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Exploring, Engaging, Understanding in Museums

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Abstract. Patterns of accessibility through the space of the exhibition, connections or separations among spaces or exhibition elements, sequencing and grouping of elements, form our perceptions and shape our understanding. Through a review of several previous studies and the presentation of new work, this paper suggests that these patterns of movement form the basis of visitor understanding and that these effects can be deliberately controlled and elaborated through a closer examination of the influence of the visual and perceptual properties of an exhibition. Furthermore, it is argued that there is also a spatial discourse based on patterns of access and visibility that flows in its own right, although not entirely separate from the curatorial narrative.

Keywords: museum, spatial layout, visitor movement and visibility.

1 Introduction

In museums the educational message is constructed through movement in space. Patterns of accessibility through the space of the exhibition, connections or separations among spaces or exhibition elements, sequencing and grouping of elements, form our perceptions and shape our understanding. These effects may be much more subtle than the influence of the content or design of the exhibition elements themselves; however, this ‘probabilistic’ pattern of movement in space forms the basis of visitor understanding. Furthermore, it is suggested that these effects can be deliberately controlled and elaborated through a closer examination of the influence of the visual and perceptual properties of an exhibition so that exhibition design is based upon a more complete understanding of the effects of space on visitor experience.

As visitors move through the museum and through its exhibition spaces, experience unfolds based on the content and sequencing of exhibitions and exhibition elements. What becomes clear from this investigation is that there is also a spatial discourse based on patterns of access and visibility that flows in its own right, although not entirely separate from the curatorial narrative.

2 Space Syntax Analysis

One of the limitations of previous research exploring the effects of spatial layout on visitor movement patterns has been the lack of rigorous tools for assessing characteristics of spatial configuration. The studies reviewed and the study reported in this paper employ systematic methods of describing the overall configuration of the museum setting. These methods primarily derive from the theory and methods of space syntax developed by Hillier et al. at the University College London (Hillier and Hanson, 1984; Hillier, 1996; Peponis and Wineman, 2002).

The techniques for the analysis of spatial form or “space syntax analysis” characterize spatial systems on the basis of the ways in which spaces are related to other spaces within a larger system, rather than through the more traditional characterization of metric distance. Syntactically a system of spaces is more “integrated” if spaces can be easily reached from one another, or more “segregated” if one must travel through many other spaces to move from one space to another.

Syntax analysis techniques can be applied to two dimensional building plans or urban layouts to produce quantitative measures of the characteristics of spatial layout. The analysis represents a spatial system as a series of smaller spatial units or as a system of lines of potential movement between these spatial units. For each of these representations, syntax analysis involves the study of patterns of connections, both in terms of the relationship of each spatial unit or line to its immediate neighbors measured by variables such as “connectivity,” and by the relationship of each spatial unit or line to the entire set of lines that constitute the spatial system being studied, measured in terms of “integration”.

The spatial units for syntactic analysis can also be based on visibility polygons or isovists. The term visibility polygon is used in a mathematical sense: a visibility polygon covers all points that can be linked to a given root-point by a visibility line that is not interrupted by any boundary. When visibility polygons, or isovists, are drawn at eye level, they capture the objective properties of the visual field as structured by the affordances of environment (Gibson, 1979). When they are drawn at floor level, they capture the objective properties of environment affecting movement. In space syntax, layouts are studied according to the pattern of intersection of visibility polygons, so that each position is described not only according to the properties of its own visibility polygon, but also according to the visibility thresholds that are involved in its relationship to all other positions in the layout. Software is used to flood-fill all navigable space within the area of study with a grid of vantage points, and to generate visibility (eye level isovists) or accessibility (floor level isovists) polygons from each of these locations. Each of these polygons generated from the grid of vantage points can be characterized by a series of properties including area, perimeter, minimum, mean, and maximum radial length, and so forth. Once the grid polygons have been calculated, we can examine the relationship between each polygon generating point and every other generating point to develop a set of ‘syntactic’ measures (including “connectivity” and “integration”).

It is suggested that a layout is more understandable and predictable if one can glean the structure of the global system on the basis of the structure of the local area. Thus, “intelligibility” is defined as the correlation between local measures (such as

connectivity) and global measures (such as integration). In museums, the intelligibility of space is intertwined with the manner in which space becomes accessible to exploration and the contents become available to search.

3 Patterns of Accessibility/Visibility and Visitor Movement

Tversky (2003), in her work on mental mapping, describes cognitive representations of large-scale space as constructed of elements (landmarks, paths, links, and nodes) that are held within an 'encompassing frame of reference'. She suggests that the experience of three-dimensional space can be schematized as a two dimensional representation in which systematic errors of judgment are introduced to maintain the overall reference frame. Kuipers and his associates (2003) reiterate this notion of the framework in navigational paths. The authors found that expert wayfinders exploring a complex environment soon 'discover' a small set of major paths (what Kuipers has termed the 'skeleton' in the cognitive map) that are then used to access neighborhood areas and ultimately destinations. These skeleton paths are those rich in links to other paths and destinations (similar to those paths that would be identified in syntax analysis as most integrated). In Kuipers' work, computational simulation to test this hypothesis of spatial navigation found that the greater the number of links to other destinations, the greater the likelihood of path usage (for paths of equal topological efficiency). Echoing Tversky's concept of the reference frame, this 'skeleton' of routes becomes more heavily used than others in the spatial system. In the Peponis et al. study (1990) of a geriatric facility, visitors unfamiliar with the facility were asked to explore freely to gain an understanding of spatial layout. Visitors were found to rapidly discern and follow routes that provided access to multiple destinations (more integrated routes).

This is similar to the exploratory behavior of other species. Ants, for example, that scout daily foraging paths begin their search with a wide array of random search trails at first, but soon consolidate these routes to a smaller series of primary access routes (a linear skeleton) which then fans out in prime foraging areas (see Gordon, 1999, p. 34; Camazine, 2001). If we consider complex systems theory, this pattern of widely arrayed trails quickly merging into a limited framework is an effective strategy to search a complex environment (Johnson, 2005).

These search patterns appear to be similar to visitor exploration in museums. As visitors explore museum space, they begin to follow a 'skeleton' of primary paths that link to multiple neighborhoods of destinations and can be defined in syntactic terms as more integrated paths of access and visibility based on global spatial characteristics of the museum. These paths lead to local exhibition 'neighborhoods' where movement becomes dependent upon local characteristics of exhibit visibility and accessibility.

Several studies underscore the strength of spatial configuration in defining exploratory paths. Studies of visitor movement in the Tate Gallery in the U.K. (Hillier et al., 1996; Turner and Penn, 1999; Turner et al., 2001) and a study of eight complex art museums in the U.S. (Choi, 1999) report the effects of spatial layout on both visitors' movement through spaces in the gallery and the number of people observed standing in rooms (occupancy rates). These studies confirm that, in museum settings

that offer opportunities for movement choice, patterns of visibility and accessibility are more powerful predictors of movement than either metric measures (for example, Euclidean shortest path lengths) or characteristics of the exhibit elements.

Furthermore, Choi noted that in museums with greater numbers of spaces (irrespective of the sizes of those spaces), and/or those that have more route choices, visitor itineraries were more selective, not exhausting the entire collection. As a consequence, individual spaces were less evenly visited. Choi also found that visitor viewing paths were more varied in museums with spatial layouts that were more highly integrated (spaces are easily accessible from all other spaces) and more intelligible (spatial characteristics at the local level were similar to those at the global level); however, in these museums, although individual visitor paths were more varied, museum spaces overall were visited more evenly. Therefore, Choi concluded that intelligibility and integration encourage more individual itineraries; yet these spatial qualities also result in more balanced viewing of spaces across the population of visitors. This suggests that when visitors have the opportunity to construct their own itineraries, in museums where the spatial layout offers choice but is accessible and predictable, the sum of their unique viewing paths will cover a broad array of the museum spaces.

Visitor activity in museums can be characterized as both movement through space, exploration on a more global scale (as discussed above), and static occupation of space, such as stopping at exhibit elements. The effect of space in predicting where visitors were likely to stop or spend more time is more complex. Choi (1999) found that the configuration of space in and of itself did not generate or structure the number of visitors occupying a space at any point in time. However, results of his study suggest that visitors tend to stop in spaces from which more people are visible. Thus, visitors stop more often in spaces that have greater visual connections to other spaces; they also stop in spaces that are visually connected to the more integrated spaces of the museum (the spaces most used by *moving* visitors). In this way the awareness of people in the museum is structured by spatial patterns of visibility and accessibility. Built form becomes instrumental in structuring the awareness of others, and in this way creating a sense of community based on visual encounter.

4 Patterns of Accessibility/Visibility within Open Plan Exhibition Space

In contrast to the previous studies that focused on exploratory movement patterns through space, we present a comparative study of relatively simple open-plan science exhibitions that explores movement within a single open space, and describes layout as a spatial pattern of visibility and accessibility arising from the distribution of objects in space. First we discuss how exploratory movement, visual contact and active engagement with individual exhibits are affected by these simple spatial variables. Then we discuss the effects of more complex spatial variables that take into account the spatial grouping and visual coordination of exhibits according to conceptual themes. This allows us to discuss how observed patterns of behavior may reflect not only simple perceptual information regarding the patterns of visibility and

permeability afforded by an exhibition setting, but also more complex perceptual information that relates to the cognitive content of exhibits.

Our study focused on two traveling science exhibitions created by Carnegie Science Center, each evaluated in two different settings. 'Robotics' introduced principles that govern robotic design and function, and traveled to the Great Lakes Science Center (Cleveland) and to the Carnegie Science Center (Pittsburgh). The second exhibition, "ZAP surgery", presented new technologies for medical operations, and was studied at The Tech museum in San Jose and at the Great Lakes Science Center in Cleveland. All four sites were moderately sized open plans that offered almost random sequences of movement and relatively unobstructed visibility.

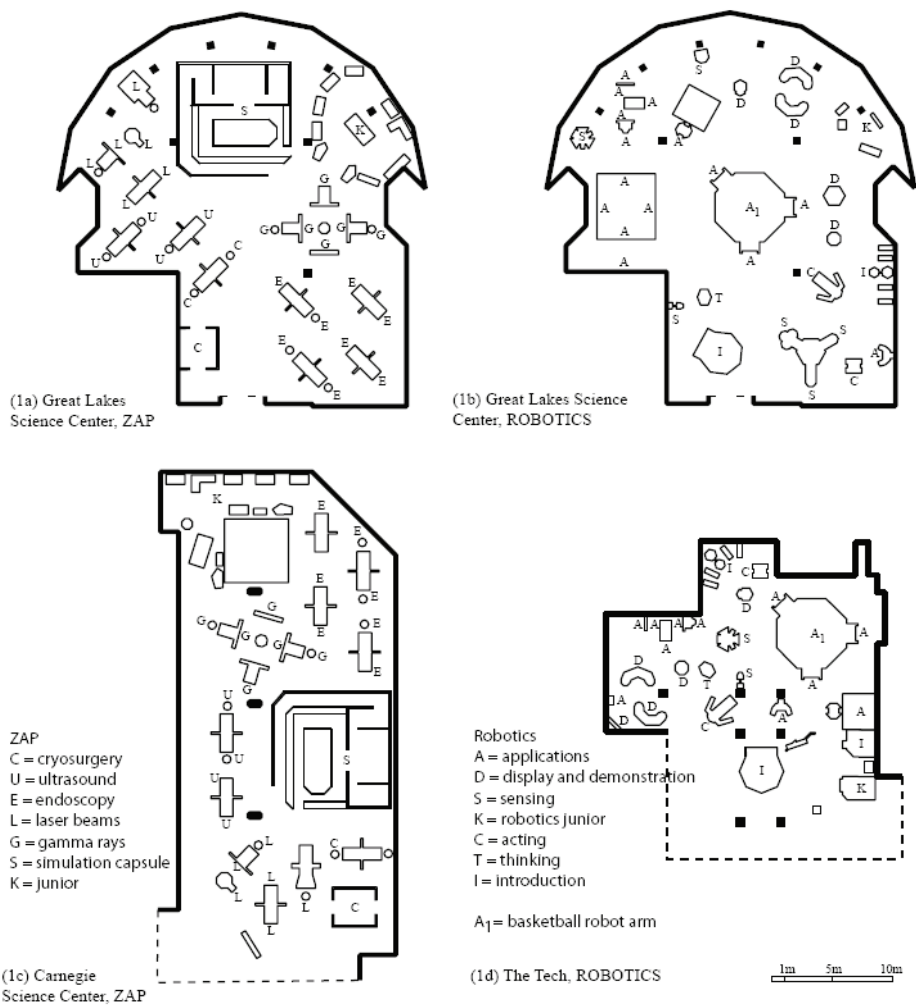


Fig. 1. Diagrammatic plans of two science exhibitions in different settings

The advantage of studying traveling exhibitions results from the spatial variability across settings. For each exhibit element, although the content and visual attraction remained constant as the exhibition is adapted to a new setting, measures of our spatial variables change. This allowed us to examine the effects of spatial variables on visitor behavior patterns above and beyond the effects of element content or presentation. Individual exhibit elements provided self-contained information; however, they were also classified according to conceptual themes. For example in the Zap exhibition, elements were visually coordinated and spatially grouped according to the following themes: gamma rays, laser beams, cryosurgery, endoscopy, and ultrasound. In the case of Robotics, the presentation of exhibits referred to aspects of acting, sensing, areas of application, demonstration of use, and exhibits aimed at “junior” visitors (see figure 1 for the spatial distribution of exhibits by theme). The conceptual themes were made more evident visually in the ZAP exhibition; in Robotics, conceptual themes were less strongly suggested, either by spatial grouping or through visual design. In both instances, however, the classification of individual exhibit elements by themes was objectively documented in the literature accompanying the exhibitions, whether in printed catalogues or webpages.

The temporary exhibition area itself varied from the relatively compact and clearly bounded shape of the Great Lakes Science Center, to the more elongated shape of the Carnegie Center, or the more compact but weakly bounded space at The Tech. The few large individual exhibit elements, such as the ZAP Cam Simulation Capsule in the ZAP exhibition (label S, figure 1a and 1c), or the Basketball Robot Arm in the Robotics exhibition (label A₁, figure 1b and 1d), tended to be so located as to divide space while at the same time acting as focal points of visual attention. There was ample cross visibility between individual exhibits. The arrangement allowed for maximum choice of exploration paths, as there were relatively few impediments to movement.

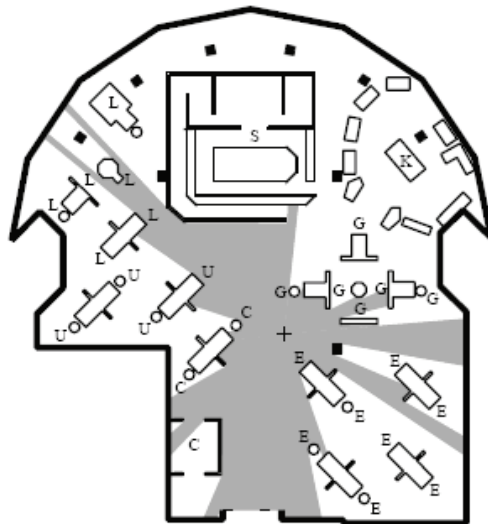


Fig. 2. Example of a projection polygon.

Behavioral descriptors. Behavioral data were collected by direct observation in the field. About one hundred randomly selected visitors were unobtrusively tracked in each setting and their paths recorded on diagrammatic plans. When a visitor path came sufficiently close to an individual exhibit, such that full awareness of the visual contents of the individual exhibit was possible, and indeed most likely, a *contact* was said to occur. When a visitor stopped at an individual exhibit element, whether to physically interact with it or to study its visual content, an *engagement* was registered. Contacts include engagements but not all contacts involve engagement. Repeat contacts and repeat engagements were also registered. Each individual exhibit was thus assigned its corresponding “1st Contact”, “1st Engagement”, “Repeat Contact” and “Repeat Engagement” counts. Repeat counts include the 1st occurrence of the relevant behavior. In the rest of this paper, these counts will be the behavioral performance scores assigned to individual exhibit elements. Table 1 provides a basic quantitative profile of visitor behavior. Visitors spent a total of between 16 and 23 minutes per exhibition, depending on the setting. Each individual exhibit element was contacted by between 46% and 59% and engaged by between 13% and 24% of the total number of visitors, also depending on the setting.

Table 1. Quantitative profile of visitor behavior in four exhibition settings.

	ZAP! Surgery Great Lake Science Center	ZAP! Surgery Carnegie Science Center	Robotics Great Lakes Science Center	Robotics San Jose Tech Museum
Number of visitors tracked	96	97	103	102
Avg. total time per visitor (minutes)	22.7	15.9	21.1	16.6
Avg. total stop time per visitor (minutes)	18.8	12.5	17.4	12.8
Avg. # of contacts per visitor	28.26	23.80	32.10	23.11
Avg. # 1 st contacts per individual exhibit	48.74	44.44	57.71	60.60
% visitors contacting each individual exhibit	51%	46%	56%	59%
Avg. # repeat contacts per individual exhibit	92.52	80.78	100.68	98.04
Avg. # of engagements per visitor	10.38	6.03	12.51	9.82
Avg. # 1 st engagements per individual exhibit	19.93	13.00	24.74	24.40
% visitors engaging each individual exhibit	21%	13%	24%	.24%
Avg. # repeat engagements Per individual exhibit	31.78	17.63	38.55	36.88

In order to determine the attraction exercised by individual exhibit elements, individual visitor paths were first described according to the sequence of contacts, including engagements, and also according to the sequence of engagements only. For example, the string of numbers {3, 2, 1, 4, 8, 12, 13, 36, 37, 35, 23, 1, 3, 2, 19} describes a visitor’s path as a sequence of contacts where each number stands for an

individual exhibit; the string of numbers describing the same visitors' engagements is much shorter: {3, 36, 3}; the first string, transcribed according to themes becomes a string of characters: {C, C, C, U, L, L, L, S, K, G, G, C, C, C, E} (exhibits 3,2,1 belong to the same theme C, exhibit 4 belongs to theme U and so on), while the second becomes {C, S, C}. The *strings according to individual exhibit elements* and the *strings according to themes* were the basis for computing the appropriate behavioral attraction scores for each individual exhibit, either based on *contacts* (including engagements) or on *engagements* only. Individual visitors are also characterized by the total time they spent in the exhibition. In the next section we will discuss how contact and engagement scores associated with individual exhibit elements are affected by simple spatial variables.

Spatial descriptors. Two kinds of spatial layout descriptors were applied, those pertaining to the relative accessibility of individual exhibit elements and those pertaining to their cross-visibility. Accessibility was measured based on the analysis of visibility polygons (drawn at floor level). Here, the Area of a projection polygon (figure 3) measures the amount of space from which the vantage point is directly accessible along an uninterrupted straight line. The indirect accessibility of each position from other positions is described according to the pattern of intersection of projection polygons. When two polygons intersect, any point on one that does not lie on their intersection is one direction change away from the vantage point of the other. Accordingly, the directional distance (number of required direction changes) of a point from any other point can be expressed as a function of the minimum number of sequentially intersecting projection polygons that must be used to move from one position to the other. Consistent with other studies, we will use the term "Mean Depth" (Hillier and Hanson, 1984) to describe the directional distance from any point taken as a vantage point of a projection polygon to all other points also taken as vantage points of projection polygons.

$$MD_{(i)} = \sum_{\substack{j=1 \\ j \neq i}}^k d(i-j) \quad (1)$$

$MD_{(i)}$ is the Mean Depth from vantage point i

$d(i-j)$ is the number of intervening polygons between vantage points i and j

k is the number of vantage points in the system

"Area" and "Mean Depth" values were computed using "Omnivista" software written by Dalton and Conroy-Dalton. Omnivista flood-fills all navigable space within each of the exhibition sites with a grid of vantage points, and generates projection polygons from these locations. Various properties are then computed for each polygon; however, "Area" and "Mean Depth" proved to have greatest relevance to our research. Average Area and Mean Depth values were computed for each individual exhibit element contact region (the region where visitors must stand in order to engage the exhibit element), taking all the vantage points encompassed by the region into account. The grid used to flood-fill space is 30cm by 30cm and so each contact region encompassed several, or even many, grid units. Figure 3a shows a

layout shaded according to the area of projection polygons drawn from each square of the 30cm by 30 cm grid. Likewise, figure 3b shows the same layout shaded according to the mean depth of the polygons.

Particularly in open plan exhibition space, it may be easy for visitors interacting with one exhibition element to see other elements. These opportunities would be revealed through analysis of projection polygons (taken at eye level). However, it is also characteristic of open plan exhibitions that one may see other exhibition elements, but perhaps only partially. The primary façade or contact area may be obscured. Our interest in looking at visibility patterns was the extent to which visitors at one exhibit element could see the contact area of another element.

Rather than all of the exhibit elements that might fall within a viewing area (projection polygon), we were interested in a graph analysis indicating the contact areas of other exhibition elements that might be viewed either fully or partially. Furthermore, in situations such as those where exhibit elements are oriented front to back, it may be that a visitor can view the contact region of another exhibit element, but someone at that location cannot see the ‘face’ of the other. To represent this cross-visibility between exhibit elements we used directed graphs, whose nodes represent individual exhibit contact regions, and whose arcs describe the visibility of one position from another. These graphs were established empirically, in the field, since the visibility of the contact face of an exhibit from the contact region of another exhibit depends on the precise details of a layout that are not available with the current automated systems. Clearly cross-visibility differs from cross accessibility in that the contact face of one exhibit element could be fully visible from the contact region of another, even when movement between the two exhibits would be hindered by the presence of intervening exhibits. One directed graph was used for Full Visibility and another for Partial Visibility. “Full Visibility” was defined as being able to see another exhibit element so as to determine its nature and contents. “Partial Visibility” was defined as being able to see enough information to determine the presence of another exhibit element, but not its contents or its nature. Thus, the “Full Visibility” graph is a subset of the “Partial Visibility” graph.

Cross Visibility graphs were analyzed using Pajek, software for graph analysis developed by Baragelj and Mrvar at the Department for Theoretical Computer Science and the Faculty of Social Sciences at the University of Ljubljana, Slovenia and available over the web (<http://vlado.fmf.uni-lj.si/pub/networks/pajek>). Of the various measures computed by Pajek, the most useful for our research was the simplest, namely degree. The degree of a node measures the number of arcs incident upon it. As we deal with directed graphs, a distinction is drawn between degree “in to” and degree “out from” a node. In order to be consistent with the terminology of previous studies, we will use the term “Connectivity” rather than degree. We will show that “connectivity in to” a node is a good predictor of behaviors. It is important that our measure of connectivity is not confused with similar measures as applied to non-directed graphs. Figure 3c shows the full cross-visibility directed graph overlaid upon a sample layout.

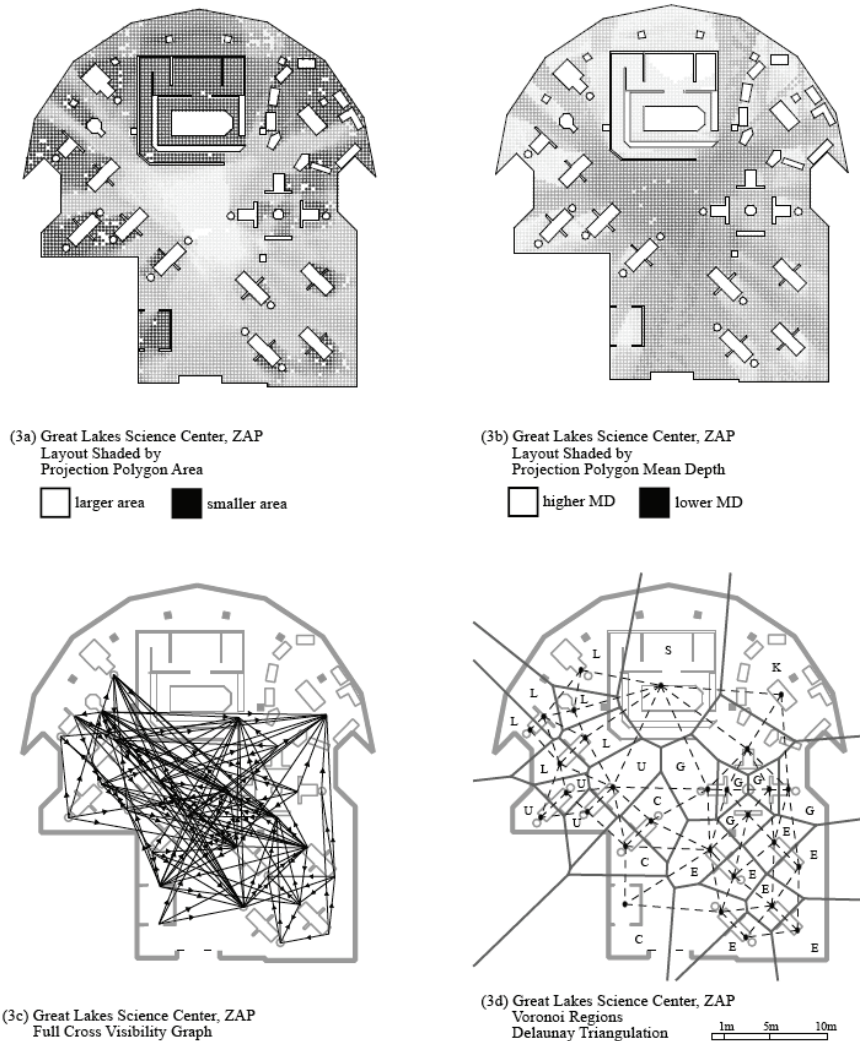


Fig. 3. Visual representations of the main spatial descriptors for one of the settings.

Table 2 presents a simple quantitative profile of the four settings. It shows that each exhibit element can be directly reached from at least 8% and up to 14% of the total exhibition area, depending on the setting. Also, no more than three direction changes are ever necessary to go from any point within an exhibition to another. Regarding cross-visibility, the table shows that between 1/3 and 2/3 of all other exhibit elements are at least partially visible from each exhibit element. These numbers confirm the permissive and open character of these layouts regarding the potential exploration paths taken by visitors.

At the simplest level, the spatial structure of layouts arises as objects and boundaries are placed in space. Objects and boundaries work as obstructions that limit

potential visibility and/or movement. The greater the limitations upon movement, the more movement patterns are distributed according to the layout. The overall question asked in this section is quite straight forward: how do patterns of accessibility and visibility affect the pattern of exploration, visual contact and active engagement with exhibition contents?

Table 2. Quantitative profile of the four exhibition settings

	ZAP! Surgery Great Lakes Sci. Center	ZAP! Surgery Carnegie Sci. Center	Robotics Great Lakes Sci. Center	Robotics San Jose Tech Mus.
Total Exhibition Area (square meters)	724	707	724	498
# of individual exhibits (excludes children's area)	27	27	35	25
Average full individual exhibit cross-visibility from other individual exhibits (% of all individual exhibits)	21.8%	12.5%	19.4%	36.6%
Average partial individual exhibit cross-visibility from other individual exhibits (% of all individual exhibits)	41.8%	28.9%	51.7%	59.9%
Avg. Projection Polygon Area (from which an individual exhibit can be reached directly)/(Square meters)	83.24	54.81	102.93	58.72
Avg. Projection Polygon Area As proportion of total Area	11.5%	7.8%	14.2%	11.8%
Avg. Projection Polygon Mean Depth (direction changes needed to reach from any position to any other)	2.472	2.280	1.958	2.067

The relationship between spatial and behavioral variables was studied based on linear correlation coefficients. We examined correlations between the Area and Mean Depth of projection polygons corresponding to individual exhibits and the four measures of behavioral attraction presented above, namely "1st Contact", "Repeat Contacts", "1st Engagement", "Repeat Engagements". We also explored these relationships for three samples: first, all people observed, that is about hundred people per setting; second, the 25% of the people that spent more time in the exhibitions; third, the 25% of the people that stayed less time. (The specific results of these analyses and statistical details are reported in a previously published paper, see Peponis et al., 2004. For the current paper, results will be presented in summary form.)

Our analyses indicated that contact counts were significantly and powerfully correlated with polygon Area. This finding, perhaps not surprisingly, suggests that exhibit elements with larger areas of direct access were associated with greater numbers of visitor contacts. Correlations with Mean Depth were less consistent,

showing only a trend that exhibit elements at greater depth were associated with fewer contacts.

When we looked at engagement with an exhibit element instead of simply contact with it, we find very different results. Engagement counts were not consistently correlated with polygon properties. Neither a larger area of direct access (polygon area) nor more direct access (fewer changes of direction or mean depth) was associated with higher levels of visitor engagement.

These results suggest that the direct accessibility of exhibit elements has a powerful effect on the manner in which the exhibitions were explored, as indexed by the distribution of contacts. Interestingly, layout seemed to work similarly for people that stayed longer and people that stayed shorter lengths of time. We might infer that layout structures the search pattern based on its most simple local properties. However, this pattern of accessibility does not similarly predict visitors' choices to engage particular exhibit elements. Further analyses showed differing effects of spatial layout on engagement patterns.

Our analysis examined linear correlations between the Full and Partial measures of individual exhibit cross visibility. Although we found correlations between our measures of visibility and visitor contacts, our results suggest that cross visibility does not affect contacts as consistently as accessibility. Cross visibility, however, had quite powerful effects upon the pattern of engagement. We concluded that exhibit elements that were visible from other elements would attract more active engagement. Furthermore, we suggest an informal pattern of spatial learning by comparing the correlations associated with visitors that stayed longer or shorter lengths of time. There was good evidence that as people stayed longer, the visibility of exhibit elements from other elements had a more detectible effect upon decisions to engage those exhibit elements. The term "informal spatial learning", as used here, refers precisely to this gradual adjustment of behavior to spatial variables; spatial variables produce more powerful affects on visitor behavior as the overall exploration time increases.

To further our exploration, we examined the effects of layout upon the sequencing of contacts or engagements. We checked to see if there were differences in the average Area and the average Mean Depth of the projection polygons for the first half of a visitor's path as compared to the latter half. We found no such tendency. Indeed, individual visit paths appeared to oscillate between more and less accessible positions, positions associated with higher and lower Mean Depth, throughout their length. Thus, the patterns of accessibility and directional distance had no strong effect upon the sequencing of exploration and individual exhibit engagement.

In an effort to extend our understanding of the visual and perceptual properties of exhibition design we examined the effect of arrangement of exhibits according to conceptual organizing themes (see theme labels in figure 3(d)). In these open plan exhibition areas, where movement and visual attention are not controlled, conceptual grouping is expressed either through inscriptions (explanatory texts affixed to the exhibits) or through design features such as color or, indeed, through the spatial arrangement of exhibits into clusters or patterns of proximity. To understand the effects of theming on visitor movement, we identified typical visitor paths and examined the extent to which exhibit elements carrying the same thematic labels appeared sequentially within the overall visit sequence or were dispersed along that

path. Plans were also analyzed to determine to what extent individual exhibits with the same thematic label were spatially adjacent (encouraging sequential viewing) or dispersed. (For this analysis, a grouping index was developed for each layout based on Voronoi diagrams and Delaunay triangulation, see example provided in figure 3(d).)

The plans were analyzed to determine the number of Delaunay arcs corresponding to adjacencies between individual exhibits belonging to the same thematic label and the number of Delaunay arcs corresponding to adjacencies between individual exhibits belonging to different thematic labels. Two grouping indexes were obtained based on the foregoing representations. The Individual Exhibit-Sensitive Grouping Index, $GE_{(i)}$ for easy reference, is the average of the ratio “internal”/“external” Delaunay arcs, computed for each set of individual exhibits corresponding to the same label “I”. The Label-Sensitive Grouping Index, $GL_{(i)}$ for easy reference, is the ratio “sum of internal”/“sum of external” Delaunay arcs considering all the individual exhibits belonging to the same label. Thus, $GE_{(i)}$ is an average of ratios, while $GL_{(i)}$ is a ratio of sums. (For further details on these analyses see the previously published paper, Peponis et al., 2004.)

The effect of the spatial grouping of labels upon the categorization of visitors' paths was analyzed by computing linear correlations between the Categorization Indices and each of the two Grouping Indices for each label. These correlations are presented in Table 3. Given that the number of thematic labels in the exhibitions under study is limited, data were analyzed not only by setting but also at different levels of aggregation, in order to allow for statistical significance in the results. When all settings are considered as a single set, we found a strong tendency for visitors' paths to be more theme-oriented when exhibit elements within thematic groupings were more clustered. The correlations are even stronger for engagements than for contacts.

This requires some explanation. It is true that contacts must, to some extent, be sequenced according to the constraints of the layout. As a visitor moves through an exhibition, she may not engage adjoining exhibit elements; however, her path will pass these exhibits (what we consider to be a 'contact'). This is why the analysis of engagements is more interesting than the analysis of contacts. Spatial groupings of themes would obviously impact contacts but less obviously engagements. *Engaging* an exhibit is different; engagement reflects a conscious decision not dependent upon adjacencies. In fact we found that the spatial grouping of themes affects engagements more powerfully than contacts, suggesting that behaviors reflect the cognitive registration of thematic labels. When we looked at these effects by setting, we found stronger correlations for the Zap exhibition than for the Robotics exhibition. In the Zap exhibition the thematic labels were more clearly grouped spatially, but also more clearly expressed visually through the use of color. (We can say with some certainty that spatial groupings of exhibition elements within themes results in visitor engagement sequences that also remain within themes; however, because of our limited sample (two exhibitions in two settings) we can only speculate regarding the effects of making the themes more visually prominent; furthermore we acknowledge that we do not know if the themes are in fact cognitively registered.)

Table 3. Correlations between the grouping of themes in the layout and the categorization of path strings representing contacts and engagements (significance shown in parentheses).

		Contacts	Engagements
All strings	GE	.551 (.0024)	.605 (.0006)
	GL	.67 (.0001)	.693 (.0001)
All ZAP! strings	GE	.471 (.0892)	.616 (.0190)
	GL	.638 (.0141)	.713 (.0042)
All robotics strings	GE	.721 (.0036)	.408 (.1480)
	GL	.582 (.0291)	.391 (.1670)
ZAP! Great Lakes Science Center strings	GE	.221 (.6341)	.644 (.1184)
	GL	.462 (.2964)	.707 (.0758)
ZAP! Carnegie Science Center strings	GE	.715 (.0710)	.586 (.1665)
	GL	.798 (.0316)	.725 (.0654)
Robotics Great Lakes Science Center strings	GE	.691 (.0855)	.338 (.4579)
	GL	.621 (.1366)	.416 (.3528)
Robotics San Jose Tech Museum strings	GE	.887 (.0078)	.515 (.2371)
	GL	.723 (.0663)	.470 (.2874)

We can summarize our findings as follows: Within open plan exhibition areas, visitors will contact more accessible exhibit elements over the course of their visit. Where visitors stop and engage exhibit elements will be influenced by spatial characteristics of visibility. Visitors tend to engage exhibit elements that are more visibly evident. As visitors spend longer in the exhibition, this effect becomes more evident.

We propose a set of principles that suggest how spatial layout affects visitor behavior:

1) The most generic, but perhaps less interesting, principle is that direct accessibility affects the exploration pattern of visitors; the more accessible an exhibit element is from all other exhibit elements, the more likely it is to be visited.

2) The less generic, but perhaps more interesting, principle is that as visitors stay longer they become more aware of those exhibit elements that are more visible from other exhibit elements and decide to engage them.

3) Although overall a visitor will contact more accessible exhibit elements and engage more visible ones, typical visitor movement paths will include more and less accessible exhibit elements as well as those that require more and those that require fewer changes of direction (directional distance) dispersed throughout their visit. This suggests that although visit paths vary by individual, as one would expect under these open plan conditions of high accessibility and high visibility, the viewing patterns across the population of visitors are more evenly distributed.

This process of relatively unstructured and locally driven exploration can be constrained by making the thematic organization of exhibit elements more apparent. If themes are not made perceptually evident, visitor search patterns tend to intersect thematic groupings randomly. However, if the curatorial intent is to channel movement more systematically according to thematic groupings, this can be achieved if themes are made perceptually evident. Thus, thematically linked individual exhibit elements could be treated as contributing to a more constrained and structured exhibition narrative. From an analytical point of view, theming can be conceptualized as the addition of relationships between objects over and above those involved with the patterns of accessibility and visibility.

To add a fourth principle:

4) Visitors tend to engage exhibit elements within thematic groupings, and the more visually coordinated and spatially grouped the elements, the stronger this tendency.

These principles suggest a model of visitor behavior that involves an open-ended search process that is subtly structured by spatial variables. Based on this model, a rather obvious prescription for exhibition design is that exhibit elements should provide relatively autonomous and self contained information at each position, and that the more critical exhibit elements should be positioned in more accessible places and made more visible from other exhibit elements in order to increase the probabilities that they will be contacted and engaged. Furthermore as the properties of layout that affect the probability of contacts or engagements vary independently of particular path sequences, the model also suggests that good exhibit element design should be independent of sequence and that the 'message' drawn from successive engagements be flexible. This is a far more demanding requirement but one naturally associated with open and permissive open plans and one clearly adopted by the designers of the exhibitions under study. Finally, designers can influence the pattern of visitor exploration through the spatial grouping and visual coordination of exhibit elements according to themes.

This link to cognitive function is worthy of further consideration. In an exploratory study, Allen (2006) found that the placement of partitions around related exhibits improved visitor recognition of common themes. For Allen's study, a small cluster of six exhibit elements was enclosed using fabric partitions. The enclosure surrounding the elements was essentially circular in shape with a large space between partitions for entry and exit, a layout described as 'a pair of parentheses' around the elements. The resulting arrangement was quite open, rather than a true enclosure. Examining the behavior of a sample of 400 visitors (half under 'no walls' condition and half under the 'walls' condition), the study assessed the cluster's attracting power (stops), number of elements visited, total holding time, and thematic coherence (understanding of the underlying theme; assessed through post-visit interviews from

160 visitors). Results indicated that the number of visitors who stopped within the cluster was significantly lower under the 'walls' condition than without walls. Of those who stopped, the holding time with walls was longer than without walls attributable to both stops at more of the elements within the cluster as well as longer engagement time with the most popular of the exhibit elements. Furthermore, significantly more of the visitors to the 'walls' condition could correctly identify the theme of the cluster.

Enclosure appears to encourage longer visit time, visiting greater numbers of elements and comprehension of common themes. However, the use of partitions constricts views, and, as we have shown, affects visitation. Although we do not have definitive results at this stage of our research, our study suggests that, through the use of spatial grouping and visual coordination of exhibit elements according to themes, a more structured exhibition narrative may be achieved without the constraints of physical containment and prescription.

In summary, it is clear that in museums, visual fields and spatial structures modulate patterns of movement and associated modes of seeing and understanding. The configuration of space structures patterns of exploration whether on the global scale of movement through the museum building or on the local scale of movement through an open plan exhibition space. Configuration also tends to structure the occupation of space through the modulation of visibility patterns, whether it is the visibility of other visitors that affects where visitors tend to stop as they explore the museum building, or the visibility of exhibition elements that affects where visitors stop in open plan exhibition spaces.

5 Concluding Comments

This paper reviews research that, taken as a whole, augments the manner in which spatial organization and its effects are understood in museum studies. Space is of course important in museum design in a number of ways ranging from the availability of areas and surfaces to display exhibits, to the creation of a particular ambience; from the construction of particular perspectives, to the creation of appropriate visual comparisons. Space is also important as a framework of orientation: when visitors know where they are in a building, they can better understand their location within the narrative presented to them by the exhibition curators. Space syntax allows us greater precision than was previously available in analyzing space as a relational structure arising from the arrangement of objects and boundaries, whether at the scale of the building as a whole, or at the scale of the individual exhibition or exhibition room. This seems particularly appropriate to museum studies. In the context of a museum, the display of the individual object can rarely be dissociated from the manner in which the individual object is related to the collection. Museum experience cannot be reduced to an accumulation of individual viewing impressions, but has to be understood as a configurational pattern encompassing many different displays as well as many different points of view, at least some of which are comparative.

The emphasis of the research reported here is on the behavioral functions and the behavioral consequences of space: we have discussed exploration and movement

paths, patterns of co-presence and co-awareness arising within the visual field, patterns of contact and exposure with displays and patterns of engagement. However, by demonstrating that these behavioral patterns are systematically correlated to spatial variables, we have also demonstrated that they can themselves be understood as spatial morphologies. In this manner, we seek to enrich the way in which visitor behavior is understood in museum studies. From a methodological point of view, learning to describe behavior as a spatial morphology is as important as learning to describe the arrangement of museum space itself.

While we have not directly engaged issues of visitor understanding and learning other than through its overt and evident behavioral dimensions, it is tempting to conclude with some comments on the prospects of spatial analysis in this regard. Should the cognitive effects of the spatial structure of museums be treated in terms of narrative? In so far as exhibition design can create spatial sequences and visual frames for viewing it would appear that space can function as a support for narration in the sense of a purposefully established sequential pattern of presentation analogous to the sequential pattern of language. This is certainly the aim of several exhibitions, especially exhibitions with historical subject matter or exhibitions presenting complex scientific discoveries. However, the research reported here suggests that the cognitive functions of museum space are not always a matter of supporting narrative presentations. Indeed, thinking of museum space in terms of narrative, in any strict sense of the word, may miss the important issues. Instead, it may be more appropriate to think of space as an independent medium for constructing meaning, that is, as an independent medium for suggesting relationships. The most generic cognitive function of museum space is that suggestion of particular ways of seeing, linked to particular ways of understanding relationships not only through seeing but also through movement. In other words, the spatial structure of a museum, or an exhibition, is its own message in addition to possible contributions to conveying linguistically stated messages. Thus, for example, space does not cease to function cognitively when possible viewing sequences are multiple and to some extent unanticipated and when viewing engagements are selective and only statistically predictable. In future work, the morphological structure described here, whether the spatial morphologies of exhibitions or the spatial morphologies of behaviors, are likely to be correlated to cognitive morphologies that cannot always be reduced to strict narrative sequencing. However dimly research reported here may point to future research on the cognitive consequences of museum and exhibition design, the need to look at space as a medium in its own right rather than as a narrative support is perhaps already clear.

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