DESIGNING THE SPATIAL SYNTAX OF OFFICE LAYOUTS

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Keywords:

Work and organizational environments
Organizational theory
Morphology and design
Design theory
Spatial and functional analysis of buildings

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Abstract

We describe here a study to understand the relationship between syntactical characteristics of layout and specific design choices made in developing these layouts. Our aim was to investigate if any design choices are systematically associated with specific syntactical outcomes. The paper is based on a year long research project aimed at developing specifications for office environments, sponsored by the General Services Administration, a US Government Federal Agency. This project involved two comparative studies of office layout—a pilot study of 8 actual office layouts, and a more involved comparative study of 48 "fictional" layouts designed for two office floor-plates. The fictional plans were designed through a systematic variation of design decisions; conventional axial maps were used to describe their syntactical structure. Statistical analyses were used to check if layouts grouped according their syntactical characteristics matched those grouped according to the type of choices made in the course of their design.

Our findings included two unexpected trends: 1) There is a surprisingly little amount of predictability associated with most of the design decisions, and 2) whatever predictability exists, it is associated with local scale, but repeatedly applied decisions, such as the choice of geometry and degree of enclosure of cubicles/offices, and the manner in which clusters of workstations are defined. We end with a discussion on how the particular nature of the design problem of designing layouts in pre-given floor-plates constrains the solution field in syntactically interesting ways and explains why only certain types of choices can lead to predictable syntactical consequences.

Designing for Specific Syntactical Outcomes

Research on office environments has suggested that syntactical characteristics of their layouts—particularly the distribution of integration values of component spaces— are critical in understanding and reshaping emergent patterns of communication and socialization amongst the inhabitants (Hillier and Penn, 1991; Grajewski, 1993; Penn, Desyllas and Vaughan, 1999; Serrato and Wineman, 1999; Peponis and Wineman, 2002, Rashid et al., 2006).

A practical question that this research raises for the designer is how to formulate design strategies for layouts that have desired syntactical characteristics. This question is directed, for the purpose of this paper, to one specific kind of design problem, which is laying out offices and workspaces (along with supporting activities) for a clerical organization, say a department or an office, on an already given floor-plate. Thus restricted, the question is still of interest. For one, this is a very common problem for interior designers to face. Buildings that form a significant bulk of office stock—at least in the US—are built as a part of a speculative development, and so have a generic plan. Even in buildings that are built, owned, and operated by a single client, there are frequent organizational events such as relocation and resizing of departments. In fact, lately, there has been a thrust towards using spatial layout as a means to effect working behavior. Physical organization is increasingly seen as a strategic part of organizational restructuring, rather than simply as a necessary outcome of such restructuring. The trend, therefore, is not just to find appropriate accommodation of the activities of the department when it relocates, but to try to define a pattern that actively contributes to better performance amongst the employees. Given that syntactical characteristics of layouts are a good predictor of its efficacy, it is natural that designers will try to design layouts with certain desired syntactical characteristics. The present project was conceived in response to such situations in the work of the General Services Administration of the US Federal Government, whose recent interest in the role of space as a means to encourage productivity and efficacy of work environments has led it to seek ways to develop design specifications to ensure such environments.

The challenge of the question—to formulate specifications for designers that will ensure particular syntactic outcomes—lies on two separate fronts. The first is the formulation of generic syntactic characteristics that office environments to be designed should possess. The second one is to find design specifications that will lead to the expected syntactic outcomes. Much of the syntactical research has focused on the first question; our focus here will be on the latter issue. The challenge arises in this case because of the nature of the design problem. One obvious approach for designers is to work in a hit or miss manner, developing spatial layouts and subjecting them to changes till an appropriate spatial structure emerges. A significant problem here is that the distribution of values of syntactical attributes such as integration values of individual spaces is, by definition, not predictable; small changes in the values of spaces in one part of the layout may have unpredictable changes in other parts, so that it is not always easy to progressively refine the design. As a result, designers end up working with some rules of thumb about the expected spatial structure, assuming, for instance, that a strong central corridor with strong local connections will result in an active integrating space. But the knowledge of such rules of thumb is limited.

In this study, we wanted to develop a more systematic understanding of type of design choices that might be involved in the design of layouts, and to see if any of these would have systematic association with syntactic qualities of layouts designed on their basis. In general, our method was to develop a set of key choices, use them to generate a set of fictional layouts that mimicked actual conditions as far as possible and see if the choices led to predictable outcomes. Since this is an almost completely unchartered territory—we have not found any systematic investigation published on this matter—our approach will be exploratory, driven as much by efforts to define methodology as to seek understanding of the subject.

Some preliminary studies of actually constructed layouts of office buildings had alerted us to the fact that different design strategies often resulted in layouts with specific structural properties. We planned here to extend this study by having one of the co-authors - an architect - actually produce working layouts for offices. The fictional layouts were produced for two floor plates, both taken from existing office buildings. Forty-six individual layouts were produced within these shells, each associated with a unique set of design choices. The relationship between the design choices and layout structure was tested statistically, basically checking to see if layouts grouped according to their syntactical characteristics matched those grouped according to specific design choices. In what follows, we describe the rather surprising results and offer a speculative account of what these results tell us about the spatial structure of offices in general.

Input Variables: Design Choices

While planning the exercise, we found it best to separate the design choices involved in the design of the layout into two categories. On the one hand, there is what may be called pre-mediated choices that are made by the designer often before the actual designing starts, so that the designer is often working with these choices rather than rethinking them—one can think of them as akin to constitutive rules. Two of these choices were especially critical to the issue at hand: the choice of floor-plate geometry and the choice of the type of workstations that our interest was focused on. Shpuza and Peponis (2007), and Shpuza (2006) have explored the relationship between floor-plates and syntactical characteristics in a far more systematic and exhaustive study. More precisely, we were interested in knowing if selecting particular systems of workstations or floor-plates of particular geometries would commit the designer to layouts with particular strategies.

The other category is of choices that are not premeditated, but that are procedural, in that they are often made during the course of designing. Even if this may not be the case in practice, these choices are unlike the premeditated choices, because the potential to change them exists throughout the design process. We define our selection within both categories of choices below.

Premeditated Choice: Selection of the Floor-plates

The floor-plates used in the study came from existing US Federal Government office buildings. Two roughly rectangular floor plates were selected, both consisting of partial floors in the buildings. The reason for selecting partial floors was to find two floor-plates, which had convex, rectangular shapes, without "holes", and which were roughly comparable in size. As it turns out, limitations in the data available to us led us to floor-plates of different sizes, but we were able to account for any differences in syntactical structure that arose. What mattered to our study more was the difference between one of the absolute dimensions of the floor-plates, in that one floor-plate was roughly square, or deep, and the other elongated and narrow (figure 1).

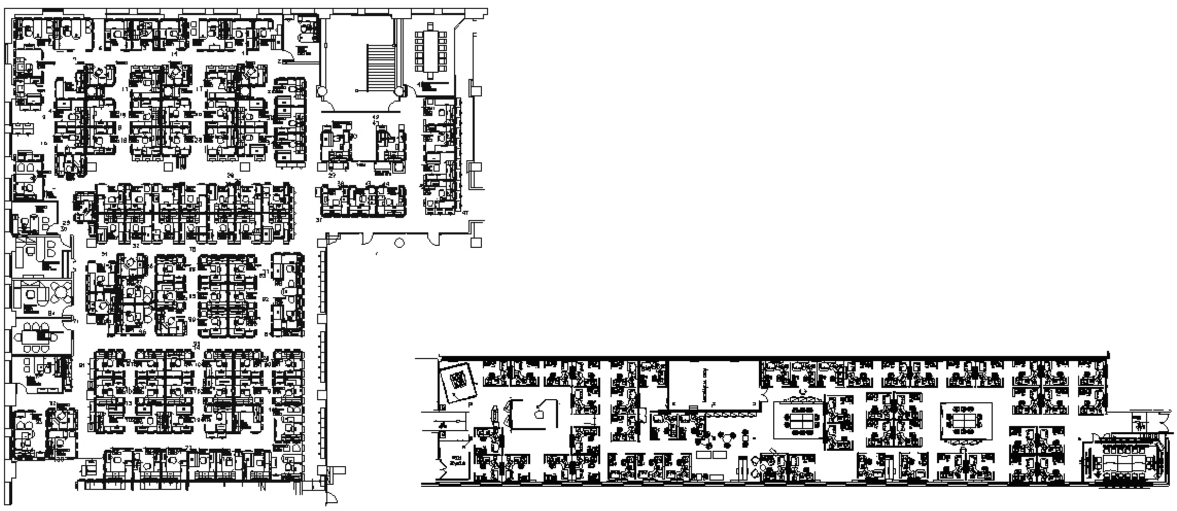
This division corresponds to a natural division within which office floor-plates can be sorted out according to their shape and size. The long narrow ones come from an older building stock in which natural light from windows is a constraining factor; the deep ones come from more contemporary buildings in which natural side-lighting is not a major consideration and which therefore have less restriction on the building site. We characterize narrow floor-plates as those that are typically not more than 25 feet wide. This number relates to what researchers have called "shallow space" floor-plates in modern office buildings, in which the distance between the core and external wall is around 4-5 meters (Shpuza, 2006, p. 16). This restriction, of course, need not be applied in both the dimensions of a floor plate, and most of the side-lighting constrained floor-plates tend to be oblong in their shape, so that the dimensional restriction results in a geometrical type that is long and narrow.

One may of course create further variation in office floor-plate geometry by introducing non-convex (which would include the most common one with cores), or irregular types. However, in order to keep the focus of this study on the variation due to design choices, we decided to restrict our explorations to the two regular convex forms. In the course of our study, we found that a lot of variation of both geometrical and syntactical characteristics could be essentially attributed to the shape of the floor-plate, and we ended up treating the shape of floor-plate essentially as a control variable.

It should also be noted that the variations were produced only in the arrangement of workstations. For better comparability, common services, such as conference rooms and individual offices were kept constant in the shells.

Figure 1:

The deep floor-plate and the long floor-plate drawn at comparative scales, with their actual layouts



a

b

Premeditated Choice: Selection of Workstation Geometry

Two characteristics define contemporary trends in design of workstation systems: use of non-orthogonal geometries, and flexibility in the use of partitions. Both lead to a much more visually open, informal, and often somewhat non-hierarchical environment. We decided to use three types of workstations, all taken from types used in the sample of buildings with which our larger project was concerned that reflected this shift (figure 2). The first type—square—consisted of partitions following an orthogonal geometry; it was almost fully enclosed, the term enclosure being measured by the number of partitions of higher than sitting eye-level surrounding the workstation. The second type—hexagon—consisted a workstation, whose partitions and furniture were arranged with 120 degree orientation to each other. This type of workstation was only partially enclosed, with partitions only coming into play to divide the actual work surfaces; however, it allowed for very close proximity of workers, accommodating a maximum of six workstations around a single work surface. The third type—polygon—was based on a loose and flexible geometry, allowing varying degrees of enclosure, but less close packing than the hexagonal one.

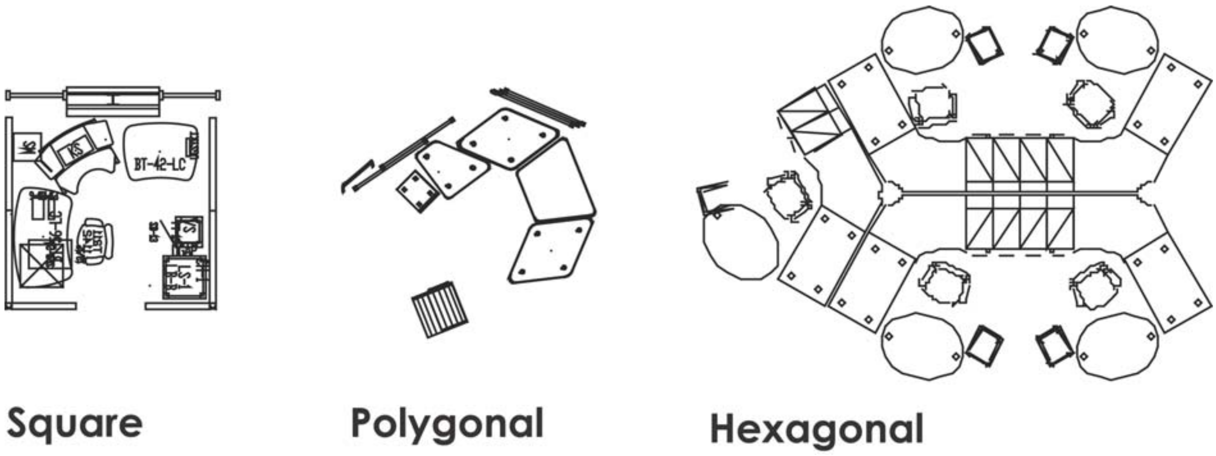


Figure 2:

The three types of workstations used in the study; note that the hexagonal type is in the form of single module of six workstations

Procedural Design Choices

Although a number of layouts were generated during the course of the study, a sample of 48 was used for most of the statistical analysis reported below. Apart from variation in the shell and cell types (the sample was divided roughly equally over both these categories), a key aspect of the study was to classify the designed layouts into different classes according to the design choices adopted during the course of design.

A methodological point needs to be made here. The layouts were produced by a single designer, and these choices are, to that extent, personal. Some variations were produced by explicit, pre-specified design choices such as deciding to either use an overarching framework (a grid) or local conditions to layout individual workstations, or deciding whether to deliberately create wider primary public passageways or hallways in the layout, or not. A majority of the variations, however, were generated by tasking the designer in an open-ended manner to self-reflectively analyze the design choices made in developing particular layouts, and altering those, to create, variations for layouts. The set of design choices that underlay a particular layout—in other words, the independent variables in our statistical model—was not systematically constructed. The following list of choices is, therefore, not a theoretically exhaustive set, but rather a listing of the various aspects of layouts that the designer consciously manipulated in developing the designs.

It is possible to find obvious disadvantages with this procedure; without systematicity in the generation of independent variables for statistical analysis it is not easy to generalize the results obtained. It is also difficult to understand the interactions, or co-dependency, between the independent variables. However, given that the process for designing layouts is a complex process, about which very little is actually known, we felt it important to create a process for the generation of the layouts in which very little was pre-empted. Our effort was to get at the concerns, which are not explicitly, or consciously reflected upon, but which underlie insightful decision-making involved in an actual design process—even in a design process that is one step removed from a real-life situation as here. In short, we felt it better to sacrifice a small amount of methodological rigor in order to gain some better insights into the nature of thinking behind a design process.

In the final accounting, the following categories of choices capture the differences between the designs (tabulated with codings for all layouts in Appendix 1):

1. The structure of the circulation passages, which included three choices: 1. ‘Two-way,’ consisting of circulation passages oriented in two directions, 2. ‘One-way,’ distinguishing between one or more major passages oriented in one specific direction; and 3. ‘Meandering,’ consisting of randomly, non-strategically, formed circulation passages that result, without explicit planning, as by-products of locating workstations.

2. The general strategy for locating workstations, which included the following three alternatives: 1. ‘grid,’ according to which each workstation is laid out following an orthogonal grid, 2. ‘linear,’ in which workstations tend to follow parallel lines, but are not necessarily co-ordinated with each other, and, 3. ‘irregular,’ in which there is no global decision to locate the individual workstations, allowing the local conditions to dictate their position.

3. Density of workstations: This category is self-explanatory; but it should be noted that we are dealing with strategic choices, not with the measured effect. Hence we recognize only two choices: ‘compact,’ in which the aim was to pack as many workstations as possible at the cost of other choices, and ‘relaxed,’ in which the other choices in other categories could over-ride the density requirements. It is quite possible, that due to choices of an overall grid, high density is achieved in effect in the resulting layout, although intention was to keep the arrangement relaxed.

4. Cluster composition, in which the clusters may be either a ‘single’ type of workstation, or of ‘multiple’ types.

5. Cluster boundary definition, which includes two choices as well: 1. ‘distinct,’ in which each cluster is clearly separated from the others, and 2. ‘overlapped,’ in which the definition of individual clusters is not always clearly distinct.

6. Cluster orientation, in which the choices are to either 1. orient units making a cluster only to other units (‘strong’ clustering), or 2. allow individual units of a cluster to be oriented to units outside the cluster (‘weak’ clustering)

7. Cluster unit, in which the clusters may formed of 1. single workstations, or 2. multiple workstations

A few observations may be made of these categories:

1. Choices made in each category are not necessarily exclusive of each other, that is to say, choices made in one category may entail particular choices in other categories. However, our purpose here is not to statistically determine which of these choices have a stronger influence on the layout structure, and from that to construct a factorial model, but rather to simply explore if any of these will a statistically predictable impact on the layout structure.

2. These were a complete set of choices, i.e. any of the given layouts necessarily includes one choice from each category.

3. Category 1 is distinguished from all others in that, where all the others deal with choices made directly about the location and orientation of the individual workstations, choices in category 1 are about the shape of the “left-over” space. Since the syntactical analysis of layout space is concerned specifically with the shape of this left-over space, one of the interesting issues under consideration is whether direct design attention to this space can predictably affect the outcome variables obtained from syntactical analysis.

4. Categories 2 and 3 are largely concerned with global strategies for laying out individual workstations (or the absence thereof), i.e. with those decisions that affect the location and orientation of all workstations. The categories 4 to 6, on the other hand, are concerned with choices that may selectively affect only some of the workstations; these choices have to do with relationships between proximal workstations, such as distances between them, their orientation with respect to their neighbors, or modes of clustering, if any.

Outcome Variables:
Variables Coding Emergent Properties of Configuration

These variables fall under two broad categories: 1. Descriptors of the geometric characteristics of the layout, consisting mainly of the variables that describe the density of space use, and 2. Descriptors of the syntactic characteristics of the layout. Regarding the latter, we focused our interest on measures related to one characteristic—the global centrality, or degree of integration, of the spatial unit, measured in terms of RRA. The values associated with these variables are presented in the table in Appendix 2.

1. Descriptors of geometric characteristics of the layout space:

The basic category of interest here was the ratio between directly assigned (pre-programmed area), i.e. the combined area of all the workstations accommodated, and the “left-over” area, for each layout. As the accompanying table indicates, the following primary variables were computed for each layout, in order compare the density of their programmatic space use (the short names for each variable as used in the table are in brackets):

Area available for layout of workstations on each floor (TotalArea)

Number of workstations accommodated in each layout (WS_num)

Area of each type of workstation (WS_area)

On the basis of these variables, these secondary variables were computed:

Area occupied by all the workstations (OccupArea):
OccupArea = WS_num x WS_area

Density of programmatic space (Dense):
Dense = OccupArea / TotalArea

Sparsity of programmatic space (Sparse):
Sparse = (TotalArea-OccupArea) / TotalArea

2. Descriptors of syntactic characteristics of the layout space:

Although several computational indices can be associated with the linear map, we chose to focus exclusively on RRA (real relative asymmetry). One reason for that is simply a matter of interest; RRA (or Integration) has been studied quite extensively as a key structural variable in charting the social impact of a design. Another more methodological reason for focusing on RRA is that it is computationally a global index, in the sense that the entire linear map needs to be considered in computing the RRA value of any line in the linear map. Thus, RRA values of individual spaces (lines) are not always easy to intuit by looking at the plan of the layout or even by looking at the linear map derived from it. A description of a plan in terms of RRA would, therefore, seem to offer genuinely unanticipated information to the designer, and the issue of predictability of the outcomes of specific choices is specially relevant here.

Each layout can be characterized by a set of numbers, one for each of component lines of its axial map. Our interest, however, is in comparing between layouts, which requires that each layout should be represented as a single data point in the statistical analyses. The conventional approach in syntactical studies is to use the mean of the integration values of all component lines of the layout's axial map as the data point. In this case, however, we found these conventions limiting. First, practically speaking, the variation between the mean of integration values of different floor-plates is rarely large enough to capture the significant differences between them. Second, there is matter of concern arising from the statistical nature of the data. Given that the distribution of RRA values of axial lines is quite often not normal, describing such a distribution only by the mean value may introduce serious errors in the arguments. Our way out of this problem, therefore, was to represent each layout by four moments of the distribution of its RRA values—the mean, the standard deviation, the skewness, and the kurtosis. This is not entirely satisfactory as certain characteristics of the data do get fudged here; for instance, it may be of interest that the RRA values of the component lines tend to cluster in discrete clumps in some layouts, and are continuous in others. However, it still offers sufficient discriminating power to be useful. More importantly, the description of the distribution in this way makes it easy to predict its behavioral implications, since the moments lend themselves to straightforward interpretation.

In addition to these four numbers, we also tabulated some basic descriptive statistics for benchmarking purposes: the range, and the number of axial lines (Appendix 2).

Statistical Analyses and Results

As described earlier, the first step was to study the correlations between the variables representing design choices and those representing the emergent spatial structure of the designed layout. We describe the analysis of the procedural design choices.

The Effect of Procedural Design Choices on the Syntactic Variables

One of our main—and somewhat disconcerting—findings was that very few of the procedural design choices show a predictable impact on the emergent spatial structure. In fact, only three categories of choices produced any systematic effect upon the syntactic variables: the choices to either maximize density or not, decisions about the types of cluster (whether one or many workstations to a unit, or whether to vary the composition of the clusters). This is seen in the accompanying results from a discriminant analysis of the data, which show that for most of the categories of choices, predictions made about the grouping of plans based on their syntactical variables do not match the groups formed by sorting out the plans according to design choices (Figure 3). Only for choices regarding density, cluster type and cluster unit definition are the misclassified plans less than 20% (Figures 3, and 4).

This result is interesting, because, it shows that direct decisions about the patterning of circulation corridors (whose spatial structure, after all, is what syntactical variables directly characterize) do not produce predictable outcomes in syntactical variables. Nor do global strategic choices, such as organizing workstations on particular types of grids, offer predictable values in the distribution of RRA values. What seem to produce layouts with more predictable syntactical characteristics are specifically decisions about how to combine workstations—whether to push them as close to each other as possible, for instance, whether to treat them as individuals or as clusters. Even in these cases, the predictability is weak, although statistically significant, for most of the layouts classified.

Hallway Str	Discriminant Scores		
Number Missclassified	19		
Percent Missclassified	39,58		
-2Log Likelihood	46,17		
Counts: Actual Rows by Predicted Column			
	Meandering	One Way	Two Way
Meandering	14	2	5
One Way	3	3	2
Two Way	5	2	12
WkStnLok	Discriminant Scores		
Number Missclassified	24		
Percent Missclassified	50		
-2Log Likelihood	42,98		
Counts: Actual Rows by Predicted Column			
	Grid	Irregular	Linear
Grid	13	5	7
İrregular	0	5	0
Linear	7	5	6
Density	Discriminant Scores		
Number Missclassified	12		
Percent Missclassified	25		
-2Log Likelihood	30,34		
Counts: Actual Rows by Predicted Column			
	Compact	Relaxed	
Compact	20	3	
Relaxed	9	16	
ClustComp	Discriminant Scores		
Number Missclassified	10		
Percent Missclassified	20,83		
-2Log Likelihood	20,32		
Counts: Actual Rows by Predicted Column			
	Multi	Singular	
Multi	29	3	
Singular	7	9	
ClustBound	Discriminant Scores		
Number Missclassified	16		
Percent Missclassified	33,33		
-2Log Likelihood	26,84		
Counts: Actual Rows by Predicted Column			
	Distinct	Overlap	
Distinct	23	13	
Overlap	3	9	
ClustOrient	Discriminant Scores		
Number Missclassified	21		
Percent Missclassified	43,75		
-2Log Likelihood	44,73		
Counts: Actual Rows by Predicted Column			
	Mixed	Strong	Weak
Mixed	4	0	3
Strong	3	17	8
Weak	5	2	6
ClustUnits	Discriminant Scores		
Number Missclassified	10		
Percent Missclassified	20,83		
-2Log Likelihood	20		
Counts: Actual Rows by Predicted Column			
	Multiple	Single	
Multiple	18	6	
Single	4	20	

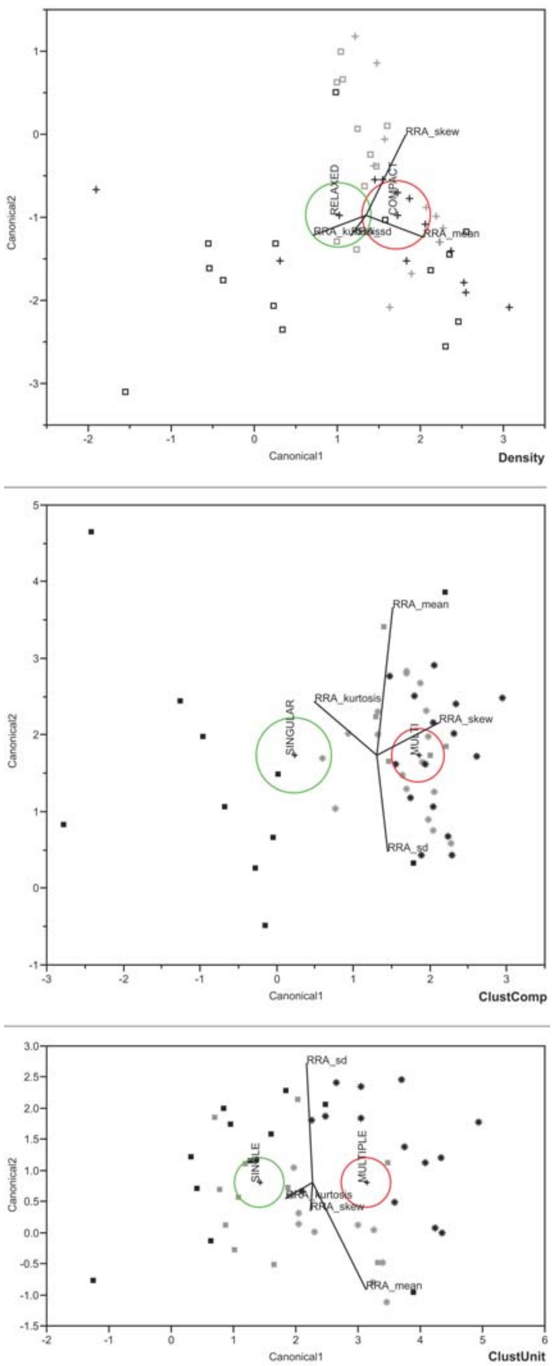


Figure 3:

Partial results of Discriminant Analysis showing that only groupings by cluster units, cluster composition and intended density are predictable through the syntactic variables (left)

Figure 4:

Canonical plot from Discriminant Analyses showing separation of plans into groups following cluster units, cluster composition, and intended density. In this, and all subsequent plots, grey points denote deep plans, and black points, denote narrow plans

The Effect of Premeditated Choices on Syntactic Variables

When examining the predictability of premeditated design choices it is not surprising, then, that the choice of workstation shows a significantly predictability with respect to the emergent spatial structure. Discriminant analysis produces a weak but nevertheless acceptable result, misclassifying 27% of the plans (figure 5).

It should also be noted that the choice of floor-plate geometry also produces layouts with predictable characteristics, and that this predictability is not entirely a result of the size difference between the two floor-plates; measures like RRA, after all, are supposed to be indifferent to the size of the system. However, given our interest in choices that designers make in the course of design, we do not discuss this effect in detail here.

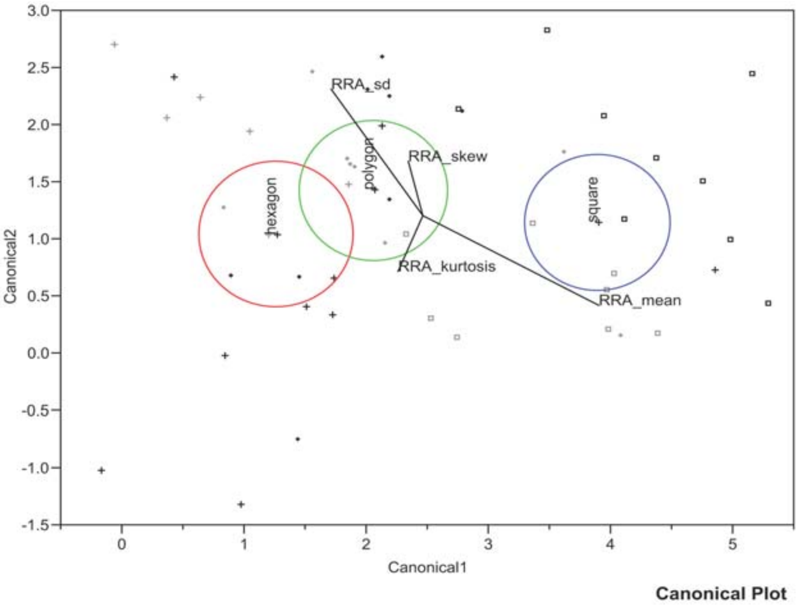
Summing up, then, the choice of workstations can lead to layouts with potentially predictable structural properties. Similarly, making choices about compactness and about the type of clustering of workstations (whether to use a cluster with a single or with multiple workstations, or whether to deploy clusters of workstations, which are of varying configurations) leads to layouts with predictable properties. No other choice gives any predictable results. This raises two questions. First, why should this be the case? And second, what specific structural characteristics of layouts may be expected, if the choices listed above are made? Discriminant analysis does not give an easy indication of this, although the clustering shown in the canonical plots does suggest that RRA mean and RRA standard deviation are probably associated with low density choice. These questions are explored further.

Patterns in the Distribution of Outcome Variables

It helps to begin by examining the distributions of basic geometric characteristics such as numbers of workstations in each layout, the densities produced by them, and the number of axial lines that they generate (figure 6). Considering the number of workstations first, what is chiefly interesting here is the difference between the two plans. It is to be expected that the number of workstations would be different given the difference in the areas of the two plans; the long plan is roughly 60% smaller than the deep plan:

- However, the lower numbers in the long plan are not merely due to difference in size; mean density of occupiable space is much lower for the long plan (0.39) than for the deep plan (0.47); the range is also smaller (between 0.3 and 0.45, as compared to 0.3 and 0.6 for the deep plan).

- This difference is similar for the number of lines axial lines that the layout can be fragmented into. Narrow floor-plates produce far fewer fragmentations into axial lines than the deep plans, and as with the workstation numbers, the difference is not entirely a product of their smaller area.



Number Misclassified	13
Percent Misclassified	27.08
-2LogLikelihood	34.79

Counts: Actual Rows by Predicted Columns

	hexagon	polygon	square
hexagon	12	2	1
polygon	4	10	2
square	0	4	13

Discriminant Scores

Figure 5:

Discriminant analysis illustrating the success of predicting, from syntactical characteristics of space, the types of workstation deployed in a plan. In the canonical plot here and all subsequent plots diamonds mark layouts with the polygonal type of workstations, squares, layouts with square type, and pluses, layouts with the hexagonal type

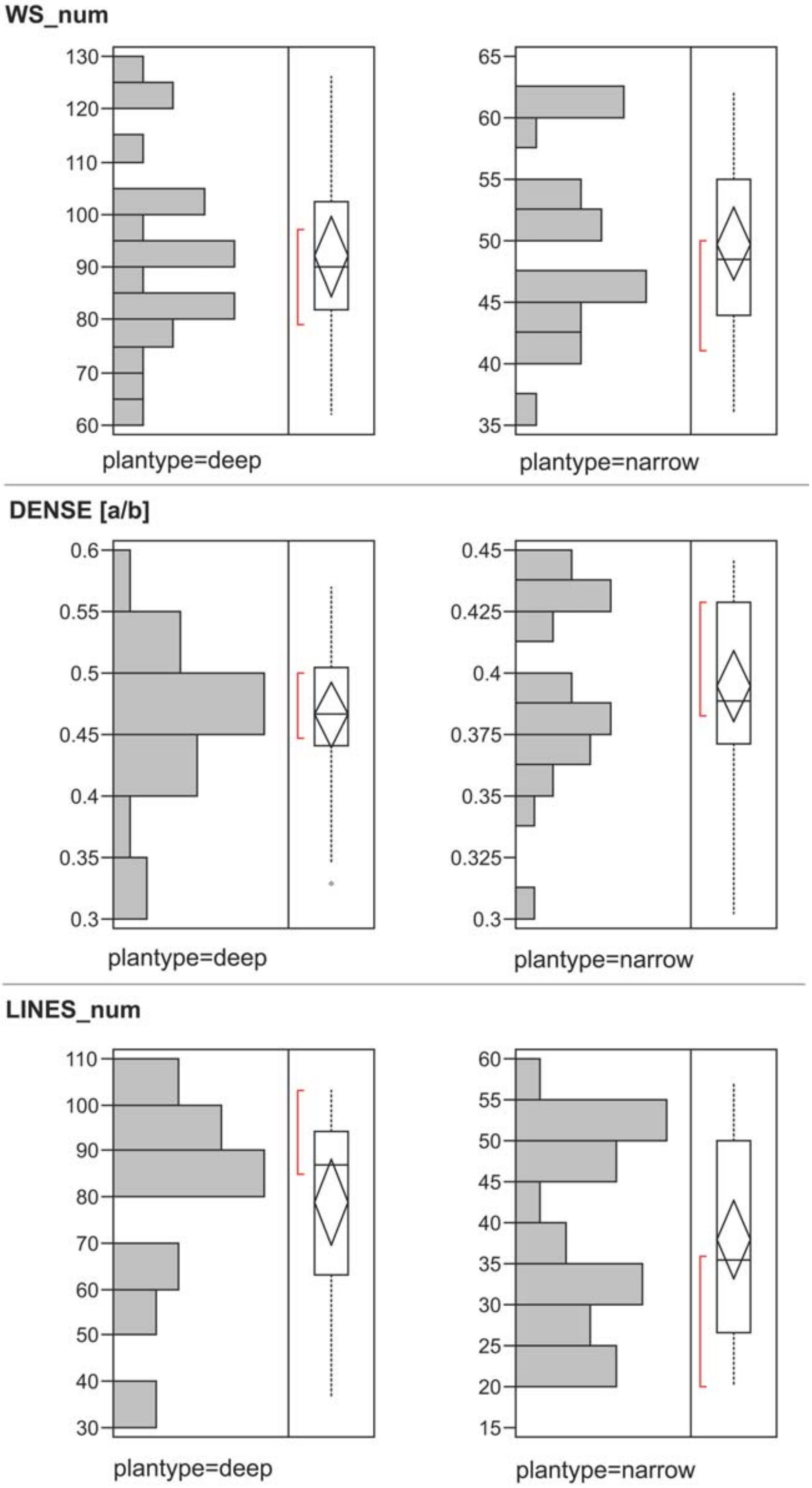


Figure 6:

Distributions of number of workstations, number of axial lines, and density of space use in all layouts, separated into narrow and deep floor-plate layouts

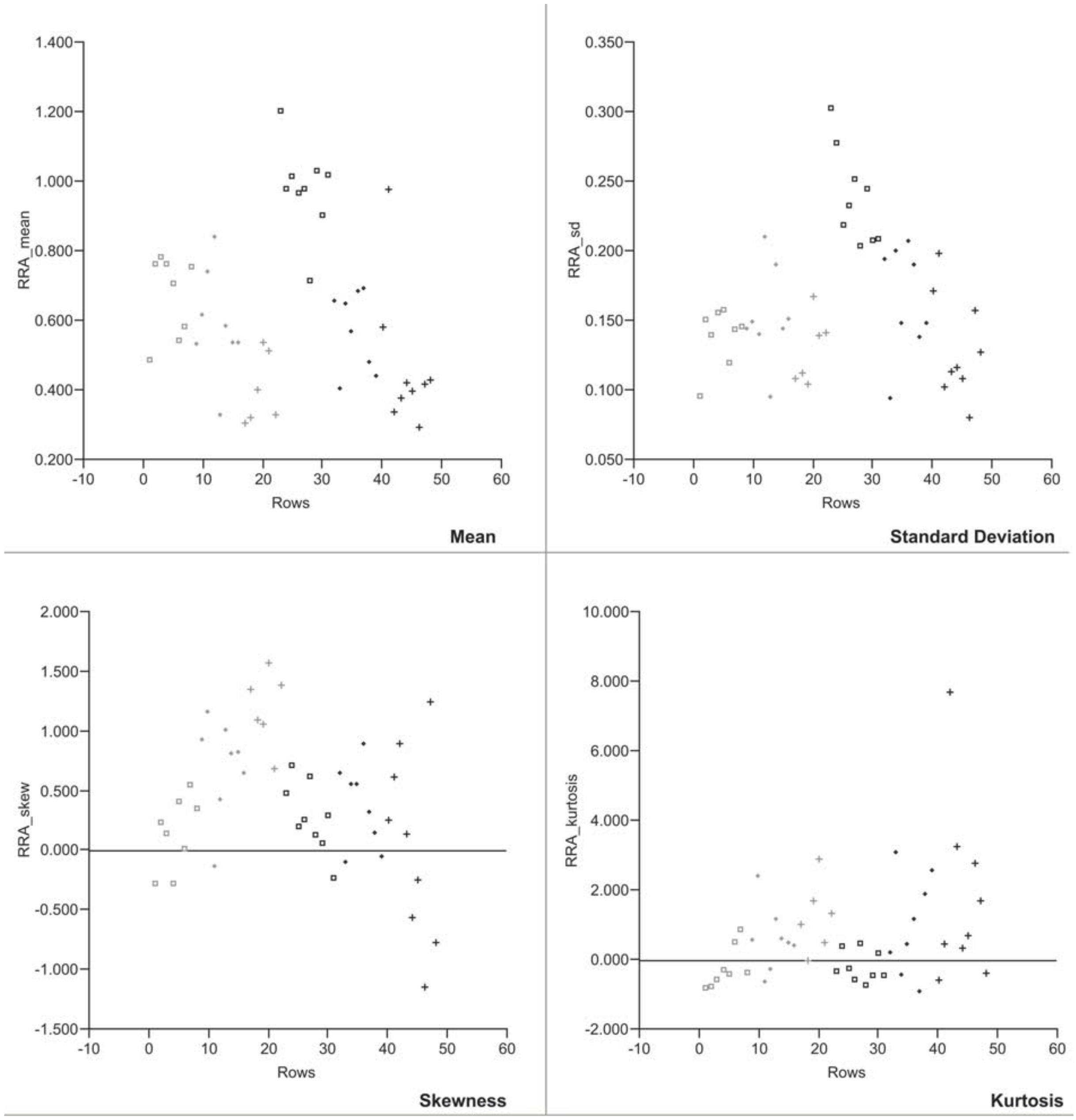
Also telling are the overall distribution characteristics of each of the four moments describing the distributions of RRA values for each layout (figure 7):

- The distribution of the mean of RRA values is quite similar for both type of floor-plates. It is actually the geometry of workstations that seems to produce the more distinctive behavior, as can be seen in the clustering of data points in the scatter-plots; the hexagonal type of workstation is consistently associated with low mean RRA values, whereas the square type of workstation as consistently gives rise to plans with high mean values of RRA, the effect being more pronounced in layouts of narrow floor-plates.

- The distribution of the standard deviation values follows the distribution of means very closely, but the distribution of skewness and kurtosis values have unique characteristics. As far as skewness is concerned, the overall distribution is itself skewed in the positive direction. More interestingly, the distribution here is also systematically affected by workstation geometry; the square type of workstations have the least variation in skewness values (between -0.4 to +0.6), while the hexagonal type have the most, the effect being more pronounced in the narrow floor-plates (between -1.1 to +1.6; as compared to between -0.1 to +1.6). The overall distribution of the kurtosis values is a power distribution (very few plans with very high kurtosis values, and most with low kurtosis values), with the overall mean being near the baseline 0 value (0.43). Once again, square workstations are distinctive in producing the most compact distribution, whereas the hexagonal ones produce the greatest range. Taking the two observations together we can see that the hexagonal type of workstation, and to a smaller extent, the polygonal type, can produce layouts with comparably high kurtosis values, but this does not seem possible with the square workstations.

Figure 7:

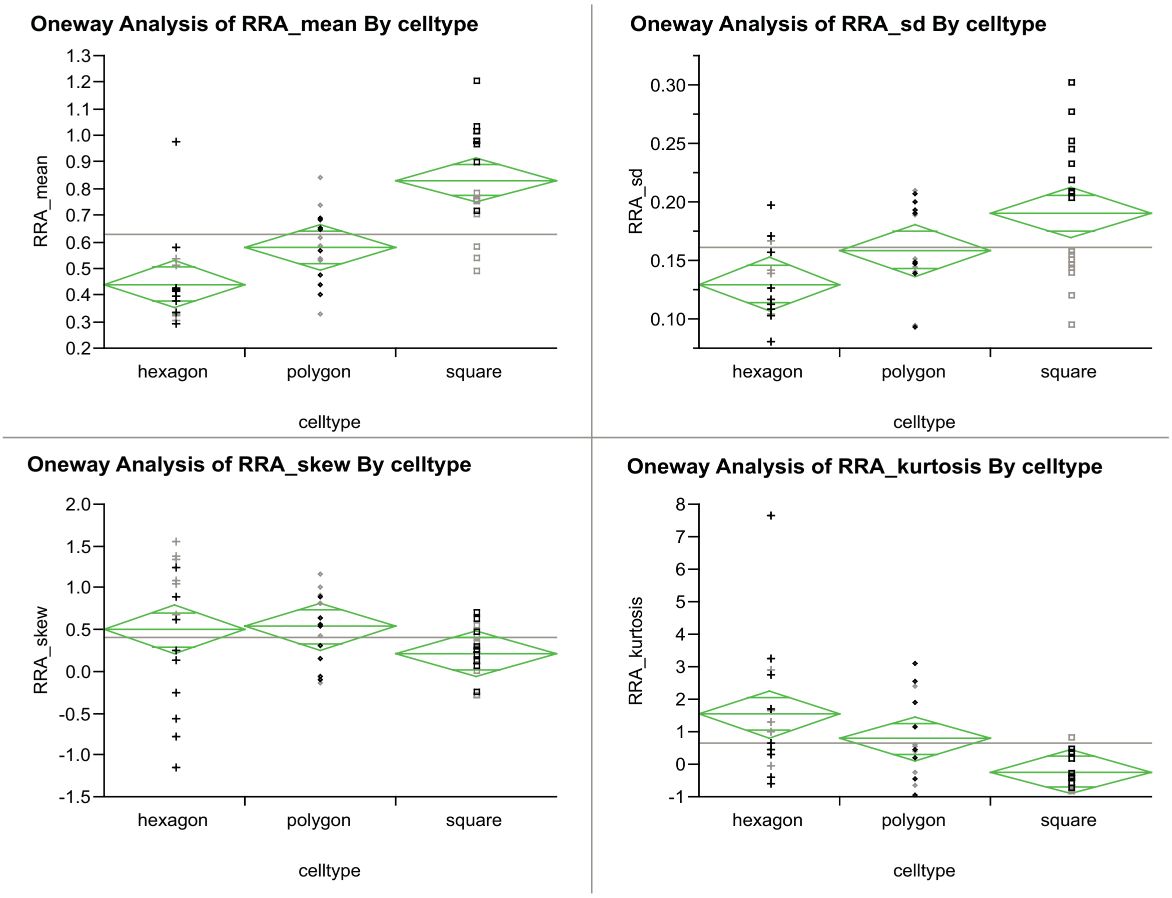
Scatterplot of distributions of RRA values in all layouts; the ordering of layouts on the horizontal axis in no particular order



These distributions indicate clearly that the choice of workstations clearly influences the possible distribution of RRA values in any layout. We decided to use ANOVAs to see if the association between workstations and any of the moments of distribution was statistically significant; the exercise is similar in effect to the discriminant analysis reported earlier, except that it checks for grouping according to each syntactic parameter rather than all of them together. Figure 8 presents some ANOVAs comparing means of the distributions of mean, standard deviation, skewness and kurtosis values for groups of layouts created on the basis of their constituent workstations. Results show that square workstations produce layouts with the least variation in values, and are consistently associated with layouts showing *high mean, high standard deviation*, but *low kurtosis* values of RRA.

Figure 8:

ANOVA results (complete results not shown here) showing the distributions of different parameters of RRA values for all layouts separated into groups according to workstation type

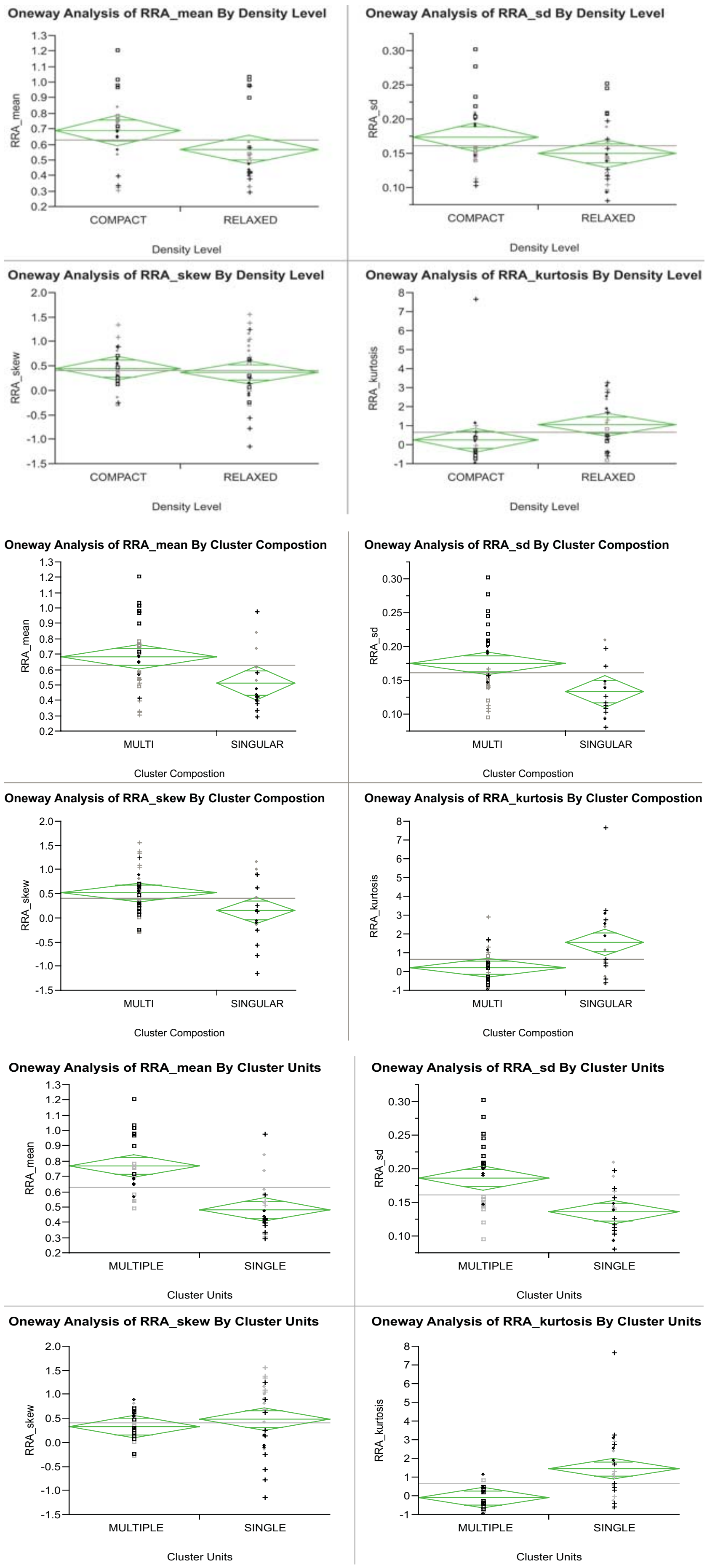


A similar pattern of association occurs for the procedural choices as well. From the accompanying ANOVA charts (figures 9a, 9b, and 9c), we see that the layouts with compactness as their strategic choice result in axial maps with high mean, high standard deviation, and low kurtosis values; similarly for layouts constituted by multiple types of clusters.

As before, the results challenge our expectations in interesting ways. We might assume that the high mean RRA values associated with the square type of workstations might be due to the fact that the square type of workstations are more enclosed, and therefore likely to produce plans with a greater number of lines with relatively high RRA values. It follows that such plans would show high kurtosis values as well (a great deal of data points having extreme values). But the distribution of kurtosis values proves otherwise. In fact, quite a few plans with very high mean RRAs actually have negative kurtosis values, characteristic of distributions with very small tails. How can one explain these results?

Figure 9:

ANOVA results (complete results not shown here) showing the distributions of different parameters of RRA values for all layouts separated into groups according to intended density (a), cluster composition (b), and cluster unit (c)

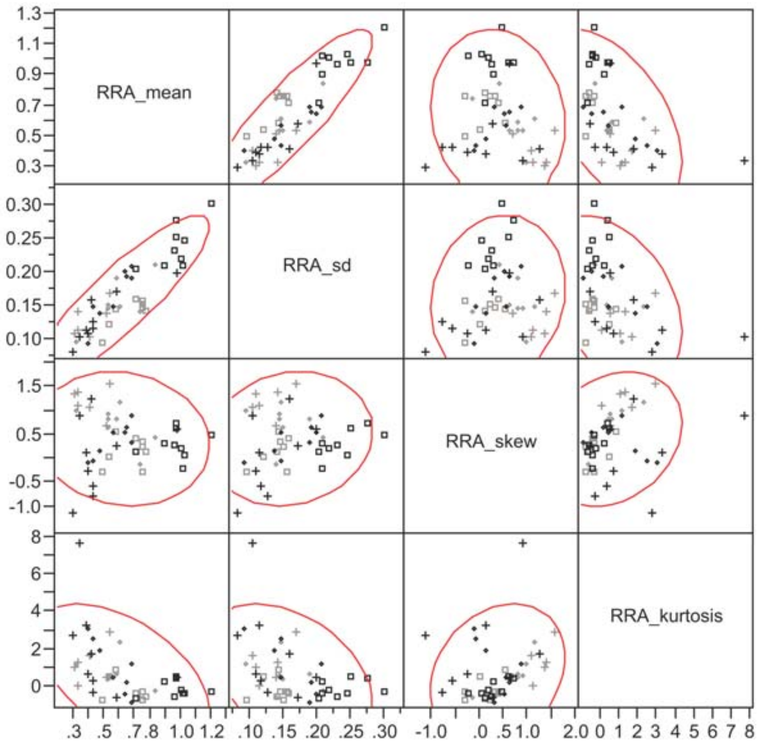


Syntactical Types of Layouts and Their Relationship with Workstation Types

The ANOVAs above suggest that the different parameters characterizing RRA distributions—mean, standard deviation, skewness, and kurtosis might relate to each other at all in a systematic way. Correlations between them confirm that they do (figure 10).

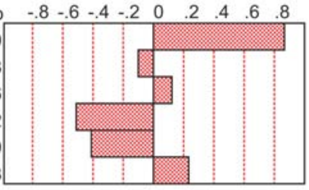
The mean and standard deviation of RRA values correlate (R = ~ 0.87, p < 0.00001). In other words, layouts with high mean RRA values will tend to have greater standard deviation. Kurtosis is mildly, but significantly, correlated with these two (R= ~0.5, p < 0.0002, in case of the mean, and R= ~0.4, p < 0.004 in case of the standard deviation); however, the correlation is negative. Plans that have high mean RRA and high mean standard deviation tend to have lower kurtosis values. Skewness seems to vary independently of these all.

Multivariate



Scatterplot Matrix

Variable	by Variable	Correlation	Count	Signif Prob
RRA_sd	RRA_mean	0.8735	48	0.0000
RRA_skew	RRA_mean	-0.1056	48	0.4748
RRA_skew	RRA_sd	0.1210	48	0.4126
RRA_kurtosis	RRA_mean	-0.5195	48	0.0002
RRA_kurtosis	RRA_sd	-0.4081	48	0.0040
RRA_kurtosis	RRA_skew	0.2370	48	0.1048



Pairwise Correlations

Figure 10:

Correlations amongst syntactic variables

These correlations begin to make sense when we consider the particular distributions of axial lines that typically happen in office floor-plates. The network of axial lines characterizing the layout tends to consist of a large number of lines whose lengths are more or less comparable to the dimensions of the floor-plate. This is another way of saying that layout designers tend to provide at least some major corridors or hallways that run through the lengths of floor-plates. These lines, given their size, and their possibilities of interactions with each other, tend to low RRA values, and often form the integration core of the system. The interesting point is that in this system, the more likely way to increase the mean RRA of the system is by adding a number of shorter lines that connect to fewer main lines or perhaps to other short lines exclusively. Adding more long lines with fewer connections may possible, but such lines will tend to intersect with several low RRA lines and, therefore, not substantially increase the asymmetry of the entire system. Shorter lines will often be of medium to high RRA values, and adding shorter lines—as happens when workstations are of enclosed kind, requiring short lines to connect them with the lines mapping the major circulation structure—will tend to have a noticeable impact in increasing the asymmetry of the whole system. The presence of an increased number of high asymmetry lines will correspondingly lower the values of the low integration lines, thus simultaneously increasing mean RRA as well as the standard deviation. This condition also explains the positive skewness that characterizes the majority of layouts in the study. More interestingly it helps us understand the relationship of kurtosis with the other variables. If the shorter lines have uniformly high RRA values, they will tend to create a bimodal distribution, with a great difference between the two modes—one consisting of the majority of lines in the system all of which have fall within a relatively low range of low RRA values, and the other consisting of a few very high RRA lines. This configuration will tend to have a low mean, low standard deviation, and high kurtosis. In contrast, layouts in which the shorter lines have less extreme RRA values, the overall distribution will tend to have several lines that deviate to a greater extent from the mean value, but these deviations will be both more frequent and modest, creating relatively high mean RRA, high standard deviation and low kurtosis. This situation can be diagrammed through two schematic distribution patterns (figure 11).

It should of course be kept in mind that these diagrams represent extreme cases, and that in practice several decisions and contingent factors will tend to create plans with intermediate types of distributions. We are now in a position to argue why each of these distributions reflects layouts produced with specific types of workstations and specific procedural choices.

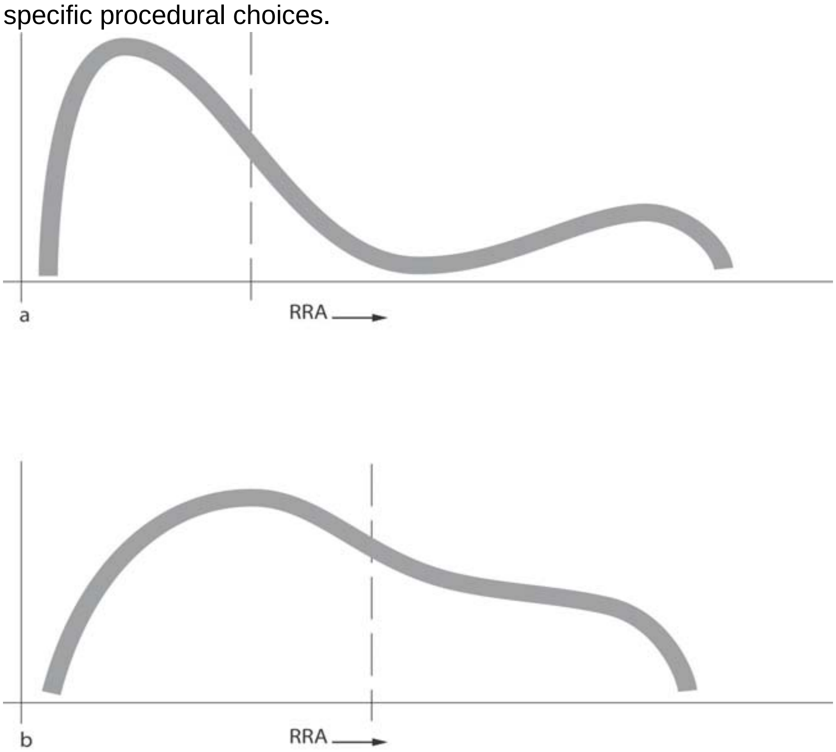


Figure 11:

Schematic distribution of two polarized schemas of layout

Before we do that, it will also help to consider correlations between some other outcome variables—the numbers of workstations, densities of layouts, and number of lines produced—and to see if these correlations are affected by the types of workstations. Taking, first the relationship between number of workstations and densities, we find an expected positive correlation between the two variables (figure 12). There is an effect of floor-plates as well, so that at a given density, there is always greater number of workstations in deep floor-plates. This is just because deeper plans allow even small left-over spaces between units to add up and accommodate entire units—thus, smaller changes in density are able provide more workstations. It is also informative to see how the workstation types produce distinct correlations—the hexagonal type not only produces layouts with greater numbers of workstations (predictably so, since it features more than one workstations fused together in one physical unit), but uses comparatively lesser area; for a given number of workstations, it produces around 8% less density of occupied space.

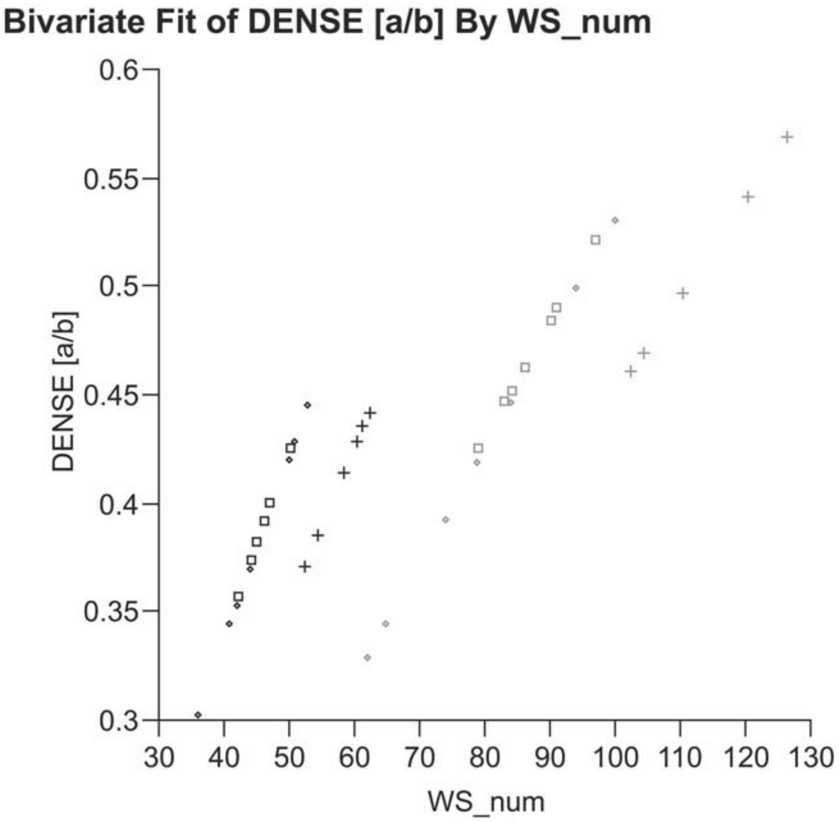


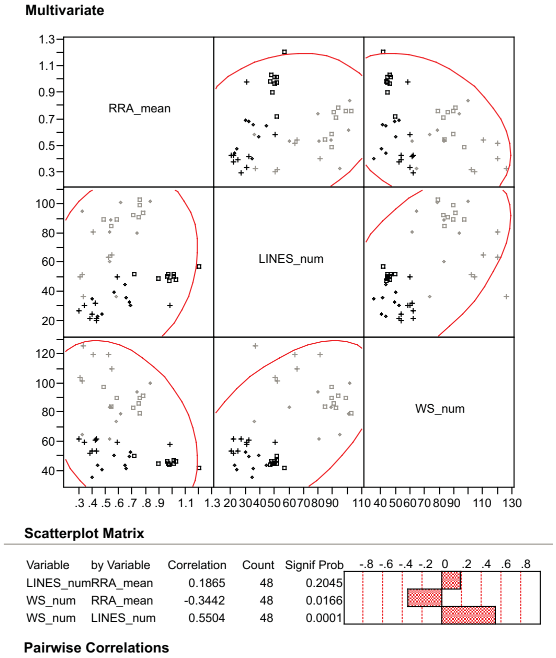
Figure 12:

Scatter-plot of the number of workstations versus density (ratio of occupied to available area)

Considering now the relationship between number of workstations deployed in a layout and the number of lines produced, we notice a weak but significant correlation ($R= 0.55$; $p < 0.000$). In fact, as the scatter-plot shows, the correlation is really an artifact of the difference between the plans (figure 13). Narrow floor-plates produce both greater number of workstations and greater number of lines—a clear effect of size. Treating the layouts on different floor-plates separately (figure 14), the correlation turns out to be negative, and this time obviously produced by the differences between the type of workstations ($R = -0.4$; $p < 0.05$, for both deep and narrow floor-plates). Square type of workstations produce layouts with higher number of lines than the hexagonal type, even though the actual number of workstations accommodated is always greater for the hexagonal type.

Figure 13:

Correlations between number of lines, density, and RRA values in all layouts



The correlations further confirm our conclusion that high RRA values correlate significantly with increased numbers of lines (R = 0.61, p < 0.002 for deep floor-plates; and R = 0.7, p < 0.000 for narrow floorplates). What we see in the scatter-plots, however, is that these correlations are almost entirely due to the types of workstations used (figure 14). For any given workstation on a particular floor-plate, the correlation is not significant.

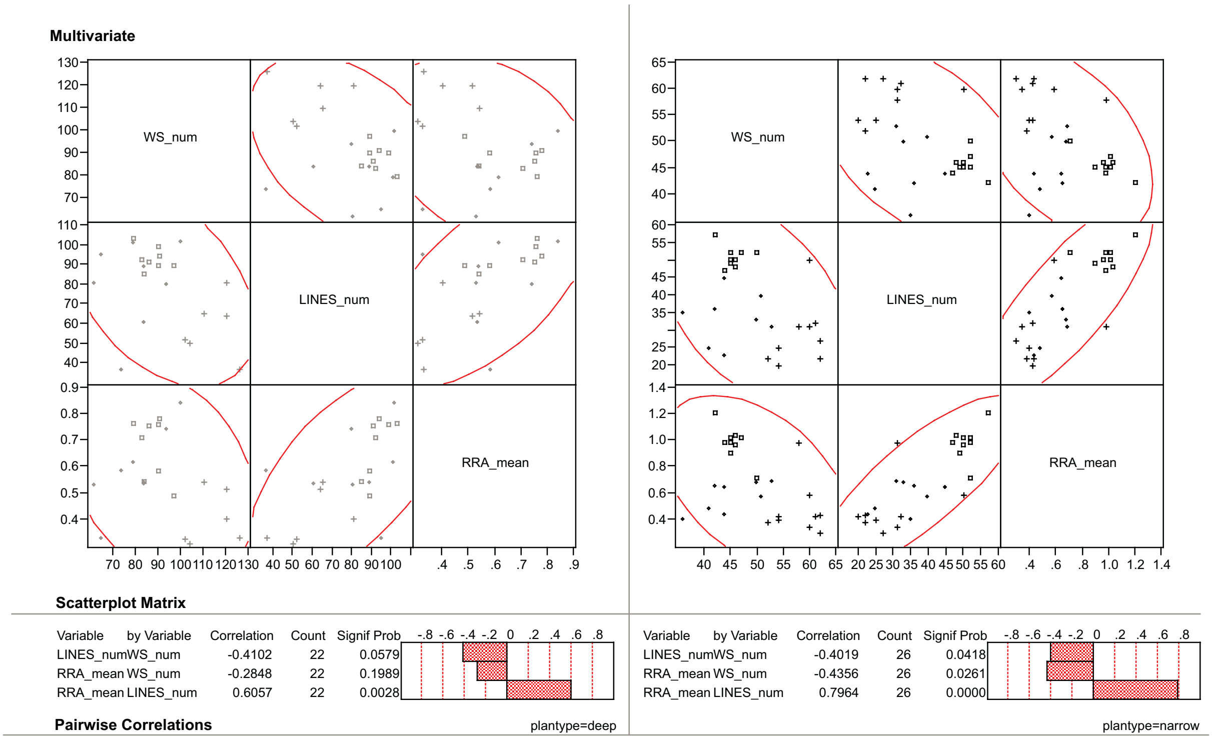
Both results are partially explained by the geometry of the workstations: the “islands” produced between lines in layouts using hexagonal type of workstations contain not single workstations, but multiple ones, and these islands are substantially larger than those produced in layouts using either the square, or the polygonal ones. It is natural then that there will be both fewer lines, and greater numbers of workstations in layouts with hexagonal workstations. Another point that may contribute to the distribution pattern seen in the scatter-plot is the fact that the square workstations are more enclosed and therefore require more lines to make sure that their interior space is traversed. This may also be the reason why the polygonal type of workstation, which is somewhat more enclosed than the hexagonal type, produces layouts with more lines.

Putting all these observations together, we can see the consequences of using the three types of workstations. Layouts with square workstations produce a greater number of lines relative to the number of workstations accommodated. The greater number of lines is associated with a greater mean RRA value in plans. This happens because in the square workstations, the added lines are short to medium lines that enter the individual cells. These have medium to high RRA values. The consequence of adding these lines is not just to add to the tail of the distribution but to also skew the values of the larger low RRA lines towards more asymmetry. This produces a more evenly varied distribution of RRA values through the layout, thus decreasing kurtosis. In contrast, in layouts with polygonal and particularly hexagonal type of workstations, several large diagonals create a situation in which there are several closely related low RRA lines. If, however, there happen to be a few shorter lines attached to this large core of lines with low RRA, the extreme differences between the RRA values will tend to produce a more polarized distribution, with the core squeezed in a smaller range of low RRA values, and a few lines of high RRA values adding a large tail. The difference between the core set and these shorter lines is large, thus creating conditions for higher kurtosis, but with low mean and standard deviation.

Applying a similar line of reasoning with respect to the procedural choices, we can see that the choice to create compactness prevents the designer from redistributing any excess unoccupied space evenly through the layout. Similarly, the impact of latter choice to deploy workstations into clusters of varying size and composition rather than treating them as individuals, is to create 'clumps' of units rather than even distributions. The result of all these choices—intended compactness, clustering workstations into groups of varying composition and sizes—is to ultimately create variation in the size and regularity of the circulation network. This, in turn, means that the RRA values of such space will also tend to vary. More importantly, in such a deformed grid network, shorter, highly asymmetrical lines, if at all present, will not create strong polarization. Thus, the overall RRA distribution will be characterized by relatively higher mean, high standard deviation and low kurtosis. If there is a more even distribution of space through the circulation corridor, there is a greater chance of more polarized distribution, and hence of the distribution that has low mean and standard deviation, but relatively higher kurtosis.

Figure 14:

Correlations between number of lines, density, and RRA values in all layouts split by floor-plate type



Conclusions

What all this means is that it is the shorter lines with high RRA values that contribute the most towards altering the syntactical characteristics of the layout in the most predictable manner. Translated into decisions made on the design table, this observation suggests that decisions that affect localized, but typical, repeated conditions in the plans can have predictable effect on the syntactical structure of the layout. In the cases where designers work with systems of furniture, several of these decisions are already taken when a choice of system is made, thus already biasing the potential outcome to an extent. Decisions that have to do with singular conditions and global conditions, such a attempting to layout an organizing grid for workstations, or creating a centralized corridor, will have far more unpredictable consequences for the syntactic structure as a whole. This account is also mirrored in the findings related to the effects of procedural choices on the emergent syntactical structure of the layout. Decisions about global conditions had unpredictable consequences, as did decisions made at local level whose impact was not felt through the system.

This is a somewhat unexpected finding, since the syntactical characteristics are really a direct description of the structure of the "left-over" circulation space in layouts, and the expectation would be that decisions that directly affect this structure—the decision to create a broad corridor, for instance—would have more predictable effects. The syntactical variation seen with procedural choices does indicate a weak predictability associated directly with the structure of the circulation space—the more uniform the circulation space, the greater likelihood of it producing a layout which is high mean and standard deviation and low kurtosis values. Uniformity here is related to both the distribution of longer hallways or passages over the floor-plate, as well as to the variation in their width, so that in syntactical terms, they have similar opportunities of intersection with other lines.

These results have interesting implications for design; first, they alert us to the limitations of rules of thumb in design. The syntactical structure of layouts is driven far too much by mutual interaction of elements to be captured in a few rules of thumb. But, at the same time, the exercise here does show the significance of local decisions—decisions about geometries of workstations, about the degree of flexibility required, and about the amount of enclosure and privacy created are not just meaningful in creating immediate or local working conditions in an office, but also crucial to the overall structure of the space—indeed far more predictably so than decisions directly about the structure of the space itself.

Acknowledgements: This project was made possible through a research sponsorship of the General Services Administration (Project No. GS00P04CYM0195/PJ4P00390) of the US Government. The authors would like to Dr. John Peponis for help in developing the research questions, and to Dr. Craig Zimring, Dr. Mahbub Rashid, Mr. Kevin Kempshroer, Mr. Kevin Powell, and Mr. Rob Obenreider for their vital contributions to the project.

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Appendix 1. *Table showing values for premeditated and procedural choices*

NAME	plantype	celltype	Hallway Structure	WKStn Location	Density Level	Cluster Compostion	Cluster Boundary	Cluster Orientation	Cluster Units
15	deep	polygon	TWO-WAY	GRID	RELAXED	SINGULAR	DISTINCT	STRONG	SINGLE
16	deep	polygon	TWO-WAY	GRID	RELAXED	SINGULAR	DISTINCT	WEAK	SINGLE
17	deep	polygon	TWO-WAY	GRID	COMPACT	SINGULAR	DISTINCT	STRONG	SINGLE
18	deep	polygon	TWO-WAY	GRID	COMPACT	SINGULAR	OVERLAP	WEAK	SINGLE
19	deep	polygon	TWO-WAY	GRID	RELAXED	SINGULAR	DISTINCT	STRONG	SINGLE
20	deep	polygon	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	MIXED	SINGLE
22	deep	polygon	ONE-WAY	GRID	COMPACT	MULTI	DISTINCT	STRONG	MULTIPLE
Random3	deep	polygon	MEANDERING	IRREGULAR	COMPACT	MULTI	OVERLAP	MIXED	MULTIPLE
21	deep	square	ONE-WAY	GRID	COMPACT	MULTI	DISTINCT	STRONG	MULTIPLE
Grid2	deep	square	ONE-WAY	LINEAR	COMPACT	MULTI	DISTINCT	STRONG	MULTIPLE
Grid3	deep	square	MEANDERING	LINEAR	COMPACT	MULTI	DISTINCT	STRONG	MULTIPLE
Grid4	deep	square	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	MULTIPLE
Grid5	deep	square	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	MULTIPLE
ORIGINAL	deep	square	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	MULTIPLE
Random1	deep	square	MEANDERING	LINEAR	COMPACT	MULTI	OVERLAP	STRONG	MULTIPLE
Random2	deep	square	MEANDERING	LINEAR	COMPACT	MULTI	OVERLAP	STRONG	MULTIPLE
1.1	deep	hexagon	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	SINGLE
1.2	deep	hexagon	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	SINGLE
1.3	deep	hexagon	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	SINGLE
1.4	deep	hexagon	ONE-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	SINGLE
Straw33	deep	hexagon	MEANDERING	IRREGULAR	COMPACT	MULTI	OVERLAP	WEAK	SINGLE
Straw44	deep	hexagon	MEANDERING	IRREGULAR	COMPACT	MULTI	OVERLAP	WEAK	SINGLE
POly1	narrow	polygon	MEANDERING	LINEAR	COMPACT	MULTI	OVERLAP	MIXED	MULTIPLE
POly2	narrow	polygon	TWO-WAY	GRID	RELAXED	SINGULAR	DISTINCT	MIXED	SINGLE
POly3	narrow	polygon	MEANDERING	LINEAR	COMPACT	MULTI	OVERLAP	MIXED	MULTIPLE
POly4	narrow	polygon	MEANDERING	GRID	COMPACT	MULTI	DISTINCT	STRONG	MULTIPLE
Straw3	narrow	polygon	MEANDERING	LINEAR	COMPACT	MULTI	OVERLAP	WEAK	MULTIPLE
Straw4	narrow	polygon	MEANDERING	LINEAR	COMPACT	MULTI	OVERLAP	WEAK	MULTIPLE
Straw5	narrow	polygon	ONE-WAY	LINEAR	RELAXED	SINGULAR	DISTINCT	WEAK	SINGLE
Straw6	narrow	polygon	ONE-WAY	GRID	RELAXED	SINGULAR	DISTINCT	WEAK	SINGLE
SQ.10	narrow	square	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	MULTIPLE
SQ.2	narrow	square	MEANDERING	IRREGULAR	COMPACT	MULTI	DISTINCT	STRONG	MULTIPLE
SQ.3	narrow	square	MEANDERING	IRREGULAR	COMPACT	MULTI	DISTINCT	STRONG	MULTIPLE
SQ.4	narrow	square	TWO-WAY	GRID	COMPACT	MULTI	DISTINCT	STRONG	MULTIPLE
SQ.5	narrow	square	MEANDERING	LINEAR	COMPACT	MULTI	OVERLAP	STRONG	MULTIPLE
SQ.6	narrow	square	ONE-WAY	LINEAR	RELAXED	MULTI	DISTINCT	STRONG	MULTIPLE
SQ.7	narrow	square	MEANDERING	LINEAR	COMPACT	MULTI	DISTINCT	STRONG	MULTIPLE
SQ.8	narrow	square	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	MULTIPLE
SQ.9	narrow	square	TWO-WAY	GRID	RELAXED	MULTI	DISTINCT	STRONG	MULTIPLE
POly10	narrow	hexagon	MEANDERING	GRID	COMPACT	SINGULAR	DISTINCT	STRONG	SINGLE
POly11	narrow	hexagon	TWO-WAY	GRID	RELAXED	SINGULAR	DISTINCT	STRONG	SINGLE
POly5	narrow	hexagon	MEANDERING	LINEAR	RELAXED	SINGULAR	DISTINCT	WEAK	SINGLE
POly6	narrow	hexagon	MEANDERING	LINEAR	RELAXED	SINGULAR	DISTINCT	WEAK	SINGLE
POly7	narrow	hexagon	TWO-WAY	GRID	COMPACT	SINGULAR	DISTINCT	WEAK	SINGLE
POly8	narrow	hexagon	MEANDERING	LINEAR	RELAXED	SINGULAR	DISTINCT	MIXED	SINGLE
POly9	narrow	hexagon	MEANDERING	LINEAR	RELAXED	SINGULAR	DISTINCT	MIXED	SINGLE
Straw1	narrow	hexagon	MEANDERING	LINEAR	RELAXED	MULTI	OVERLAP	WEAK	SINGLE
Straw2	narrow	hexagon	ONE-WAY	LINEAR	RELAXED	SINGULAR	DISTINCT	WEAK	SINGLE

Appendix 2. *Table showing values for outcome variables*

NAME	RRA_mean	RRA_sd	RRA_skew	RRA_kurtosis	LINES_num	WS_num	WS_area	OCCUPAREA [a]	TOTALAREA [b]	SPARSE [b-a]/b	DENSE [a/b]
ORIGINAL	0,487	0,095	-0,286	-0,803	89	97	1215	117855	225780	0,478	0,522
Random1	0,761	0,151	0,235	-0,77	103	79	1215	95985	225780	0,5749	0,4251
Random2	0,782	0,14	0,14	-0,577	94	91	1215	110565	225780	0,5103	0,4897
Grid2	0,76	0,156	-0,282	-0,304	99	90	1215	109350	225780	0,5157	0,4843
Grid3	0,707	0,158	0,408	-0,401	92	83	1215	100845	225780	0,5533	0,4467
Grid4	0,541	0,12	0,009	0,49	85	84	1215	102060	225780	0,548	0,452
Grid5	0,583	0,144	0,549	0,84	89	90	1215	109350	225780	0,5157	0,4843
21	0,754	0,146	0,346	-0,364	91	86	1215	104490	225780	0,5372	0,4628
15	0,534	0,145	0,93	0,589	81	62	1200	74400	225780	0,6705	0,3295
16	0,616	0,15	1,164	2,405	101	79	1200	94800	225780	0,5801	0,4199
17	0,742	0,141	-0,125	-0,622	80	94	1200	112800	225780	0,5004	0,4996
18	0,843	0,21	0,426	-0,247	102	100	1200	120000	225780	0,4685	0,5315
19	0,331	0,096	1,015	1,171	95	65	1200	78000	225780	0,6545	0,3455
20	0,587	0,19	0,815	0,632	37	74	1200	88800	225780	0,6067	0,3933
Random3	0,538	0,145	0,832	0,498	61	84	1200	100800	225780	0,5535	0,4465
22	0,54	0,152	0,651	0,408	89	84	1200	100800	225780	0,5535	0,4465
Straw33	0,306	0,109	1,355	1,015	50	104	1020	106080	225780	0,5302	0,4698
Straw44	0,323	0,113	1,091	-0,008	52	102	1020	104040	225780	0,5392	0,4608
1,1	0,401	0,105	1,065	1,687	81	120	1020	122400	225780	0,4579	0,5421
1,2	0,54	0,168	1,57	2,908	65	110	1020	112200	225780	0,5031	0,4969
1,3	0,515	0,14	0,683	0,486	64	120	1020	122400	225780	0,4579	0,5421
1,4	0,328	0,142	1,388	1,339	37	126	1020	128520	225780	0,4308	0,5692
SQ.2	1,203	0,302	0,474	-0,351	57	42	1215	51030	142833	0,6427	0,3573
SQ.3	0,977	0,277	0,714	0,378	52	45	1215	54675	142833	0,6172	0,3828
SQ.4	1,013	0,219	0,203	-0,259	52	47	1215	57105	142833	0,6002	0,3998
SQ.5	0,965	0,232	0,252	-0,575	50	46	1215	55890	142833	0,6087	0,3913
SQ.6	0,98	0,252	0,621	0,456	47	44	1215	53460	142833	0,6257	0,3743
SQ.7	0,714	0,204	0,13	-0,727	52	50	1215	60750	142833	0,5747	0,4253
SQ.8	1,032	0,245	0,058	-0,442	48	46	1215	55890	142833	0,6087	0,3913
SQ.9	0,901	0,208	0,293	0,188	49	45	1215	54675	142833	0,6172	0,3828
SQ.10	1,016	0,209	-0,237	-0,448	50	45	1215	54675	142833	0,6172	0,3828
POly1	0,658	0,194	0,65	0,22	36	42	1200	50400	142833	0,6471	0,3529
POly2	0,405	0,094	-0,099	3,103	35	36	1200	43200	142833	0,6975	0,3025
POly3	0,65	0,201	0,554	-0,434	45	44	1200	52800	142833	0,6303	0,3697
POly4	0,571	0,148	0,565	0,467	40	51	1200	61200	142833	0,5715	0,4285
Straw3	0,687	0,208	0,898	1,181	33	50	1200	60000	142833	0,5799	0,4201
Straw4	0,695	0,191	0,326	-0,91	31	53	1200	63600	142833	0,5547	0,4453
Straw5	0,481	0,139	0,155	1,901	25	41	1200	49200	142833	0,6555	0,3445
Straw6	0,441	0,149	-0,043	2,595	23	44	1200	52800	142833	0,6303	0,3697
POly5	0,583	0,172	0,252	-0,575	50	60	1020	61200	142833	0,5715	0,4285
POly6	0,98	0,198	0,621	0,456	31	58	1020	59160	142833	0,5858	0,4142
POly7	0,337	0,103	0,903	7,69	31	60	1020	61200	142833	0,5715	0,4285
POly8	0,38	0,113	0,136	3,266	22	52	1020	53040	142833	0,6287	0,3713
POly9	0,424	0,117	-0,563	0,345	20	54	1020	55080	142833	0,6144	0,3856
POly10	0,397	0,109	-0,241	0,686	25	54	1020	55080	142833	0,6144	0,3856
POly11	0,292	0,081	-1,147	2,761	27	62	1020	63240	142833	0,5572	0,4428
Straw1	0,419	0,158	1,244	1,71	32	61	1020	62220	142833	0,5644	0,4356
Straw2	0,428	0,127	-0,769	-0,362	22	62	1020	63240	142833	0,5572	0,4428