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Innovation spaces: Workspace planning and innovation in U.S. university research centers

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Abstract

This paper reports findings of a study designed to test whether differences in spatial layout of research offices and labs (workspace planning) affects face-to-face technical consultations, and ultimately innovation process outcomes in research settings critical to government supported innovation strategies—university research centers (URCs). The study involved a mixed-method (multivariate predictive and multiple case comparison) evaluation of six organizationally similar but spatially different URCs. Data analysis revealed relationships between workspace planning, consultations and innovation process outcomes. Multivariate analyses showed that configurational accessibility, visibility and walking distances significantly affect the frequencies and locations of unprogrammed face-to-face consultations. Cross-case comparisons revealed that URCs featuring overall high configurational accessibility, shorter walking distances and intact territories exhibit higher face-to-face consultation rates, consultation network connectivity, and subjective/objective innovation process outcomes. Implications for research policy, practice and research are discussed.

Keywords: University research centers; Innovation; Workspace planning; Workspace design; Task-related consultations

1. Introduction

Over the past decade or so space, or perhaps more accurately spatial analyses, has begun to play an increasingly prominent and important role in the innovation process literature. Interestingly, most of this recent work has focused on spatial relationships that happen at a very large scale, such as the national, regional or local level. For instance, stimulated by a recognition of the importance of technological clusters in local economic development, Porter and Stern (2001) in their influential "Innovation: Location matters" and others (Castells and Hall, 1994) have examined the role played by spatial factors like geographic proximity and concentration of various industrial, educational and technological assets (including firms, universities and research laboratories) on innovation outcomes and ultimately economic development. Not surprisingly, based on an empirical analysis of data from the European Regional Innovation Survey (ERIS), Koschatzy and Sternberg (2000) acknowledge the complexity of these relationships by concluding, "spatial proximity might be a prerequisite for certain kinds of innovation networks within national boundaries, i.e. innovation systems, but is outweighed by cultural and

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institutional distance when spatially close knowledge sources are divided by national border" (pg. 492).

Research at a local level (e.g., Casas et al., 2000) has had a similar focus but has also included a more defined examination of the spatial factors underlying the value and success of initiatives like research parks (e.g. Appold, 2004). Similarly, Adams (2001) and others who have examined factors that affect the payoffs from interorganizational relationships between firms and cooperative research centers have noted the importance geographic proximity plays in the receipt of various benefits.

Interestingly, there has been much less recent interest in and research on spatial factors operating at a micro-level of analysis. For instance, in spite of a long-standing consensus about the importance of workspace-level spatial factors for innovation-related outcomes, very little recent research has focused on this connection. Further, with the advances in information technologies, arguments about the "death of distance", hence the decreasing need for spatial proximity based on electronic communications, are becoming more and more common. We find this surprising, since there is a substantial amount of evidence about the effects of spatial factors on human behavior in a variety of contexts. Hall's seminal work on space (1966) suggests a proxemic framework that offers three levels of spatial analysis: fixed-feature space (i.e. defined by walls, slabs, etc.), semi-fixed feature space (i.e. defined by furniture arrangements), and non-fixed feature space (i.e. perception and use of space based on behavioral thresholds or socially acceptable behavior). Over the last few decades, research in environment–behavior studies and environmental psychology has demonstrated how each of these spatial levels relate to human behavior—such as socializing behavior in schools (Peatross and Peponis, 1995), and interactive behavior in workspaces (Bechtel, 1977). Nevertheless, very few studies have considered the innovation process in relation to individuals' and organizations' day-to-day work patterns and the immediate spatial context they operate in.

The current paper begins to fill this void by summarizing a recent mixed-method (multivariate predictive study and a multiple case comparison) research study (Creswell and Clark, 2006) that focused on the relationships among workspace planning, technical "consultation" and innovation process outcomes in a work setting that has great importance for the research policy community—university research centers. Toward this end, we will review the existing body of literature related to workspace design and innovation from both S&T and design research traditions, highlight a promising new analytical tool – space syntax analysis, present our research questions and describe our methodologies. Findings of the study will then be reported through discussions about the observed relationships between workspace planning and scientist-to-scientist consultation, and, ultimately, innovation process outcomes in university research centers.

2. Workspace planning, consultation and the innovation process

To a large extent, a belief in the impact of workspace spatial factors on the innovation process appears to rest on two related but surprisingly distinct research foci: (i) research on consultations (face-to-face and other types) and various innovation process outcomes, and (ii) research on workspace design and face-to-face consultations. Based on theory and research from these two traditions, it is possible to construct a conceptual model of relationships that can be represented by a three-ring chain: workspace–consultations–innovation process outcomes. This conceptual model suggests that consultations, particularly face-to-face consultations have a mediating role in the relationship between workspace and innovation. Surprisingly, however, research support for the linkage between these three rings is neither complete nor methodologically robust. In the following sections, we will focus on information consumption, its facilitating role in the innovation process, and how workspace may relate to information consumption through facilitating idea exchange.

2.1. *Information consumption for innovation: information resources and information horizons*

Given the demonstrated importance of social and cognitive factors in the innovation process, it should not be surprising that there also near-universal agreement within the science and technology (S&T) literature on the importance knowledge plays in the innovation process (i.e. Kanter, 1988; Tornatzky and Fleischer, 1990; Hargadon and Sutton, 1997; Nonaka and Konno, 1998; Mascitelli, 2000; among others). In her conceptual framework of access to information, Sonnenwald (1999) indicates that the information resources available to individuals form their information horizons, which are critical in facilitating information consumption. In this respect, being exposed to higher numbers of information resources (i.e. availability of peers for consultation, available literature, subject matter experts, among others) expands the available knowledge base for individuals and organizations, and thus facilitates consumption and utilization of that information.

While many information resources are discussed in the literature, there has been considerable interest in the importance of face-to-face consultations with peers. The term consultation indicates those encounters (face-to-face or via other media) that involve task-related information exchange (i.e. Allen, 1984). Several studies from the S&T research literature demonstrate the significance of face-to-face consultations among scientists. For example, Allen (1984) has shown in his seminal study of R&D projects that, higher levels of consultations among research groups correlates with higher ratings of R&D effectiveness as measured through subjective ratings of experts. In their study of an engineering design project, Sonnenwald and Lievrouw (1996) report that as individuals' communication behavior (via face-to-face, e-mail and telephone) increases, their individual effectiveness (as perceived by team members) increase. Ancona and Caldwell's (1992) study of two sets of product development teams in high-technology companies has indicated that higher levels of inter-group face-to-face consultations are positively associated with team performance. In another study, Ancona (1990) reports similar positive effects of face-to-face consultations on team performance, as perceived by the team members and superintendents in a state education department. In an inquiry into the sources of ideas for engineers in a major engineering consultancy, Salter and Gann (2003) report that individuals involved in non-routine work patterns of this organization are highly dependent on face-to-face consultations with peers for problem solving and idea generation.

While mainly correlational, this body of research suggests that face-to-face consultations constitute a significant information resource for the innovation process. This finding has provided a basis for the design community to build an argument about the potential contributions of workspace planning to the innovation process: it is the built environment that forms a mold to human behavior and encounters, including face-to-face consultations in R&D oriented organizations.

2.2. *Workspace planning for innovation*

Over the years, the importance of workspace characteristics for the innovation process has been discussed by various scholars in the S&T research community. For instance, Kanter summarizes an organization's attempts to foster face-to-face communications through physical arrangements as follows:

> "One manager had a 'real' office enclosed by chest-high panels with opaque glass, but people dropped by casually, hung over the walls, talked about anything, and looked over his desk when he was not there. In general, people walk around freely and talk to each other; meetings and other work are easily interrupted, and it is hard to define 'private' space (Kanter, 1988: 189)."

Meanwhile, workspace planning for new work patterns, particularly for knowledge-based organizations has been the concern of a number of designers and design researchers especially in 1990s. This work differs from more conventional office planning work and its explicit focus on maximizing productivity in a linear, clerical-based line of work (Duffy, 1997). Several of these authors claim that new work patterns need workspaces that do not conform to conventional workspace planning approaches such as cellular offices or open-plan offices with cubicles (i.e. Becker and Steele, 1995). Various authors have underlined the importance of information for knowledge-based organizations and proposed that workspaces will support productivity in such organizations by simultaneously promoting interactive work and autonomous work. This line of work on knowledge-based organizations emphasizes the provision of a combination of work settings for the needs of different tasks that may be undertaken within the knowledge-based organization: informal, ad hoc spaces to promote social interaction, information exchange and idea generation, private spaces to be used for concentrated work, and formal meeting spaces for discussions (i.e. Duffy, 1997; Laing et al., 1998). In spite of this continuing interest, there is surprisingly little empirical research available to guide the design of these new work environments.

Examples of this line of research include Allen's pioneering (1984) work and more recent studies (Allen, 2000), on the positive effects of shorter walking distances and other spatial factors on communication behavior among individuals in R&D projects. More recently, Moenaert and Caeldries (1996) report positive effects of physical proximity of R&D personnel on the quality of communications in a Belgian company. In a similar vein, but focusing on co-location instead of metric distance, Van den Bulte and Moenaert (1998) looked at the communication frequency of R&D groups before and after co-location. Based on statistical analysis of sequential social network data, the authors report that co-location has enhanced the communication frequencies among R&D groups.

More recently, interest in a new and more advanced analytical technique, space syntax, has helped stimulate renewed interest in workspace–innovation relationships. Space syntax is a methodology that provides algorithms for measuring spatial configurational accessibility. Utilizing graph theory, it provides quantitative measures of configurational accessibility for (i) individual spaces in buildings, or (ii) entire buildings (Hillier and Hanson, 1984). This tradition has also developed computer software for fast utilization of the space syntax method based on its algorithms (Hillier, 1996a). Over the last two decades, significant positive correlations have been found between configurational accessibility of spaces at different scales (i.e. rooms in buildings, streets in cities) and certain human behavior in a variety of settings, such as the positive correlation between configurational accessibility and pedestrian traffic movement on streets (Hillier, 1996b).

Building on Allen's (1984) findings about the importance of face-to-face consultations to R&D effectiveness, space syntax researchers have conducted two key studies into spatial configuration–observed face-to-face interaction relationships in innovation settings. In the first of these two studies, Hillier and Penn (1991) report findings from an observational study of two research laboratories in the UK, and point out how observed patterns of space use (contemplative activities, practical activities, movement and interaction) relate to spatial configuration. The authors illustrate that in the first laboratory, rooms are directly connected to a main corridor, and inter-room connections are located closer to the periphery of the building. However, in the second laboratory, while the rooms are still directly connected to a main corridor, inter-room connections are located closer to the main corridor side. Based on observations of space use, the authors show that in the second laboratory, interactions take place closer to the main corridor, where the inter-room connections are provided. They suggest that this creates a potential for inter-group interactions by being close to through movement. In the first laboratory, however, interactions are observed in spaces closer to the periphery of the building, minimizing the potential for inter-group interactions, while maximizing local intra-group interactions. The authors therefore propose that spatial configuration can facilitate or inhibit space use and encounter patterns among scientists, changing the probability of scientist-to-scientist consultation. However, it is important to note that the authors focus on observed face-to-face interactions rather than actual consultations, and do not make any statistical connections to innovation process outcomes.

In the second study, Penn et al. (1999) report findings from a quantitative study of an energy utility company and an advertising company. The authors use the space syntax method for spatial analysis, and observations identifying patterns of talking, sitting, standing and moving employees. They show positive significant correlations between global integration values of spaces (a measure of configurational accessibility) and observed numbers of moving employees (therefore frequency of contacts among employees). Based on the results of a survey, Penn et al. then show that as frequencies of cited contacts increase, work-related communications cited as useful also increase. The authors finally report positive bivariate correlations between the usefulness of employees as perceived by their peers, and the configurational accessibility of the areas they occupy. Similar to Hillier and Penn's observational study (1991), Penn et al. conclude that high levels of configurational accessibility (i) facilitate work-related communications by generating movement, and therefore (ii) have a high potential of affecting actual innovation process outcomes.

2.3. Summary

At first glance, there appears to be adequate support for the three-ring chain proposed earlier, linking workspace design, consultations and various innovation-related outcomes. However, a closer examination of this body of research suggests that causal relationships between these domains are neither clear nor certain. At least three factors appear to undermine confidence in these connections.

2.3.1. Limited body of research

On balance, the amount of research available to support even the workspace design–face-to-face consultations and the face-to-face consultations–innovation process outcomes links is surprisingly small. Most of the published research we found appeared to follow up on Allen's pioneering research (1984) or was stimulated by the recent space syntax movement.

2.3.2. Methodological concerns

With very few exceptions, research on the workspace design–face-to-face consultation–innovation process outcomes connection suffers from a variety of methodological shortcomings. First, a number of the studies cited in our literature review fail to even identify various factors, such as the visibility of spaces or the means of consultation through non-face-to-face media, such as e-mails and phone calls. Further, none of the predictive studies we reviewed get beyond simple bivariate relationships. As a consequence, the effects reported may be due to other variables like the roles played by various individuals, etc. In short, the methodological bases for arguing covariation let alone causality are not present (Shadish et al., 2001). In addition, most of the key constructs of interest have been examined at only a very global level. For instance, observational studies (e.g., Hillier and Penn, 1991; Penn et al., 1999) provide no basis for differentiating between face-to-face consultations among individuals and non-work related interactions, let alone different types of consultation (e.g. coincidental vs. preprogrammed). Finally, the fact that one of the two key studies report from an energy utility company and an advertising company – two contexts traditionally not associated with innovation settings – add context-related questions to our concerns (Penn et al., 1999).

2.3.3. Failure to examine critical variables within a single study

Perhaps the biggest shortcoming in the available literature is the failure to examine workspace, consultations and innovation process outcomes in the same study. Our literature review suggests that the role workspace plays in the innovation process is mediated through its effects on the consultations of individuals. However, none of the empirical studies we have reviewed seem to study these phenomena in a single study. Since this is the case, studies focused on the workspace design–face-to-face consultations connection must assume increased consultations results in increased innovation process outcomes while studies focused on the face-to-face consultation–innovation process outcome connection must make an inferential leap about the role spatial factors played in fostering face-to-face communication.

In short, at this point the causal linkage between workspace design, face-to-face communications and innovation outcomes must be considered at best a working hypothesis. In the next section, we discuss a unique setting that is both increasingly important for the research policy community and that makes a quantitative and qualitative multi-method study possible for examining these relationships—university research centers.

3. University research centers and their significance as innovation settings

While university campuses are generally viewed as highly traditional and unchanging physical settings, this is far from the truth. Over the past several decades a great deal of construction and workspace changes have taken place on or adjacent to campuses within the US and abroad. On the university periphery, a great deal of attention has been paid to the growth of research parks. For instance, the two largest research parks in the US, Stanford Research Park (established in 1951) and Research Triangle Park in North Carolina (established in 1959) have built 3.58 and 2.62 buildings per year respectively since their creation (Link and Link, 2003), while the five largest parks in the US have somewhere between 40 and 165 buildings (Link and Link, 2003).

At the same time, growth and workspace changes are also having a profound impact on the core university campuses. A nearly sixfold increase in research expenditures at U.S. universities since 1972 (National Science Board, 2004) has necessitated construction of many new buildings and facilities. The 2001 Survey of Scientific and Engineering Research Facilities reports that the total amount of academic science and engineering research space grew more than 38%, from approximately 112 to 155 million square feet from 1988 to 2001 (National Science Board, 2004). While these developments are undoubtedly significant, we believe that changes in how universities conduct research may be having an even more profound impact on the importance of university workspace arrangements for innovation outcomes.

Over the past several decades, universities have been under considerable pressure to make a greater and more direct contribution to their national innovation systems (Tornatzky and Fleischer, 1990; Etzkowitz and Leydesdorff, 2000). As a consequence, at least in the hard sciences and engineering universities have been moving away from reliance on an individual investigator award mode of operation (and the dyadic relationship between a graduate student and his or her academic advisor) that did not require very sophisticated workspace planning and toward a larger scale, more multidisciplinary, team-based, in short, more collaborative and innovation-focused, model for conducting research. Evidence of this trend can be found in the dramatic increase in multi-investigator grants (about 20% to near 60%) and drop in single PI grants (about 80–40%) from NSF's Engineering Directorate over the past two decades (National Science Board, 2006).

To a large extent, the major vehicle for promoting these changes has been an increased emphasis on and funding for University Research Centers or URCs. Over the past several decades, the National Science Foundation alone has invested hundreds of millions of dollars into a variety of center-based funding models including Materials Research Centers, Industry/University Cooperative Research Centers, Engineering Research Centers, and Science and Technology Centers (Gray, 2000). While accurate estimates are difficult to come by, according to research by Cohen and his colleagues (Cohen et al., 1994), there were well over a 1000 industry-university research centers on college campuses in the mid-1990s with expenditures of $4.12 billion, approximately $2.53 of it for R&D. This estimate does not include the thousands of other institutes, labs, and centers known to be located on or affiliated with universities (Wood, 2002). The value of URCs has become so obvious that Feller has concluded that they have become the dominant mechanism for promoting university-based technology transfer (Feller, 1997).

Unfortunately, while workspace arrangements undoubtedly do matter for research mechanisms that are intended to be team-based and multidisciplinary like URCs, many observers believe university workspace strategy focuses primarily on reaching adequate square footage and locating laboratory equipment based on certain technical criteria (i.e. Watch, 2001). In truth, we know very little about the type of spatial arrangements used by these emergent and increasingly important research organizations nor their relative efficacy. However, our own research with one center program revealed a great deal of variability in center spatial arrangements: some centers had their own building, others had a designated floor in a building while others occupied multiple spaces within and even across different buildings.[1]

The workspace heterogeneity observed in URCs actually represents an interesting research opportunity. Since URCs are relatively homogeneous in terms of goals (e.g., research), context (e.g., university-based), organizational factors, many of the well established social and cognitive precursors of collaboration and innovation like culture, leadership, creativity, and in terms of expected outcomes (scientific knowledge, that can be quantified by counting journal articles, conference papers, algorithms, patents, etc.), they provide a methodologically attractive target for evaluating the impact of spatial factors on innovation-related outcomes (Bamberger, 1991).

In summary, there appear to be a number of reasons to examine workspace issues in URCs in greater detail. First, URCs' spatial heterogeneity and contextual and organizational homogeneity, seems likely to produce findings without the validity problems that have plagued other innovation workspace studies (Allen, 1984, 1997). Secondly, a comparative study of URCs with a focus on their workspaces, consultations and innovation process outcomes should help shed some light on linkages between the conceptual three-ring chain described earlier. Finally, and perhaps most importantly, the findings from such a study should yield guidelines for S&T policy makers and other stakeholders (i.e. university presidents, design professionals, center directors or participants) on how to use workspace design to affect innovation in these increasingly important boundary-spanning institutions.

4. The current study

In the following sections of the paper, we will report findings from an inquiry that has attempted to link the three rings of the workspace–consultations–innovation process outcomes chain. Six URCs from US universities were studied using a mixed-methods approach including quantitative multivariate predictive analyses along with multiple case study methodology. The overarching objective of the study was to identify how workspace planning (individual spatial predictors and overall workspace planning approaches that define main locational decisions, such as whether offices and laboratories will be interconnected or not) relates to consultation and ultimately to innovation process outcomes. In order to address this objective, we attempted to answer the following research questions:

1. What method of consultation do scientists use to obtain technical information?
   a. What method of obtaining technical information do scientists prefer?
2. To what extent do individual spatial variables predict consultations within URCs?
   a. What are the net or multivariate effects of significant individual spatial variables on consultations within URCs?
3. Across URCs, what is the relationship of overall workspace planning approaches to consultations?
4. Across URCs, what is the relationship between overall workspace planning approaches and innovation process outcomes?

As discussed in Section 2.1, throughout the study, the term consultation will be used to refer to all research task-related information exchange among scientists within an URC via various media (i.e. face-to-face, e-mails, telephone calls, etc.). The term scientist will be used to indicate individuals employed by URCs who produce scientific knowledge outputs (Allen, 1997) in line with their URCs' objectives.

[1] "Shell structures (buildings built with definitive facades but non-divided floor planes)" seem to be the ideal medium for this. In this model, a shell structure is built, and the space available is simply "divided" into pieces as tenants request space in time. Consequently, later arriving tenants might end up with space that meet their square footage requirements, but divided into a number of floors, for example.

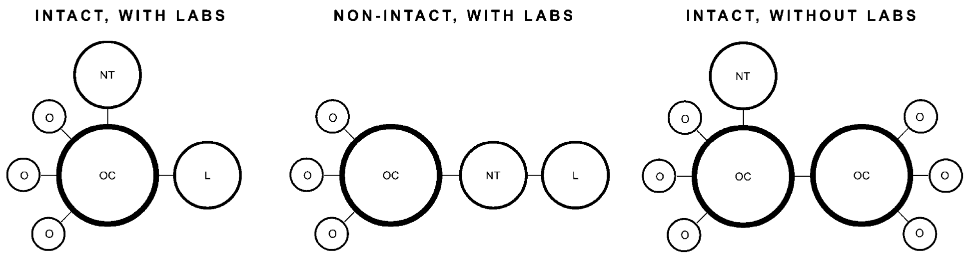

Fig. 1. Categorization of contemporary U.S. URC territories. Circles represent spaces, and each line between pairs of circles represent a direct connection, such as one through a door (O: office, OC: spaces to which offices are directly connected, L: laboratory, NT: non-territorial, publicly accessible, shared spaces).

5. Methodology

5.1. Research design

A mixed-methods approach was used to address our research questions. A cross sectional predictive design (with multivariate quantitative analyses) was used to address research question 2 (Agresti and Finlay, 1997), while a multiple-case study design with pattern matching was used to address research questions 3 and 4 (Yin, 1994). Space was the unit of analysis for research questions 2–4. More specifically, individual spaces within the six URCs were the unit of analysis for answering research question 2, while whole URCs were the unit for addressing research questions 3 and 4. Simple descriptive analyses were used to address question 1.

5.2. Case selection

In order to be able to understand the effects of workspace planning on consultation and innovation process outcomes, two case selection criteria were used to select six URCs within a multiple case study research strategy. Specifically, cases were selected so that they were different in spatial organization but relatively similar in organizational context and their scientific focus.

5.2.1. Criteria for case selection 1: workspace planning approach

In order to understand how workspace planning influences task-related consultations and innovation process outcomes, cases were selected to be spatially different. Two workspace factors were used as part of the case selection process: whether URCs occupied intact or non-intact territories[2] and whether in addition to offices their territories included laboratory space. These two factors were used to frame three types of overall workspace planning approaches for URCs (see Fig. 1): intact, with labs; intact, without labs; and non-intact with labs.

5.2.1.1. Intact, with labs. These URCs have both offices and laboratory spaces within an intact territory. A scientist within an intact-territory URC with labs can reach any territorial space without having to pass through spaces shared by other non-URC units.

5.2.1.2. Non-intact, with labs. These URCs have both offices and laboratory spaces within a non-intact territory, in a shared building. The offices and laboratories of a non-intact territory URC with labs are segregated by shared or public spaces such as corridors or stairways.

5.2.1.3. Intact, without labs. Due to the nature of the research they conduct, these URCs only have offices and no laboratory spaces within an intact territory. In order to insure spatial variance, the first criterion for case selection was that, the cases for the study would be selected from these three URC spatial categories.

5.2.2. Criteria for case selection 2: organizational context

In order to understand the influence of these three workspace planning approaches on consultations and innovation process outcomes, we also wanted to minimize the influence of confounding factors. As a consequence, cases selected for the study should be as

[2] A URC territory is composed of all the individual spaces designated exclusively for the use of that particular URC (territorial spaces), and excludes all spaces that are used or shared by any other non-URC unit. In the case of an intact territory, all the territorial spaces of the URC are interconnected. An intact territory URC may be located in either a shared or unshared building. Non-intact territory URCs, however, occupy shared buildings. Their territorial spaces are segregated by non-territorial spaces. A good example is the segregation of offices and laboratories across floors in a shared building. In addition, based on the type of research they conduct, some URCs can have laboratories while others do not.

organizationally similar as possible. In order to satisfy this criterion, a structured interview was conducted with URC directors to identify URCs that were relatively similar based on seven organizational characteristics and three individual characteristics of their scientists.[3]

5.2.3. Sample: URCs, spaces and respondents

5.2.3.1. URCs. After defining the criteria for case selection, 40 URCs were initially contacted. The directors of 23 URCs expressed some interest in participating in the study and were interviewed, which was followed by a walk-through of the URC territory or review of floor plans. At the end of this process, six organizationally similar URCs (two for each workspace category) were selected based on our case selection criteria for further study: URC1 and URC2 occupied intact territories with laboratories; URC3 and URC4, occupied non-intact territories, but had laboratories, and URC5 and URC6 had only offices but no laboratories within intact territories.

While it was impossible to precisely match cases based on all the organizational context variables, all six URCs were university-based and were conducting what could be called strategic basic or use-based research (Stokes, 1997). That is, while the research conducted in these centers was relatively fundamental in nature, there was an implicit or explicit intention to capture the benefit of the research for applied use. All URCs used their funding to support the center as a whole rather than supporting individual projects, and all centers had at least one other source of funding in addition to its parent university. In all six cases, scientists reported to either the center director or their project leaders; therefore their level of formalization was two. The URCs were also quite similar on six other key organizational characteristics (e.g., number of scientists). In addition, all but one center (optics) had a scientific focus in genetics/genomics or biology.

5.2.3.2. Spaces. The six selected cases occupied a total of 114 common spaces and 120 workspaces. While each cellular office, open office and formal meeting space was considered one workspace, each corridor, hallway, informal common space/lounge was considered one common space. Common spaces with complex geometries (i.e. L-shaped corridors, donut-shaped hallways surrounding a set of open workspaces, etc.) were divided into their largest possible rectangular components, which were considered one common space. The same strategy was applied to laboratories with complex geometries, where largest possible rectangular laboratory spaces were considered one laboratory workspace.[4]

5.2.3.3. Respondents. The 104 scientists working with the six selected URCs were asked to participate in the study. Eighty-five scientists (82%) completed the week-long activity logs and the other instruments used in the study and were included in our analyses. There were no statistically significant differences between URCs on key organizational characteristics including number of scientists, level of interdependence among scientists, coherence on research agenda, alignment with strategic plan and response rate.

5.3. Instrumentation

Spatial predictors were obtained via space syntax analysis and other software-based tools. Other data were collected from respondents using two instruments: an activity log and a follow up survey.

5.3.1. Spatial predictors

Three types of spatial variables were calculated to operationalize the properties of individual spaces and the overall spatial characteristics of the six URCs examined in the study: configurational properties (spatial configuration), visibility and walking distances. Spatial variables were calculated based on floor plans provided by each URC using several software programs.

5.3.1.1. Configurational properties. The configurational properties of URCs' territories were measured utilizing the space syntax method. The particular advantage of using the space syntax method for this study was its ability to measure configurational accessibility quantitatively. Since it is based on graph theory, the algorithms used in this method take into account the numbers of spaces to be passed through in order to reach from one space to another in a system (i.e. a building). Using

[3] Organizational: formalization, complexity, available resources, independence among researchers, coherence of research agenda, alignment to strategic plan, number of projects. Individual: years of technical experience, years of working in the center and level of education.

[4] Except URC6, all URCs shared their building with one or more other centers or university units. While URC1 and URC6 had their own unshared lounges for maximizing informal consultations, URC2, URC3, URC4 and URC5 had to share a lounge for informal consultations with other centers or university units. In terms of office workspaces, URC2, URC3 and URC5 had a combination of open and cellular offices, whereas URC1, URC4 and URC6 scientists occupied only cellular offices. In URC1, URC2, URC3 and URC4, laboratory spaces were composed of large areas containing work counters and peripheral small specialized spaces such as a dishwashing room.

this method, it is possible to attribute numerical configurational accessibility values to individual spaces in a building or entire floor plans. The individual configurational accessibility measures provided by this method are with respect to all other spaces in a system, which makes these measures comparable to each other (Hillier and Hanson, 1984; Hillier, 1996a).

Global integration is a widely used measure of configurational accessibility, enabling comparison of individual spaces from buildings of varying sizes. This measure identifies the degree to which an individual space remains on the paths among all other spaces in the system (Hillier and Hanson, 1984). A higher global integration value for a space indicates its higher configurational accessibility. In the current study, the measure of global integration was utilized to measure the configurational accessibility of individual spaces.

The configurational properties of entire URC territories were measured utilizing the measure of intelligibility. Intelligibility is an overall configurational accessibility value that can be calculated for entire spatial systems (in this case, a URC territory). It signifies to what extent all spaces are highly integrated and highly connective to other spaces at the same time. Higher intelligibility of a spatial system indicates that the majority of spaces are highly integrated and highly connective to each other. For further information on the space syntax method and its algorithms, please refer to Hillier and Hanson (1984).

5.3.1.2. Other spatial properties. *Visibility*: Since most unscheduled encounters require co-presence and co-action in a space, they tend to be a byproduct of eye-to-eye contact between two people which requires a clear line of sight at that particular moment. Consequently, the visibility of spaces from their surroundings gains importance in facilitating unscheduled information exchange by maximizing the possibility of coincidental encounters. Visibility was based on Benedikt's (1979) definition as the area that can be seen from each particular space. Visibility graph analysis software developed by space syntax researchers (Hillier, 1996a) was used to measure visibility of spaces based on floor plans.

Walking distance: The walking distance between individuals has been the most frequently analyzed spatial predictor in studies that have considered space as a factor in the innovation process (i.e. Allen, 1984, 1997, 2000; Moenaert and Caeldries, 1996). Walking distances between spaces (or between origins and destinations of face-to-face consultations) were measured from floor plans as the actual walking distance (in feet) between the midpoints of their entrances.[5] For cross-case comparisons, mean walking distance for reported unprogrammed encounters was calculated for each URC.

5.3.2. Consultations

The activity log was used by study participants to record their consultations with fellow scientists within their URC for five consecutive weekdays during a typical week.[6] In order to capture all task-related information exchange among scientists, consultations were defined as research-related interactions. The activity logs distributed within each URC included a rendering of that particular URC's floor plan(s), with all its spaces given a space code. The space codes were mostly the existing room numbers used in the URC, but unnumbered spaces were given new codes (i.e. C01, C02... for corridors, K for a kitchen, etc.). Scientists used this instrument to record each individual consultation that they initiated.[7] As described in the following sections, where necessary, consultation measures were standardized based on the number of scientists participating in each URC.

Recording a consultation involved entering (i) the space code of its location within the URC's territory, and (ii) the type of consultation used on a matrix. Seven different types of consultation were examined within three major categories (Toker, 2006). Face-to-face consultations consist of unprogrammed and programmed encounters. Unprogrammed encounters include unscheduled office visits (consultation by stopping by a colleague's office without an appointment) and coincidental consultations (consultation with a colleague

[5] By rounding walking distances to the closest multiple of 10, 10-foot walking distances were assigned a value corresponding to the number of different types of consultations reported to have taken place within them.

[6] Data collection was timed to insure that it did not coincide with an event (e.g., conference) that would take a significant number of scientists away from the URC.

[7] In order to insure that scientists only recorded consultations (research-related information exchanges) and to avoid double-counting of consultations these issues were emphasized during a study briefing and in writing. First, a meeting was held before the study began with participants to go over the study protocol and data collection instruments. Scientists were able to ask questions about issues like the definition of a consultation, etc. A point of emphasis at these meetings was the importance of only recording consultations that the scientist initiated and in a prompt manner. The activity log that the scientists used on a daily basis also emphasized these points in writing. Therefore, each single consultation within each URC was recorded by the initiator, and counted once. Since the study was concerned with the locations, quantities and types of consultations, this method also insured that group meetings in formal or informal meeting spaces were recorded once.

Table 1
Seven consultation types – Consultations (encounters that involve task-related information exchange) within a URC

Face-to-face consultations		Consultations through e-media
Unprogrammed encounters	Programmed encounters	
Unscheduled office visits *Coincidental consultations*	*Prescheduled office visits* *Prescheduled group meetings* *Unscheduled group meetings*	*E-mails* *Telephone calls*

These types were (in italics) made available for selection on the activity log (based on Toker, 2006).

by 'bumping into each other' in a common space such as a corridor). Programmed encounters include prescheduled office visits (consultation in a colleague's office with an appointment) and group meetings (meetings with more than one colleague), which are either prescheduled group meetings (scheduled at least an hour before the meeting) or unscheduled group meetings (scheduled impromptu prior to the meeting).[8] Consultations through e-media include intra-URC e-mails and telephone calls. Table 1 depicts the classification of seven consultation types provided for selection on the activity log.

5.3.2.1. Consultation and networking measures. Space – either individual spaces or a whole URC territory – was the unit of analysis for evaluating consultations. Since URCs differed in the number of participants involved in a center, standardized consultation indices and consultation network measures were developed. An *"index of consultation for..."* was calculated for each space in an URC by type of consultation (e.g., coincidental, unscheduled office visits). For instance, an index of coincidental consultation was calculated by dividing the number of reported coincidental consultations that took place in that space over 5 days by the total number of respondents in that URC. Similarly an index of outgoing e-media was calculated for e-mail and telephone consultations.

Consultation reports were also used to create two URC-level measures: an index of face-to-face consultations and an index of unprogrammed encounters. The index of face-to-face consultations was simply the percentage of face-to-face consultations of all reported consultations in an URC, while the index of unprogrammed encounters was the percentage of unprogrammed consultations (coincidental consultations and unscheduled office visits) of all reported consultations.

In addition, consultation reports were subjected to social network analysis to produce individual level (social centrality) and URC-wide (connectivity of consultation networks) network indices. Social centrality values of scientists were calculated by dividing the number of their relational ties (the number of different colleagues consulted in 5 days, as opposed to the frequency of consultations) by the number of all possible ties that they could have (Wasserman and Faust, 1994). The connectivity of consultation networks was calculated for an URC by summing the scientists' number of relational ties and dividing it by the total number of possible ties in each URC (based on Wasserman and Faust, 1994).

5.3.3. Innovation process outcomes and other measures

The second instrument, the follow-up survey, was filled out after the activity logs were completed. This instrument was used to collect scientists' reports of objective and subjective innovation process outcome indicators and priority ratings on information sources.

We attempted to measure variables that represent both processes that contribute to innovation (e.g., publications) and outcomes themselves (e.g., patents). Standardized innovation process[9] outcomes were operationalized for each URC by means of objective and subjective ratings provided by scientists (based on Bamberger, 1991). The objective innovation process outcome measure was based on reports of research outputs that were produced individually within the time period each scientist had been working with his/her URC (books, articles, papers, project proposals, conference papers, technical manuscripts, patents, new algorithms, new applications, blueprints, reports or experimental prototypes). An aver-

[8] The unscheduled group meeting was considered a programmed encounter, since it involved the pre-meeting identification of attendants and location, as well as the announcement of these to attendants. Therefore, the term unscheduled mainly refers to the fact that it is an impromptu call for a meeting, rather than a preprogrammed meeting already on every attendant's schedule.

[9] Since innovation is difficult to pin down and operationalize and because one often has to measure processes that ultimately lead to innovation, we prefer to use the term "innovation process" (e.g., Tornatzky and Fleischer, 1990).

age value of objective ratings was calculated for each URC through the following procedure: the total number of innovation-related items (i.e. number of books, papers written) reported by each scientist was initially summed, and the total number of objective outcomes produced in each URC was calculated. Then, the average time (in months) scientists have been working with each URC was calculated. Finally, for each URC, the objective innovation outcomes scale was calculated by dividing by the number of scientists and the average number of months scientists have been working with that URC. Thus, each URC was attributed an average number of innovation outcomes items per scientist, per month.

URC scientists were also asked to provide subjective ratings of research processes within their URC, by rating four statements on a seven-point Likert scale ("creativity and innovativeness of research conducted in the URC", "the URC's overall contribution to the field", "the URC's recognition/reputation", and "overall satisfaction with the research processes in the URC"). Based on item reliability analysis, a subjective innovation scale was calculated for each URC, based on the average of the sum of the scientists' ratings of their URCs on these four items.[10]

The follow up survey also asked the scientists to prioritize the importance of nine types of information resources. The information sources examined included face-to-face consultations as well as a number of other widely used sources including: literature, customers, previous research conducted in the URC, personal experience, vendors, external sources, experimentation, other. These priority scores were used to find out what methods of obtaining technical information scientists preferred (Question 1a).

5.3.4. Other measures and analytical tools

A variety of analytical tools were used to interpret within case relationships including behavior maps, graphic representations of spatial features, etc. but are not presented in this paper.

6. Findings

6.1. Overview: consultation utilization and preference in six URCs

A series of descriptive analyses were performed to address the question: What method of consultation do scientists use to obtain technical information? What method of obtaining technical information do scientists prefer? In order to answer these questions a tally of all consultations reported by scientists during the 5-day study period was made and consultation preference ratings obtained in the follow up assessment were evaluated. Data were collected from a total of 85 scientists employed by the six URCs.

Face-to-face consultations formed the main medium of information exchange among scientists within all six URCs. Of the 1763 research-related consultations reported in six URCs, 57% were unscheduled office visits, 23% were coincidental consultations (both unprogrammed encounters), 3% were prescheduled office visits, 3% were prescheduled group meetings, 2% were unscheduled group meetings (programmed encounters), 8% were e-mails, and 4% were telephone calls (consultations through E-media).

These results indicated that an overwhelming majority (80%) of consultations occurred through unprogrammed encounters (unscheduled office visits and coincidental consultations), followed by consultations through e-media (12%) (e-mails and telephone calls) and finally programmed encounters (8%) (group meetings and prescheduled office visits).

These analyses showed that face-to-face consultations, specifically unprogrammed encounters formed the main media for consultations. However, since numerous other information resources are available to scientists, it was also important to understand how scientists preferred to obtain information. Scientists' priority ratings for nine information resources were used to address this question. The information sources rated included face-to-face consultation and a variety of other mechanisms for obtaining knowledge including: literature; customers, previous research conducted in center; personal experience; vendors; external sources; experimentation. Responses from six URCs indicated that face-to-face consultations had the lowest mean priority rating (e.g., highest priority) when compared to other available information resources This rating was consistent across all six sites. Literature and personal experience were ranked second and third.

In summary, these findings indicate that face-to-face consultations are the most frequently utilized form of consultation and highest priority source of information for the study scientists. In addition, among all types of face-to-face consultations, unprogrammed encounters (unscheduled office visits and coincidental consultations) formed the primary mechanism for information exchange. Since all types of face-to-face consultations require co-presence and co-action in the workspace,

[10] Cronbach's $\alpha > 0.8$. Bivariate correlation analyses among the four items yielded positive Pearson's r-values between 0.48 and 0.80.

Table 2
Bivariate relationships (Pearson's r-test) between spatial predictors and coincidental consultations

	Index of coincidental consultations (per scientist)
Global integration (configurational accessibility of common areas)	$r = 0.66$; $r^2 = 0.44$, $p < 0.0001$
Visibility (of common areas)	$r = 0.56$; $r^2 = 0.32$, $p < 0.0001$
Walking distances (between the origin and the destination of 405 reported coincidental consultations)	$r = -0.70$; $r^2 = 0.50$, $p < 0.0001$

In common spaces ($n = 114$ common spaces).

these findings suggest that workspace planning might affect the frequency of these activities and possibly innovation process outcomes.

6.2. Consultation and individual spatial predictors: bivariate predictive analyses

A series of bivariate correlations were examined to answer research question 2, "To what extent do individual spatial variables predict consultations in URCs?" As described above, the six URCs occupied a total of 114 common spaces (corridors, informal common spaces, lounges, etc.) and 120 workspaces (formal meeting spaces, open and cellular offices). In order to answer this question the spatial variables, global integration, visibility and walking distance, assigned to all 234 spaces were correlated with the various consultation indices (e.g., index of unscheduled office visits). Of the seven consultation types analyzed, only index of coincidental consultations (which occurred in common spaces), index of unscheduled office visits (which occurred in workspaces) and index of e-media consultations yielded significant relationships with global integration, visibility and walking distance.

6.2.1. Coincidental consultations

Bivariate analyses of 114 common spaces from six URCs showed that there was a significant relationship between global integration, visibility and walking distances and the index of coincidental consultation (Table 2). Global integration correlated 0.66 and had an r^2 of 0.44, visibility correlated 0.56 and had a r^2 of 0.32 and walking distances correlated −0.70 and had a r^2 of 0.50 with the index of coincidental consultations. Coincidental consultations were composed of research-related interactions reported by scientists that were initiated by bumping into each other in a common space such as a corridor. Descriptive analyses demonstrated that the majority of coincidental consultations appeared to happen within 50 feet of an individual's office. The results of the bivariate analyses within each URC were consistent with these overall analyses.[11] These findings indicate that as configurational accessibility, visibility of individual spaces increased and walking distances decreased the occurrence of coincidental consultations increased.

6.2.2. Unscheduled office visits

Bivariate analyses of 120 workspaces from six URCs showed that there was a significant relationship between global integration, visibility and walking distances with the index of unscheduled office visits. Global integration correlated 0.48 ($p < 0.0001$) ($r^2 = 0.23$), visibility correlated 0.30 ($p = 0.008$) ($r^2 = 0.09$) and walking distances −0.54 ($p = 0.0009$) ($r^2 = 0.29$) with unscheduled office visits (See Table 2). Unscheduled office visits were composed of research-related interactions reported by scientists, which took place in a colleague's office without an appointment (i.e. by stopping by his/her office).

6.2.2.1. Exploratory analyses: controlling for key communicators. A major concern for understanding the relationships between spatial predictors and unscheduled office visits was the potential bias created by scientists' individual roles. To some extent scientists pay unscheduled office visits to individuals they select before hand, based on what they may want to discuss and with whom. Thus, a significant individual role, such as the expertise of a scientist in a particular computer application, can significantly increase the numbers of unscheduled office visits paid to a particular office. Further, such individuals might choose and/or be assigned particularly accessible office spaces. Consequently, in order to accurately assess the role of spatial factors, it was necessary to control for the effects of individual roles. This was accomplished by trying to identify and control for key communicators.

Key communicators are those individuals who serve as important sources of technical information in the orga-

[11] These analyses yielded statistically significant correlation coefficients between $r^2 = 0.40$ and $r^2 = 0.57$ for global integration, $r^2 = 0.27$ and $r^2 = 0.61$ for visibility and $r^2 = 0.20$ and $r^2 = 0.90$ for walking distances.

Table 3
Spatial predictors and unscheduled office visits: bivariate analyses

		Index of unscheduled office visits (per scientist)
Global integration (configurational accessibility of individual offices)	(1) With key communicators ($n = 120$)	$r = 0.48$; $r^2 = 0.23$, $p < 0.0001$
	(2) Without key communicators ($n = 114$)	$r = 0.65$; $r^2 = 0.42$, $p < 0.0001$
Visibility (of individual offices)	(1) With key communicators ($n = 120$)	$r = 0.30$; $r^2 = 0.09$, $p = 0.008$
	(2) Without key communicators ($n = 114$)	$r = 0.53$; $r^2 = 0.28$, $p < 0.0001$
Walking distances (between the origin and destination of each reported consultation)	(1) With key communicators ($n = 1012$ unscheduled office visits)	$r = -0.54$; $r^2 = 0.29$, $p = 0.0009$
	(2) Without key communicators ($n = 805$ unscheduled office visits)	$r = -0.61$; $r^2 = 0.37$, $p < 0.0001$

One hundred and twenty individual offices including the offices of key communicators, 114 individual offices excluding the offices of key communicators. A total of six key communicators were identified in four URCs.

nization and facilitate information flow (Allen, 1984). In the current study, these individuals were found by evaluating individuals' social centrality scores. Distributions of social centrality values were analyzed in each URC. Those scientists whose social centrality values stood out as outliers within their URC (i.e. more than one standard deviation above the mean social centrality value in their URCs) were flagged as possible key communicators. After the true key communicators were confirmed based on their roles,[12] a total of six communicators from four different URCs (i.e. unscheduled office visits to their offices) were excluded from data sets, and bivariate correlations were recalculated ($n = 114$) for indices of global integration, visibility and walking distance (Table 3).

The findings from this set of analyses indicated that the relationships between these variables and unscheduled office visits were much larger when the analyses "controlled for" key communicators. With key communicators excluded, the effect of global integration on unscheduled office visits almost doubled ($r^2 = 0.23$ to $r^2 = 0.42$), while the r^2 for visibility increased threefold ($r^2 = 0.09$ to $r^2 = 0.28$) and the r^2 for walking distances increased from 0.29 to 0.37. The results of the analyses within each URC were consistent with these overall analyses.[13] Interestingly, after key communicators were eliminated, global intergration surpassed walking distance as the largest single predictor.

6.2.3. Consultations through e-media

We were also interested in whether spatial predictors had a relationship with e-media consultations. Overall bivariate analyses showed that there was a negative relationship between spatial predictors and the index of outgoing e-media consultations. Global integration correlated -0.24 ($p = 0.008$), and visibility correlated -0.17 ($p = 0.07$) with unscheduled e-media consultations (Table 4).

The relationship of walking distance could not be tested for this type of consultation.[14] Consultations through e-media were composed of research-related interactions reported by scientists, that took place via e-mails and telephone calls within URCs. While the effect sizes observed here are substantially smaller than those observed for face-to-face consultations, these findings indicate that scientists occupying offices that were configurationally segregated (low global integration) and less visible (low visibility) tended to exhibit higher rates of e-media consultation than their more configurationally and visually connected colleagues.

[12] In four URCs, a total of six outliers/key communicators were identified. There were no key communicators in two URCs. When the job descriptions of these individuals were checked with URC directors, their roles as key communicators were further confirmed. In other words, all individuals identified as key communicators because of their outlier status on social network analyses were associated with either a particular expertise in certain research areas (i.e. a specific statistical analysis method) or computer applications (i.e. knowledge of a particular research-related software).

[13] These analyses yielded statistically significant effects between $r^2 = 0.28$ and $r^2 = 0.54$ for global integration, $r^2 = 0.27$ and $r^2 = 0.71$ for visibility and $r^2 = 0.23$ and $r^2 = 0.68$ for walking distances.

[14] Since scientists were asked to enter the locations and types of consultations they *initiated*, the data showed the origins, but not the destinations of emails and phone calls within URCs. Therefore, it was not possible to analyze how walking distances affected consultations through e-media.

Table 4
Bivariate relationships between spatial predictors and consultations through e-media, originating from offices ($n = 120$ individual offices)

	Index of outgoing consultations through e-media (per scientist)
Global integration (configurational accessibility of individual offices)	$r = -0.24$; $r^2 = 0.06$, $p = 0.008$
Visibility (visible area from individual offices)	$r = -0.17$; $r^2 = 0.03$, $p = 0.07$

6.2.4. Summary

According to these analyses, individual spatial variables significantly predict unprogrammed and e-media but not programmed consultations. While the effect sizes differed somewhat global integration, visibility and walking distance each predicted coincidental consultations that took place in URC common spaces as well as unscheduled office visits that took place in private workspaces. The impact of spatial variables on unscheduled office visits increased substantially when scientist role was controlled for by excluding a very small number of "key communicators". Interestingly, global integration and visibility were negatively correlated with use of e-media consultation. Thus, when scientists occupy configurationally and visually segregated offices, they appear to increase their use of e-media for consultations. The remainder of our analyses will focus exclusively on face-to-face consultations.

6.3. Consultation and individual spatial predictors: a multivariate evaluation of effects

The bivariate data analyses we have just presented indicate that higher global integration, higher visibility (of common spaces and workspaces) and shorter walking distances contributed to more frequent coincidental consultations and unscheduled office visits. However, without multivariate analyses it is unclear whether these effects are relatively independent or highly redundant and ultimately how important each predictor is. Thus, in order to address research question 2a, *"What are the net or multivariate effects of significant individual spatial variables on consultations within URCs?"*, multivariate analyses of the relationships of our three significant spatial predictors on the indices of coincidental consultations and unscheduled office visits were conducted (Table 5). The multivariate models for both coincidental consultations and for unscheduled office visits were both statistically significant. They indicated that by combining global integration, visibility and walking distance we increased our ability to predict coincidental consultations and unscheduled office visits. For instance, the combined effect of the three predictors on the index of coincidental consultations increased from an r^2 of 0.50 (the bivariate effect of the largest predictor, walking distance) to an R^2 of 0.62 ($p < 0.0001$). Interestingly, in the multivariate model global integration now clearly makes the largest contribution ($\beta = 0.41$), followed by visibility ($\beta = 0.23$) and then walking distance ($\beta = -0.18$). Note that the global integration's effect is almost twice the size of the other two predictors.

Similar results were observed for unscheduled office visits. The combined effect of the three predictors increased from an r^2 of 0.42 (bivariate effect of global integration, without key communicators) to an R^2 of 0.57 ($p < 0.0001$). While global integration remained the best predictor ($\beta = 0.69$), the standardized beta weights for visibility ($\beta =$ of 0.50) and walking distance ($\beta = -0.34$) were also substantial.

6.3.1. Summary

Our multivariate analyses demonstrate that each of our three spatial variables make a unique and statistically significant contribution to both coincidental consultations and to unscheduled office visits. While global integration exhibits the largest effect for both types of

Table 5
Multivariate analysis of the relationships between spatial predictors and unprogrammed encounters (coincidental consultations and unscheduled office visits)

	Coincidental consultations (per scientist), combined effect ($n = 114$ common spaces): $R^2 = 0.62$, $p < 0.0001$	Unscheduled office visits (per scientist), combined effect (without key communicators, $n = 114$ individual offices): $R^2 = 0.57$ $p < 0.0001$
Global integration (configurational accessibility)	Standardized $\beta = 0.41$	Standardized $\beta = 0.69$
Visibility (visible area from individual spaces)	Standardized $\beta = 0.23$	Standardized $\beta = 0.50$
Walking distance (mean distance walked to each space for consultations–feet)	Standardized $\beta = -0.18$	Standardized $\beta = -0.34$

consultations, relative to other predictors, its effect is much larger for coincidental consultations that take place in common areas than for unscheduled office visits. Interestingly, in our multivariate models walking distance, while still significant, now has the smallest effect of the three spatial variables.

6.4. *Overall workspace planning approaches and consultation*

Multivariate data analyses revealed that individual spatial predictors significantly influenced the location of unscheduled office visits, coincidental consultations, and consultations through e-media within an URC. This indicates that individual spatial predictors did make a difference in where consultations will take place within these six URCs. However, in order to support a three-ring chain connecting workspace planning approaches, consultation and innovation process outcomes, one needs to also demonstrate that between URCs workspace differences affect levels of consultations. Thus, in order to address research question 3, "Across URCs, what is the relationship of overall workspace planning approaches to consultations?" we will make across URC comparisons. Because of the limited number of cases available, these analyses utilize a pattern matching approach rather than the statistical approach used above (Yin, 1994).

As described earlier, the six cases could be grouped into three workspace planning approaches: intact URCs with laboratories (URC1 and URC2); non-intact URCs with laboratories (URC3 and URC4); and finally, intact URCs without laboratories (URC5 and URC6). Since we did not make a priori predictions about the relative merits of these approaches, we will simply evaluate the extent to which these approaches explain a pattern of spatial characteristics and consultation activity. We will evaluate the spatial characteristics of these approaches with two variables: intelligibility (an overall measure of configurational accessibility) and mean walking distance for reported unprogrammed encounters. Consultation will be evaluated by three variables: percentage of face-to-face consultations, ratio of unprogrammed encounters per scientist and the connectivity of consultation networks.

As the top part of Fig. 2 demonstrates, there appears to be a clear pattern between workspace planning approaches and our two spatial variables. Intact URCs with laboratories have the highest intelligibility scores and also have the shortest mean walking distance reported unprogrammed encounters (0.5188, 0.5262; 43.5 ft., 33.6 ft.), followed by intact URCs without laboratories (0.4446, 0.4275; 47.9 ft., 52.1 ft.) and non-intact URCs with laboratories (0.1581, 0.1010; 72.9 ft., 88.5 ft.). Obviously, non-intact territories were not only affecting overall configurational accessibility, but also walking distances due to the relative locations of offices and laboratories.

A further review of Fig. 2 demonstrates an identical pattern for the three consultation variables. Intact URCs with laboratories had the highest percentage of face-to-face consultation (92% and 95%), ratio of unprogrammed encounters and connectivity of consultation network scores (0.0496 and 0.0741; 0.462 and 0.659), followed again by intact URCs without laboratories (90% and 89%; 0.0467 and 0.05; 0.368 and 0.258) and non-intact URCs with laboratories (84% and 84%; 0.0392 and 0.0416; 0.230 and 0.214).

Thus, intact URCs with laboratories had the highest mean percentage of face-to-face consultation (93.5%), highest mean ratio of unprogrammed encounters (0.0619), and mean connectivity of consultation networks (0.561). The mean scores of intact URCs without laboratories followed these scores (89.5%, 0.048, 0.313). The mean scores of non-intact URCs with laboratories were the lowest (84%, 0.040, 0.222).

These comparisons revealed that intact URCs with laboratories, whose territories featured the highest levels of overall configurational accessibility and shortest mean walking distance for unprogrammed encounters, also had the highest scores on a variety of face-to-face consultation measures. The pattern across individual URCs (ignoring workspace type) is also remarkable. A rank-order correlation for social connectivity of consultation networks and intelligibility across our six cases was $r = 0.77$ ($p = 0.07$). In the discussion section we will try to explain why these workspace planning features resulted in this particular pattern of results.

Taken as a whole, these findings suggest that the overall workspace planning approach influences not only the location of unprogrammed encounters within a URC, but also rate of face-to-face consultations, the rate of unprogrammed encounters, as well as the average connectivity of a scientist's consultation network across URCs.

6.5. *Evaluating the three ring chain: overall workspace planning approaches, consultation and innovation process outcomes*

The study's fourth and final question asked, "Across URCs, what is the relationship between overall workspace planning approaches and innovation process outcomes?" This question was also evaluated based on cross-site analyses, in this case using objective and subjective innovation scores for each URC (Fig. 2).

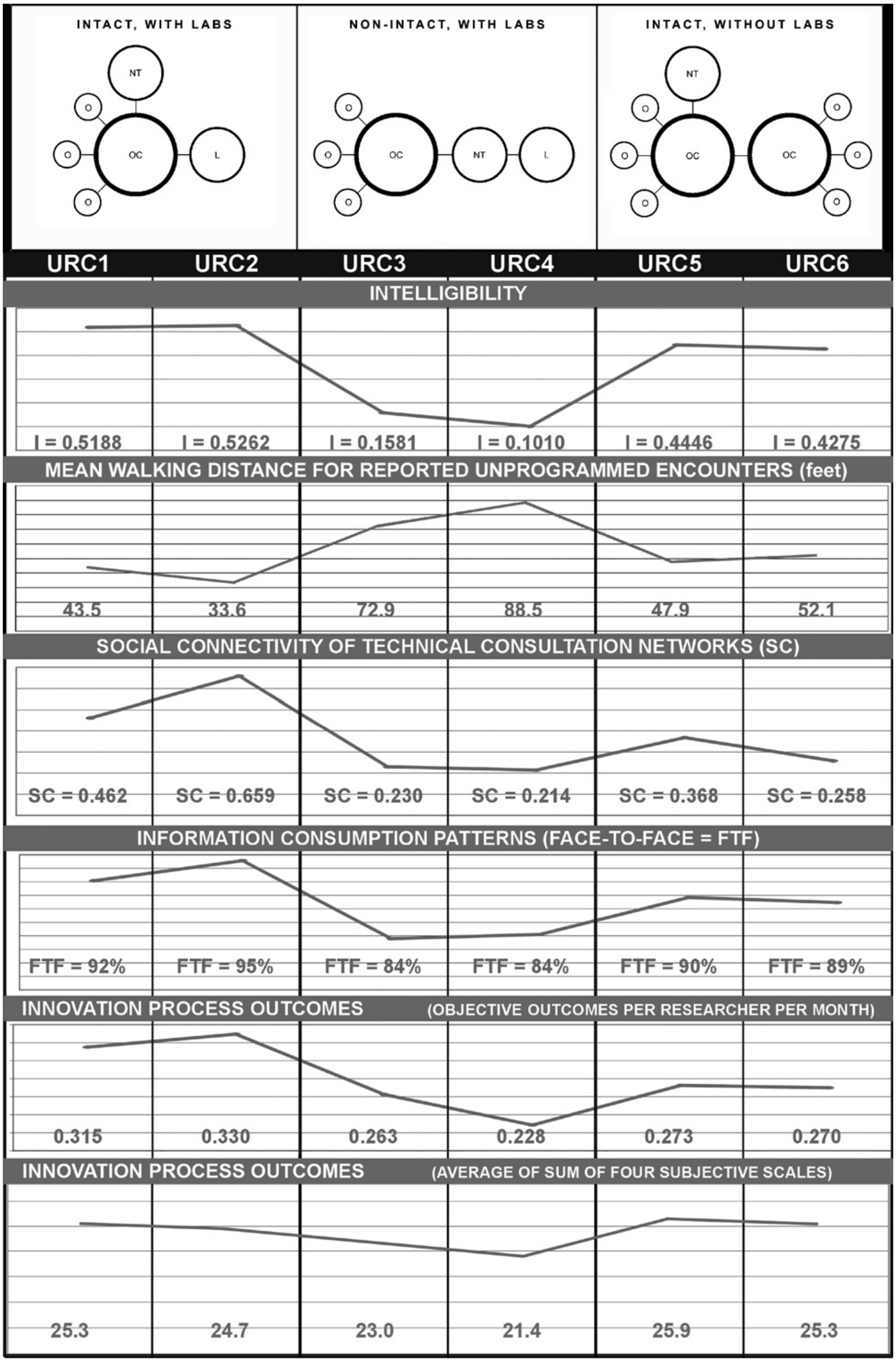

Fig. 2. Summary of cross-case comparison findings and repeating patterns of relationships found in the study.

As Fig. 2 reveals, there is a very similar, but not identical, pattern of relationships observed between workspace planning approaches and innovation outcomes to the pattern just observed between workspace planning and consultation. For objective innovation outcomes the pattern is identical: intact URCs with laboratories exhibited the highest objective innovation outcome scores (0.315 and 0.330), followed by Intact URCs without laboratories (0.273 and 0.270). Non-intact URCs with laboratories yielded the lowest scores (0.228 and 0.263) for the objective innovation outcome measure.

For the subjective innovation scale, the pattern while similar was not perfect with intact URCs without laboratories having about the same subjective innovation score as the intact URCs with laboratories (25.3 and 24.7 vs. 25.9 and 25.3) However, the non-intact URCs with laboratories continued to exhibit the lowest scores (23.0 and 21.4).

6.5.1. Summary

As Fig. 2 demonstrates, the congruence of the patterns of relationships across our major constructs is quite remarkable and provides the basis for process tracing, a more robust and systematic approach to pattern matching (George and Bennett, 2005).

When all six cases were considered, it can be observed that as URCs' overall configurational accessibility increases, and overall walking distances decrease, their (i) utilization of face-to-face consultations, (ii) ratio of unprogrammed encounters, (iii) connectivity of consultation networks and (iv) objective innovation outcomes increase (Fig. 2). The same pattern of relationships was observable in the case of subjective innovation process outcomes, with the exception discussed above. The various cross-case comparisons have shown that the planning of URC workspaces is strongly related to how scientists within URCs exchange research-related information and to various innovation process outcomes across URCs. As we will discuss in the next section, these findings appear to provide additional support for a three-ring model linking workspace planning, consultation and innovation process outcomes.

7. Discussion and conclusions

The overarching objective of this study was to identify how workspace planning (individual spatial predictors and overall workspace planning approaches) relates to consultation and ultimately to innovation process outcomes in a setting, university research centers or URCs that have become increasingly important to national and subnational innovation strategies. In order to address this objective we attempted to draw upon two surprisingly independent research traditions: workspace design and innovation studies. In doing so, the research team used a strategically selected mixed methods approach that included quantitatively based multivariate analyses and case study-based analyses suitable for small N situations while making extensive use of space syntax analysis, a relatively new analytical tool based on graph theory.

Our exploratory analyses showed that URC scientists make extensive use of face-to-face consultations for information exchange and that such consultations mainly take place in the form of unprogrammed encounters. Face-to-face consultations also constitute the first preference of scientists for information retrieval, from among a selection of other information resources. These circumstances and the workspace planning variability observed across sites, made our six URCs rich and interesting research settings for examining our study's research questions.

Our findings appear to add to our understanding of how and why workspace features affect technical consultations within and between URCs and in so doing provides methodologically robust support for linking the three-ring chain of relationships among workspace planning, information flow through consultations, and innovation. At a time when the research policy community is focusing considerable attention on spatial factors at a macro-level, these findings should serve as a reminder of the importance of micro-level workspace spatial factors.

7.1. Spatial features and consultation within URCs

Consistent with previous research, our analyses demonstrated that spatial variables, specifically global integration, visibility and walking distance, were associated with face-to-face consultations. However, our findings shed additional light on the nature and magnitude of these relationships. First, they demonstrated that these effects were statistically significant and were observed on both coincidental consultations that take place in common areas and for unscheduled office visits that take place in private offices. We were also able to show that effects of spatial factors increases substantially when one controls for the role of key communicators. More importantly, our multivariate analyses demonstrated that the combined effects of these three variables were quite large and their individual effects were relatively independent. That is, while global integration, a measure of configurational accessibility, was the largest predictor for both types of consultation, visibility and walking distance also have significant effects. These findings should both heighten our interest in using global integration in space-innovation studies while cautioning future researchers not to "put all their measurement eggs in one basket".

The logic behind these observed effects probably warrants some discussion. Specifically, these findings suggest that configurationally more accessible common spaces increase chances for bumping into other scientists, since they are on a higher number of paths between other spaces. Similarly, high visibility common spaces increase chances for catching eye contact with fellow scientists passing-by, which facilitates discussions. Common spaces that are shorter walking distances from other spaces also increase chance encounters. Thus, it appears that those URCs with relatively compact territories and shorter walking distances would benefit from these features through increased occurrences of coincidental consultations. Therefore, it is possible to suggest that main circulation corridors and informal common spaces need to be configurationally highly accessible, highly visible and reachable through shorter walking distances so as to form an environment more conducive for technical exchange via coincidental consultations.

A similar set of processes apparently affect receipt of unscheduled office visits. Our findings suggest a scientist would be likely to receive more unscheduled office visits, when he/she occupied an office that is (i) configurationally accessible (i.e. on more paths among other spaces in a URC) (ii) highly visible from common areas such as corridors and (iii) a shorter walking distance from other spaces. In other words, in a given period of time, such a scientist would receive more unscheduled office visits than his/her colleagues in less visible and segregated offices. Not surprisingly, the size of these effects are much larger when one controls for key communicators in a given URC.

Interestingly, but perhaps not surprisingly, we also find that those scientists who do not occupy "favorable" spaces according to these conditions tend to substitute consultations through e-media for face-to-face consultations. However, our cross-case analyses suggest these consultations may not provide the same value as face-to-face consultations.

7.2. *Workspace planning strategies, consultations and innovation outcomes across URCs*

Our findings also show that workspace planning strategies, defined by whether URCs were intact and had a lab, had an obvious impact on a variety of territory-wide spatial measures and ultimately face-to-face consultations and the connectivity of consultation networks. Most importantly, our findings also showed that these spatial and consultation differences are associated with differences in both objective and subjective innovation process outcomes. Thus, our results appear to provide support, within a single study, for linking the three circles of workspace planning, consultation and innovation.

At this point, it is also important to recognize the wide range of findings on the appropriateness of the workspace environment for the kind of work done. While our findings highlight the importance of promoting contact and interactions among researchers, it is important to remember that researchers also need privacy and space that meets this need. Although significant amount of face-to-face consultations facilitate innovation, the need for privacy for concentrated work cannot be neglected. In fact, various authors have pointed at provision of a variety of environments for different work patterns, so that privacy needs of users are accommodated along with frequent idea exchange (i.e. Duffy, 1997; Laing et al., 1998).

With respect to consultation effects, we observed that URCs with intact territories provided greater opportunities for face-to-face consultation and that intact URCs with labs were superior to those without. This latter difference was unexpected. We suspect this effect is caused by the fact that scientists in intact URCs with laboratories need to go through territorial common spaces when they go between their offices and their laboratory spaces and scientists without laboratories do not. This difference results in increased travels within the territory, thus increasing the chances of unprogrammed encounters. Obviously, future space-consultation research should try to control for this effect.

Most importantly, our results also show that higher rates of face-to-face consultation and network connectivity are associated with higher scores on both objective and subjective innovation process outcome scales. In fact, in spite of a minor discrepancy for subjective innovation outcomes, the congruence of the process-tracing pattern across spatial, consultation and innovation variables across types of workspace and across individual URCs was quite remarkable. We suspect the integrity of this pattern was aided by our ability to study a set of URCs that were organizationally and structurally homogeneous. Since previous research has not demonstrated the space–consultation–innovation link within a single study, we believe our findings provide important new support for the hypothesis that face-to-face consultation can mediate the effect of workplace arrangements on innovation outcomes—the three-ring chain.

7.3. *Implications for design, research management and policy communities*

While a comprehensive discussion of the implications of our results for the design community are beyond the scope of this paper, these findings clearly have implications for workspace designers involved in R&D settings like URCs.

First, our findings confirm what the design community has taken for granted, that the built environment forms a mold to human behavior and encounters and those effects have important consequences for research settings like URCs. However, the mechanisms that produce those effects appear to be more complex than reported in previous research. Specifically, our findings demonstrate that those effects are determined by a complex interplay of the overall workspace planning approach used plus the configurational properties, walking distance and visibility and common rooms of a research setting. Taken together these findings should provide guidance for the design of more effective research settings.

For the research management community, including university CEOs responsible for planning new research buildings on their campuses, the major message from this study may be "you get what you pay for". From a practical point of view, it needs to be emphasized that non-intact URC territories, including use of ad hoc space on campus, inhibit face-to-face consultations through segregation of offices and laboratories, long walking distances, decreased configurational accessibility levels, and non-territorial connections between offices and laboratories. Although this model seems to save time and money by avoiding the project phases required for designing and building customized buildings (or at least customized URC territories), in the long run, innovation-related losses caused by such URC territories are likely to be much more significant.

Considering that over a period of 10 years, operating and maintenance costs of an organization remains around 8%, whereas human costs remain around 85–90% (Brill et al., 2001), it becomes clear how advantageous it would be to invest in the productivity and information exchange of scientists rather than short-term savings. In this respect, it is reasonable to suggest that strategic workspace planning for facilitating face-to-face consultations among scientists will be advantageous over dwelling merely on concerns of cost reduction, efficiency for equipment, and square footage.

At a time when the innovation community is showing increasing interest in spatial analysis at the national, regional and local levels, our findings suggest that S&T researchers and policy makers need to begin paying more attention to a micro-level of analysis that acknowledges the importance of the R&D workplace. More specifically, our findings suggest that, in addition to trying to foster synergistic technology-based clusters and research parks, policy makers and planners should consider workspace planning of publicly funded settings like URCs an important tool for fostering information flow, collaboration and ultimately publicly beneficial innovation.

Implications of our findings for the scholarly community interested in these issues seems relatively obvious. While our results provide new support for the belief in a causal connection between the three rings of the workspace–consultation–innovation process outcomes chain, there is a need for additional research on these connections. This research will need to both replicate what we found in other settings and go beyond our study both methodologically and conceptually before we can confirm the reliability and size of these effects. It will also need to estimate the relative contribution of spatial factors that meets the need for both face-to-face consultation and privacy compared to factors like culture, team compatibility, leadership, creativity. This would allow one to examine the possibility that spatial factors might mediate or moderate the effects of these and other well established social and cognitive precursors of collaboration and innovation.

From a quantitative research standpoint, improvements could be made in statistical conclusion, construct, internal and external validity (Shadish et al., 2001). For instance, statistical conclusion validity could be improved by using larger sample sizes (for increased power). Statistical and conceptual benefits could be realized by using more sophisticated statistical tools like hierarchical linear modeling (Raudenbush and Bryk, 2001) which seems ideally suited to unraveling the relative importance of spatial and other factors (e.g., organizational climate, leadership) when individuals are nested in groups (or buildings). Longitudinal designs, particularly designs that take advantage of circumstances where teams move from one setting to another, could be used to improve the internal validity of conclusions. Construct validity could be enhanced by improving the ways in which research days and/or encounters are sampled (e.g., randomly) and by increasing the diversity and validity of innovation process and outcome measures. Finally, external validity could be improved by expanding the types of URCs and research settings studied, even including traditional academic departments (including ones in the social sciences and humanities) and the national contexts in which they are embedded. Obviously, increased sample size and improved sampling (of sites), construct validity and longitudinal designs would also benefit the kind of cross-case analyses we used in our study (George and Bennett, 2005).

In addition to encouraging and supporting more research on the influence of workspace planning for publicly funded research buildings, implications for the policy maker are similar to those for research manager but on a grander scale—"you also get what you pay for". Since national and sub-national governments often pay for or at least cost-share the expense of building university research buildings, they will have to decide to weigh tradeoffs between square footage and more pro-collaboration workspaces. While such funding decisions are always difficult, trying to build a local, regional or national innovation system on building blocks comprised of poorly designed public research facilities appears to be "penny-wise and pound foolish".

Finally, it would be misleading to suggest that increased funding is the only avenue to improving the design of our URCs (or other R&D spaces for that matter). Increased engagement and dialogue between the innovation and design communities by itself can make a big difference. As our study suggests, effective workspace planning and design needs to account for multiple issues rather than focusing on a conventional dialectic of open versus enclosed office arrangements and the actual users of that space should play an important role in that discussion.[15]

A brief look at the history of workspace planning and design for organizations with varying objectives reveals that using a knowledge-base derived from the occupiers of planned and designed space has been critical to various workspace advances since the early twentieth century. The work of Michael Brill and the BOSTI Associates (Brill et al., 2001), Frank Duffy and DEGW (Laing et al., 1998) and the participatory planning and design processes advocated by Sanoff (1992) and others, constitute good examples of how a new tradition of knowledge-based, end-user sensitive workspace planning and design can be implemented. We believe the time for a serious dialogue between the innovation and workspace design communities toward the creation of pro-innovation URC and R&D workspaces is long overdue.

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[15] Against its director's deliberate request for an intact territory, one URC was provided with a non-intact territory in a recently built shell structure, due to a shortage of space. When approached for data collection, this director was really anxious to participate, since he wanted to report the findings of this study in his ongoing argument with decision-makers as evidence of how its territory undermined this URC's work. Similar concerns were discussed by many URC directors and scientists that were interviewed or visited during case selection.

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