The influence of spatial organization of the home on inhabitant activity

S o n i t B A F N A*, E a r l e C H A M B E R S**
* College of Architecture, Georgia Tech, Atlanta GA 30318 USA
** Department of Family and Social Medicine, Albert Einstein College of Medicine, Bronx, NY, USA

Abstract:
We describe a study to test whether the arrangement of rooms in an apartment has any systematic association with the levels of activity of its inhabitants. This study was conducted in a sample of Latino adults living in the Bronx, New York. A convenience sample of 19 apartments was selected within the Bronx, NY and one adult volunteer was selected from each household based on who was present at the time of a home visit conducted to collect information on extent of activities. Floor plans for the apartments were obtained from the city authorities.

The paper begins by reasoning about the mechanism by which the organization of space can influence levels of activity in the house, and goes on distinguish, first, habitual from deliberate and planned activity, and second, sedentary from more vigorous activity. It is argued that habitual activity would be more susceptible to the influence of spatial organization, and that such habitual activity is likely to be sedentary activity around the house rather than moderate or intense activity. Furthermore, different types of sedentary activity should respond differentially to spatial organization. Specifically, sedentary activities that are susceptible to social life in the house, or require social participation like watching TV or playing cards, should show a positive association with how closely the rooms are knit together, while sedentary activities such as reading, working on computers, and playing video games, that are better conducted in solitary situations, should not.

Bivariate analyses showed that interconnectedness (a modified version of integration) was significantly associated with hours spent in socially susceptible sedentary activities but not with hours spent in sedentary activities that occur in solitary conditions, like using the computer or reading. In multivariate analyses, conducted to control for the effects of age and educational level, interconnectedness was still significantly associated with sedentary activity hours. A separate test showed that the positive association with interconnectedness also held for sitting/reclining Hours reported over the day; unlike sedentary activity hours, sitting/reclining hours included activity outside the home as well, so the result raises issues of additional interest.

The paper concludes by presenting methodological implications, focusing particularly on how the study could be further developed to model the specific mechanisms by which spatial organization exerts its influence on behavior.

Keywords: *Sedentary activity, habitual behavior, socialization, domestic life, methodological individualism, functional explanation.*

Does the interior spatial organization of a residence have any systematic association with the levels of activity of its inhabitants? In a pilot study conducted to explore the issue, we found not just a confirmation of this question, but, more interestingly, results that give insights into what kind of behaviors might be susceptible to influence from spatial organization. This study came about as a result of a larger project concerned with identifying factors that could impact obesity levels in a population of adult, low-income, Latinos inhabiting an urban environment in New York City. The causal structure that we worked from (Figure 1), drawn from space syntax research and from work of environmental behavior researchers like Evans (2003), suggested that spatial organization of the house should have an impact on the health of inhabitants through mediating factors like levels of activity and psychosocial constructs like perceptions of closeness, of crowding, or of awareness of others. But before investigating the more complex issues related to the role of psychosocial variables, we wanted to confirm that there was strong evidence for the influence of space on levels of inhabitant activity.
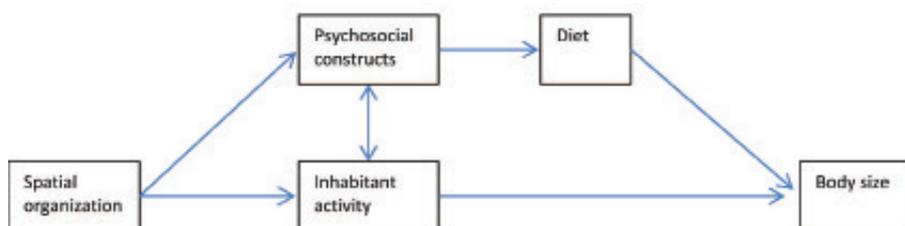

Figure 1. *Model describing how spatial organization can influence obesity rates. The present study is concerned only with the direct association between spatial organization and inhabitant activity (bold arrow); it seeks to articulate a mechanism, and through that, identify conditions under which the expected causal link shown can hold.*

1. Background: A mechanism for describing the impact of space on activity

Although the empirical association spatial configurational variables and behavioral ones has been a dominant feature in space syntax studies, there has been very little active speculation on the nature of the mechanism that would produce such associations. We approached our study with the premise that any empirical association between the two would have the necessary generality only if supported by at least a posited mechanism, if not one that could be necessarily established. Increasing interest in spatial cognition in the last decade or so has produced some speculations about such mechanisms, but by and large the studies in which mechanisms have been more explicitly discussed have been those in which the individual is involved in activities that require an explicit perceptual involvement with the environment—way-finding, for instance, or interacting with paintings in a gallery (Dalton 2003, in particular, but also Penn, Desyllas and Vaughan 1999, Kalff et al. 2012).

This study is concerned instead with the influence of space on activities where deliberate attention to the physical environment is not a requirement—the daily life in an apartment home. The working hypothesis here is that in such activities the effect of space on behavior is not constant, but modified by the

social life within it, and by the type of activity conducted within it. The origins of the idea of such a mechanism lie in the Bernsteinian distinction between weak and strong program buildings, made very early on in the literature in the context particularly of workplace settings (Hillier, Hanson and Peponis, 1983) and in the implication that it is in the weak program spaces that the generative effects of space would be most strongly observed. Although well known to syntax researchers it is worthwhile to lay it out explicitly. The generative mechanism may be described as a sequence of three sequential propositions: 1) once a spatial setting is described as a configuration of discrete component spaces, the component spaces can be distinguished structurally in terms of different levels of visual exposure and differential access to other spaces; 2) this allows them to provide different kinds of social affordances—opportunities for unplanned encounters, places for visual surveillance, and for withdrawal and refuge, ability to monitor and control access, places that allow visual and other kinds of privacy, which in turn, 3) allow particular habits or patterns of behavior to develop, patterns that begin to characterize the emergent social life in that setting and that may observed. If this schematic argument holds, then one has grounds for positing that the role of space in any observed statistical association between spatial organization and behavior in weak program settings would be causal.

This mechanism can be applied to a variety of settings and to explaining different types of behavior, and is implied in characteristic studies of different types of behavior: way-finding (Peponis et al., 1990, Haq and Zimring, 2003), various types of informal communication that help create and maintain social networks in workplace settings (Peponis et al., 2007, Penn et al., 1999, Wineman et al., 2009), habitual patterns of nursing-rounds (Choudhary et al., 2009); fall rates in hospitals; choice of locations for impromptu work-related conversations in corridors (Lu, Peponis, and Zimring 2009). By and large, however, the studies have tended not to test the entire mechanism, but focus on issues related to proposition #2—the association between the syntactic values of component spaces and social affordances, with the affordances operationalized in terms of specific observed behaviours associated with them. As a result, the hypotheses tested, and therefore the methodological approaches, in all such studies, share a common set-up: the unit of analysis is always the component space of a larger setting, and what is explained by the variation in observed behavior amongst the component spaces of the setting, the explanans being the variation in syntactic values of the component spaces.

Such an approach was not suitable for our study. The house—particularly, given that we were concerned with 2 to 4 bedroom apartment units—is not quite the weak program setting that one finds in very large institutional buildings. This because even in homes where labels like bedrooms and kitchen do not dictate activity, there is generally a strong matching of specific activities to specific spaces, not by dictates of the program and social relations implied by it, but by habitual patterning of daily life. In addition, the numbers of inhabitants are not large enough to produce generative effects of space that are characteristic of weak program settings. The implication is that a mechanism that explains variation in behavior amongst the various parts of a given spatial setting is not suitable here; our interest is in thinking of a related mechanism that would explain behavior across spatial units. The appropriate unit for our study is the entire house—an apartment unit, more accurately— and as we shall see, for practical methodological reasons, primarily having to

do with how the behavioral data were collected, the practical unit would be an individual mapped to an apartment.

1.1 The influence of spatial organization on daily activity in the house: two distinctions

There have also been attempts to link spatial organization of the house to psychosocial outcomes such as social isolation, social control, and psychological distress (Evans and Lepore, 1993, Evans et al., 1989, Evans et al., 2003). But because these studies were concerned with psychological causes, the mechanism articulated in them assumes spatial organization acts as a mediating element and not a causal one, and this is not transferrable to our case.

Is it possible to conceive of a mechanism, then, by which the individual's level of activity is not merely mediated by overall spatial organization of the house but actually generated by it, even if partially so? To answer this question, two distinctions can help. The first is between deliberate and habitual activity. This distinction comes from the observation that human behavior—particularly the everyday behavior that characterizes routine activity at home—often includes activity that may be conducted habitually without deliberate thought being given to its planning or execution. It is important to note that this distinction does not imply that habitual activity cannot be wilful or intended, but rather that it is something that proceeds from following a sort of automated procedure rather than from a process that requires deliberate thinking and decision making.

Such habitual activity is, we believe, particularly susceptible to spatial organization. The focus on informal activity and chance encounters in studies about workplace settings and urban environments, and the distinctions between strong and weak program buildings, all arise from similar observations. When negotiating the everyday, familiar, environment, we relegate our awareness of it to a state of background consciousness. It is common experience that we while going about in such environments, we are free to engage our conscious thought on other things—interacting with others, with specific things we encounter, or engaging in thought. But since we do not at the same trip over, or run into things, we must of course be aware of the immediate environment and respond to it. The process of becoming familiar with the environment, thus, not only involves developing cognitive maps of it (O'Keefe and Nadel 1978), but also developing specific procedures of negotiating it—procedures that may be invoked and executed almost entirely in a state that psychologists identify as background attention (Iwasaki 1993). Although there is not much research that specifically demonstrates this point, our contention is that the formation and subsequent of such procedures is strongly influenced by spatial configuration—this is because even when we are in the process of becoming familiar with the environment and developing habitual pathways through it, the spatial configuration determines how the environment is revealed to us. What is important to note here is it is the overall configuration of a spatial setting to which this activity responds—the habits of selecting a particular path through a setting, of frequently breaking off from a desk activity to make short excursions. Even if such habitual activities are spatially localized, the influence of spatial organization will be on the frequency of activities rather than on determining what sub-spaces within the overall setting that the activity occurs in.

The other distinction has to do with levels of activity: of vigorous, moderate, light, and sedentary levels of activity that researchers in public health distinguish, the effects of space should, by our account, be more strongly felt on sedentary activity. Moderate and vigorous activity is naturally conducted outside homes, but more to the point, it is likely to be conducted deliberately. On the other hand, a fair amount of sedentary activity in the house may happen in unplanned situations. This is particularly true of activities that are part of the day-to-day social life in the house. Watching TV, for instance, is a particularly good example of such sedentary activity—although it may happen as a result of deliberate intention to watch specific shows, it can also be instigated simply by decisions to participate in an ongoing social activity. Specific to our study sample, research (Lindsay et al., 2009) shows that among Latino families, watching TV is a social activity that accompanies mealtime, babysitting children, and learning English.

Recognizing these distinctions, we can posit a possible mechanism in which the syntactic variables of space would influence behavior, not through inciting or motivating particular actions, but rather through patterns that emerge in habitual and generally unreflective choices made in the day to day business of living, in planning paths, in organizing activities and in selecting locations for them. If this is correct, then one way to demonstrate this would be to show that there is differential association of space with activities that differ in their motives.

For instance, we can expect that the influence of the overall integration levels should be felt selectively on different types of activities; more highly integrated homes—homes with rooms that are connected to each other through fewer intermediate doors on the average—should offer greater opportunities for socialization and encourage greater interaction amongst the inhabitants. So deliberate moderate and vigorous activities should not be influenced by overall integration, but certain types of sedentary activities should. And of the sedentary activities, it is the unplanned activities whose occurrence or duration is influenced by incidental situations that emerge in the normal social life of the house that should show greater association with overall degree of integration in the house.

These distinctions are also relevant from the point of view of some recent trends in obesity studies. Sedentary activities have recently emerged as a focus of interest in public health research. Watching television specifically has been shown to contribute to the risk for cardiovascular disease (Dunstan et al., 2010, Hansen et al., 2012, Healy et al., 2008b). There is a growing recognition that limiting the time spent in sedentary activities has significant cardio-metabolic benefit (Dunstan et al., 2012, Owen et al., 2010). Studies show that breaks in sedentary time are associated with a decrease in waist circumference, body mass index, and triglyceride levels (Healy et al., 2011, Healy et al., 2008a). These health advantages can be observed independent of overall physical activity (van der Ploeg et al., 2012, Healy et al., 2011). However, few interventions to reduce physical inactivity incorporate the spatial context of sedentary behaviors which may be important to understanding the barriers to reducing sitting time. As Chambers and Fuster have advocated, demonstrating the influence of physical characteristics of individual homes on the extent and nature of their inhabitants' sedentary activities is an important next step in developing policies and guidelines that would lead to healthy environments (Chambers and Fuster, 2012).

If our account concerning the influence of spatial configuration on activity levels is correct than the following conditions should hold:

1. inhabitants in apartment homes with a greater degree of integration amongst their rooms should report greater time spent in sedentary activities that are typically social such as watching TV, or playing cards, but

2. time spent in solitary social activities such as using the computer, knitting, or needle work, should not show any strong association with integration, and

3. time spent in vigorous, or moderate activity levels, should not show any significant association with integration or other spatial variables.

2. Methods

In order to make initial, exploratory tests of our hypotheses, we developed a pilot study for a sample of Latino adults living in the Bronx, New York. A convenience sample of 21 apartments was selected within the Bronx, NY chosen based on whether they were in an elevator building (N=5), a walk-up building/ no-elevator (N=6) or a detached or semi-detached building (N=10). Once the home was selected, one adult volunteer was selected from each household based on who was present at the time of the home visit. The participant had to be 18 years or over, a resident of the household, and mentally and physically able to complete study. Age (years) and education level (≥ college/ university), as a measure of socioeconomic status, were collected by questionnaire during in-home interview. These potential confounders were chosen to be included in the analysis based on their known relationship with sedentary behaviors and their potential to be associated with the type of home residing within. This study was approved by the institutional review board of the Albert Einstein College of Medicine. All participants gave written informed consent in either English or Spanish.

2.1 Activity data

Information regarding the amount of activity by the subject was collected by questionnaire during in-home interview. Sedentary activity, only in the home, was measured by a questionnaire item asking: On a typical day, how many hours do you spend in these activities? a) Sit at the computer, outside of work; b) Watch TV; c) Play video games; d) Reading; e) Playing cards or board games; f) Doing needle work, like sewing or knitting. Another questionnaire item identifying sedentary activity, not solely in the home, asked: How many hours a day do you spend sitting or reclining? This variable captures sitting or reclining in any environment throughout an average day of the participant.

2.2 Syntactical data

Syntactical data associated with each individual were determined by mapping the individual's apartment unit. Syntactical values, therefore, were computed for the entire apartment. The floor plans for the apartment were requested from the New York City Department of Buildings and analyzed using UCL Depthmap version 10.14.00b (Copyright: University College London, Alasdair Turner, Eva Friedrich, 2010-11). For partitioning the homes into its components spaces, (here "rooms"), we used a modified boundary-map method.

This procedure was thought to be better suited to our project than more conventional technique of convex-space partitioning. As Peponis et al. (1997) discuss, the procedure for creating a convex partitions is ambiguous in its

specification—the demand that both fewest and fattest spaces be created cannot always be satisfied, and as there is no rule for preferring one over the other, there is no guarantee of a unique partition. Given the generally small number of component spaces in our sample floor plans, we wanted to use a more reliable procedure for generating the plans. The partitioning in our plans was accomplished by separating rooms either at doorways or where the transition from one room to another is unambiguous and sharp. In all cases, this specification led to an unambiguous identification of individual spatial units. The second advantage of our procedure was the simplicity of interpreting the graph that was created. Not only were the spatial units created by the partition all identifiable as distinct spaces, often with labels attached to them, but more importantly the links between them also carried a distinct identification—they all referred to a physically identifiable boundary being crossed in the actual plan (cf. Bafna 2001). Labels are significant not so much because they identify specific activities associated with space, but because they give evidence of a culturally determined segmentation of spaces (Kent 2001). The result of partitioning procedure was to create a map that confirmed closely to the way the house was understood by its inhabitants.

2.3 Modeling technique and variables

The response variables in our statistical analysis were sedentary activity variables (daily hours reported for social and sedentary activities, and daily hours reported as spent sitting or reclining). Treating them as count data, we modelled them using the generalized linear modelling techniques, assuming Poisson distribution for the hours reported, and a log link function.

The only syntactic variable that our hypotheses required was that of overall integration of the unit; we chose to define this as mean of the total depth values of all the rooms in the unit. The reasoning behind using actual depth values rather than conventional Integration values, and using the total, rather than mean, depth of each room, was that the association between inhabitants' behavior and actual depths between rooms is more straightforward to explain than one between behavior and relativised depth values. The distribution of total depth values of components spaces in any typical building is usually very asymmetric, but even so, we decided to go with their mean to characterize the entire home rather than a median or a trimmed mean, since the mean takes into account the relative role of each space in determining the perceived or active integration of the rooms within the network describing the home and so is more representative of the entire home in this case.

Because mean total depth values increase exponentially with number of rooms, and their distribution was skewed in initial descriptive analyses of our data, and because depth is inversely related to integration, we transformed the mean total depth values to create new variable called "interconnectedness," defining it as the negative of the log of mean total depth. Interconnectedness can be interpreted as a direct measure of the degree of mutual integration of all the rooms in an apartment; greater values of interconnectedness correspond with high integration, and differences in smaller values count more than those at higher values.

All analyses were conducted using JMP®, Version 9.0.2, (SAS Institute Inc., Cary, NC, 2010).

3. Results

The 21 participants were mostly female (90%), 43% had a college education or more, and the average age was 39.57 (±15.58) years. Half of all participants came from households with either 3 or 4 inhabitants, but the overall size of household ranged between 1 and 7. The participants reported an average of 6 (±3.73) hours per day for sedentary activities. Much of the reported sedentary activity consisted of watching TV (Mean=3.33 ±2.12 hours) and using the computer (1.86 ±1.74 hours). Only 38% of the participants reported time spent in reading (between 1 and 4 hours per day) and just two subjects reported between 1 and 3 hours of other activities like playing video games or cards.

Each apartment unit had a mean total depth of 18.02 (±9.2) steps, ranging from a minimum of 6.4 to a maximum of 27.1, excluding one outlier (51 steps). Its distribution was skewed (skewness=2.23), but transforming it to internconnectedness produced a much less skewed distribution (Mean=-2.8 (±0.45), skewness=-0.18). The average floor area of the apartments (internal, not including exterior walls) was 844 square feet (5% trimmed mean = 844.51 sq. ft.), with an inter-quartile range between 638 sq. ft. and 998 sq. ft.; the smallest apartment had an area of 444 sq. ft. and the largest, an outlier by some distance, was 1759.5 sq. ft.

Bivariate analyses showed that the total of sedentary hours reported by all 21 subjects were significantly associated with interconnectedness (β = 0.41, s.e.= 0.20, p = 0.0427). Furthermore, splitting up the sedentary hours reported into hours reported for distinct activities, we found that much of the association between interconnectedness and sedentary activity was due to hours spent watching TV (β = 0.59, s.e. = 0.26, p = 0.0318). Hours spent using the computer did not produce significant association with interconnectedness (β = 0.29, s.e. = 0.37, p = 0.440), nor did hours spent reading (β = 0.17, s.e .= 0.61, p = 0.790). The number of subjects reporting hours spent on playing video games, playing cards, or knitting was too low to be modelled. Our results thus bore out our main hypotheses: sedentary activities showed association with spatial configuration of the unit, and of these only those with social and incidental participation showed association with spatial configuration.

In order to further confirm this result, we conducted multivariate analyses on activity hours, adjusting for two potential confounding factors: age and educational level of the subjects. Sex was not included since our sample was overwhelmingly (19 out of 21) female. We first modelled our response variables independently for each of the confounding variables. Neither age nor educational level showed any notable association with the activity hours. The association of age with total sedentary hours was nearly significant (p=0.0737), but not with TV watching (p=0.262), computer-work (p=0.376), and reading (p=0.420). Educational level was recorded as a nominal variable with two categories: those with post-school education (university or trade school) and those without (only high or middle school education). No significant differences were recorded between these categories either for the total sedentary hours (p=0.162), or for TV (p=0.971) or computer-work (p=0.459). The only significant difference was in reading hours, where subjects with university/trade school education reported more than half an hour on an average more of reading hours (significant at p=0.0373) as compared to those with only high school or lower education.

Multivariate analyses taking all the potential explanatory variables into account reconfirmed our hypotheses. Adjusting for both age and educational levels, interconnectedness was still a significant factor in the explanation of the total sedentary hours (β=0.52, s.e.=0.20, p=0.0117), as it was in the case of hours reported for TV (β=0.65, s.e.=0.28, p=0.0196). In both cases, omnibus tests comparing the complete model against simpler models with only the intercept and no explanatory variables, produced low chances of Type 1 error (p=0.007 for total sedentary hours, and p=0.08 for TV). Residuals were distributed randomly around zero and looked satisfactory as well (Figure 2). And, as in the case of bivariate tests, interconnectedness was not significantly associated with either hours reported for computer-work (β=0.38, s.e.=0.38, p=0.31), or for reading (β=0.42, s.e.=0.62, p=0.50) when age and education were taken into account.
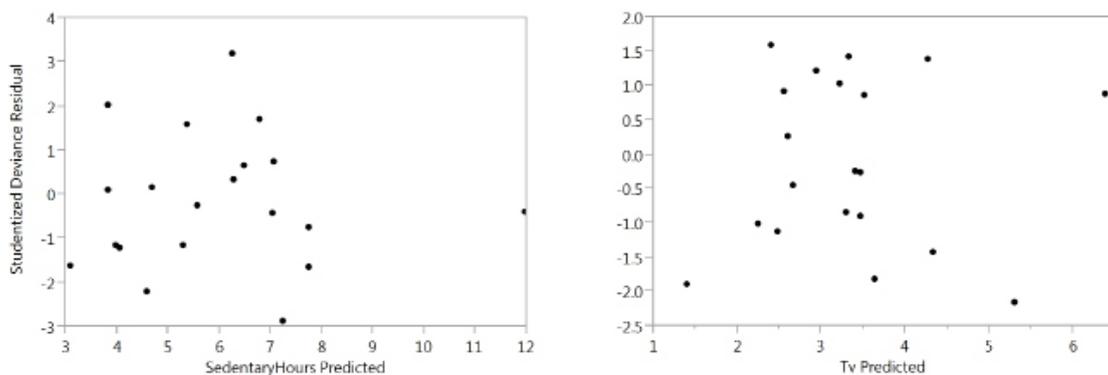

Figure 2. Deviance residuals for GLMs predicting sedentary hours (left) and hours spent watching TV (right); the residuals are distributed evenly and randomly around zero and confirm the quality of the generalized linear models.

An interesting result from the multivariate models was that once interconnectedness was included, age showed significant (negative) association with both overall sedentary hours (β=-0.01, s.e.=0.006, p=0.0352). It was not associated with hours spent in either computer work (p=0.549), or in reading (p=0.758). Thus, once the effects of spatial configuration are parcelled out, older subjects in our sample seemed to spend less time watching TV, and in sedentary activities overall. The profiler plots (Figure 3) give an idea of the amount of differences involved. There is no straightforward interpretation of this result, but we discuss some possible implications for our theory in the discussion section that follows.

Table 1 gives a summary of relevant outcomes (parameter estimates along with their confidence intervals, and the omibus tests for overall significance) of the four multivariate modelling exercises.

A multivariate model of sitting/reclining hours reported by the subjects, with interconnectedness, age, and educational level, as explanatory variables, was significant at p=0.0015. Both interconnectedness (β=0.66, s.e.=0.20, p=0.0019) and age (β=-0.019, s.e.=0.007, p=0.005) were significantly associated with the sitting/reclining hours. The sitting and reclining hours reported here could include time spent outside the home, and so, although the result seems to be in line with the other results, its interpretation is not straightforward.
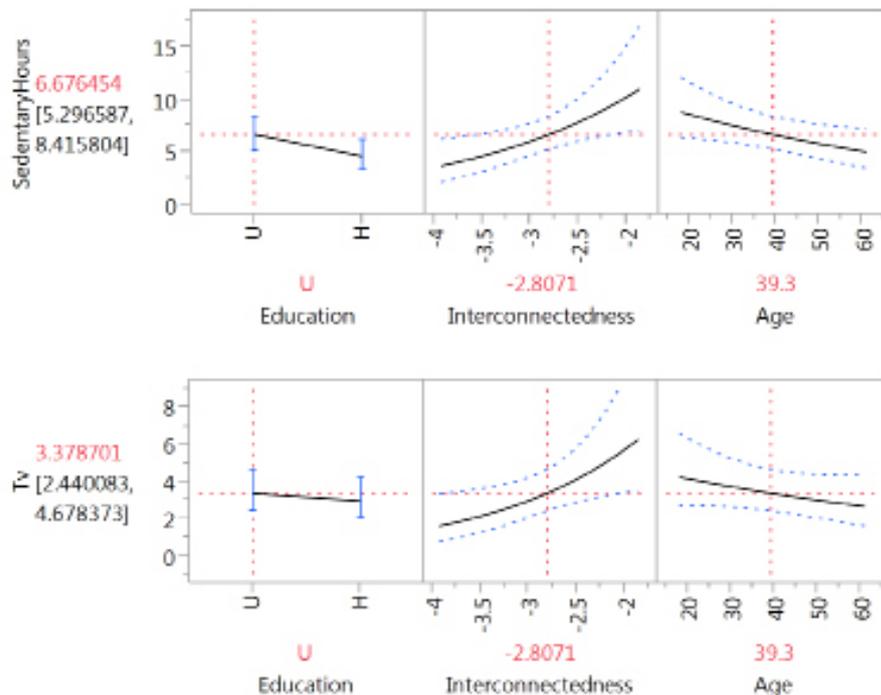
Figure 3. *Predictor profiler plots produced by two multivariate GLMs (Sedentary hours, above, and TV, below). The plots show the predicted effects on the response variables of change in values of each of the explanatory variables. Values in red, for continuous scale variables are means, and the values in black for response variables show the 95% confidence interval at the mean levels of all the explanatory variables.*

We also ran some tests to see if some of variation in sedentary activity levels was better predicted simply by area of the individual units, rather than interconnectedness. Area did not show any significant correlation with time spent in most of the sedentary activities—working on computer (R=-0.141; p=0.563); reading (R=-0.142; p=0.562); playing videogames (R=-0.007; p=0.98). The correlation was better with time spent in watching TV-R=0.40, but still not significant (p=0.09).

When we substituted area for interconnectedness in our multivariate generalized linear models controlling for age and education, we found that it produced models with lower explanatory power and an omnibus test statistic that did not reach statistical significance. Modelling overall sedentary hours by area, age, and education did not give significant results on the omnibus test (negative loglikelihood= 3.75, or, -2LL=7.5 (df=3); p=0.06; compare with omnibus test reported in Table 1.1) and produced a larger AICc number (110.97) compared to the model for the same data using interconnectedness (AICc = 107.29). The models for individual sedentary activities using area did not reach significance as well.

4. Discussion
The comparisons with the models using area instead of interconnectedness give some support to our thesis that the configuration of space within buildings--how much it is partitioned and how the partitioned rooms are linked

Table 1. *Parameter estimates from multivariate generalized linear models (assuming Poisson distributed variable with log link function) for 1) all sedentary hours reported by the subjects and for hours reported as spent in 2) working on the computer, 3) watching TV, and 4) in reading per day. The columns from left to right show the estimated values of the parameters and of their standard errors, the values of the chi-square distributed likelihood ratio test-statistic computed for each parameter and the probabilities of obtaining the statistic purely by chance. The final two columns give the lower and upper values of the 95% confidence interval for the estimated value of the parameter. Note that Interconnectedness is significant (at 95% or below) for all sedentary hours and TV watching, but not for reading or computer hours.*

Parameter	Estimate	Std Error	L-R ChiSquare	Prob>ChiSq	Lower CL	Upper CL
1. All Sedentary						
Intercept	3.6940564	0.6322875	32.46502	<.0001*	2.4425373	4.9199548
Education[U]	0.1836861	0.0952555	3.7944978	0.0514	-0.001125	0.3733262
Interconnectedness	0.5237691	0.2070276	6.3539742	0.0117*	0.1168804	0.9287193
Age	-0.012949	0.0059473	4.7714894	0.0289*	-0.024696	-0.001329

Omibus test : LR ChiSquare=12.10 (df=3); p=0.007

Parameter	Estimate	Std Error	L-R ChiSquare	Prob>ChiSq	Lower CL	Upper CL
2. Computer						
Intercept	2.0689578	1.1587634	3.0992665	0.0783	-0.23762	4.2967064
Education[U]	0.1679395	0.1735211	0.9534665	0.3288	-0.167641	0.5188903
Interconnectedness	0.3807689	0.3774538	1.0119165	0.3144	-0.363432	1.1177448
Age	-0.01182	0.0107783	1.2086771	0.2716	-0.03329	0.0092814

Omibus test : LR ChiSquare=2.58 (df=3); p=0.46

Parameter	Estimate	Std Error	L-R ChiSquare	Prob>ChiSq	Lower CL	Upper CL
3. TV						
Intercept	3.4155878	0.8492148	15.293054	<.0001*	1.7259325	5.0534635
Education[U]	0.0653949	0.124202	0.2781464	0.5979	-0.177362	0.3118018
Interconnectedness	0.6548044	0.2789744	5.4457285	0.0196*	0.1054024	1.1997673
Age	-0.010824	0.0079891	1.8409093	0.1748	-0.026621	0.0048211

Omibus test : LR ChiSquare=6.68 (df=3); p=0.08

Parameter	Estimate	Std Error	L-R ChiSquare	Prob>ChiSq	Lower CL	Upper CL
4. Reading						
Intercept	1.1097561	1.9044855	0.3350526	0.5627	-2.688986	4.737069
Education[U]	0.7525057	0.3898521	4.8930927	0.0270*	0.0784773	1.6918435
Interconnectedness	0.4156005	0.6200418	0.4482497	0.5032	-0.808368	1.63819
Age	-0.02059	0.0185827	1.263652	0.2610	-0.059367	0.0152861

Omibus test : LR ChiSquare=5.95 (df=5); p=0.11

to each other-is a strong predictor of behavior over and above more general descriptors of space such as areas and dimension. In fact, we suspect that the results obtained using the area variable (its stronger correlation with TV watching over other sedentary activities, for instance) are partially because area itself correlated quite strongly and significantly with interconnectedness (R=-.62; p=0.004). Larger houses will have larger number of rooms, and given that average connectivity between rooms does not increase in larger houses, will have less interconnectedness overall.

Admittedly, these findings from a small pilot study, even though they support our hypotheses, do not give fully adequate ground for establishing a consistent causal link between spatial organization and inhabitant behavior. To do that would require a longitudinal assessment with a more complete

model. Normally, such a model would, at the least, specify some psychosocial variable that mediates between the cognized environmental configuration and a motivating desire to act in a particular way.

A brief note to contextualize the philosophy of our approach may help clarify our broader intent here. Our interest in identifying causal mechanisms seems to be an implicit acceptance of methodological individualism -the philosophical position that any social phenomenon should be explained by identifying beliefs and desires underlying actions of individual actors (Elster 2007). But our proposed mechanism, and the fact that it was borne out in our study, also suggests complications with such an approach. In our case, even though the individual is still at the center of explanation, the explanation lies not in psychosocial or psychological motivations but in non-deliberated choices, i.e. choices made perhaps unawares without any considered motivation. Our approach, actually, is an instance of functional explanation- a form of explanation in which actions are explained by their functional consequences (Hempel 1994 [1959], Douglas 1986). Functional explanation assumes that agents are not aware of these functional consequences and so their individual reasons for acting do not have explanatory power. Functional explanation in social science has been criticized on the grounds that it denies agency to actors and that it results in just-so explanations (Elster 1983), but we feel that articulating and testing the mechanism by which a functional explanation may be related to individual decisions would avoid these two problems. Our study is a first step in this direction.

The idea of a mediating psychosocial factor does suggest some explanation of two unexpected results that we obtained. Age by itself was not associated with sedentary activities, but it significantly contributed to explaining social sedentary activities (primarily watching TV in our sample) once interconnectedness was taken into account. One possible interpretation is that older adults tend to watch less TV, but that in more highly interconnected houses, are induced to watch it at greater length than they would otherwise as a way of participating in the social life of the household. Similarly, the positive association between TV watching and overall sitting/reclining hours both inside and outside the house also supports our argument about psychosocial variables mediating between spatial configuration and behavior. If it is true that more mutually integrated rooms show a higher propensity for socialization, and that such socialization manifests in increased sedentary activity, then not only time spent in specific sedentary activities like watching TV, but also time spent sitting or reclining should show corresponding increase - manifested not just in the time spent specifically in the specific sedentary activities, but also in increased habits of sitting or reclining generally. Tests of mediation on our data, taking social sedentary hours as a mediating variable (not reported here) did support this hypothesis, but this needs to be explored with more explicit causal models, using a mediating variable that better defines the degree of socialization within the apartment. The best approach for such causal models would be conduct longitudinal studies. The research on household crowding may provide an avenue to pursue this line of inquiry.

The role of crowding in the home has been examined in relation to health indicators in many contexts (Evans et al., 1996, Evans et al., 2000, Evans et al., 1989, Fuller et al., 1993). Prior work by our research team showed that household crowding is associated with obesity in adults (Chambers et al., 2010). This work may shed light on the results observed in this study. Using

household crowding (e.g. number of people per bedroom) as an example, it could be that the lower the interconnectedness in crowded apartments the more likely the inhabitants within the space are to participate in sedentary activity if, for example, sedentary activities are social interactions to be sought out. While these conclusions are beyond the reach of these data, the results do suggest an area for further investigation.

Lifestyle counselling aimed to reduce obesity is beginning to add targeted approaches towards sedentary behavior in addition to counselling around overall physical activity (Shuval et al., 2012, Saelens et al., 2002). Our results can help offer practical recommendations on this issue. But a cautionary point needs to be noted here. There is a temptation in studies that successfully show association between organization of physical space and behavior to base recommendations on the assumption that appropriate changes in the former could lead to desired changes in the latter. But our results show that simply making changes in spatial layout may not always bring about change in sedentary behaviors in all individuals. We do not, therefore, recommend increasing the size or partitioning of apartments as way of decreasing sedentary activity; not only are such recommendations impractical, they wrongly suggest that interconnectivity acts casually on all behavior. This is not say that causality is not involved, but rather that it is indirect, and since it operates through a mediating factor, it's influence is felt differently on different kinds of behavior. Practically therefore, this suggests the usefulness of targeted interventions; if the inhabitants of more integrated houses have increased tendency to engage in sedentary behavior by habit, those inhabitants might require additional support to promote non-sedentary activities.

5. Limitations
The small sample size limits the conclusions that can be drawn from these analyses. However, as preliminary analyses on a potentially innovative area of physical activity research this study offers a possible additional piece to the mechanisms linking the built environment to health behaviors.

It may be objected that the way sedentary behaviors were operationalized for this analysis could have resulted in some misclassification, as it is possible, for example, that those watching TV could be doing so alone. We think that the likelihood if this type of bias is small since preliminary data shows that very few individuals live alone and the questionnaire item asks to report TV watching on a typical day.

It is also important to note that because interconnectedness is computed from the average of all the total depths separating a room from others in the house, it may not differentiate between homes in which the total depth values of all individual rooms are very similar and moderate, versus those in which the individual total depth values of the individual rooms may vary considerably, but are averaged out over the entire house. It also does not take into account the differences between homes where, for example, the most interconnected rooms are passages or corridors, versus those where such rooms are living and working areas. These objections do not delegitimize our results, since in all cases, the arithmetic mean still provides an appropriate reflection of the all connections over the house. But the objections do suggest a direction for further work -exploring structural types of layouts (for instance, layouts in which rooms are interconnected through corridors and lobbies, versus

those in which circulation is assimilated within individual rooms) that lead to different distribution of depth values and checking to see if particular types are associated with variation in time spent in sedentary activities.

5. Conclusion
In the end, the main outcome of our study has been to show both the need for a more nuanced understanding of the relationship between space and behavior, and a glimpse into the implications of such an understanding. Studying the role of environment on day-to-day behavior not only brings one more set of important factors to bear on an overall explanation of behavior, it also challenges us to rethink the mechanism by which human behavior can be explained and if necessary modified. After all human behavior, even when it counts as conscious action, is not always deliberate; it is driven by habits and predispositions and it is often these which may be quite central to issues like obesity and health, and which are likely to be influenced by environment as compared to activities done with deliberate intent.

References
Bafna, S. (2001). *A Morphology of Intentions*, Unpublished Doctoral Dissertation, Georgia Institute of Technology, Atlanta GA.

Bafna, S. (2003). Space Syntax: A Brief Introduction to Its Logic and Analytic Techniques, *Environment and Behavior* Vol.35: 17-29.

Chambers, E. C., and D. Fuster (2012). Housing as an Obesity-mediating Environment, *International Journal of Public Health,* Vol. 57: 453-4.

Chambers, E. C., C. Schecther, A. Tow, L. Torrens, R. Kohlieber, and R. Calderon (2010). Household Density and Obesity in Young Black and White Adults, *Ethnicity and Disease*, Vol.20: 366-9.

Choudhary, R., S. Bafna, Y. Heo, A. Hendrich, and M. Chow (2009). A Predictive Model for Computing the Influence of Space Layouts on Nurses' Movement in Hospital Units, *Journal of Building Performance and Simulation* Vol.3: 171-84.

Dalton, R C. (2003). The Secret is to Follow Your Nose, *Environment and Behavior*, Vol.35, No.1: 107-31.

Douglas, M. (1986). *How Institutions Think*, Syracuse University Press, Syracuse NY.

Dunstan, D. W., E.L. Barr, G.N. Healy, J. Salmon, J.E. Shaw, B. Balkau,D.J. Magliano, A.J. Cameron, P.Z. Zimmet, and N. Owen (2010). Television Viewing Time and Mortality: The Australian Diabetes, Obesity and Lifestyle Study (AusDiab), *Circulation,* Vol.121: 384-91.

Dunstan, D. W., B.A. Kingwell, R. Larsen, G.N. Healy, E. Cerin, M.T. Hamilton, J.E. Shaw, D.A. Bertovic, P.Z. Zimmet, J. Salmon, and N. Owen (2012). Breaking Up Prolonged Sitting Reduces Postprandial Glucose and Insulin Responses, *Diabetes Care*, Vol.35, No.5: 976-83.

Elster, J. (2007). *Explaining Social Behavior*, Cambridge University Press, Cambridge.

Elster, J. (1983). *Explaining Technical Change: A Case-Study in the Philosophy of Science*, Cambridge University Press, Cambridge.

Evans, G., S.J. Lepore, and A. Schroeder (1996). The Role of Interior Design Elements in Human Responses to Crowding, *Journal of Personality and Social Psychology*, Vol.70: 41-6.

Evans, G., N. Wells, and A. Moch (2003). Housing and Mental Health: A Review of the Evidence and a Methodological and Conceptual Critique, *Journal of Social Issues,* Vol.59: 475-500.

Evans, G. W., and S.J. Lepore (1993). Household Crowding and Social Support: A Quasi-experimental Analysis, *Journal of Personality and Social Psychology,* Vol.65: 308-16.

Evans, G. W., S.J. Lepore, and K.M. Allen (2000). Cross-cultural Differences in Tolerance for Crowding: Fact or Fiction?, *Journal of Personality and Social Psychology*, Vol.79: 204-10.

Evans, G. W., M.N. Palsane, S.J. Lepore, and J. Martin (1989). Residential Density and Psychological Health: The Mediating Effects of Social Support, *Journal of Personality and Social Psychology,* Vol.57: 994-9.

Fuller, T. D., J.N. Edwards, S. Sermsri, and S. Vorakitphokatorn (1993). Housing, Stress, and Physical Well-being: Evidence from Thailand, *Social Science and Medicine,* Vol.36: 1417-28.

Hansen, A. L., K. Wijndaele, N. Owen, D.J. Magliano, A.A. Thorp, J.E. Shaw, and D.W. Dunstan (2012). Adverse Associations of Increases in Television Viewing Time With 5-year Changes in Glucose Homoeostasis Markers: The AusDiab Study, *Diabetic Medicine,* Vol.29, No.7: 918–25.

Hanson, J., and B. Hillier (1998). Two Domestic Space Codes Compared, in Hanson, J. (ed.), *Decoding Homes and Houses*, Cambridge University Press, Cambridge, pp.109-33.

Haq, S., and C. Zimring (2003). The Development of Topological Knowledge of Building Layout, *Environment and Behavior*, Vol.35: 132-60.

Healy, G. N., C.E. Matthews, D.W. Dunstan, E.A. Winkler, and N. Owen (2011). Sedentary Time and Cardio-metabolic Biomarkers in US adults: NHANES 2003-06, *European Heart Journal,* Vol.32: 590-7.

Healy, G. N., D.W. Dunstan, J. Salmon, E. Cerin, J.E. Shaw, P.Z. Zimmet, and N. Owen (2008a). Breaks in Sedentary Time: Beneficial Associations with Metabolic Risk, *Diabetes Care* Vol.31: 661-6.

Healy, G. N., D.W. Dunstan, J. Salmon, E. Cerin, J.E. Shaw, P.Z. Zimmet, and N. Owen (2008b). Television Time and Continuous Metabolic Risk in Physically Active Adults, *Medicine and Science in Sports and Exercise,* Vol.40: 639-45.

Hempel C. (1994). The Logic of Functional Analysis, in M. Martin and L. Macintyre (eds.), *Readings in the Philosophy of Social Science*, MIT Press, Cambridge MA, pp.349–76. Originally published in Llewellyn Gross (eds.), (1959) *Symposium on Sociological Theory*, Harper and Row, New York.

Hillier, B., and J. Hanson (1984). *The Social Logic of Space*, Cambridge University Press, Cambridge.

Hillier, B., J. Hanson, and J. Peponis (1984). What Do We Mean by Building Function?, in *Proceedings of the 1st Annual EDRA Meeting*, pp.61-72.

Iwasaki, S. (1993). Spatial Attention and Two Modes of Visual Consciousness, *Cognition* Vol.49: 211-33.

Kalff, C., D. Kühner, M. Senk, R.C. Dalton, G. Strube, and C. Hölscher (2012). Turning the Shelves: Empirical Findings and Space Syntax Analyses of Two Virtual Supermarket Variations, in M. Greene, J. Reyes, and

A. Castro (eds.), *Proceedings of the 8th International Symposium on Space Syntax*, Pontificia Universidad Católica de Chile, Santiago, Chile, pp.8020.1-23.

Kent, S. (1991). Partitioning Space: Cross Cultural Factors Influencing Domestic Spatial Segmentation, *Environment and Behavior,* Vol.23: 438-73.

Lindsay, A. C., K.M. Sussner, M.L. Greaney, and K.E. Peterson (2009). Influence of Social Context on Eating, Physical Activity, and Sedentary Behaviors of Latina Mothers and Their Preschool-age Children, *Health Education and Behavior,* Vol.36: 81-96.

Lu, Y., J. Peponis, and C. Zimring (2009). Targeted Visibility Analysis in Buildings: Correlating Targeted Visibility Analysis with Distribution of People and Their Interactions within an Intensive Care Unit, in D. Koch, L. Marcus, and J. Steen (eds.), *Proceedings of the 7th International Space Syntax Symposium*, KTH, Stockholm, Sweden pp.068.1-10.

O'Keefe, J., and L. Nadel (1978). *The Hipppocampus as a Cognitive Map*, Clarendon Press, Oxford.

Owen, N., P.B. Sparling, G.N. Healy, D.W. Dunstan, and C.E. Matthews (2010). Sedentary Behavior: Emerging Evidence for a New Health Risk, *Mayo Clinic Proceedings,* Vol.85: 1138-41.

Penn, A., J. Desyllas, and L. Vaughan (1999). The Space of Innovation: Interaction and Communication in the Work Environment, *Environment and Planning B: Planning and Design, Vol.*26: 193-218.

Peponis, J., S. Bafna, *et al.* (2007). Designing Space to Support Knowledge Work, *Environment and Behavior,* Vol.39: 815-40.

Peponis, J., J. Wineman, M. Rashid, S. Kim, and S. Bafna (1997). The Description of Shape and Spatial Configuration Inside Buildings: Convex Partitions and Their Properties, *Environment and Planning B: Planning and Design, Vol.*24: 761-81.

Peponis, J., C. Zimring, and Y. Choi (1990). Finding the Building in Wayfinding, *Environment and Behavior, Vol.*22, 555-90.

Saelens, B. E., J.F. Sallis, D.E. Wilfley, K. Patrick, J.A. Cella, and R. Buchta (2002). Behavioral Weight Control for Overweight Adolescents Initiated in Primary Care, *Obesity Research,* Vol.10: 22-32.

Shuval, K., L. Dipietro, C.S. Skinner, C.E. Barlow, J. Morrow, R. Goldsteen, and H.W. 3rd.Kohl (2012). 'Sedentary Behaviour Counselling': The Next Step in Lifestyle Counselling in Primary Care; Pilot Findings from the Rapid Assessment Disuse Index (RADI) Study, *British Journal of Sports Med*icine, Vol.46: 625-33.

van der Ploeg, H. P., T. Chey, R.J. Korda, E. Banks, and A. Bauman (2012). Sitting Time and All-cause Mortality Risk in 222 497 Australian Adults, *Archives of Internal Medicine*, Vol.172:s 494-500.

Wineman, J., F. Kabo, and G. Davis (2009). Spatial and Social Networks in Organizational Innovation, *Environment and Behavior,* Vol. 41: 427-42.