Geometrical Intuitions of Genotypes

20

Sonit Bafna
Georgia Institute of Technology, USA

Key words
Geometry, Genotype, Graph, Design, Mies van der Rohe, Design Strategy, German country houses

Sonit Bafna
PhD Program, College of Architecture, Georgia Institute of Technology
327768a Georgia Tech Station, Atlanta GA 30318
Tel. 1 404 892-1437
sonit.bafna@arch.gatech.edu

Abstract
A case study of Mies's designs for country houses, and a sample of contemporary German villas, is used to study sociologically genotypical trends. It is argued that the genotype for these houses is best reflected in a family of permeability graphs of plans that offer a statistically stable ranking of individual spaces according to their integration values. This is used to explore a more general question regarding the relationship of the graphical genotype to the conscious designer. It is proposed that working strategies formulated within a geometrical realm are central to both generating variations in graphs and also to constraining these variations to sociologically relevant forms.

Syntax and Design
It is almost a truism within space syntax research that the sociologically significant aspects of a building are directly reflected in its spatial configuration. Since spatial configuration, within space syntax, is essentially described as a mathematical graph whose nodes are the spatial elements of the building plan, and whose links are the direct connections between them, it follows that the graphical representation of the plan should offer us a direct insight into the sociological structure embedded within the plan, and, furthermore, that the graphs of building plans housing similar societies should bear some similarities with each other.[1] The most common basis of comparison has been what is generally referred to as the "inequality genotype": the ranking of programmatic labeled spaces according to their mean depth (most often described in terms of integration values) of the nodes in the graph of the spatial configuration to which they correspond.[2]

---

1 There are a number of ways in which the "individual" spatial elements may be identified in the plan; the most common is as the set of fattest and largest convex spaces into which it is possible to partition the plan.

2 First offered publicly in B Hillier B, J Hanson, and H Graham, "Ideas are in things: the application of the space syntax method to discovering house genotypes," *Environment and Planning B* **14** (1987) 363-385. the idea of the inequality (or space)genotype has been reiterated in several subsequent publications, most notably, Julienne Hanson *Decoding Homes and Houses* (Cambridge: Cambridge University Press, 1999) 32-35. For those not familiar with the terminology of Space Syntax, asymmetry and integration values are best defined in Hillier B, A Leaman, P Stansall, and M Bedford, "Space syntax," (*Environment and Planning B* **3** (1976):147-185. For a more technical treatment, refer J A F Teklenburg, H J P Timmermans, and A F van Wegenburg, , "Space Syntax: standardized integration measures and some simulations," *Environment and Planning B* **20** (1993): 347-357.

The argument above has provided the basis of much useful research, but to me it has always raised the puzzle of design generation. How are architects, particularly those consciously playing with the spatial organization of the activities within a house, able to incorporate the "inequality genotype" within their designs. There is no record so far of architects computing the integration values of the spaces in their design to match it against a given set; nor even of them playing with graph of convex spaces. So how are they able to produce plans that are sociologically functional? This question is not an original one by any means, and the space syntax literature itself provides an outline of a possible answer—one that actually prefigures the ideas of the graphical description of buildings and the definition of the inequality genotype. In "How is Design Possible?" Bill Hillier and Adrian Leaman argued that no designers, whether unselfconscious builders working within a tradition, or self-reflective architects seeking to transcend it, really work with a clean slate.[3] Rather they always modify existing patterns. In terms of our question, then, the genotype of a building exists within each phenotype and it is the cultural knowledge of what a building involves essentially and what liberties can be taken with it that guide the intrepid builder. To some extent, and
20.2
particularly in the case of the traditional builder, this explanation is useful; the builder will follow conventions that have evolved over time to ensure that there is possibility to permit any variation that personal taste, site conditions, or any other requirements specific to the project will call for, and still preserve the genotype.[4] In fact, the argument that we began with is a direct consequence of this line of thinking, it being implied that the conventions are evolved in such a way as to allow only those geometrical variations that keep the topological—and therefore the graph—invariant. In practice, some variation in graph is allowed, since it is not in the actual graph, but in the ranking of spaces that emerges from it where consistency has to be maintained. The argument can be extended, as Hillier has done, to account for architectural work as well; according to him architecture arises as a theoretical reflection on the conventions of traditional building, and is essentially a reflective casting of those conventions into overt rules.[5]

From a more operational point of view, this argument raises questions about the limits of architectural innovation. Given that the graphical structure is, invariably, not overtly available even to the reflective designer, this line of thinking leaves the onus of spatial change upon the social process; sociologically relevant spatial patterns or any modifications to them, can only arise from covert sociological processes, not overt reflection. But there have been periods in history, most notably during the emergence of the free plan in the early 1920s, when precisely the spatial planning of buildings came to be challenged. How, then, would a radically inclined architect, seeking to rework accepted conventions of spatial organization, be able to ensure a functional house?[6] I had attempted to address this question in an earlier

3 Bill Hillier & Adrian Leaman, "How is design possible?" *Journal of Architectural Resesarch*, **3** (1) (January 1974).

4 There does remain the question of where the cultural knowledge resides. Roughly, it seems to reside partly in cultural conventions (rules that are followed from habit), but also partly in the "media" in which the designer works. Henry Glassie in his well known "Folk housing in middle Virginia: a structural analysis of historic artifacts" (Knoxville: University of Tennessee, 1974), for instance, has shown how the traditional technique of wood-working is an important factor in shaping folk housing. This brings us back to the issue of self-reflective architect whose medium traditionally is not the actual constructional material for building, but that of geometry and form.

5 These views are pervasive in Hillier's work. Perhaps the most comprehensive account is in his *Space is the Machine* (Cambridge University Press, 1996). See particularly, Ch. 1 "What architecture adds to building," 15-53. My statement above takes some liberties with his terminology, but, I believe, maintains the essential meaning.

paper, (presented at the second Space Syntax Symposium in Brasilia), by taking the case of Mies van der Rohe's early residential designs. He provides a good example of an architect trying to break away from the established traditions, specifically at the level of planning, destroying not just conventional layout patterns, but, through his open plan, glass partitions and non-supportive walls, even the cellular "language" in which they were established. My initial effort in examining these houses was directed towards establishing the genotypical consistency in these houses by describing the inequality genotype underlying them, and using that as a basis upon which to study their phenotypical differences.

Esters	e > g > f > c > t > s=l > k=d > b > p
Exp(BBE)	d=l > s > c=e=f > k=p > t
Gericke	c=e > b=l=d > k > p > f > s > t
Hubbe	c=e > k=p > d=l > f=b > s > t
Lange	e=g > l > d > k > f=b > s > t > p > c
Lessing	d > p > c > e > l > k > b > f > s > t
Nolde	k=p > d=l > e=c > g > f > t > s > b
Nolde(1)	k=p > d=l > e=c > f > g > b > s > t
Nolde(2)	c=e=l=d > k=p > f=g > s > b > t
ThreeCourt	c=e=l=d > k=p > b=f > t
Tugendhat	c=e > p > d=l=b > k > f=g > t > s
Ulange	c=d=e=b=l > k=p > f > g=s > t
Ulange(1)	c=e > l=d > s > p > f > g=t > k
Wolf	l > e > p > g > d > c=s > k=f > b > t

Figure 1: Variation in ranking by Integration values of space labels in selected Miesian houses

The surprising result that I found was that there was no discernible pattern within the ranking of the individual space labels in any of his houses (figure 1)—or, simply put, that there appeared to be no inequality genotype. My response to this unexpected result was to argue for a slightly modified definition of the genotype. I argued that the representation of a building as a graph was a two step abstraction, involving, first, a discretization of the continuous space of the building into a configuration of individual elements, and second, a mapping of that space into the graph. Space Syntax theory holds this procedure as one that separates out the topological structure of the spatial arrangement of the given building, by doing away with the relations of higher geometry. However, the step of mapping the configuration onto the graph also subsumes several topological relations such as those of enclosure, between-ness, and so on, within the graphical structure.[7] The graph, in other words, while distilling out several topological properties of the original spatial structure of the house, also leaves implicit several others. In the case of Mies's houses, I showed that representing this graph in a hierarchical structure helps recapture several of these latent properties. Such a graph showed much more stability across the sample (figure 2).

The Miesian Country Houses Revisited

Since then, I have had occasion to develop my ideas further, and to revise some of my earlier conclusions. Two questions have guided my further exploration of the issue: the first, whether my conclusion of there being no inequality genotype was hasty, or if there was some other way to interpret the rank order data, and second, whether the stable hierarchical graph that I found in Mies's houses was characteristic specifically of Mies's design techniques, or whether it spoke of the larger sociological situation within contemporary German domestic or archi-

6 The key point here seems to arise from a twist that is given to the underlying analogy as it is moved from biology to design. At the biological level, the definition of the genotype coincides with the description of the generative elements—the nucleic acid based genome is carried within each phenotype and carries all the essential information needed for the development of the continuing phenotype. In the realm of architecture, however, the level at which the genotype is described—the graph—does not coincide with the level at which the generative process occurs—that of conscious human agency.

7 This is best illustrated by the example where a room inside another one, as well as two rooms directly linked to each other are mapped essentially into equivalent graphical structures. In practice, using convex elements effectively precludes such similarity of mapping from arising, but it also "reduces" different types of topological relations between spatial objects to relations of adjacency.

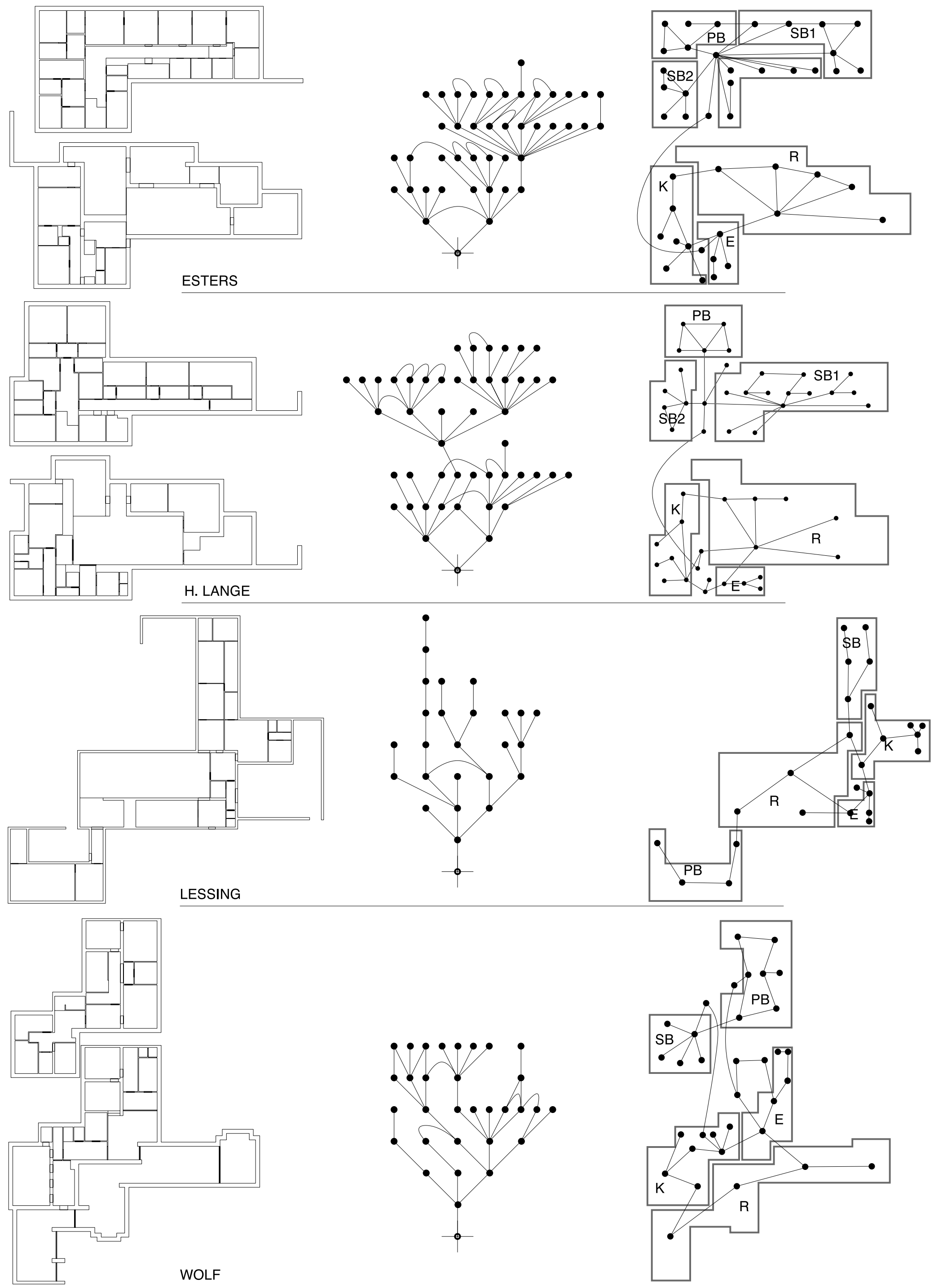
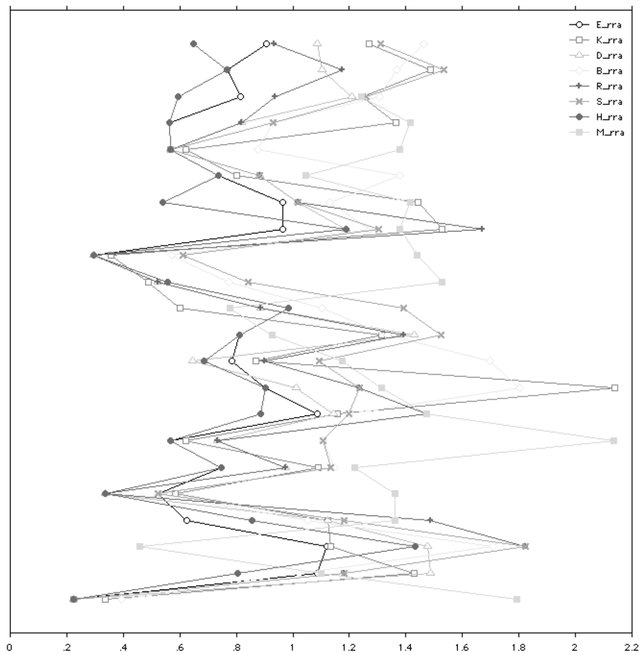


Figure 2: The consistency of the clusters (column 3) in selected Miesian houses despite the actual variation in plans (column 1), and graphs (column 2).

tectural culture. Both these questions call for an increase in sample size: in the first case, to include all the possible residential designs of Mies, and in the second case, to have a sample of German houses from the same period to compare with.

Increasing the sample of Mies's houses gave me an opportunity to subject the entire sample to a more involved statistical treatment. Following established precedent, I had originally relied on just a visual inspection of the data in order to determine the inequality genotype, but with the enlarged sample, I could now pose questions of statistical significance, and test the validity of a hypothesis of there being no genotypical pattern in the rank order of labeled spaces. My enlarged sample included almost all the plans of independent residences (*Landhauser*, or country houses) that Mies had designed during the period between 1907, when he executed his first independent commission, and 1937, when he moved to the United States. The choice of the plans excluded all those in which a complete domestic program was not discernible—and this included well known projects such as the Brick and the Concrete country houses of the early 1920s, as well as several experimental courthouse schemes of the mid 1930s. The resulting set of 24 house plans included a variety of types ranging from traditional designs of the houses of the teens to the more radical examples with free plans and extensive use of light glass, and stone partitions.

Visual inspection of the details of the ranking of the houses showed the expected characteristic randomness in the variation of the ranks of labeled spaces. But visual inspection is not all that satisfactory since the houses have different sets of spaces, varying both in type and quantity. In order to systematize this data, I selected a set of 8 spaces labels that recur in each house, are sufficiently distinct, and capture the full spectrum of domestic activity. These include the Entrance, the Kitchen, the Dining room, the master Bedroom, the Study (*Herrenzimmer*), the Reception room (*Empfangszimmer*), the Hall, and the Maid's room, the last, only if present within the main body of the house.[8] The selection covers the main categories of activity—service, reception, retiring, and circulation—in the house, as well as those associated with the three main categories of inhabitants—family, domestic staff, and guests. Any change in the domestic pattern therefore should be reflected in the RRA values of these spaces or to the corresponding rankings. These may be taken as a complete set of representative spaces—most others are either repetitive (such as toilets, baths and closets), non-programmatic (corridors and lobbies), or need not occur in all houses (sewing rooms, guest rooms, secondary bedrooms and so on).



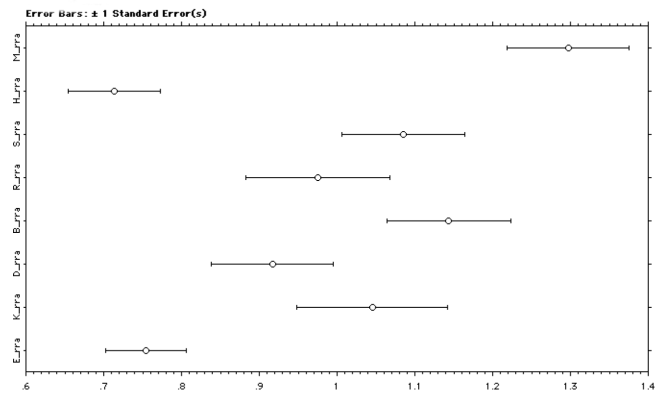


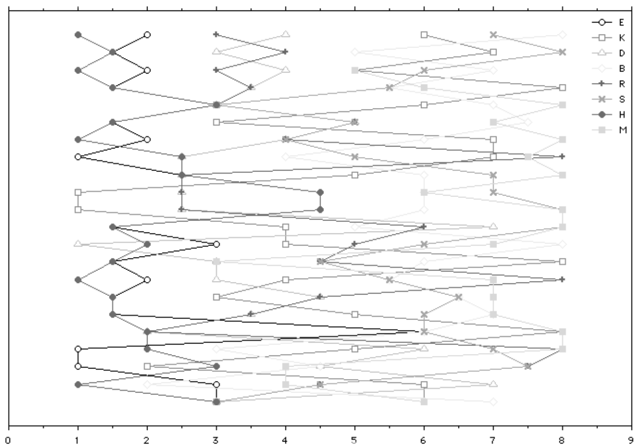
Figure 3. Univariate chart of RRA values. The individual houses are ranged along the Y axis. Lines connect identical space-labels.

Figure 4. Cell plot showing the mean and standard deviation of the RRA values of each space over the Miesian sample.

The genotype: a statistical description

Once the RRA values of these selected space labels are listed for each house, the distribution of ranks can be more easily verified. The univariate line chart in figure 3 shows this variation. The fervor of the switching ranks is obvious, but the graph also shows the overall variation the distribution of RRA in each house. A better sense of the variation in the values of each type of space can be seen in the cell plot in figure 4. Here it is easy to see that Entrance and Hall have both lower values of RRA on the average, and a low degree of variation.

8 Whenever the reference is to any of the categorical labels, these terms will be capitalized. Non-capitalized terms will refer to actual activities, or functional spaces in a house.



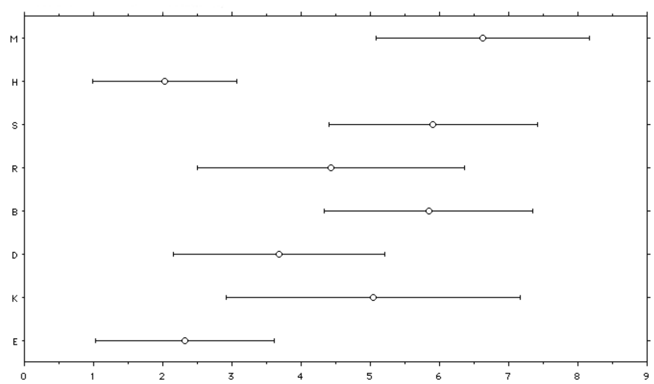


Figure 5. Univariate chart showing ranking of selected labels. The individual houses are ranged along the Y axis. Lines connect identical space-labels.

Figure 6. Cell plot showing the mean and standard deviation of the rank values of each space (according to their RRA) over the Miesian sample.

Similarly, the Maid's Room stands out at the other end of the spectrum with the highest mean value for RRA. The other spaces seem to vary in a more equivocal way however. It is difficult to see much of a pattern here.

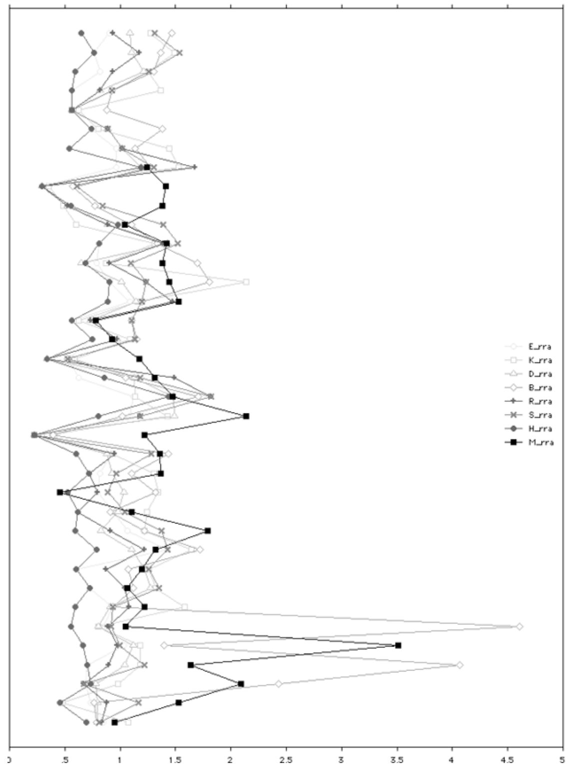
The reading improves considerably when the relative ranks of these spaces, rather than their RRA values are considered—first, it takes out the differences of variation and, second, it also makes the scale of variation comparable. The univariate line chart of the rankings of spaces (figure 5) shows the tremendous variation in ranks of spaces even more clearly than charting their RRA values. But the cell plot (figure 6) shows that the comparison between the different variables (space labels) is much more clear. As in the case of the RRA values, the Entrance and Hall do stand out at the lower extreme (the lower ranks correspond to lower RRA values) and the Maid's Room at the higher extreme. There is sharper separation amongst the other spaces as well. The Reception and Dining areas are now in a middle range, lower than the Study and the Master Bedroom. The ranking of the Kitchen however varies more generously and more equivocally between these two groups.

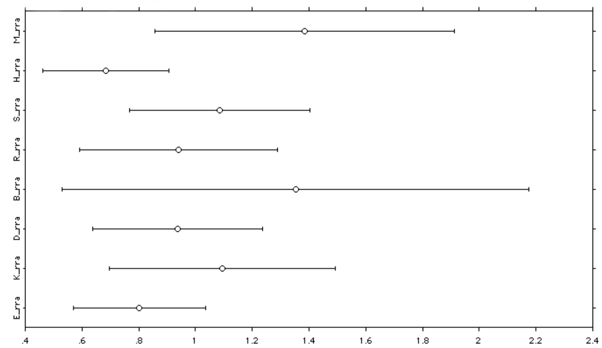
A Friedman Rank Test, (see appendix 1) confirms that the variation is not random; it gives the probability of error in rejecting a hypothesis of complete randomness as being less than .001.[9]

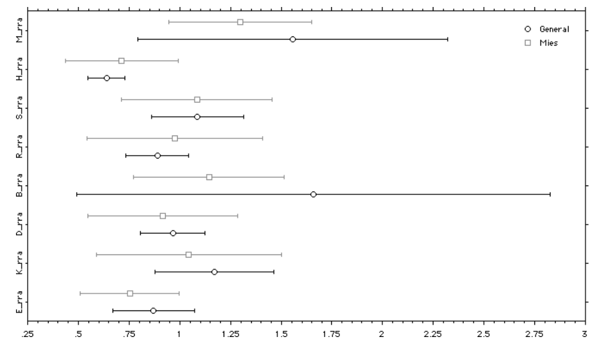
The charts and the Friedman test above indicate that there is a strong pattern to the variation in ranks of the spaces, and confirm that it is not a random variation, but we still need to confirm that the variation is genotypical. Genotype, to reiterate the premise behind this analysis, refers to the sociologically important structure of the spatial configuration—it is the part of the design that the architect cannot tamper with, if the design is to function as a working house. If the pattern of rankings is to represent a genotypical trend, then it must be present in other houses, not just the Miesian ones. Before anything further can be said about the ranking pattern of spaces in Mies's houses, it is necessary to compare them with data from comparable houses.

Figure 7 shows the RRA values of a larger set of houses that includes 15 country houses from the same period as the Miesian houses, along with the Miesian sample. The country houses in question were culled from a set of publications of the period between 1918 and 1933, all of them devoted to a description of the state-of-the-art advances in residential architecture of that period in Germany.[10] The variation in the RRA values of the houses of

9 Generally, the assumption of normality in the distribution of RRA values within a given system seems to be difficult to meet. In the light of this, all the inferential tests employed below were all conducted on non-parametric versions of the data. Parametric versions of these tests, just made as a test, gave confirmatory results, but since there is doubt about their reliability, are not reported here.







the combined sample is as chaotic as those of the Miesian sample (the houses are divided into two groups vertically in the figure). However, a more summary view using a cell plot (figure 8), as used earlier, gives us some idea of the distribution. As before, the Hall and Entrance are the least assymetrical to the rest of the house in terms of their means, and show a comparatively lesser degree of variance. The Maids' room, also as in the case of Miesian houses has the highest asymmetry on the average.[11] The rest of the spaces show an almost equal amount of overall range of variation—though here it is the Bedroom for which the overall range of variance is excessively large.

The whole pattern is seen much better when the cell plot here is split into two groups—Mies and General (figure 9). One can see side by side that means of the two groups for each variable pretty much accompany each other across the scale of RRA values. The only difference is in the Bedroom and the Maid's room, where the excessively high standard deviation of the general sample is matched by its somewhat higher mean. There is hint, in other words, of a genotypical pattern, but it is not strong enough to be conclusive.

But as discussed earlier, it is the variation of ranks of these space labels that is of interest here—partly in view of our definition of the genotype, and partly because it is the pattern of ranks that we can submit to tests of statistical significance. Once again, figure 10 shows the variation, within the combined sample, of the RRA values of each selected space label in each house. The result is the expected crisscrossing of connecting lines as the space labels shift ranks seemingly without order. And once again, it is the cell plot (figure 11) showing the distribution characteristics of each label that provides us with the interesting information. We

Figure 7. Univariate chart of RRA values in a combined sample of Miesian and General German houses. The individual houses are ranged along the Y axis. Lines connect identical space-labels.

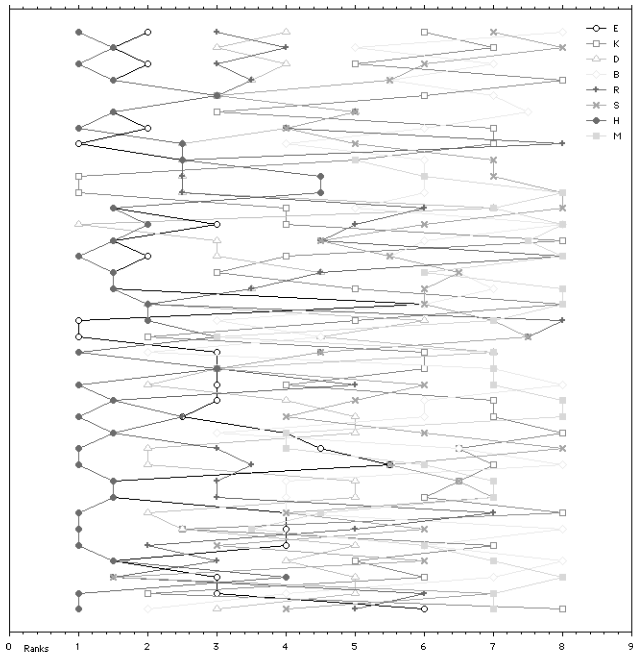
Figure 8. RIght above. Cell plot showing the mean and standard deviation of the RRA values of each space over the combined sample.

Figure 9. Right Below. The cell plot of figure 8 split into two groups: Miesian and General

---

10 H de Fries, *Moderne Villen und Landhôuser*, (Berlin, 1924), E Haenel and H Tscharman, *Das Einzelwohnhaus der neuzeit.* (Leipzig: J J Weber, 1909), C, Scherzer and Carl Ulrich, *Neue Wohn Bauten.* (np. nd.). Additional material has been drawn from J Popp. *Bruno Paul.* (Munich, 1921) and F Hoeber, *Peter Behrens.* (Munich, 1913).

11 My regular use of the term symmetry (and assymetry) here is in space syntactical terms—if the more general meaning of geometrical symmetry is intended, I will specify it explicitly.



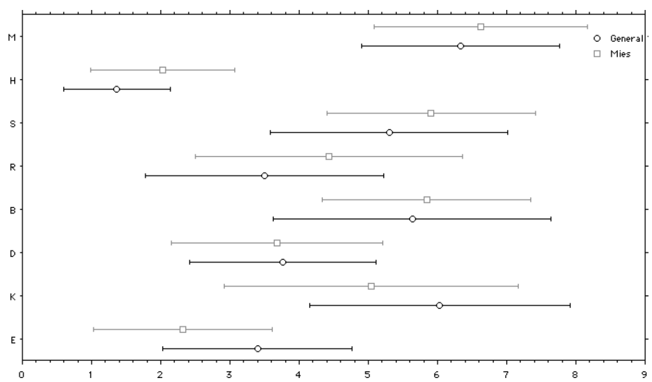


Figure 10. Univariate chart showing ranking of selected labels in a combined sample of Miesian and General samples. The individual houses are ranged along the Y axis. Lines connect identical space-labels.

Figure 11. Cell plot showing the mean and standard deviation of the rank values of each space (according to their RRA) over the combined sample, with the data split into two groups.

can see how closely, in the case of each variable, the means of the two groups follow each other. For no variable, bar the Kitchen, is the difference of mean rank between the two groups more than 1. Even more the range of variation for each variable is comparable between both the groups.

Once again a check against true randomness can be made with the Friedman's Rank test (Appendix 2). The results confirm the non-random variation in the values ($p < .001$). A final check can be made at this stage by comparing the values for each space label and checking to see if they come from the same population, or if they show a tendency to split into two groups—Mies and General. The results of the Mann-Withney rank-sum test (Appendix 3) show that in all cases except the Entrance and the Hall, the null hypothesis cannot be rejected, or in other words, it cannot be concluded that the data come from different groups. In the case of the Hall, the probability of error in rejecting the null hypothesis is .0095, and in the case of Entrance .015, both of them just within acceptable margins of rejection of the null hypothesis. Overall, therefore, it seems reasonably safe to say that there is no significant difference between the data from Mies's houses and those of the General sample. However, looking at the results, it would also be useful to consider why the RRA values for Entrance and Hall in Mies's houses are considerably different from those in the General Sample. It is interesting that in the case of the Entrance, the mean rank is lower in the Miesian sample (~16), compared to the General sample (~24), while in the case of the Hall, the situation is reversed, the mean rank for the Miesian sample being ~23 and the General one, ~14. Thus, Mies significantly made his entrance less asymmetrical, and his hall more asymmetrical as compared to the other German houses.

Comments:Genotype as statistical consistency

From the point of view of sociological interpretation—there is a very little that is surprising about structure of ranking of the programmatic spaces that occur above. It is natural that the circulation areas and lobby will be more integrated and that the bedrooms and the servants will occupy the other pole along the integration-segregation axis. But that, again, is to be expected. Sociologically, the German house of the period is not so distinct from any house today—its programmatic requirements would fit, with a few modifications, a typical European family. At the most, perhaps, two noticeable observations serve to give some typological distinction to the German house.

One is the relatively high RRA of the kitchen. Unlike, say, a suburban house in the United States today,, the kitchen in the *Landhaus*, much more of a preserve of the servants than of the family, and therefore, was relative segregated. What is more interesting is the comparatively high integration of the Entrance. The obvious implication seems to be that the house is relatively shallowest when seen from the entrance—or, in other words, that it requires a relatively fewer thresholds, on the average, to go from the entrance to any other space in the house. The inference is better understood perhaps in an inverted sense—that a greater number of thresholds have to be negotiated to go from any space in the house to any of the selected spaces (leaving, of course, the hall) as compared to the entrance. Or, stated more directly, it is easier to leave and enter the house from any of its rooms than it is to move within it.

Both these features seem to support the picture of a formal, segregated household, separated into groups (parents and children, family and servants, guests and hosts) and housed in a building where casual interaction or encounter between them is designed to occur in specifically designated rooms, and generally even at specifically designated hours. Examples from contemporary German literature (fiction, and non-fiction addressing architectural and social issues) tend to confirm this, in general, though it is also true that the picture presented by the house form itself is a little too sharp, and that in actuality the German household seems to have been more internally gregarious and informal than it appears. The point is that, to some extent, the form of the German country house is mediated by convention and habit and does not arise in directly response to the internal social mechanisms of the daily life within.

Given this, it may be legitimately inquired whether the statistical analysis above is more belabored than required. The returns seem to be not equal to the effort. My point, however, in the extended analysis above was to show, essentially, that despite what appears to be a visual chaos of values, there is still a non-random consistency amongst the observed RRA values. The genotype, perhaps, is better defined, not as a given rank order of labeled spaces, but a *statistically stable pattern of variation* of those. This is important because it has a direct bearing on the question that we began with; how is an architect, supposedly unaware of the rank order of spaces by integration able to ensure its stability. Obviously, as we have concluded in the paragraph above, this consistency is maintained through following certain rules and conventions.

Consistency and variation: the formal structure of the Landhaus

This, then, is the point that interests us—what are the conventions that maintain the structure of the German house and still allow the amount of variation that is seen? Part of the answer is actually easily given (though I will only provide an outline here in the interest of brevity). Spatially, the Landhaus is actually composed of a number of groups or clusters—there is a reception/dayroom cluster, a kitchen cluster, an entrance cluster and one or more bedroom clusters (serving family and servants). Within each cluster, the specification of the actual rooms may vary considerably, but each cluster is always completely connected spatially (it is possible to go from each room in the cluster to any other without going out of it), and each cluster in itself has a functional structure—it will include one or more primary (or programmed) spaces, and some service spaces. Typically the relationship between the primary spaces and service spaces is syntactically asymmetrical; but if there are more than one primary spaces, they need to be symmetrical with respect to the cluster, and this is handled by adding unprogrammed circulation spaces to the cluster. Organization into such structural clusters allows for the required range of programmatic variation in the actual examples of the

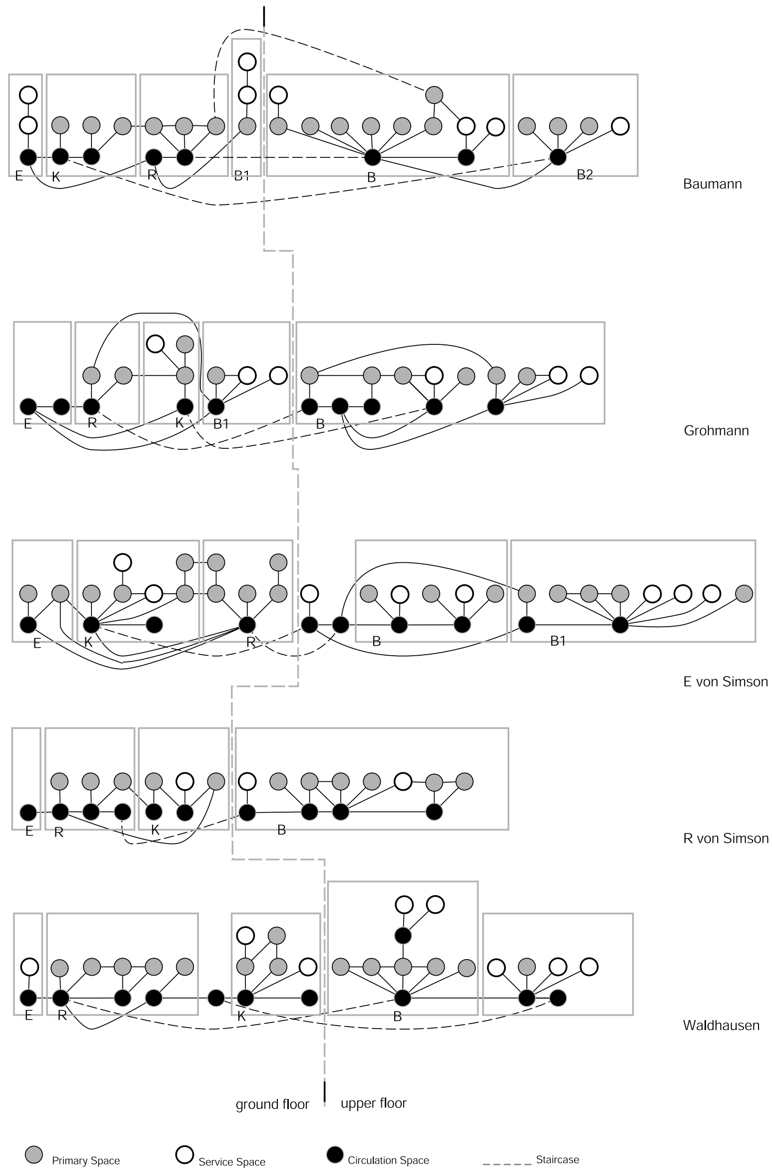


Figure 12. Accessibility graphs of a random sample of German country houses, showing the consistent structure of clusters. The graphs are justified with respect to the circulation core that nodes representing circulation elements are all at the base level.

Landhaus: the reception cluster, for instance, may include separate men's and women's parlors or a single living room, the bed cluster may include one or more bedrooms, each may have attached toilets, or not, and so on.

What is more, the structure of the house into clusters ensures the stability of the inequality genotype by fixing the range of the integration values that these spaces have. The clusters are not collected together randomly within each house, but actually connect to each other according to a loose, but definite, set of rules. First, the clusters attach to each other through their circulation spaces. This, in effect, results in the creation of the circulation core of the house. Figure 12 shows this quite clearly. It is interesting to note that syntactically this has the tendency of flattening out the house—most major programmatic spaces connect directly to the circulation core, and others are just one more threshold away—[it is in extremely rare cases that programmatic spaces are located two or more thresholds away from the core]. Note also the paucity of connections between spaces *across* clusters. Apart from a connection via the circulation core, there is only one inter-cluster connection that features regularly in each house—between the dining room and the pantry. This connection is almost invariably separate from the regular circulation-core connection of the kitchen cluster to the rest of the house (unlike, say, in the contemporary *English* country house). This, along with the fact that the kitchen cluster is almost always connected to the entrance cluster, results in a characteristic ring between the kitchen, entrance and the reception cluster.

Together, the organization into clusters and the brief specification of their interconnection seems to provide a generative model for the spatial organization of the *Landhaus,* which is both comprehensive and robust. But this is still not a model of the actual design activity—it still leaves our question of design intentions moot. There is no evidence that the German architects of the early twentieth century actually designed in this hierarchical manner, specifying the clusters first and then determining their constituency. The clusters are an underlying phenomenon—perhaps an artifact of the cognitive understanding of the residential program that the architect has. Their role in the design process is to specify the permeability requirements without there being an explicit list of programmatic spaces, and they do this by adding some semantic tinge to the abstract graph. A node in the hierarchically organized graph has an added layer of meaning—an *identity* of sorts—depending upon which cluster it belongs to, and what structural role it plays within the cluster (whether it represents a principal space, a service space, or a circulation space). To put it differently, a distinction appears between the specification of local relationships (within clusters) and global relationships (between clusters).[12] Within a cluster, nodes may be added during a design process, either by adding an unprogrammed circulation space, or by splitting a node into two (as when two activities taking place originally in a single room are split-off into two separate rooms), or subtracted from it, following a similar logic. This possibility induces an apparent fluidity within the design as it progresses, allowing temporary discretizations without commitment to a particular set of discrete spaces.

Geometry and graphs

Interestingly, it is within a higher geometrical realm that this is made possible, for the creation and subsuming of nodes would not make any sense within the restricted topology of the pure graph. It is only with geometrical consciousness, in other words, that reasons for variations within the graphs are produced. This is best seen through an example. Figure 13 shows two plans that Mies worked out for the ill-fated Dexel house project of 1925.[13] The graphs between the two houses are obviously quite different—the difference is made sharper in the justified form with the entrance as the root. What is interesting to note is the appearance and disappearance of new spaces. The structure of clusters helps us understand which spaces are created or removed. As we see it, the maids' room cluster with its three spaces—the main (bedroom), the service (toilet), and the circulation (lobby), remains constant, as does the single space cluster of the living room. The kitchen cluster shows variation with the loss of a service space (larder), while the entrance cluster is the most affected—in scheme 2, it gains

12 There is an important argument that emerges here about the discretization already implicit in the identification of nodes—it is quite possible that nodes may belong to more than one structural category, and that there may exist rooms that share nodes that actually belong to separate clusters. The premise here is that while this may be true as a final outcome, during the design process, each node will be generally manipulated as a discrete entity.

13 The house was designed for Arthur Dexel, well known artist very much in sympathy with Mies's *avant garde* experimentalism of the early twenties. Mies's procrastination and the Dexels' rude intolerance of it combined to put an end to the project shortly after it reached the first level of concretion. Refer Wolf Tegethoff, *Mies van der Rohe: Villas and Town houses*, R Stockman (trans.), (New York: MOMA, 1985) for a brief history of the project.

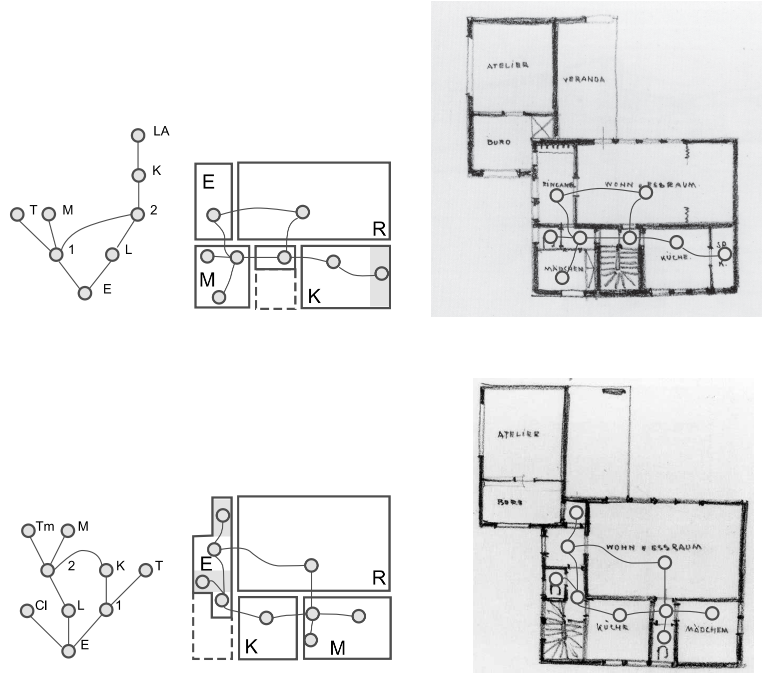


Figure 13. Intermediate designs for the Dexel house, along with the accessibility graphs drawn as both mapped onto the plan, and justified from the carrier.

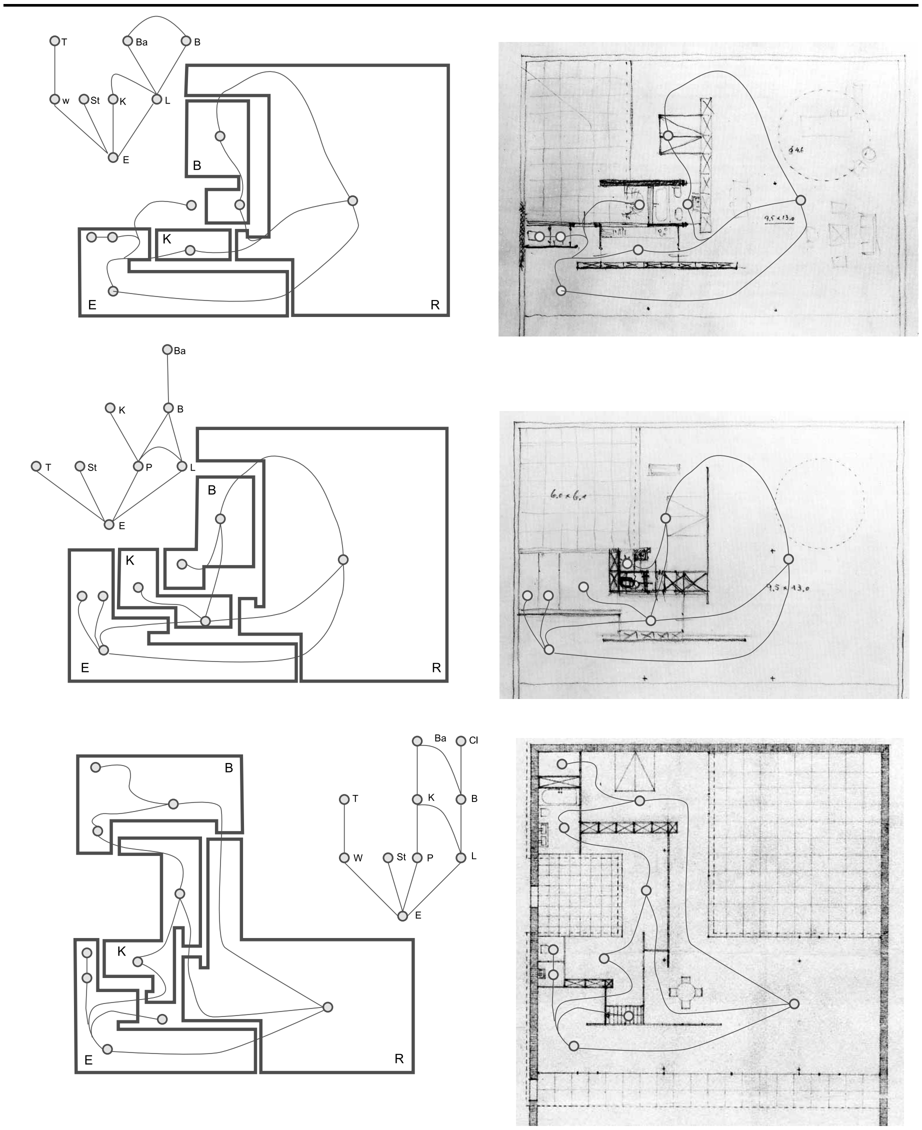


Figure 14. Intermediate designs for the House with Three-Courts, along with the accessibility graphs drawn as both mapped onto the plan, and justified from the carrier.

an additional list of service spaces—a closet and a toilet—as well as a circulation space (lobby). It is easy to see that these extra spaces result from geometric manipulation—what has moved during the design process, is the relative organization of clusters vis-a-vis one another. If this move was purely topological, the issue would simply have been that of finding a proper embedding for the graph. However, treating these spaces as geometrical quantities gives rise to the additional problem of finding a proper tesselation of the larger rectangle—these extra spaces act as a buffer for contingencies that emerge as a consequence.

In a more general sense, the designer formulates his or her design moves within a geometrical framework. In the case above, this involves starting with a rectangular outline of the main block, and trying to separate it into individual rooms through a process of subdivision achieved by a recursive partitioning of internal rooms through walls that run from one end to another. The purpose of this, of course, is to create the "genotypical" graph which is sociologically valid. But the fact that the operation happens within a geometrical setting (i.e. it is limited by geometrical constraints), makes this a difficult exercise—the process of subdivision may not create spaces of correct size at correct places. A flexibility at the levels of graphs therefore becomes useful and is guaranteed by the hierarchical structure of clusters, which allows the introduction of provisional spaces throughout the system.

The structure of clusters represents the essential genotype—the mediating element that includes both the sociologically significant structure of permeability relations between the individual spaces of the house, and the classificatory structure of spaces that represents the shared cognitive understanding of the spatial program of the house in the mind of the individual designers. If one were to take help from an overused analogy here, the structure of clusters would be analogous to the grammar of a language and the pattern of permeability relations (the inequality genotype) analogous to the observable statistical patterns that emerge in the sequence of words in the language. Geometry, then, would be analogous to the medium of the language—the phonemes and words in terms of which the grammar is defined. The significance of geometry lies, therefore, in acting as the medium through which the spatial structure of the house (or any other designed building) is formulated.

To see this better, we can compare the Dexel house designs with Mies's working sketches for the plans of what was to gel into the "House with Three Courts" project (figure 14).[14] By this time, Mies's working strategy has become strikingly different. Although even here he begins with a well defined boundary, the inner spaces are not formed by progressive and recursive partitioning, but more suggestively by inserting walls that do *not* run from edge to edge. There are, it is true, some walls that do run from partition to partition, but these are clearly secondary elements (the premier walls being unambiguously identified by their "free" edges).

As a result of both these factors, the trend of exploration in the House with Three Courts project, as its design evolves, is much more consistent and stable. The structural consistency of the justified graph is quite apparent (figure 14); in each case, it has three branches, two linear involving the wash and the staircase to cellar, and a third made up of two rings connecting the kitchen and bedroom clusters. The stability is even more apparent in the

14 The "house with three-courts" was so named by Phillip Johnson, in his *Mies van der Rohe*, (New York: MOMA, 1985) the first ever monograph on the architect and has continued to be recognized as such. It is one of a series of exercises by Mies and his students during the mid-thirties of secluded houses located in adjacent lots in urban settings—several of these houses seemed to have been designed without any detailed programmatic restrictions; but this and the "house with curved walls" remain notable exceptions.

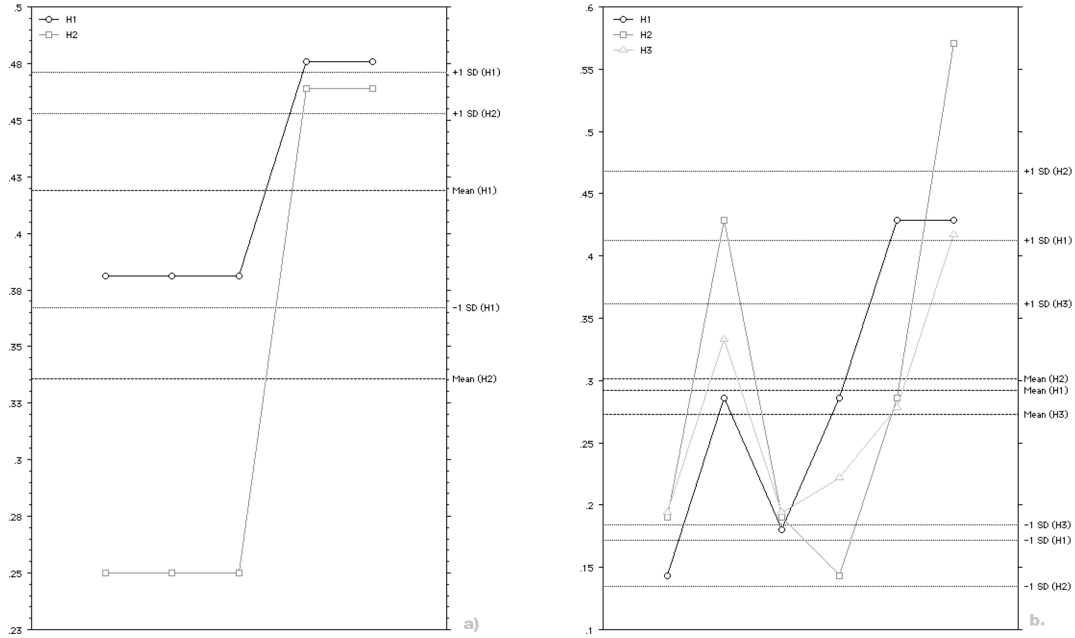


Figure 15. Ranking of space labels for all the intermediate designs for a) Dexel house and b) the House with Three Courts.

diagram of clusters, showing that the progress of design has merely involved a plastic reshaping of the clusters in more or less the same configuration. But if the impact of these exploratory processes on the actual description of graphs is observed, the results are quite surprising. The Dexel house, where the clusters are recombined in different arrangements shows an amazing consistency of the ranking pattern between both the plans (figure 15a), while the Three-Court house where the clusters are simply molded into different shapes within a consistent topology, shows as surprising a variation in rankings from one sketch plan to another (figure 15b).

The result can be explained as a direct consequence of the design strategy employed. First, this strategy does not result in left-over, unprogrammed spaces, as the previous one (more correctly, it does, but such spaces invariably remain parts of a larger irregular space). And second, this strategy allows much more dimensional flexibility. This is possible because the moving of the partition walls does not result in global changes (as, for instance, would happen if the wall separating the living and the kitchen in the Dexel house was to be moved) and can remain a local event. The result is that as dimensions of spaces change their programmatic alignments can shift too—the kitchen can turn into a pantry, the dining room can migrate into what used to be a nook, a small lobby can grow to accommodate the kitchen, and so on. In the case of the Three-Court house, even though the topological structure remains consistent, there is a great possibility of reassigning spaces to labels with local moves. In the case of the Dexel house, variation in deployment of programmatic labels is only possible with the actual variation in the graphical structure itself—the programmatic labels remain wedded to geometrically constrained spaces.

In summary there is a means-end distinction to be made here: the clustered organization does not enter into the designer's conscious design process; it is rather an artifact of the conventions that the designer follows (both personal and those deriving from his culture). The conventions are formulated in geometrical language—the rooms must have correct orientation, the shape of the house is large and square, or it is fragmented and picturesque, the rooms must be regular, and so on. This is well understood, and has inspired a line of thinking where the geometry is seen as an aesthetic fine tuning for the "graphical" core of the house. However, we need to see it more as a means for formulating the core of the house. After all, higher geometrical constraining already includes lower order (topological) relationships, so that, rather than seeing it as providing an additional constraint over a more flexible topology, it is better seen as providing a flexible means to accommodate a range of topological orders. In a strange way, therefore, this inverts the traditional argument; within architectural design, spatial organization has generally been seen as happening decisively within an entirely topological space, with geometry providing an opportunity for embellishments.What I have wanted to show, instead, is that it may be better to see the design as progressing essentially in a fully geometrical space which permits, and indeed makes possible, a great deal of topological variation within certain restrictions. The architect's task, to keep up with Hillier's formulation, is really the formulation of this design strategy in the fully geometrical space. The geometrical formulation is therefore not merely an end (an architect's, or a culture's, personal aesthetic preferences dressing up an essential topological armature), but rather a means to effect a topological scheme that works at a sociological level.

Note

As always, I must acknowledge a fundamental intellectual debt to John Peponis. A long and intense period of involvement in research with him has left my ideas irretrievably intermingled with his. This work was done as part of a doctoral dissertation under John's guidance at Georgia Tech.

Appendices

Appendix 1

Friedman Test for 8 Variables

DF	7
# Groups	8
# Ties	27
Chi Square	72.300
P-Value	<.0001
Chi Square corrected	75.303
Tied P-Value	**<.0001**

2 cases were omitted due to missing values.

Friedman Rank Info for 8 Variables

Count	Sum	Ranks	Mean Rank
E_rra	20	45.000	2.250
K_rra	20	100.500	5.025
D_rra	20	70.000	3.500
B_rra	20	119.500	5.975
R_rra	20	90.000	4.500
S_rra	20	122.500	6.125
H_rra	20	40.500	2.025
M_rra	20	132.000	6.600

2 cases were omitted due to missing values.

Friedman Test for 7 Variables

DF	6
# Groups	7
# Ties	29
Chi Square	60.916
P-Value	<.0001
Chi Square corrected	65.601
Tied P-Value	**<.0001**

Friedman Rank Info for 7 Variables

Count	Sum	Ranks	Mean Rank
E_rra	22	50.000	2.273
K_rra	22	103.500	4.705
D_rra	22	78.000	3.545
B_rra	22	124.500	5.659
R_rra	22	92.500	4.205
S_rra	22	123.000	5.591
H_rra	22	44.500	2.023

Appendix 2

Friedman Test for 8 Variables

DF	7
# Groups	8
# Ties	36
Chi Square	99.902
P-Value	<.0001
Chi Square corrected	103.251
Tied P-Value	**<.0001**

8 cases were omitted due to missing values.

Friedman Rank Info for 8 Variables

Count	Sum	Ranks	Mean Rank
E	29	81.500	2.810
K	29	155.000	5.345
D	29	98.500	3.397
B	29	173.000	5.966
R	29	125.000	4.310
S	29	171.000	5.897
H	29	50.500	1.741
M	29	189.500	6.534

8 cases were omitted due to missing values.

Appendix 3

Mann-Whitney U for E
Grouping Variable: Sample

U		89.500
U Prime		240.500
Z-Value		-2.336
P-Value		.0195
Tied Z-Value	-2.375	
Tied P-Value	.0175	
# Ties		8

Mann-Whitney Rank Info for E
Grouping Variable: Sample

Count	Sum	Ranks	Mean Rank
General	15	360.500	24.033
Mies	22	342.500	15.568

Mann-Whitney U for S
Grouping Variable: Sample

U		132.500
U Prime		197.500
Z-Value		-1.005
P-Value		.3147
Tied Z-Value	-1.015	
Tied P-Value	.3103	
# Ties		9

Mann-Whitney Rank Info for S
Grouping Variable: Sample

Count	Sum	Ranks	Mean Rank
General	15	252.500	16.833
Mies	22	450.500	20.477

Mann-Whitney U for K
Grouping Variable: Sample

U		116.500
U Prime		213.500
Z-Value		-1.500
P-Value		.1335
Tied Z-Value	-1.515	
Tied P-Value	.1298	
# Ties		9

Mann-Whitney Rank Info for K
Grouping Variable: Sample

Count	Sum	Ranks	Mean Rank
General	15	333.500	22.233
Mies	22	369.500	16.795

Mann-Whitney U for H
Grouping Variable: Sample

U		85.000
U Prime		245.000
Z-Value		-2.475
P-Value		.0133
Tied Z-Value	-2.593	
Tied P-Value	.0095	
# Ties		6

Mann-Whitney Rank Info for H
Grouping Variable: Sample

	Count	Sum Ranks	Mean Rank
General	15	205.000	13.667
Mies	22	498.000	22.636

Mann-Whitney U for D
Grouping Variable: Sample

U		153.000
U Prime		177.000
Z-Value		-.371
P-Value		.7105
Tied Z-Value	-.375	
Tied P-Value	.7074	
# Ties	8	

Mann-Whitney Rank Info for D
Grouping Variable: Sample

Count	Sum	Ranks	Mean Rank
General	15	297.000	19.800
Mies	22	406.000	18.455

Mann-Whitney U for M
Grouping Variable: Sample

U		73.500
U Prime		106.500
Z-Value		-.778
P-Value		.4367
Tied Z-Value	-.804	
Tied P-Value	.4214	
# Ties	4	

8 cases were omitted due to missing values.

Mann-Whitney Rank Info for M
Grouping Variable: Sample

Count	Sum	Ranks	Mean Rank
General	9	118.500	13.167
Mies	20	316.500	15.825

8 cases were omitted due to missing values.

Mann-Whitney U for B
Grouping Variable: Sample

U		160.500
U Prime		169.500
Z-Value		-.139
P-Value		.8893
Tied Z-Value	-.141	
Tied P-Value	.8880	
# Ties	9	

Mann-Whitney Rank Info for B
Grouping Variable: Sample

Count	Sum	Ranks	Mean Rank
General	15	280.500	18.700
Mies	22	422.500	19.205

Mann-Whitney U for R
Grouping Variable: Sample

U		119.500
U Prime		210.500
Z-Value		-1.408
P-Value		.1593
Tied Z-Value	-1.419	
Tied P-Value	.1560	
# Ties	10	

Mann-Whitney Rank Info for R
Grouping Variable: Sample

Count	Sum	Ranks	Mean Rank
General	15	239.500	15.967
Mies	22	463.500	21.068