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Designing Space to Support Knowledge Work

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Based on spatial analysis, network analysis, self-assessment questionnaires, field discussions and accounting documents, the authors discuss how workplace design and spatial layout support productivity in a communication design organization. The authors suggest that the impact of design goes beyond supporting more intense patterns of interaction and smoother flows of information. Workplace design and layout provide an intelligible framework within which collective knowledge is continuously explored, represented, interpreted, and transformed in relation to ongoing projects. Thus, the structure of space supports an organizational culture with cognitive functions.

Keywords: *office design; network analysis; space syntax; productivity; community-based planning*

Spatial Design as an Organizational Resource

In organizations whose business is the production, application, or transformation of knowledge and whose success depends on human creativity, a critical management question is how to make a given set of individuals

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collectively more creative and cognitively effective. In this article, we discuss how the design and layout of the workplace can be leveraged to support not only the formal, but also the informal, processes that make an organization productive.

We will argue that the design of space is important because it supports and restricts how two kinds of potential cognitive resources become available, so as to benefit an organization: first, people with different kinds of expertise, experiences, and skills; second, various forms of material inscriptions that are part of the cognitive creative process, such as visual representations and diagrams of different kinds, symbolic expressions, models, charts, or images. The role of space, in this respect, cannot be fully understood in terms of either providing access to people and resources or facilitating the flow of information.

We suggest that we have to move beyond two particular models that have been often applied to the study of office space: the "flow model" and the "serendipitous communication" model. Both argue that design and layout can influence information exchange and communication and hence can improve productivity. The "flow model" argues that communication is most effective if the office layout directly reflects the required flow of information, such as by placing people who need to communicate near each other. However, the flow model has obvious problems if workers need to communicate with too many others or if the patterns of communication are unpredictable. The serendipitous communication model argues that providing informal interaction nodes, such as cafes, helps to bring people together outside of normal workspaces. Thus, it partially compensates for the unpredictability of communication by encouraging frequent unplanned interactions that will increase a worker's range of communication.

We complement these models by discussing how space provides a framework within which people are related to one another and pieces of information are placed in a relevant context so that they can inform ongoing projects. We will suggest that the key to this is to look at space in terms of its intelligible structure rather than in terms of accessibility alone. Space supports organizational productivity when it provides an intelligible framework within which copresence, coawareness, and interaction patterns become engaged in the exploration, representation, interpretation, and transformation of collective knowledge in relation to ongoing projects.

In the next sections we explore a case study and bring to bear two analytic tools: *space syntax*, which will allow us to create a precise quantitative description of office layout; and *social network analysis*, which provides a quantitative description of the patterns of communication by office workers.

These complement more traditional questionnaire-based postoccupancy evaluation data and also data on productivity that are specific to the organization that is being studied.

The Organizational Charge of Spatial Design: A Case Study

Our argument, which is largely exploratory, is based on a case study: the relocation of ThoughtForm, a communication design firm, in new premises designed to support organizational culture and creativity. ThoughtForm, previously known as Agnew Moyer Smith, was founded in 1980 and specializes in communication design problems for corporations, government, and institutions. The firm deals with computer interface design, information design, identity products and names, marketing support and promotion, product packaging and sign systems, and environmental graphic design. In 2002, ThoughtForm, with about 50 employees at the time, moved from their 18,000 square foot first office in the Clark Candy Building to a new space, a 16,000 square foot floorplate in the Rivertech Center, on the Monongahela River. The interior was designed by Michael Fazio, of Archideas, Chicago. The design program as well as the final solution were based on Community-Based Planning.

Community-Based Planning refers to a Steelcase, Inc., research project aimed at developing ways for better understanding the needs of clients by using a variety of techniques. These include surveys, interviews, and questionnaires aimed at providing information about the organization; ethnographic observations and documentation aimed at understanding how the organization operates in its physical environment and how it uses various relevant technologies; and, finally, codesign, involving users in the process of formulating design aims and design solutions. Community-Based Planning has led to the development of tools that are applied as part of Steelcase's consulting services or made available to independent design firms. Both the principles and the tools associated with Community-Based Planning have been used in the case of ThoughtForm.

From the point of view of this article, one of the resulting advantages is the explicit specification of design aims based on a systematic examination of patterns of space use and patterns of organizational behavior, and involving the members of the culture themselves. However, our joint research team, including researchers from the Georgia Institute of Technology and Steelcase, only studied the effects of relocation to the new office after the process was

completed, including a postoccupancy evaluation using the same tools as those used for planning. Productivity by knowledge worker organizations is difficult to measure, and productivity by creative organizations is even more difficult. One of the goals of this project has been to develop ways of measuring both design and productivity more rigorously. The analysis reported in this article primarily relied on existing data; unless otherwise stated, we have analyzed data in new ways but have not collected new data. The purpose of our analysis is to construct a theoretical framework that can be used to further develop the knowledge base that can support similar design projects in the future.

The planning process led to the following objectives for the design of the new space:
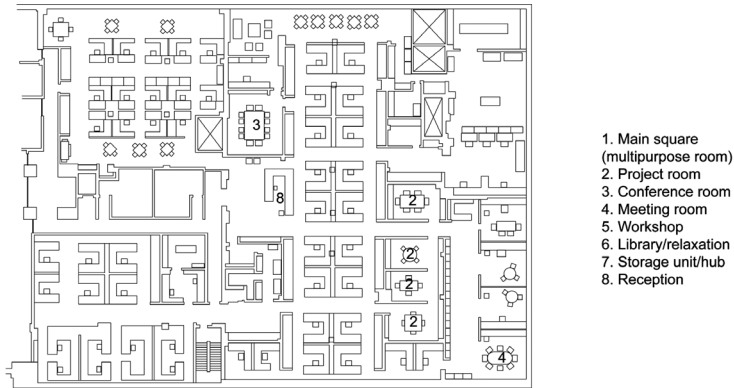
1. Expressing ThoughtForm identity in space,
2. Making the work process visible,
3. Fostering the sharing of ideas,
4. Attracting and retaining a great staff,
5. Supporting the better integration of technology,
6. Inspiring ThoughtForm clients and staff,
7. Supporting diverse work styles,
8. Accommodating growth and diversity.

These aims address three general but inherently different ways in which workplace design can contribute to organizational success.
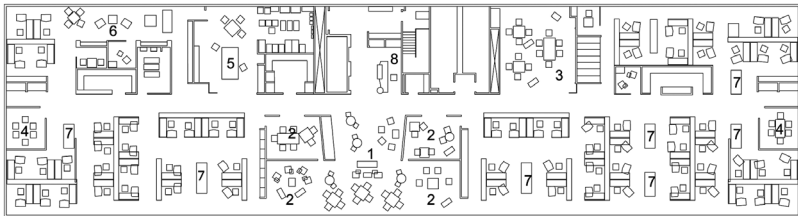
First, architectural and spatial design may project organizational identity by expressing values that are important to the organization, its fields of expertise, or its future growth (Duffy, 1974, 1992). This is a representational function, which is germane to architectural design more generally. Its relevance to management arises from its potential contribution to creating the "brand identity" of an organization within the relevant communities of the public, including actual or potential clients.

Second, architectural and spatial design may contribute to organizational effectiveness by supporting employee satisfaction and morale. The potential of the work environment to contribute to employee satisfaction and morale is well recognized in the management literature ever since the earlier human relations research (Roethlisberger & Dickson, 1939) and supported by multiple studies of office environments (Brill, Margulis, Konar, & Bosti, 1984; Brill, Weidemann, Alard, Olson, & Keable, 2001; Wineman, 1986). Its relevance to management is associated with employee motivation, which is in turn one of the bases for employee productivity.

Figure 1
The Layout of ThoughtForm Before and After Relocation,
Drawn to the Same Scale

1. Main square
(multipurpose room)
2. Project room
3. Conference room
4. Meeting room
5. Workshop
6. Library/relaxation
7. Storage unit/hub
8. Reception

ThoughtForm: old layout

ThoughtForm: new layout

Third, architecture and spatial design may affect the work process itself. This will be the focus of our argument, as mentioned earlier. Thus, we are particularly interested in Objectives 2, 3, 5, and 7, as stated above. The new layout, which arose in response to these objectives, is compared to the old layout in Figure 1.

The old layout was perceived as fragmented into several distinct spaces with connections that were unsatisfactory. By contrast, the new layout was designed around a single main longitudinal circulation space, called "the main

street," traversing a large shared social space in the middle, called "the square." The square is in front of the main entrance and reception. It can be flexibly partitioned off by foldable partitions. It is immediately accessible from four project rooms, two on each side. Project rooms are team spaces used to work on projects collectively. The "square" itself can be used for projections, presentations, meetings, and social events, as well as for informal breaks, lunch breaks, and other occasions.

Project rooms existed in the old building but were deemed to be "claustrophobic" and difficult to share because they provided no convenient way for information linked to one project to be stored away to make room for another project. Also, they were poorly equipped with information and video technologies. In the new building, project rooms were centrally located and designed with greater care. Visual information can be placed on demountable boards which can be easily stacked and moved; all walls are designed to host such boards. The rooms have audiovisual capability and movable power/cable access.

In addition to the "square" and project rooms, other shared rooms are provided, including meeting rooms, a conference room, a workshop, and a library. Of particular interest are the open spaces provided in the middle of workgroup bays. A custom-designed physical device acts as the fulcrum of these spaces. This is a storage unit, with drawers for drawings and shelves for folders and books, which functions as an information center and depository for a given group and project. The top surface of the unit doubles as a worktop and focal point, allowing people to stand around and talk or review documents over relatively brief and usually impromptu meetings. Overall, therefore, there is a clear shift toward more shared space of different kinds. Whereas in the old premises individual workstations covered 70% of the layout, with only 30% devoted to shared space, in the new setting only 55% was individual, with the rest shared. To complement this, small enclosed rooms are provided for individual privacy and for receiving calls.

Access and Interaction

The Community-Based Planning processes made available two sources of information regarding the impact of relocation: first, self-assessment questionnaires; and second, an analysis of interaction network data. We will highlight relevant information from each source. As shown in Table 1, the self-assessment questionnaires revealed very strong positive shifts with regard to perceptions of four affordances:

Table 1
Employee Perceptions of the Workplace
Pre- and Postrelocation (in Percentages)

Agreement with the following statements	Pre	Post	Change
A variety of spaces are available to meet the needs of different activities.	83	94	11
I have access to quiet private spaces when I need them.	39	92	53
It is important that I am aware of other people's activity around me.	63	33	−30
I have a personal workspace that is designed to minimize distractions.	32	33	1
I frequently have "hallway" conversations with my coworkers.	78	69	−9
I can quickly access information that is relevant to my job.	98	100	2
I have a workspace that is designed and laid out to help me work effectively.	56	69	13
I have access to spaces for my unplanned meetings.	95	100	5
Meeting spaces are available when I am trying to schedule a meeting.	98	100	2
I have access to project or team rooms when I need them.	68	100	32
I have access to right technology to support collaboration with others.	80	89	9
The team spaces I use are designed and laid out to support teamwork.	54	83	29
I have access to spaces that support exchanging ideas with others.	84	94	9
I have access to casual spaces when I need to relax.	51	83	32
I can easily access food and beverages when I need.	95	97	2
The spaces I use are comfortable to work in.	78	86	8
I can easily locate the people I work with and places I use in buildings.	100	100	0
I am comfortable with the amount of natural light in the spaces I use the most.	66	89	23
I am pleased with the views I have from the spaces I use most.	66	83	17

1. Access to team work spaces,
2. Access to informal relaxation spaces,
3. Access to quiet work spaces, and
4. The presence of natural light and views.

The first three affordances suggest that the workers felt that relocation made more abundantly available a variety of work settings. By inference, there is progress toward facilitating a variety of work styles. In this respect, the simultaneous satisfaction of the need for teamwork and the need for quiet areas is particularly noteworthy. The fourth perception underscores the awareness of perimeter and the availability of external and internal views.

Network data is based on questionnaires asking people to identify those with whom they interact on a daily, weekly, monthly, quarterly, and yearly basis. Six kinds of interactions are studied: work-process interactions; social interactions; interactions linked to looking for improvements in work practices; interactions linked to seeking expert advice; interactions linked to innovation; and interactions linked to decision making. It is held that network analysis provides us with a good description of both formally prescribed and informal interaction processes that are the working mechanism of an organization (Cross, Borgatti, & Parker, 2002; Tichy, Tushman, & Fombrun, 1979). Network analysis uses the measure of *density* to express the reported interactions as a proportion of all possible interactions for a set of individuals. There is some evidence in the literature that the intensification of interaction has positive effects on productivity by supporting greater coordination (Reagans & Zuckerman, 2001), by making advice available (Sparrowe, Liden, Wayne, & Kraimer, 2001), or by spreading specialized knowledge (Rulke & Galaskiewicz, 2000); it may also have positive effects on product quality (Rubinstein, 2000).

The density of interaction can be studied at different time frames, by including in the analysis either all interactions, or only those interactions that occur at least once within a given time interval. The Steelcase network questionnaire asked people to identify those with whom they interacted at the daily, weekly, monthly, quarterly, and yearly time intervals. No data were collected regarding the number of interactions between a given pair of people within a single interval. Thus, although we can distinguish frequent (for example, daily or weekly) and less frequent (for example, monthly or quarterly) interaction pairs, we cannot determine the exact frequency of a given interaction (for example, whether it occurs two or three times a day, two or three times a week, and so on).

The standard Steelcase tool creates a weighted index that combines interactions at different time scales to give an overall characterization of an organization and its dynamics. For the purposes of this analysis, we also computed unweighted measures of interaction density for all time intervals, taken individually as well as cumulatively. Comparisons of densities taking into account all time frames before and after the relocation suggested little

change, as shown in Table 2. Disregarding the distinction between different kinds of interaction, we see that each individual talks to about 65% of all other available individuals. When we look at specific kinds of interaction we see that the work-related and social interactions make the highest contribution to this overall density. In short, ThoughtForm is a closely knit organization, partly because of its small size.

We augmented the analysis by computing the densities corresponding to frequent interactions, the term frequent referring to the densities of interactions within shorter periods—the daily, the weekly, and the aggregate daily and weekly periods. Here, a reminder is useful. The densities of frequent interactions do not measure how frequent the frequent interactions are, but how many people are involved in frequent interactions. For example, the density of the daily time period measures how many pairs of people interact one or more times a day. We found consistent and often strong density increases, as shown in Table 2. After relocation, more pairs of people talk to each other at the daily and at the weekly time period. This is true for all kinds of interaction, including those related to work process and social. Thus, we can say that the change in premises is associated with an intensification of interaction in the shorter time periods. This does not mean that the same people talk to each other more frequently, but rather more people talk to each other daily and weekly. The intensification of interaction was the most tangible evidence of the impact of design on the functioning of the organization, as captured by the data collected for the Community-Based Planning process.

Can we attribute the intensification of interaction to the new design? Previous studies (Wineman & Serrato, 1998; Serrato & Wineman, 1999) linking interaction patterns to spatial layout, the provision of shared group spaces, and the relationship to well-connected circulation systems would lead us to expect so. The self-assessment questionnaire and the findings regarding the availability and quality of spaces for teamwork in the new premises would suggest that the new design is indeed responsible, at least in parts, for the intensification of interaction patterns. The issue, however, merits further discussion. How might the design of the workplace contribute to more intense interactions?

Any building provides for two kinds of interaction—planned and unplanned. Planned interactions are usually accommodated in formally scheduled meeting rooms or individual offices. Unplanned interactions can occur everywhere and can arise as a by-product of copresence and movement in and around work areas (Hillier, 1996; Hillier, Hanson & Peponis, 1984; Peponis & Wineman, 2002). Planned interactions, such as weekly or monthly

Table2
Changes in Network Densities Associated With Relocation

	Social	Working	Innovation	Improvement	Expert Advice	Decision Making	All Networks
Total network densities before the move	.324	.298	.148	.201	.139	.141	.644
Total network densities after the move	.317	.265	.143	.176	.137	.129	.651
Daily network densities before the move	.061	.035	.012	.025	.015	.011	.071
Daily network densities after the move	.083	.042	.013	.026	.013	.012	.106
Weekly network densities before the move	.127	.107	.046	.067	.046	.041	.212
Weekly network densities after the move	.137	.126	.051	.076	.053	.042	.233
Daily + weekly network densities before the move	.189	.142	.058	.092	.061	.053	.283
Daily + weekly network densities after the move	.220	.167	.063	.101	.066	.054	.339
(Daily + weekly)/total before the move	.582	.477	.389	.459	.443	.373	.439
(Daily + weekly)/total after the move	.693	.630	.442	.577	.484	.420	.521

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meetings, are not likely to occur in the shorter time periods. The increase of densities at these periods would suggest that much of the additional interaction is due to unplanned encounters. In the case of ThoughtForm, this inference seems especially warranted for the social and work networks, which show a significant increase of density not only at the weekly but also at the daily interval. And yet, a more careful examination of the self-assessment questionnaire would seem to challenge the interpretation that the new premises are more conducive to unplanned interactions. Although the perception that in the new premises there is access to spaces for unplanned meetings is universal, this represents no great change in comparison to the old premises. At the same time, the perceived frequency of "hallway conversations" in the new premises drops rather than increases.

We suggest that there is a way to reconcile the seemingly opposed inferences that can be drawn from the interaction and the self-assessment questionnaires. We propose that the new building allows more people to talk to each other at the shorter time periods but also incorporates such interactions in spaces that are associated with the work process, rather than locating them in seemingly detached hallways or in dedicated meeting areas alone. In short, we propose that the intensified pattern of interaction is integrated with the work process and appears to employees as a natural part of it. This hypothesis will be supported by our discussion of productivity below.

The Impact of Design on Productivity

As mentioned above, our involvement with ThoughtForm was initially an attempt to arrive at measures of the impact of design on the productivity of the work process. This is a difficult question not least because it is not readily clear what measures of productivity are appropriate. Some of the obvious candidate measures, such as profitability per project or per time period, are evidently subject to the influence of variables that can neither be controlled nor systematically correlated with workplace design—for example, periodic or longer term shifts in the economy. Such measures would cancel out the possible effect of good design by confounding it with the effect of other factors. Other obvious measures, such as the real estate cost per employee, or as a proportion of business turnover, are too narrow and insensitive to the possible influence of design on the work process. They implicitly treat the building as a necessary cost rather than as a management resource. The problem, therefore, is to arrive at measures of productivity that make sense from a management point of view, while at the

same time incorporating some understanding of how workplace design might influence the work process.

This is by no means an easy task. It essentially requires that we adjust organizational reporting and accounting procedures so as to provide for tests of our ideas of how workplace design should serve management ends. This is not always possible. For example, in our case study we retrospectively evaluate a change that was not planned in conjunction with reporting and accounting models. Under the circumstances, the best-alternative scenario is to review the current ways in which a company accounts for its work process and mine them for information that is likely to be sensitive to the effect of workplace design. This is the path that we took in our present case study, in consultation with ThoughtForm management.

The starting point for our inquiry was provided by some of the outcomes of the process of Community-Based Planning. The success of ThoughtForm depends on its ability to foster creativity among teams of highly skilled and qualified individuals. Thus, as we noted earlier, the charge for the design of the new workplace included some of the perceived requirements of creative work, such as supporting diverse work styles, attracting and retaining great staff, making the process transparent, fostering and sharing ideas, or integrating technology within the pattern of space use.

There are good reasons to suggest that creative work is design-dependent. These can be intuited more clearly if we think of a number of contrasts that are familiar in the organization theory literature, such as the contrast between routine versus nonroutine work (Perrow, 1970), predictable and standardized versus changing tasks (Trist, Higgin, Murray, & Pollock, 1963), predefined patterns of the division of labor versus continuously adjusted and emerging patterns of collaboration (Burns & Stalker, 1961), and formal procedures for decision making versus informal processes (Etzioni, 1961; Gouldner, 1954). Such contrasts are relevant to forming a better understanding of the role of physical design.

When work tends to involve more routine, predictable, and standardized tasks with well-defined divisions of responsibility or formal procedures for decision making, then workplace design has to enable, with greater or lesser success, processes of work and communication that can be independently prescribed. When work tends to involve nonroutine, changing tasks, shifting patterns of collaboration, or informal processes of consultation, then workplace design provides a tacit but rather unique means to structure the processes of work and communication.

The potential of workplace design to support processes of communication that are not constrained by formal organization and task assignment has

regularly been noted in the literature. Thus, Allen (1977) has advocated open office planning based on a finding that in research companies that submitted successful contract bids faster, engineers sustained patterns of interaction beyond their assigned workgroup or department, and sometimes outside the organization; these patterns created a large potential pool of ideas and information that exceeded organizationally formalized arrangements. Peters (1982) similarly recognized the importance of serendipitous encounter as a means for sustaining organizational creativity and flexibility.

With these ideas in the background, and being aware of the importance of creative work to the success of ThoughtForm, we looked more carefully at the way in which spent hours and billable hours per project are accounted for and recorded. For each project, five stages of work are distinguished:

1. Proposal development,
2. Understanding the project,
3. Envisioning the response to the project,
4. Design,
5. Production.

In consultation with management, it was determined that the proportion of group work increases sharply from the first to the second stage and decreases gradually after that. Furthermore, the extent to which tasks become predictable and open to routine increases in the production stage. With this in mind, and accepting management's perception that the quality of projects delivered remained relatively constant before and after the move to new premises, we decided to look at the proportion of effort that was devoted to the different kinds of work. We hypothesized that the move to new premises made creative work and group work more efficient and productive. Consequently, the proportion of time spent on such work would decrease. In formulating this hypothesis we supposed that the change in premises did not similarly affect the efficiency and productivity of the more routinized production work.

Company management agreed to examine their records to identify projects of comparable nature that were completed in the two years before and after the change of premises. Four such pairs of projects were identified. Of course, the sample of projects is too small to allow statistical analysis. Furthermore, the way in which employees log their time to track different categories of work for billable hours cannot be but an approximation to the nuances of the work process as it unfolds in real space and time. Still, the analysis of project records provides some revealing insights.

As shown in Table 3, the proportion of billable hours devoted to design consistently went down and the proportion of billable hours devoted to

Table 3
Proportions of Different Kinds of Working Time Spent on Similar Projects Pre- and Postrelocation

|	Total Hours	Proposal (%)	Understand (%)	Envision (%)	Proposal + Understand + Envision (%)	Design (%)	Production (%)	Management (%)
Project Type A before	288	0.0000	1.3889	4.8611	6.2500	90.6250	3.1250	0.0000
Project Type A after	97.5	0.0000	13.0769	5.8974	18.9743	34.8718	43.3333	2.8205
Project Type B before	3599.75	0.0000	3.7780	14.2718	18.050	41.3154	34.0580	6.5768
Project Type B after	1057.75	0.3072	0.4018	4.0652	4.7742	36.1144	57.2442	1.8672
Project Type C before	292	1.1986	5.1367	3.9384	10.2737	62.2432	25.3425	2.1404
Project Type C after	105.75	0.0000	2.1276	4.0189	6.1466	45.3901	43.9716	4.4917
Project Type D before	2777	1.9175	5.7166	12.2884	19.9225	57.0490	21.0839	1.9445
Project Type D after	682	0.1026	6.6349	10.8138	17.5513	52.5660	24.5601	4.3988
All types before	6956.75	0.8157	4.510	12.6568	17.9825	50.5157	27.2325	4.2692
All types after	1943	0.5275	3.3196	6.5234	10.3705	42.3314	44.3515	2.9465

production went up for all four pairs. The trend is not equally clear for the other categories of work taken one at a time. Envisioning, for example, which is clearly essential to the creative component of any project, was evenly split with the proportion of time spent on it going up in two cases and down in the other two. However, when the proportions of time devoted to proposal development, understanding, and envisioning are added up, the overall proportion is lower for the projects after the change of premises compared to the those before the change for three out of four pairs. In addition, after the move, the proportion of total time spent on each of the four categories of proposal development, understanding, envisioning, and design went down, whereas the proportion spent on the fifth category, production, went up. Thus, there is some systematic evidence that the measurable changes in the pattern of interaction associated with the change in premises, as well as the reported changes in the suitability of the design to support creative work, are associated with quantifiable positive changes in productivity, especially where nonroutine tasks are involved.

The Functions of Space

The design of the new workplace is therefore associated with positive changes in user perceptions about how well the workplace supports their work, an intensification of work-related interaction and, more importantly, a positive change in productivity. In short, ThoughtForm provides us with a success story regarding the relevance and contributions of workplace design as an aspect of organizational success. However, to really understand how design can work as an instrument of management, we have to describe exactly which properties of the new workplace are important and understand how they function. From the point of view of architectural research, the success story as presented so far is not just a finding but also a question. To address this question we have applied two particular techniques of spatial analysis to the old and the new premises; both techniques are common in the field of space syntax (Bafna, 2003; Hillier, 1996; Peponis & Wineman, 2002).

The first technique of spatial analysis is based on a representation of the layout that reflects the fewest and longest circulation lines that are needed to connect all spaces, complete all circulation loops and reach into each individual workspace (Peponis, Wineman, Bafna, Rashid, & Kim, 1998; Turner, Penn, & Hillier, 2005), as shown in Figure 2a. Circulation lines are then evaluated as to their connectivity (number of other lines intersected by

Figure 2
Spatial Analysis of the Layout of Thought
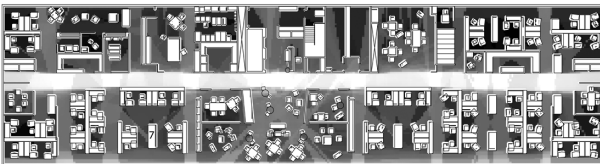**Form Before and After Relocation**
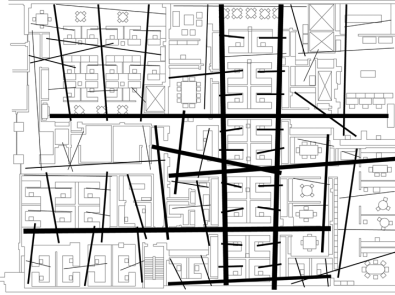
ThoughtForm: old layout, linear integration map
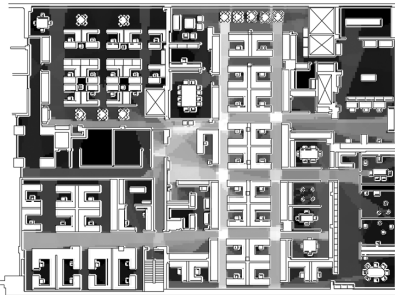
ThoughtForm: old layout, knee-level visibility polygon analysis

ThoughtForm: new layout, linear integration map

ThoughtForm: new layout, knee-level visibility polygon analysis

each line) and their degree of integration into the system, with the integration being measured in terms of their directional distance from all other lines in the system (average number of direction changes needed to reach all other lines). More integrated lines are shown thicker. Previous studies have already demonstrated that integration affects the distribution of movement and also the density of interaction over a layout (Grajewski, 1993; Penn, Desyllas, & Vaughan, 1999).

The second technique of spatial analysis is based on the analysis of the visibility polygons drawn from each of a grid of tiles covering all accessible areas (Turner, Doxa, O'Sullivan, & Penn, 2001). The word *visibility* is used in a mathematical sense, so that the visibility polygon of a viewing point covers all other points that can be linked to the viewing point without crossing a boundary. Thus, when visibility polygons are drawn at knee level, as here, they represent all areas that can be accessed in an uninterrupted straight line of movement from a point of origin. Other areas beyond this polygon cannot be accessed by a direct line of sight from the origin. Some of the areas outside the visibility polygon, however, can be accessed from that lie in it. Based on this, all areas beyond the visibility polygon of a point of origin can be recursively partitioned into regions that can be accessed by at least some point in the original visibility polygon or a previously defined region. As a result, any points in the plan beyond the visibility polygon of the origin are one or more such recursively defined regions, or steps, away. In Figure 2b, gradations from lighter to darker gray indicate shifts from tiles from which other tiles are few or many steps away, respectively. Numerical data associated with the two kinds of analysis are provided in Table 4.

The analysis shows the new premises to be more integrated and better connected than the old. Thus, in addition to the emphasis on shared spaces, the new design brings everyone closer together. More specifically, because we measure directional rather than metric distance, we can say that the plan reduces the perceived or cognitive distance between people. This is largely achieved by virtue of connecting most spaces to the central circulation spine, as well as a secondary circulation route by the front windows. There is, however, a second difference. In the old design some work areas were much more integrated than others; this means that different groups have different degrees of spatial membership to the overall community as expressed in the layout. The new design, by contrast, is not only more integrated, but also more egalitarian. In addition, when one stands in the work areas there are extensive views across the low partitions, which make the egalitarian nature of the design explicitly visible.

Table 4
A Syntactic Comparison of the Old and New Premises

	Old Premises	New Premises
Lines Analysis		
Area	1672 m^2	1486 m^2
Number of lines	90	71
Integration	1.45	1.68
Connectivity	2.64	3.07
Total line length	786.29 m	735.43 m
Visibility Polygon Analysis		
Number of tiles	17,012.00	17,841.00
Integration	9.4883	15.1745
Connectivity	445.7961	808.3257

The quantitative description of the layouts of the old and the new premises in terms of connectedness allows us to bring together social networks and space in ways that are more precise than those typically found in the literature. Indeed, although there are some studies of the positive effects of colocation (Bulte & Moenaert, 1998), there are few studies of the way in which the internal spatial structure and design of an organizational setting affects network measures. We ask whether there is a correlation between the spatial connectedness of a person's work station in the layout and their connectedness in the networks of interaction (Peponis, 1985). The Steelcase Network Analysis Tool computes three measures that describe an individual's position in the network, all of them based on Niemenen's (1974) and Freeman's (1979) work on the description of centrality in networks.

The *hub value* (related to *degree* in network theory) simply measures the number of other individuals with whom the given individual interacts. It is a local measure, in that it only takes into account direct relations reported by an individual. The next two are considered global measures because they take into account indirect relations as well, and effectively describe an individual's relation to all other individuals in the system.

The *pulse-taker value* (related to *closeness centrality*) measures how many intervening information transfers are needed for a given individual to communicate with all other individuals, including those with whom there are no direct contacts.

The *gatekeeper value* (related to *betweenness centrality*) measures the number of communications between pairs of individuals that a given individual controls, in the sense of acting as a mediating channel. The values reported

Table 5
Correlations Between Networks and Space

Correlation Matrix	Linear Integration of Workspace Location in		Correlation Between Rankings Before and After Move
	Old Premises	New Premises	
Social hub value	.097 (.51)	.480 (.003)	.489 (.000)
Social gatekeeper value	−.161 (.27)	.471 (.003)	.254 (.028)
Social pulsetaker value	.037 (.08)	.506 (.001)	.494 (.000)
Work hub value	−.081 (.58)	.400 (.014)	.456 (.000)
Work gatekeeper value	−.083 (.57)	.613 (.001)	.322 (.006)
Work pulse-taker value	−.138 (.34)	.327 (.048)	.422 (.000)

Note: Linear Integrations columns reflect Pearson correlation coefficients between descriptors of an individual's position in the social and work networks and the location of the individual's workspace in the layout. The correlation column reflects Kendall correlation coefficients between the rankings of individuals according to network values before and after relocation.

here are computed based on the assignment of weights according to the frequency of interaction represented by a relation, whether it is daily, weekly, monthly, quarterly, or yearly. Of course, in relatively dense networks, such as the ones typical of ThoughtForm, gatekeeper values tend to be relatively small.

We looked for associations between these descriptors of an individual's position in the interaction networks and *integration*, which is a descriptor of the individual's position in the structure of circulation (Figure 2). For the purposes of this exercise we focused on the social and work process networks because they are the most pervasive and most characteristic of the function of an organization. We looked at the aggregate connections of each individual over all time intervals. Scattergrams suggested a linear pattern, so we computed linear Pearson product moment correlation coefficients. There were no significant correlations in the old premises but in the new premises five out of six correlations were significant at the 1% level and all six at the 5% level, as shown in Table 5. Thus, relocation is associated with a change in the way in which interaction patterns are mapped onto space.

To interpret this result with greater precision, we also looked at the Kendal correlation coefficients between the rankings of individuals before and after the change of premises, based on hub, pulse-taker, and gatekeeper values. The aim of this analysis is to check whether relocation caused a change in the internal structure of interaction networks, by recalibrating the relative contribution of individuals to the aggregate densities of interaction networks. As

shown in Table 5, all coefficients are strong and significant, indicating that the internal order of networks did not change much. In simple terms, the relative contribution of individuals to the networks remained unaffected by relocation. This is independent of our previous finding, reported in Table 2, that the densities of interaction in the more frequent time periods were increased. We therefore conclude that the correlation between network and layout measures indicates that the new layout acts as a reliable map of the overall structure of interaction networks, whereas the old layout could not play that role. There is no evidence that the new layout altered the roles of individuals within the interaction networks. The new layout simply placed individuals who make a greater contribution to the networks in more integrated locations.

As mentioned earlier, one of the explicit aims of the design was to make the work process visible, and, by implication, better understood. Our findings show that the new premises are associated with a different, perhaps subtler, understanding—the new layout makes the interaction pattern more intelligible according to space because the contribution of each individual to the network of interaction is correlated to the integration of the individual's workplace in the layout as a whole.

Clearly, intelligibility is not at all equivalent to accessibility. Accessibility makes organizational function possible and it allows people to meet face to face, or reach sources of information or other resources. Intelligibility, however, has the potential to express and stabilize an otherwise invisible overall pattern of relationships. When there is a relationship between space allocation and the role of individuals in the interaction network, as with the new premises of ThoughtForm, the clarity of the layout serves to make the structure of interaction intuitively clearer. Thus, intelligibility comes to reflect the spatial culture of an organization (Peponis & Stansall, 1987).

Should we infer from these findings that people who interact more are located in proximate workspaces? To explore this question we chose the work-related network and constructed a spatial map of the interactions that occur in the most frequent—that is, the daily—time interval. We did this by drawing lines connecting the workspaces assigned to the pair of people involved in each reported interaction. The spatial maps of work related daily interaction networks are shown in Figure 3. Each map extends to cover the entire premises. When we look more carefully we see links that span short distances but also links that span longer distances, sometimes across from one side of the layout to the opposite. Thus, the map does not take the form of a lattice that covers the plan by progressing from node to proximate node in two dimensional sequences. We are dealing with a tangle of intersecting lines of very diverse lengths. Frequent (daily) interactions span proximate spaces and distant space alike.

Figure 3
Spatial Maps of Daily Work-Related Interaction Networks at
ThoughtForm Before and After Relocation
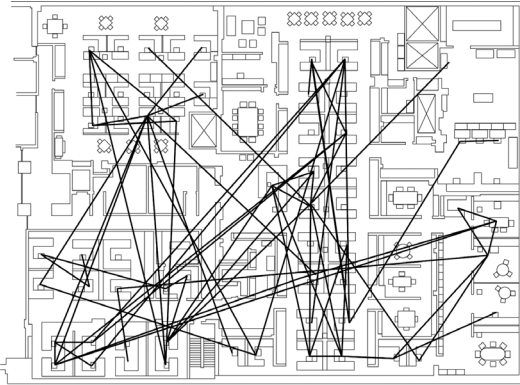
ThoughtForm: Old layout, daily work-process network
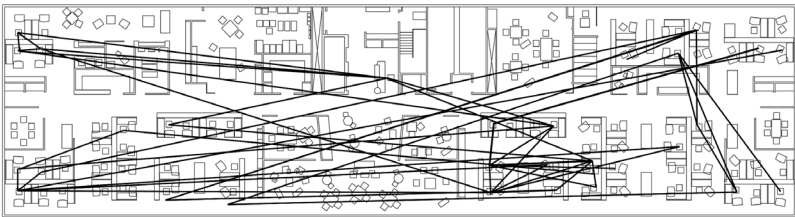
ThoughtForm: New layout, daily work-process network

Thus, the intelligibility of the overall network according to space in the new layout does not arise from a pattern of space allocation aimed at rationalizing information flows as it was often recommended in the earlier open plan office literature (Duffy, Cave, & Worthington, 1976; Pile, 1978). Instead, we are dealing with a congruence between structural properties of space (the order of workspace integration) and structural properties of networks (the order of people according to hub, pulse-taker, and gatekeeper values).

The spatial mapping of daily work-related interactions holds more clues as to how the new layout supports the spatial culture of the organization. Interactions between people occupying proximate workspaces occurs within the purview of shared horizons of visual coawareness; the open plan allows

people to stand up and have the overview of their neighborhood. However, face-to-face interactions between people occupying distant workstations imply movement. In the context of this plan, movement works as a mechanism that generates exposure to ongoing activities, visual records, and displays of ongoing work not necessarily linked to one's own; it also generates an awareness of other people that are not necessarily visible from one's workstation. Thus, the spatial distribution of the daily work network implies a continuous reproduction of a ubiquitous pattern of tacit awareness that exceeds the density of the interaction network itself. The coherent, egalitarian, and integrated spatial structure of the new layout provides a stable framework for this pattern, thus reinforcing it. However, we can be more specific. The plan of the new premises is such that it is not possible to move from one end to the other without going past or through the project rooms and central "square." Thus, many of the interactions mapped in Figure 3 imply paths that must cross the central hub of shared spaces. Therefore, awareness of what is going on is intensified by virtue of the potential exposure to activities in the central hub, over and above the more distributed exposure to what is going on in other parts of the plan. In the old layout there were alternative connections between the various areas and the project rooms that, although located centrally, were closed so as to make it less likely that people passing by would become aware of internally arranged activities or information displays.

As the awareness, which arises as a by product of movement, intensifies, so the likelihood that people can use other people as resources as needed also intensifies. The same is true for the likelihood of identifying potential contributions to work not formally assigned to oneself. Finally, the same is true for the likelihood of finding some indirect, or lateral, relevance of visible work to a question dealt with in one's own work. In this way, the new layout functions not merely as passive accommodation but actually as a generative mechanism—we borrow the idea of the layout acting in this way from Hillier and Penn (1991). It generates intensified awareness and cognitive opportunity precisely because it sets work processes within an integrated, intelligible, and behaviorally diversified spatial ecology.

Discussion

Hutchins (1995) has underscored how the division of tasks within a social group, the tools used, and the organizationally defined modes of communication become elements of a structure of socially distributed cognition, along with the more formal constrains and conceptual frameworks implied by the definition and the nature of the collective task.

Our analysis suggests that the physical design of the workplace is one of the tacit cognitive mechanisms that frame and support distributed cognition in an organizational setting. In Hutchins's (1995) case study of navigation, the physical setting acts as a constraint that determines what information can be directly shared and what has to be formally transmitted. Thus, the physical setting interacts with the available modes of transmission and the objective requirements of the task in determining the flow of communication.

Our work addresses a very different kind of situation—one where, unlike navigation, the task is open ended, the relevant knowledge is continuously renegotiated, and the constitution of the collaborative group is open. Thus, we come to see the physical setting not only as a constraint but also as an enabling and generative mechanism.

Our inference that knowledge work entails a relationship between spatial layout, organization, and distributed cognition is supported by our analysis in some direct and indirect ways. There is direct and statistically supported evidence that layout can contribute to the density of different networks of interaction at the shorter time intervals. There is some evidence, which cannot be supported statistically, that layout can indirectly contribute to productivity, by facilitating the sharing of ideas, communication, and the joint exploration of possibilities in the nonroutine phases of knowledge work. Finally, there is evidence, partly supported statistically and partly relying on an interpretation of context, that an intelligible and integrated layout provides a framework that makes patterns of informal coawareness and interaction more intelligible.

From a methodological point of view it seems clear to us that progress in addressing the questions raised in this article and in testing the hypotheses formulated in the later part of our argument would become easier if we were to adopt and adapt the framework of cognitive anthropology proposed by Hutchins (1995). For example, future studies should involve a detailed tracking of the processes of formulation, envisioning, and design, paying attention and recording with precision how projects and problems travel and distribute themselves across the different behavioral settings, the way they involve multiple actors, some formally assigned to them and some not, and the way in which various technologies of inscription, display, projection, relocation, and regrouping of visual information help to create a variable field of collective awareness and memory that is much more extensive than the network of verbal communication. Our specific contribution, in this article, is to suggest that the syntax of the spatial relationships of a setting provides an important underlying structure within which such processes can become stable, despite the inherent fluidity of the tasks.

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