Influences of Building Design and Site Design on Physical Activity

Research and Intervention Opportunities

Craig Zimring, PhD, Anjali Joseph, MArch, Gayle L. Nicoll, MArch, Sharon Tsepas, MArch, MCP

Abstract: Americans spend much of their days in buildings, yet relatively little is known about how the design of buildings or their site influences physical activity. Although some evidence suggests that using specific features of buildings and their immediate surroundings such as stairs can have a meaningful impact on health, the influences of the physical environment on physical activity at the building and site scale are not yet clear. While there is some research suggesting that people will be more active in buildings that have visible, accessible, pleasing, and supportive features, such as motivational point-of-decision prompts and well-designed stairs, there is only limited evidence to support that assertion. This paper reviews the available evidence linking design and site decisions to physical activity, and suggests a framework for connecting research and implementation strategies for creating activity-friendly buildings. In consideration of the kinds of physical activities associated with buildings and their sites, it is proposed that the form of buildings and sites affect physical activity at several spatial scales: the selection and design of sites with respect to a building's location on its site and within its immediate community and the provision and layout of site amenities; building design such as the programming, layout, and form of the building; and building element design such as the design and layout of elements such as stairs or exercise rooms. The paper concludes with an overview of opportunities for research and intervention strategies within the building industry, focusing on public buildings, which provide numerous high-leverage opportunities for linking research and implementation.
(Am J Prev Med 2005;28(2S2):186–193)

Introduction

The persistence and seriousness of the epidemic of diseases related to obesity and inactivity in the United States and elsewhere have led to a rapid expansion of research and policy development aimed at understanding the role of the physical environment in active living. One consequence of this work has been much greater understanding of the correlates of physical activity at the urban and neighborhood scale, focusing on issues such as the role of the availability, structure, and attributes of parks, trails, and sidewalks.[1] However, most adults and children spend the vast majority of their day in buildings and on the sites immediately around buildings. This would appear to open up new opportunities for promoting physical activity. And, indeed there is evidence that interventions at the building scale such as motivational point-of-decision prompts, aesthetically pleasing staircases, and accessible physical activity facilities can result in increases in physical activity.[2] However, there has been no systematic review of what aspects of building and site design influence physical activity at the building and site scale. This article proposes a working model for considering correlates of physical activity at the building and site scale through a review of the research literature, and identifies potential opportunities for policy interventions that might increase physical activity. The primary focus of this article is on larger multiple-unit residential, workplace, and public buildings, where the greatest physical activity gains can be achieved.

From the Georgia Institute of Technology, College of Architecture, Atlanta, Georgia

Address correspondence and reprint requests to: Craig Zimring, PhD, Georgia Institute of Technology, College of Architecture, PhD Program, 245 Fourth Street, Atlanta GA 30332. E-mail: craig.zimring@coa.gatech.edu.

A Social Ecologic Model of Influences on Physical Activity

While buildings and sites provide significant opportunities for increasing physical activity, they also represent difficult theoretical and methodologic challenges. In comparison with urban infrastructure and community-scale designs, individual buildings and their sites often change much more quickly. It can take decades to alter urban infrastructure in order to effect change in the pedestrian and mass transit patterns of a city, but pedestrian movement and activities within buildings can be

0749-3797/05/$–see front matter
doi:10.1016/j.amepre.2004.10.025

affected by alterations that may require only a few months to achieve. However, as the 40-year history of environment and behavior studies has shown, the causal relationships between building design and human behavior are very complex. Buildings and sites are deliberately designed to support a set of activities and to create or reinforce a set of cultural assumptions. So, at the outset of any design, it can be said that behavior causes environment. However, as individuals and groups use buildings on a daily basis, they are affected by the built-in physical aspects of the building and site, such as the availability of space for different functions, relationships among spaces, aesthetics, and symbolism. Each of these relationships are potentially mediated and moderated by individual and group knowledge and attitudes. Nonetheless, in the short term, environment influences behavior.

The relationships of design to behavior also vary by building type. Some buildings such as courthouses, hospitals, or prisons are "strong program" buildings, where a relatively small range of activities are allowed in a given space, and where the design is intended to support those specific functions. Often, strong program buildings also closely constrain where people are allowed to walk within the building and on the site. Other buildings such as art galleries, museums, or university buildings are "weak program" buildings, where a much wider range of activities is allowed in a space and a more unstructured pattern of movement is often allowed.

The relationships between policy and behavior are also complex because buildings and sites can be considered at multiple spatial and temporal scales. Duffy et al.[3–6] have argued that office buildings can be considered at the spatial scales of site location, building shell and systems, "scenery" of interior partitions, and "props" such as furniture. Each of these spatial scales can plausibly affect physical activity, and are discussed further below. Each of these spatial scales changes at different rates and often has different decision makers. For example, the decision for organizations to relocate to a new building and location most often requires considerable time and resources while changes in interior layouts or furnishings can happen much more quickly. However, the design of a new building or site can be an opportunity for an organization to pursue fresh goals, while interior changes are often constrained by the design of a shell or basic systems.

In developing an approach that links evidence to decisions that can be influenced through policy development and information dissemination, it is important to recognize that designed environments are very heavily dependent on the physical, organizational, and social context within which they are created. Architecture, especially workplace, institutional, public, and multiple-unit residential buildings are not generic, but rather are designed for and occupied by specific organizations. These organizations have particular staff, customer, and visitor needs; their own rules, histories, and cultures; and are located in unique locations that have specific surrounding and spatial connections. These establish complex relationships among the needs of building users, the organization, and the built environment.

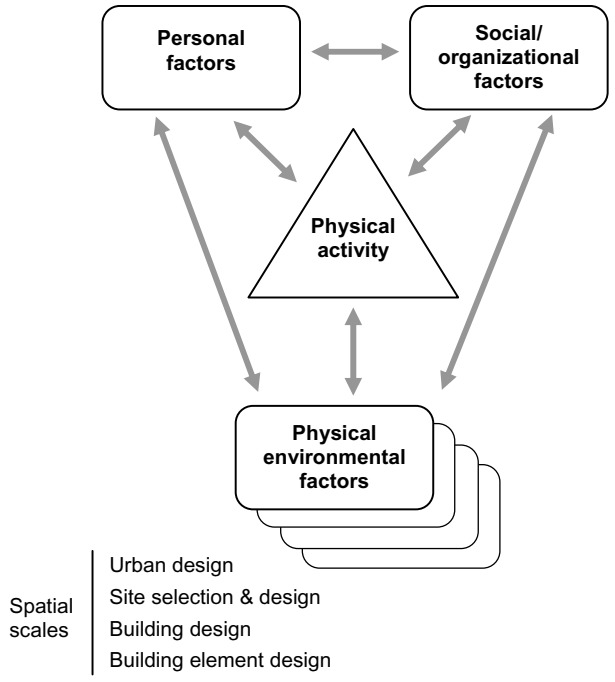

Figure 1. A social ecologic model of influences on physical activity.

A social ecologic model has been adopted for exploring the relationship of design to physical activity in an attempt to capture these multiple relationships.[7,8] Social ecology models seek to understand complex patterns of causation where individual and group behaviors are influenced by, and influence, social and physical structures. As illustrated in Figure 1, physical activity is related to environmental factors, but where organizational and personal factors both moderate the role of the environment and have direct effects. Personal factors include demographics, health variables, attitudes and beliefs related to physical activity, and psychological or behavioral attributes and skills.[9] Social/organizational factors include the goals, philosophies, and culture of organizations, and social structures and supports that may facilitate or impede efforts to participate in physical activity.[10]

Physical environmental factors can be considered at four nested levels of spatial scale: (1) urban design, (2) site selection and design, (3) building design, and (4) building element design. In addition to describing the physical environment, these spatial scales reflect the general temporal flow of a design project. In the case of new construction, most clients choose a site before they design a building, and design a building before they design elements. In building renovation,

the order may be reversed, as the assessment of changes to building elements and layouts are considered prior to changes in the building form or the decision to relocate rather than renovate. The focus of this paper is to consider the potential role of the selection and design of sites, the design of buildings, and the design of building elements in relation to opportunities for physical activity.

While there are many important interactions between personal factors, organization, environment, and physical activity, the intention of individuals toward their physical activities appears to be particularly significant. Intention highlights the kinds of support required for different types of activity. Recreational physical activity is aimed at pleasure, diversion, exercise, and improving health and functioning; it can be individually or facility-organized such as would be found in exercise rooms or outdoor exercise areas. instrumental physical activity is the byproduct of engaging in an activity in which recreation or physical activity was not the purpose of the action. Instrumental physical activities may be the result of routine activities such as walking to or from transit or home or housework like laundry or situational activities such as household repair. Hybrid physical activity results when health or physical activity may not be the primary goal, although the individual may make a decision to be physically active while working toward that goal, such as choosing to use the stairs instead of the elevator. The distinction between instrumental activities and hybrid activities is a subtle but important one. For example, in a multistory building with no elevators, climbing stairs is the only option—it is an instrumental activity. However, when the individual decides to takes stairs even when elevators or escalators are present in the building, he/she is consciously choosing to do so for any number of reasons, such as the route is faster or more attractive. Here stair-climbing is neither instrumental nor purely recreational, but a hybrid of the two. Recreational, instrumental, and hybrid activities emphasize different facilities. Encouraging recreational activities focuses on providing access to indoor and outdoor facilities such as exercise rooms and walking or bike paths. On the other hand, promoting instrumental and hybrid activities requires an understanding of the relationship between layout, design, and everyday life.

In the following sections the roles of sites, buildings, and elements for physical activity are reviewed.

Site Selection and Site Design

Site selection is an important stage for a building client. The ability to use the site for pedestrian features as well as the relationship to off-site destinations are important to consider when encouraging building occupants to engage in physical activity. Site design involves the location and orientation of specific features and buildings as well as layout of the path system. Not many controlled studies have been conducted focusing on physical activity on building sites, but if the available evidence is assembled with case studies and recommendations for pedestrian-oriented development, some issues appear.

People will walk more if they have destinations such as transit, shopping, eating, or home within 0.25 miles to 0.5 miles from their workplace.[11–14] Research supports the concept of the workplace as a base for walking trips in urban settings.[15,16] Wegmann and Jang's[15] study of trip-linkage patterns showed that the highest percentage of non–work activity trips made via walking were before, during, and after work, and that work was second only to home as a base for activity trips.[15] The types of activities that people engaged in most during work/lunch hours were personal business, work business, shopping, and socializing/entertaining.[15] Locating parking away from the building may also increase physical activity. Studies suggest that employees are willing to walk longer distances from parking than business visitors or shoppers,[12,16] and will walk longer distances if the price of parking is less at distant lots.[16]

Public transit is a key consideration for maximizing walking activity.[11,12] One factor is that public transit is often paired with walking[17] in a single trip. In addition, studies have shown that people will walk longer distances to and from transit, home, and parking facilities to work than other types of walking trips.[12,14] Research further suggests that land uses and density around settings that are served by public transportation encourage trips during work and lunch hours.[15]

The presence of others and other visual stimuli seem to play key roles in pedestrian choices and behavior. Research suggests that pedestrians will move toward areas of more activity, or people, that are within view.[18,19] Decisions about activity scheduling, activity area choice, and route choice are influenced by external factors, such as presence of others and stimulation of the environment.[20–24] Attractors and navigational landmarks can impact the route and distance a pedestrian travels,[20,22] In a study of pedestrian activity in St. Mark's Square in London, it was observed that people did not take the shortest route (diagonally), but instead moved between lampposts.[20] Specific characteristics of stimuli may be important in motivating movement. Strength of the stimulus, its size, location, prominence, contrast against background, use, and symbolic significance are among these characteristics.[24,25]

Trips through pleasant and interesting places seem shorter than trips in dull areas.[24] Pedestrians will often choose their routes based on interest rather than distance.[23] Imagery that supports culture, worldview, and values is a key aspect of perceived environmental quality, and thus, fundamental in environmental choice.[23,26] A study of pedestrians within a Montreal marketplace revealed that aesthetic and visual experience were fundamental in guiding movement over and

above configurational aspects.[27] In European PROMPT (PROMote Pedestrian Traffic) research, the variety of details and finishes are considered indicators of quality in the pedestrian environment.[26]

Safe and comfortable environments that include sidewalks, lighting, pedestrian amenities, and traffic calming are more attractive to pedestrians.[28–33] The fear of walking in the dark, especially by women, is a disincentive to walking.[22,29,30] Appropriate levels of pedestrian lighting can promote walking by alleviating this fear. A pre- and post-test study in Glasgow, Scotland showed a significant increase in pedestrian activity after street and sidewalk lighting was introduced.[31] Evidence suggests that heavy traffic is a deterrent to walking,[29,30] and in some cases, the perception of danger is greater than the actual levels as indicated by accident statistics.[33]

A visible walking surface (sidewalk, path) is a fundamental provision for the promotion of pedestrian movement.[25,34] On-site paths can be seen as connectors to off-site paths. According to Gibson's[25] ecologic theory of perception, "surface" is the provider of possibility for movement. Visible connections and walking surfaces are key elements of Lynch's[23] concept of legibility, in which the pedestrian uses visual cues to gain an understanding of the environment and organize it into coherent patterns.

Recent research on urban configuration patterns indicates a strong correlation between properties of street and path layout and pedestrian movement.[19,35,36] In particular, space syntax researchers have developed several rigorous mathematical descriptions of layout that are good predictors of the presence of people walking.[35] (Space syntax is a theory- and computer-based methodology that links quantitative descriptions of form of cities and complex buildings with culture, behavior, and cognition.[37] Originally developed at the University College London, it is now also being developed at the Georgia Institute of Technology and elsewhere.) Space syntax studies looking at site strategies include South Kensington Station, Swiss RE, and most notably, Trafalgar Square, all in London. The primary measurement used is "integration," which measures the local properties of a space in relation to the larger urban system. Each of these studies showed a strong correlation between integration values and actual presence of pedestrians.[35,37] In the Trafalgar Square study, accessibility calculations using space syntax techniques accounted for approximately three quarters of the actual movement pattern.[37] It is important to note that the correlation between integration and pedestrian activity seems consistent in a system with multiple choices.[38] Research suggests that if path choice is limited (i.e., there is only one street with a sidewalk), these relationships are weakened.[39]

Limited evidence suggests that building orientation and setback (distance from street curb to building) may be important factors to consider in promoting pedestrian activity.[24,40] As a part of the Portland Land Use Transportation and Air Quality (LUTRAQ) study, commercial building age was used as a proxy measure for building orientation and setback. Typically, commercial buildings built before 1950 are oriented to the street, and have minimal or no setback from the sidewalk. The study showed that when the proportion of buildings built before 1950 was ≥30%, the average vehicle miles traveled per household decreased by 1.3.[40]

Inclusion of pedestrian amenities such as lighting, benches, water fountains, and bicycle racks on site can increase pedestrian activity.[28,32] In a survey conducted as a part of the Louisiana Statewide Bicycle and Pedestrian plan, 30% of the respondents said they would walk more often if more benches and water fountains were available.[32] In addition, amenities designed specifically to promote physical activity, such as walking/jogging paths and par courses, have been implemented at several public facilities and reported as successful in a survey of state agencies.[41]

Building Programming and Design

Building programming occurs in the early planning stages of a building project, and requires the programmer or architect to identify, quantify or qualify, prioritize and allocate the functional, spatial, budgetary, structural, service, operational, and maintenance requirements that support the goals, values, and objectives of the building's owner and users. The task of creating activity-friendly buildings may depend a great deal on the integration of environmental philosophies and features of the building's program. During the programming stage of a project, the attributes and relationships between the specific spaces of the building are determined. While programming can be used to specify the preferred size and physical attributes of spaces that may promote physical activity, many activity-friendly features of the environment may be in competition with higher prioritized values or needs such as functional and budgetary considerations, increasing the difficulty in incorporating them. The perceived or actual cost and benefit of activity-friendly features play a large role in whether they become part of the program. Furthermore, while activity-friendly programming may be compatible with some issues that are being actively promoted to the architectural industry, such as sustainability, it may be incompatible with other current issues such as the requirement for greater security and control within the building and site.

Building design is both a structured and innovative process where the spaces identified in the building program are configured in a building that has structure, circulation, services, form, and aesthetics. While architects may endeavor to design with uniqueness

and significance, the methods of design also depend on the influence of other building genotypes and their own past practices and methods of design. Architects reuse both specific case studies and more generic patterns of building form and organization. As there are very limited examples of activity-friendly buildings for architects to assess or emulate, the development of activity-friendly design practices has received minimal attention in both research and practice. The idea that environments could be designed to promote physical activity, although accepted intuitively by architects and designers, is based on limited evidence and experience.

The effect of building programming and design on physical activity may be conceptualized in terms of three basic features within the building: (1) the provision and design of activity-programmed spaces, (2) the provision and desirability of activity-inducing spaces and amenities, and (3) the design of the building's circulation system. Activity-programmed spaces include specialized spaces like exercise rooms, swimming pools, running tracks, and multipurpose rooms that could be designed as venues for physical activity. Views of people, activity, and nature from exercise areas[42] as well as views into these spaces from the paths of travel along the building's circulation system potentially increase use of these spaces.[42,43] It has also been suggested that the central location of exercise and activity areas, and the presence of wide, unobstructed circulation corridors with seating at regular intervals supports walking behavior within a setting such as a retirement community.[44] Activity-inducing spaces can increase physical activity derived from travel for regular necessary activities to destinations such as laundry rooms in residential buildings or cafeterias in workplaces. For example, the walk to the dining room or mailroom for many elderly in residential facilities constitutes a physical activity derived from a regular necessary activity. The provision and location of services and other activity attractors such as coffee kiosks outside the immediate work environment may promote workers to engage in physical activity by instrumental or hybrid walking and stair climbing to these destinations.

The building's circulation system comprises the interior spaces, corridors, elevators, stairs, and lobbies that connect the programmed spaces of the building. The circulation system provides opportunities for walking, the most popular type of physical activity. While little research has measured actual walking behavior, environmental cognition research has suggested that the configuration of the physical environment can influence occupant behaviors, such as how occupants develop strategies to understand the layout of their environment and move through it.[45–47]

Building Elements

The design of individual building elements such as stairs, exercise rooms, shower rooms, or plazas can either promote or deter activities by features of their individual design that affect availability, convenience, desirability, safety, and comfort. The provision of amentities such as benches and protection from adverse climate can support physical activity. Features such as elevators, and barriers such as door locks, grade changes, non-ergonomic design, and poor placement of building elements can not only deter physical activity, but potentially can neutralize other features designed to promote physical activity.[48,49]

Among all building elements, stairs have a real potential for effective, accessible, and economical health impact. Stairs are already present in almost every building, and people can use them without changing clothes or engaging in major lifestyle changes. Several studies have found that relatively modest increases in stair use can have positive health and lifestyle effects.[50] The Harvard Alumni Health study of >11,000 men found that those who climbed at least 20 floors per week had a 20% lower risk of stroke or death from all causes when controlling for a large number of demographic and other risk factors.[51] It has been suggested that 2 minutes of additional stair climbing per day would result in weight reduction of >1.2 pounds per year, more than eliminating the 1-pound per year average weight gain by U.S. adults. (This calculation is based on a discussions with J. Sallis of San Diego State University who explained that based on estimates of energy expenditures for physical activities, if people spent 2 minutes more per day going up stairs, they would burn an extra 5800 kcal per year, or 1.6 pounds; and with A. Dannenberg of the Centers for Disease Control and Prevention [CDC] who has found that the average weight gain for U.S. adults from 1990 to 2000 was about 1 pound per year.)

Several studies suggest that point-of-decision prompts can increase stair use, but this is dependent on demographic and contextual factors and might be temporary.[52,53] Nonetheless, the weight of the evidence and low cost of the intervention has caused the CDC's *Guide to Community Preventive Services* to recommend point-of-decision prompts as one of six recommended interventions aimed at increasing physical activity.[2] At least three well-controlled studies have used both motivational signs and aesthetic interventions such as music and artwork, and have found that more people used the stairs.[54] For example, in a 2-year study in one of their own buildings in Atlanta, the CDC progressively improved the lighting, and added art, music, and color; they found persistent modest increases in use, all at a cost of $16,000.[55] The results of the CDC study led them to recommend improved stairs in all of their facilities worldwide.

Stairs provide an example of the complex interactions between environmental scales that characterize building design and use. Local characteristics of a building such as color or art in a staircase, or even point-of-decision prompts, can influence behavior, as can relational characteristics such as views to and from a staircase. However, these operate within global configurations of building layout that dictate distance and accessibility. These scales interact with the ways in which people make decisions. Some decisions are made locally, such as when someone sees a point-of-decision prompt; other decisions are part of more considered trip planning.[46]

Much less is known about how other building elements influence physical activity. While it is plausible that the design of exercise rooms or hallway amenities influence activity, no research evidence has been found about these issues.

Research Directions

There are at least five general categories of site/building/element research that seem particularly fruitful:

- Describe physical activity patterns in and around work sites. How much do people walk before, during, and after work? What are the trip types? How many flights of stairs are people willing to travel? How many people use recreational and exercise facilities located in their workplaces and residential buildings?
- Develop and validate global, relational, and local measures of the physical setting. Establish relationships and measures of the facilitators and barriers for physical activity, such as building configuration, presence of views and local attractiveness, and task support or barriers.
- Explore the analogues of selected urban-scale variables in sites and large buildings. What are the roles of destinations, route quality, connectivity, and attractors in generating movement? What are the nature and types of attractors?
- Understand the role of element design. How does stair design and location affect use? How do views to and from activity areas affect use? How can we construct interior paths that can be used by individuals and walking clubs?
- Conduct case studies. Decision makers consistently request well-documented case studies that describe both outcomes and the process of implementation, including issues such as first costs and maintenance costs.

Interventions

The building industry needs help to make buildings and sites more activity friendly. The problem is that while the U.S. building industry is very large—over $997 billion in the year ending July 1, 2004—it remains primarily a patchwork of small clients, builders, and consultants with multiple methods of building delivery. This makes it difficult for any initiative to have wide influence. However, public construction represents one important exception to this. Public construction in the year ending July 1, 2004, totaled about $238 billion.[56] Whereas some of this is scattered among myriad local authorities, a good portion is concentrated among several large state and federal agencies. The U.S. General Services Administration (GSA) houses some 1.1 million U.S. office workers, and state agencies house another 2.6 million. While GSA and the U.S. Department of Defense are the largest federal builders and landlords, the group of 27 federal agencies belonging to the Federal Facilities Council is a coherent group representing all federal construction of some $18 billion in 2003. Some 38 states, and all of the large states other than Texas, have central general services agencies that coordinate most or all construction for the state. There are also several well-attended organizations that appear open to active living workshops. For example, the association manager of the National Association of State Facilities Administrators has expressed considerable enthusiasm for the topic (M. Stone, personal communication, 2003).

In addition to being centralized, federal and state agencies are likely to have cradle-to-grave responsibility for buildings, from initial planning through occupancy, and hence to have a concern for how planning and design affects health and worker effectiveness. They often tend to be programmatic in that they develop methods, procedures, and systems for delivering buildings that are used over a long period of time. Also, public agencies have actually proven to be innovative. The State of California and the U.S. government are both building office buildings in California where the main elevator banks will stop only on every third floor, and where able-bodied workers and visitors will be expected to walk up or down to their floor. Many public agencies are entering into public–private partnerships for developing cities and neighborhoods, and can set the tone of much larger private development. Also, public buildings do more than enclose public functions. They have a symbolic function that goes beyond daily activities. It is not a coincidence that Martin Luther King marched to the Montgomery County Courthouse rather than to Woolworth's.

Public architecture provides a real opportunity for enlisting the support of top decision makers. In a 2003 study conducted by Georgia Tech for the Robert Wood Johnson Foundation, state architects and CEOs of state general services departments were surveyed online. The survey (not yet published) found that these senior executives were widely supportive of active living research and implementation initiatives. There is an

opportunity for creating programmatic support for active living in public agencies and particularly for creating "plug-ins"—modules of pre-established language or policy that agencies can use to add active living programs without creating new ones. There is a role for the creation of model language, such as how to specify an activity friendly circulation system as well as developing procedures for tasks such as creating budget documents, health impact assessment, and value engineering. Many building delivery organizations are now using the balanced scorecard to evaluate their performance, and might be open to considering health and activity as a component of it. There is also a chance to impact the regulatory structure and to impact education and certification.

In summary, there appear to be several opportunities for research for linking physical activity opportunities with design decisions at building and site scale that can result in effective and relatively rapid interventions. As a fledgling field of research, it is necessary to establish the baselines for building- and site-related activities, create measures, and identify the variables of the environment which impact on physical activity within layout and attributes of the building's site, program, configuration, and elements. There are real opportunities for linking research and implementation by creating awareness, developing a buy-in by decision makers in the building process, enlisting organizations, especially within public building agencies, and developing programmatic support, tools, and measures to facilitate and evaluate activity-friendly buildings.

Some of the work described in this article was supported by Active Living Research and by the Robert Wood Johnson Foundation, for which we are profoundly grateful. We also thank Bill Kohl and Andy Dannenberg of the Centers for Disease Control and Prevention, Nancy Wells of Cornell University, and Jim Sallis of San Diego State University, as well as the anonymous reviewers, for their encouragement and thoughtful comments on earlier drafts.

No financial conflict of interest was reported by the authors of this paper.

References

1. Humpel N, Owen N, Leslie E. Environmental factors associated with adults' participation in physical activity: a review. Am J Prev Med 2002;22:188–99.
2. Kahn EB, Ramsey LT, Brownson RC, et al. The effectiveness of interventions to increase physical activity: a systematic review. Am J Prev Med 2002;22:73.
3. Duffy F. The new office. Facilities Design Manag 1998;17:76–9.
4. Duffy F, Powell K. The new office. London: Conran Octopus, 1997.
5. Duffy F, Laing A, Crisp V. The responsible workplace: the redesign of work and offices. London: DEGW London Ltd., Building Research Establishment; Oxford, Butterworth-Heinemann, 1993:230–1.
6. Duffy F, Hannay P. The changing workplace. London: Phaidon, 1992.
7. Sallis JF, Bauman A, Pratt M. Environmental and policy interventions to promote physical activity. Am J Prev Med 1998;15:379–97.
8. Grzywacz JG, Fuqua J. The social ecology of health: leverage points and linkages. Behav Med 2000;26:101–15.
9. King AC. Interventions to promote physical activity by older adults. JGerontol A Biol Sci Med Sci 2001;56a:34–46.
10. King AC, Stokols D, Talen E, Brassington GS, Killingsworth R. Theoretical approaches to the promotion of physical activity: forging a transdisciplinary paradigm. Am J Prev Med 2002;23(suppl 2):15–25.
11. O'Sullivan S, Morrall J. Walking distances to and from light-rail transit stations. Transportation Res Record 1996;1538:19–26.
12. Seneviratne PN. Acceptable walking distances in central areas. J Transportation Engineering 1985;111:365–76.
13. Vuori IM, Oja P, Paronen M. Physically active commuting to work-testing its potential for exercise promotion. Med Sci Sports Exerc 1994;26:844–50.
14. Frank L, Anderson M, Schmid T. Obesity relationships with community design, physical activity, and time spent in cars. Am J Prev Med 2004;27: 87–96.
15. Wegmann FJ, Jang TY. Trip linkage patterns for workers. J Transportation Engineering 1998;124:264–70.
16. Pushkarev B, Zupan J. Urban space for pedestrians. Cambridge MA: MIT Press, 1975.
17. Bureau of Transportation Statistics. American travel survey. Washington DC: U.S. Department of Transportation, 1995.
18. Beaumont P, Gray J, Moore G, Robinson B. Orientation and wayfinding in the Tauranga Departmental Building. Milwaukee, WI: University of Milwaukee, 1983.
19. Peponis J, Zimring C, Choi YK. Finding the building in wayfinding. Environ Behav 1990;22:555–90.
20. Haas H. The human animal. London: Hodder and Staughton, 1970.
21. Hoogendoorn SP, Bovy PHL. Pedestrian route-choice and activity scheduling theory and models. Transportation Research B 2002.
22. Lynch G, Atkins S. The influence of personal security fears on women's travel patterns. Transportation 1988;15:257–77.
23. Lynch K. The image of the city. Cambridge MA: MIT Press, 1960.
24. Rapoport A. Human aspects of urban form: towards a man–environment approach to urban form and design. New York: Pergamon Press, 1977.
25. Gibson JJ. The ecological approach to visual perception. Boston: Houghton Mifflin, 1979.
26. Martincigh L. Attractiveness for pedestrians: a most fickle aspect of urban quality. Paper presented at Fourth International Conference on Walking in the 21st Century, Portland OR, May 2003.
27. Zacharias J. The impact of layout and visual stimuli on the itineraries and perception of pedestrians in a public market. Environ Planning B 1997;24:23–5.
28. Lee RE, Castro CM, Albright C, Pruitt LA, King AC. Neighborhood topography and physical activity in ethnic minority women (abstract). Ann Behav Med 2000;22.
29. Forward SE. Behavioural factors affecting modal choice. Project ADONIS UR-96-SC.326. European Commission under the Transport RTD Programme of the 4th Framework Programme. Linköping, Sweden: Swedish Road and Transport Research Institute, 1998.
30. Forward SE. Modes of transport on short journeys: attitudes and behaviour of the inhabitants of Gothenburg. Report 437. Linköping, Sweden: Swedish Road and Transport Research institute, 1998.
31. Nair G. In the dark, a taper better than nothing. A one year follow-up of a successful street lighting and crime prevention experiment. Lighting J 1994;59:25–7.
32. Louisiana statewide bicycle and pedestrian plan. State of Louisiana. Louisina Department of Transportation and Development (LADOTD), 1998.
33. Forward SE. Walking, communication and practice: attitudes and motivations. Paper presented at 14th International Cooperation on Theories and Concepts in Traffic Safety Workshop, Caserta, Italy, 2001.
34. Turner A, Penn A. Encoding natural movement as an agent-based system: an investigation into human pedestrian behaviour in the built environment. Environ Planning B 2002;29:473–90.
35. Hillier B, Penn A, Hanson J, Grajewski T, Xu J. Natural movement or, configuration and attraction in urban pedestrian movement. Environ Planning B 1993;20:29–66.
36. One Thousand Friends of Oregon. Making the land use transportation air quality connection. Vol. 4A. The pedestrian environment. Portland OR: One Thousand Friends of Oregon, 1993.
37. Hillier B, Stonor T, Major M, Spende N. From research to design: re-engineering the space of Trafalgar Square. London: Space Syntax Laboratory, 1998.
38. Peponis J, Wineman J. The spatial structure of environment and behavior: space syntax. In: Bechtel R, Churchman A, eds. Handbook of environmental psychology. New York: John Wiley, 2002:271–91.

39. Zacharias J. Modeling pedestrian dynamics in Montreal's underground city. J Transportation Engineering 2000;126:405–12.
40. Baker B. Building orientation—a supplement to the pedestrian environment. Washington DC: U.S. Department of Transportation, 1993.
41. Tsepas S, Zimring C. Physical activity and space: promoting physical activity through the design and planning of public buildings. Princeton, NJ: Robert Wood Johnston Foundation, November, 2004.
42. Regnier V. Assisted living housing for the elderly: design innovations from the United States and Europe. New York: Van Nostrand Reinhold, 1994.
43. Howell S. Designing for aging: patterns of use. Cambridge MA: MIT Press, 1980.
44. Parker D, Joseph A. Creating environments to promote physical activity among older adults. Presentation at Environmental Design Research Association 34/2003, People Shaping Places Shaping People, Minneapolis MN, 2003.
45. Hillier B. Space is the machine. Cambridge: Cambridge University Press, 1996.
46. Haq S, Zimring CM. Just down the road a piece: the development of topological knowledge of building layouts. Environ Behav 2003;35:132–60.
47. Dalton RC. The secret is to follow your nose, route path selection and angularity. Paper presented at 3rd International Space Syntax Symposium, Atlanta GA, 2001.
48. Leibrock C. Beautiful barrier-free: a visual guide to accessibility. New York: Van Nostrand Reinhold, 1993.
49. Leibrock C. Design details for health: making the most of interior design's healing potential. New York: John Wiley and Sons, 2000.
50. Boreham C, Wallace W, Nevill A. Training effects of accumulated daily stair-climbing exercise in previously sedentary young women. Prev Med 2000;30:277–81.
51. Paffenbarger Jr, RS Hyde RT, Wing AL, Hsieh CC. Physical activity, all-cause mortality, and longevity of college alumni. N Engl J Med 1997;314:605–13.
52. Kerr J, Eves F, Carroll D. Encouraging stair use: stair-riser banners are better than posters. Am J Public Health 2001;91:1192–3.
53. Coleman K, Gonzalez E. Promoting stair use in a US–Mexico border community. Am J Public Health 2001;91:2007.
54. Boutelle K, Jeffery R, Murray D, Schmitz K. Using signs, artwork and music to promote stair use in a public building. Am J Public Health 2001;91: 2004-6.
55. Kerr NA, Yore MM, Ham SA, Deitz WH. Increasing stair usage in a worksite through environmental change. Am J Health Promotion. 2004;18:312–15.
56. U.S. Census Bureau. Construction spending, 2004. Available at: www.census.gov/const/www/c30index.html. Accessed September 30, 2004.