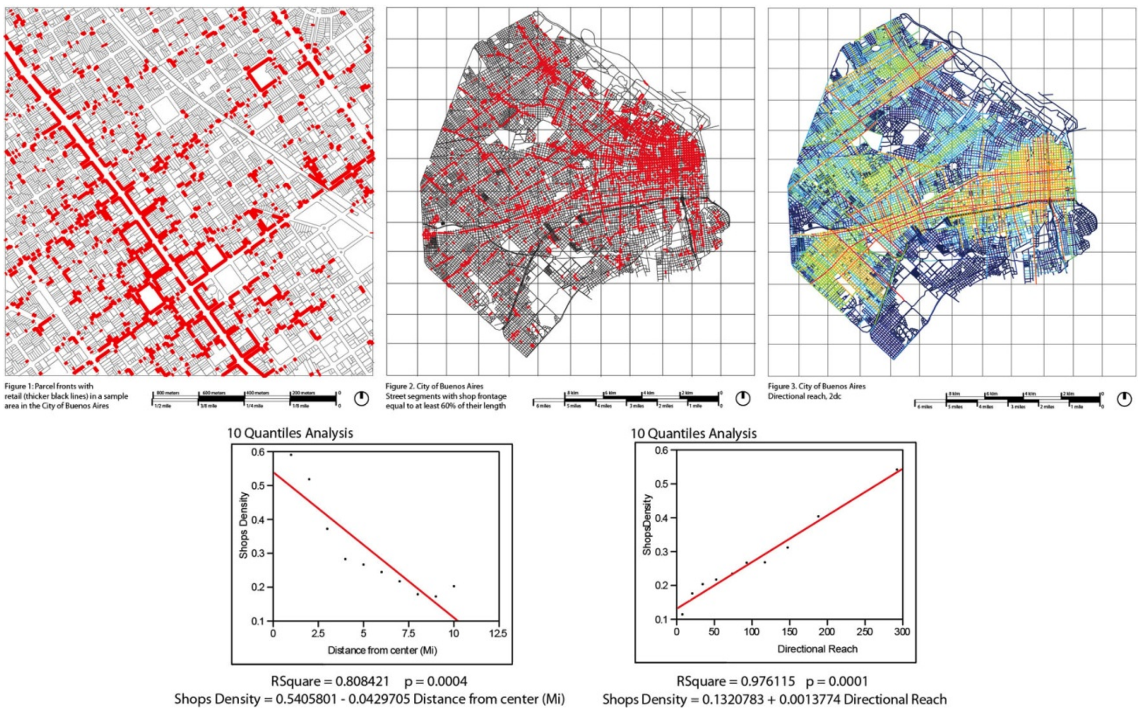


Figure 3: City of Buenos Aires. Commercial frontage falls with increasing distance from center and increases with increasing 2 direction changes reach (10° threshold).

We take these associations not as findings in their own right, but rather as a foundation for asking questions. In this case, the central question is: can we complement our modeling of attraction towards key destination-locations or central places, by a theory of distributed attraction exercised by the street network over the entire surface of the city? Martin Scoppa has studied the distribution of commercial frontage per street segment and also per named street, using the rich GIS data base provided by the City of Buenos Aires – a joint paper based on the study is currently under review. Table 1, extracted from our paper, presents a multiple regression model, with the commercial frontage density per street segment as the dependent variable and a large number of independent variables: population and employment density per street segment, zoning, the density of attraction of the surrounding area (based on the presence of other commercial parcels as well as the density of population and employment), distance from the nearest metro and railway stations; also, several variables that describe the street network: distance from center, street width, metric betweenness centrality and 2 direction changes reach. The strongest effects are associated with population and employment density, the density of attraction and zoning. However, with all these variables in the model, metric betweenness centrality and 2 direction changes reach have significant effects which are stronger than the effects of distance from center, street width or distance from the nearest transit station. This allows us to speak of the functional significance of syntactic variables with much greater confidence. Our paper also reports that zoning is itself intrinsically linked to syntactic variables: When we average syntactic values and commercial densities by zone we get very high correlations. More work is needed in order to test whether zoning rationalizes prior associations between syntactic and land use variables.

We have developed similar models studying the distribution of pedestrian movement in relation to syntactic variables taking into account land use. I will not summarize our results here because they are available in print (Ozbil, Peponis and Stone, 2011). Rather I suggest that by developing richer models we gain more solid insights on the effects of syntactic variables than we were able to attain in the 1980s and 1990s. We take a step (and only a step) towards establishing a causal effect between syntactic variables and variables describing aspects of space use. We also give greater credibility to our work in relation to other kinds of study – for example studies of the effect of transportation infrastructure or population density on commercial land uses. As a consequence, our work reaches audiences that it would not reach if it was limited to establishing simple associations between syntactic and functional variables. We can thus enter discussions regarding policy, regulatory frameworks and planning on a stronger footing.

Of course, research at KTH is also moving towards more sophisticated models, indeed models that address the core problem of multi-dimensional description. More particularly, the emerging convergence between Lars Marcus' (2010) idea of spatial capital and Meta Berkhauser-Pont's benchmarking of urban morphology and density (2004, 2010) has the potential to bridge across hitherto poorly connected scales of morphology. More important, the idea of density, often ill-defined, is central to much social, economic and planning theory, but also to regulatory frameworks. Thus, the work at KTH not only picks up the thread of the seminal work of Martin and March (1972) on "the grid as generator" but opens up the way to engage more deeply urban design. Alice Vialard, at Georgia Tech, has analyzed building footprints against the morphology of urban blocks and the street network for the portion of the City of Atlanta which lies in Fulton County, using the GIS data base of the Atlanta Regional Commission. Vialard's work is, in parts, inspired by work at KTH; it is also motivated by a parallel desire to bridge across scales of morphological studies, most notably space syntax and urban morphology as defined by Anne Vernez Moudon and as now featured in the Handbook of the American Planning Association (2006).

Values and judgments towards design propositions

The perception that architecture is rich in normative opinions and poor in analytical or explanatory theories (Hillier, 1996) has naturally led us to address the questions "how does the built environment work" and "how do built environments significantly differ". However, we should not dismiss the need for, or the functions of, normative theories. Design is normative by nature. Here I will explain in what sense design depends on normative theory with reference to an idea that I introduced while ago (Peponis, 2005), and which took a sharper and more useful form as I discussed it with Daniel Koch. Every design is a proposal addressing, to the best ability of an architect, the requirements of a client and a program, for a given budget and a given site. Every design is also a proposition, stating implicitly, by imitation, or explicitly, by intentional new formulation, what is significant about architecture, about program and about culture. Propositions, by definition, involve judgment and preference, they are ultimately aesthetic, political or moral statements: hence the normative nature of design, at its most ambitious, when it explicitly seeks to advance a proposition at the back of a proposal. Daniel and I are working towards a full presentation of these ideas, but I hope that the outline of the argument just given makes sufficient sense on its own.

I have no explanation to offer as to why space syntax researchers, in their majority working in Schools of Architecture, including myself, have not used the opportunities offered by the design studio to deliberately and reflexively explore normative propositions through design as well as analysis. The task, however, remains ahead of us. If I had to speculate, I would speculate that we have been shy because the last few decades were characterized by a systematic avoidance of the question of the value of architecture to the agendas and programmatic aims of client organizations, and even more so of the idea of the larger public good. I think this is likely to change, but I do not want to digress too far.

In this context, we may remind ourselves that "space syntax," as a term describing a larger paradigm of architectural research, has had two nominal dates of birth in print, 1976 (Hillier, Leaman, Stansall, Bedford), and 1983 (Hillier, Hanson et al.). The second article introduces "space syntax" specifically to the profession of architecture, in a publication of high professional standing and large circulation internationally: The Architects' Journal. It argues that syntactic analysis reveals a systematic flaw in the architecture of state-housing in London which is developed with the good intention of supporting community. The architects' effort to separate housing estates from the surrounding environment in order to give them identity and empower their inhabitants backfires. The excessive fragmentation of the street network and access paths discourage "through" movement and impoverish the life of public spaces. This sets off a negative multiplier effect whereby inhabitants, instead of taking special advantage of internal public spaces, as intended, take the shortest path to the perimeter instead. A feeling of urban desolation ensues, adding architectural stigma to the social distinctions implicit in the idea of state housing. Based on this criticism, the article takes a case study, the Limehouse Basin, then primed for redevelopment, and evaluates alternative designs for their power to seamlessly integrate spaces internal to the development site into their surroundings. The normative principle that we can state more clearly with hindsight is as follows: The identity of urban developments must be sought within the discipline of continuity of connections, and must be conceptualized not in terms of a boundary that separates the development from the surrounding city, but rather in terms of a deliberate and modulated way of linking back into it. Indeed, Hillier's term "deformed grid" originates in the effort to name this normative principle as much as it originates in the effort to characterize traditional urban forms. In short, the presentation of space syntax to the profession has conjoined analysis to the criticism of pervasive normative design ideas often taken for granted.

As I try to pick up the thread of proposing and criticizing normative principles so I am reminded of how fundamental the syntactic dilemma raised in the 1983 article was to the whole discussion associated with the modern city up to the late 1960s. Let me, one last time, argue through examples. Figure 4 presents a standard axial analysis of the Perry-Whitten proposal for a neighborhood plan (Perry, 1929) and the Doxiadis plan for a sector in Islamabad (Doxiadis, 1968), the same kind of analysis as used in the 1983 article. In both cases the axial integration core remains external to the schemes, much as it did in the housing estate under consideration in the article. This is true even as, for Islamabad, all the streets, not only the dendritic ones that accommodate vehicular traffic are included in the analysis.

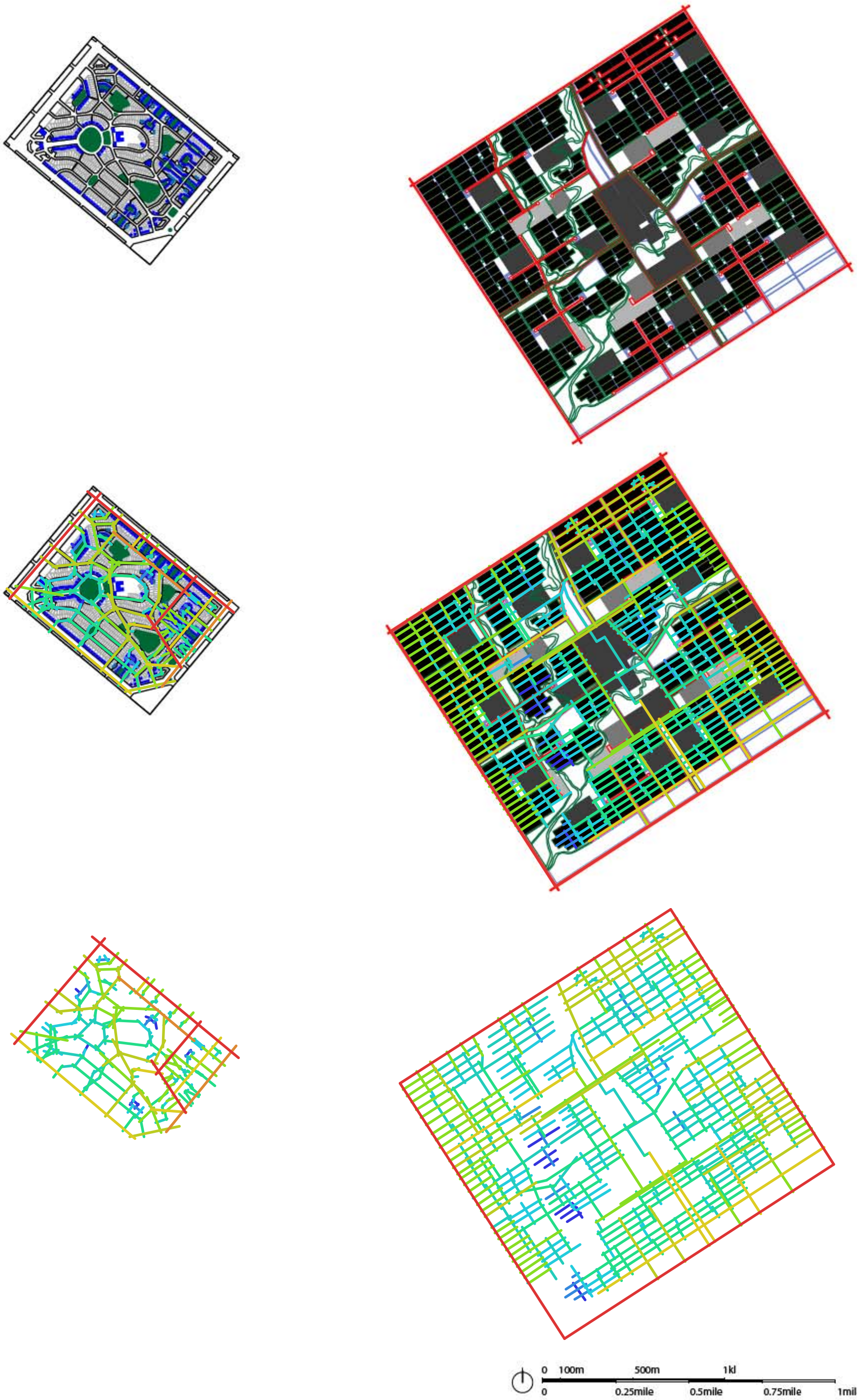


Figure 4: Axial integration analysis for the Perry-Whitten neighborhood plan, 1929 (left) and Doxiadis' plan for the G6 sector of Islamabad, 1968 (right).

Both designs aim to enhance local identity and create a sense of urban place, and both also aim, quite specifically, to mitigate the adverse effects of vehicular traffic upon the life of public spaces. Both avoid the imposition of radical separations. Both operate within the discipline of street grids, deformed or enmeshed, rather than on the principle of free standing buildings in an open space field – the principle applied in Brasilia and much of early planning in Chandigarh. Perry and Whitten use sinuous roads in order to reduce the likelihood of through movement – should this be retrospectively interpreted as pushing the idea of the deformed grid to the extremes typical in garden cities? Doxiadis focuses various scales of community upon central destinations, the most prominent of which is in the middle of the sector. The emphasis on providing access to pre-specified destinations expresses the priority given to land use planning over street design in much city planning and design since the 1960s. Instead of being conceived as the long term framework for flexible futures and changing land use patterns, the street grid is used to service a very particular idea about the distribution of central places. While the schemes therefore deploy divergent principles towards the deliberate creation of urban communities, they converge towards similar syntactic effects – the externalized integration core. At the same time and in varying extents, both schemes also animate the perimeter with commercial uses. Thus, both schemes think of the perimeter in part as a boundary, defining the neighborhood or the sector as a semi-autonomous unit within the larger city, and in part as a stitch between the units and their surroundings.

Quite clearly space syntax offers us a way for reviewing and comparing normative ideas and their design implications, perhaps even for exploring alternative ways to realize the same normative desires. The more sophisticated models that we have been developing recently would make a return to the review, criticism and exploration of normative ideas more thoughtful than it was at the second birthday of space syntax. Engaging in this way the history of the profession, the history of design, is likely to facilitate our exploring new normative ideas or new interpretations and adaptations of old ones. In this respect, the work of Frederico de Holanda over many years stands apart, for the systematic way in which it has analyzed one of the key normative cities of 20th century modernity, Brasilia, as well as the vernacular or merely commercial satellite cities that have populated its hinterland and acted as a counterpoint to the design principles deployed in the Federal District.

Concluding comments

I have given an eclectic overview of some of the present preoccupations at Georgia Tech. We seek a better balance between the continuing growth of analytic and explanatory theories and a renewed engagement with normative ones. I have pointed out that the empirically grounded criticism of normative theories was at the core of the early research program of space syntax; of course, much is still to be done to own the history of architecture and city design from a space syntax point of view and to make a genuine contribution to that history – we all too often discuss buildings and cities as given objects, not as results of particular design intentions interacting with generic constraints and the laws of the field. I have further suggested that a step must be taken towards developing new normative propositions, or new formulations of older propositions, in the light of our research. As we ask “what is interesting” we must also ask “what is desirable”.

The new dialogue, or perhaps creative tension, between the scientific and design attitudes occurs at a time when computational tools become more powerful and their development more ubiquitous. What is needed, above all else, is a sense of direction towards the desirable futures that computational tools must serve, even as we are unlikely to immediately agree on what is desirable. This is a time when space syntax will be defined afresh by substantive scientific and normative claims more than by analytical technique. Any claims, however, will only be credible if they are backed by our ability to measure, or at least to benchmark good layout and good form. From a technical point of view, the core of our efforts is a continuous striving towards simple, precise and distinct measures whose intuitive appeal is as strong as their contribution to analytical models of the human functions of built space. In short, the discussion of measures will remain central to our work as we ask afresh: “measures for the sake of what higher normative aim”, in addition to the quest for measures that allow us to build powerful explanatory models.

References

APA (American Planning Association). 2006. *Planning and urban design standards.* Hoboken, New Jersey: John Wiley & Sons.

Berghauser-Pont Meta & Haupt. 2004. *Spacemate: The spatial logic of urban identity*. Delft: Delft University Press.

Berghauser-Pont Meta & Per Haupt. 2010. *Spacematrix: Space, density and urban form*. Rotterdam: NAi Publishers.

Coulson, Michael R. C. 1987. "In the matter of class intervals for choropleth maps: with particular reference to the work of George F Jenks." *Cartographica* 24, 16-39

Doxiadis, Constantinos A. 1968. *Ekistics: an introduction to the science of human settlements*. New York: Oxford University Press.

Figueiredo, Lucas & Luiz Amorim. 2005. "Continuity lines in the axial system." In Akkelis van Nes (ed), *5th International Space Syntax Symposium*, TU Delft, 161-174

Fisher, Walter D. 1958. "On grouping for maximum homogeneity." *Journal of the American Statistical Association* 53, 789-798.

Hillier Bill. 1996. *Space is the machine*. Cambridge (UK): Cambridge University Press.

Hillier Bill, Julienne Hanson, John Peponis, John Hudson & Richard Burdett. 1983. "Space syntax, a different urban perspective." *Architects' Journal* 178, 47-63

Hillier Bill, Alan Leaman, Paul Stansall & Michael Bedford. 1976. "Space syntax." *Environment and Planning B: Planning and Design* 3, 147-185

Jenks George F. & Michael R. C. Coulson. 1963. "Class intervals for statistical maps." *International Yearbook of Cartography* 3, 119-133

Marcus, Lars. 2010. "Spatial capital: a proposal for an extension of space syntax into a more general urban morphology." *Journal of Space Syntax* 1, 30-40.

Martin Leslie & Lionel March. 1972. *Urban space and structures*. London: Cambridge University Press.

Ozbil, Ayze, John Peponis & Brian Stone. 2011. "Understanding the link between street connectivity, land use and pedestrian flows." *Urban Design International* 16, 125-141.

Perry C A, Heydecker W D, Goodrich E P, Adams T, Bassett E, M., Whitten R. 1929. *Neighborhood and community planning* (Regional Plan of New York and its Environs, New York)

Peponis, John. 2005. "Formulation." *The Journal of Architecture* 10, 119-133

Peponis John. 2012. "Building layouts as cognitive data: purview and purview interface." *Cognitive Critique* 6, 11-52

Peponis John, Sonit Bafna, Zongyu Zhang. 2008, "The connectivity of streets: reach and directional distance." *Environment and Planning B: Planning and Design* 35, 881-901

Rousseeuw, Peter J. 1987. "Silhouettes: a graphical aid to the interpretation and validation of cluster analysis." *Journal of Computational and Applied Mathematics* 20, 53-65.

Steadman, Philip. 1983. *Architectural morphology*. London: Pion Press.

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