Health Promoting Community Design

Spatial Measures Associated with Stair Use

Gayle Nicoll, PhD

Abstract

Purpose. *Although stair use in workplaces can provide an accessible means of integrating physical activity into work routines, there is little information available on how building design influences stair use.*

Design. *This cross-sectional study assessed the relationship between stair use and the design and location of stairs.*

Setting. *Ten three- or four-story academic buildings on two university campuses.*

Sample. *The buildings contained a total of 38 stairs and 12 elevators.*

Measures. *Stair use was measured using infrared monitors. Eighteen environmental variables that operationalized the appeal, convenience, comfort, legibility, and safety of stairs were measured.*

Results. *Regression analysis identified eight spatial variables associated with stair use: travel distances from stair to nearest entrance and the elevator, effective area or occupant load of each stair, accessibility of each stair, area of stair isovist (a graphic representation of the horizontal extent of a person's visual field from a specific point of reference within a building floor plan), number of turns required for travel from the stair to closest entrance, and the most integrated path (MIP). Three variables (effective area, area of stair isovist, and number of turns for travel from the MIP), explained 53% of stair use in the 10 buildings. Most variables operationalizing the appeal, comfort, and safety of stairs were not statistically influential.*

Conclusions. *This study suggests that the spatial qualities that optimize the convenience and legibility of stairs may have the most influence on stair use in buildings. (Am J Health Promot 2007;21[4 Supplement]:346–352.)*

Key Words: Physical Activity, Obesity Prevention, Spatial Measures, Stairs, Prevention Research. Format: research; Research purpose: relationship testing/cross-sectional study; Outcome measure: spatial measures; Setting: academic workplace buildings; Health focus: physical activity; Strategy: built environment; Target population age: adults; Target population circumstances: increasing physical activity in the workplace

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INTRODUCTION

Although increasing stair use among adults with sedentary occupations can provide an accessible and cost-effective means of integrating moderate physical activity into daily work routines, there is little evidence-based information available to guide architects in designing buildings that promote stair use. Some previous health promotion studies have focused on changing individual beliefs toward stair use through the intervention of motivational signs that link stair use to attitudes about healthy lifestyle, personal health outcomes, and familial responsibility.[1–6] Another approach has explored increasing stair use through interventions that change the qualities of the physical environment of staircases by adding art, music, and improved interior finishes to an existing office-building staircase.[7,8] While these studies have identified several local features of the stair environment that may influence stair use, they overlook that stair use is an auxiliary activity of purposeful travel and influenced by the way people understand and move through buildings. This suggests that another approach for exploring the determinants of stair use may be to broaden the scope of stair use research by examining the relationship between stair use and the physical environmental characteristics of stairs within the greater building environment.

With the aid of a literature review of stair use from the fields of health promotion,[1–9] environmental cognition,[10,11] and architecture,[12–16] a theoretic model, illustrated in Figure 1, was proposed that identified and categorized the range of possible physical environmental influences of voluntary stair use. Potential environmental determinants for voluntary stair use during travel within buildings were categorized within five themes: appeal, comfort, convenience, legibility, and Safety. The framework also addressed evidence that patterns of purposeful travel in buildings may be related to how well people know their environments. People make decisions about movement based on three levels of understanding about their environment: local, relational, and global.[10,11] The framework reflects that stair use is likely related to different levels of spatial knowledge: at the local scale of the design and physical attributes of

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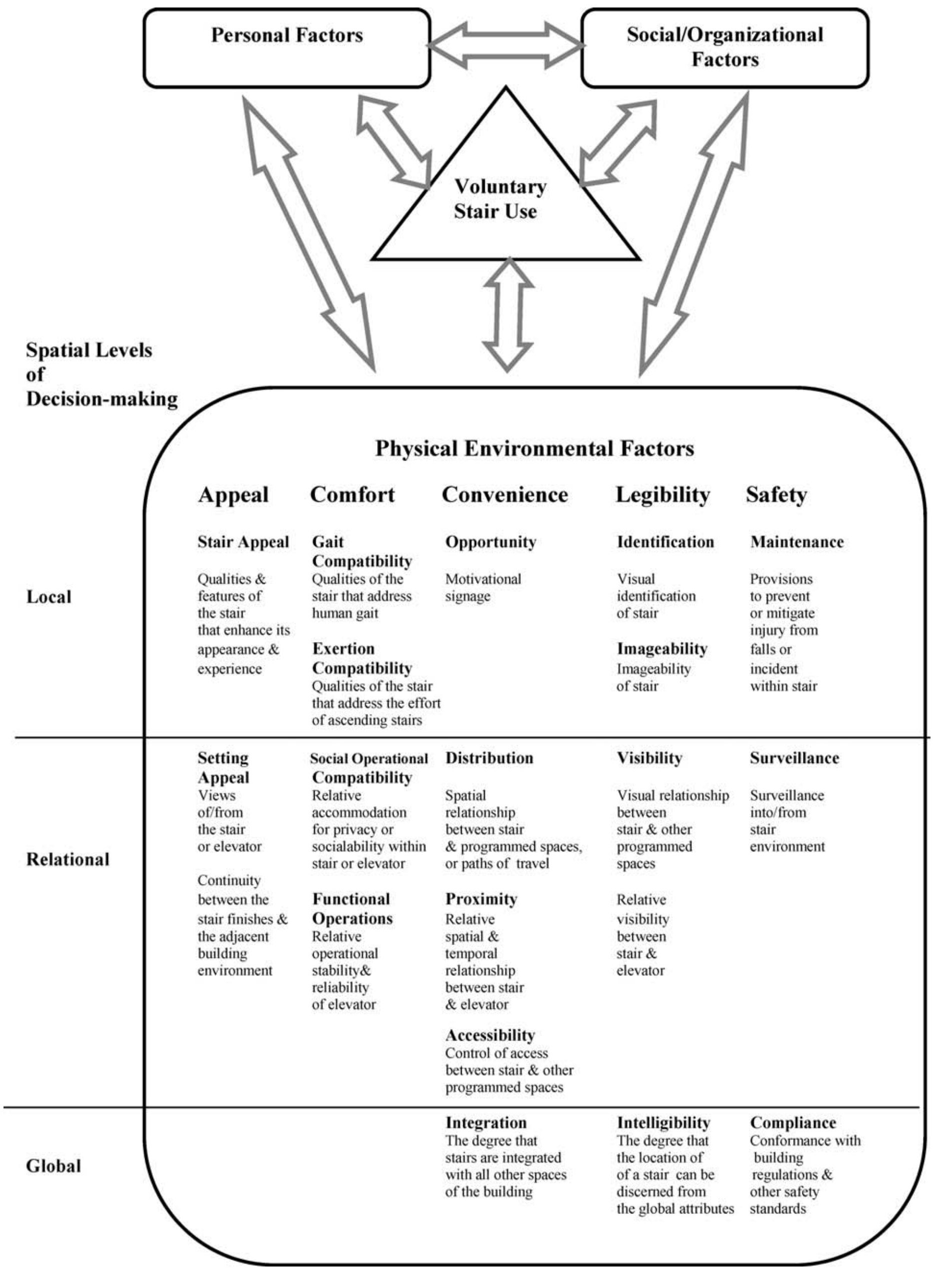
Figure 1
A Social-ecologic Framework for Identifying the Physical Environmental Features That May Influence Voluntary Stair Use



the stair and immediate adjacent surroundings; at a relational scale that reflects the spatial relationships among the stair and specific places within the building; and at a global scale which reflects how the stair is related to all other spaces within the entire spatial system of the building. Variance in a building user's level of spatial knowledge of a building environment may impact the relative importance of building features in influencing voluntary stair use. For example, infrequent visitors place greater emphasis on local and relational features of the stairs directly adjacent to the building's main corridors to attract users as they explore the building. Long-term occupants of buildings, who have developed a global understanding of the relational and global arrangement of their building, have a greater ability to preplan their trips and choose from alternative routes through a building.

Figure 1 illustrates a social-ecologic model for considering the range of possible determinants of voluntary stair use. The thematic-cognitive structure of the environmental features provides a structure to identify the possible influences of voluntary stair use that may exist within building populations. Although not the focus of this study, the framework also acknowledges that personal factors (demographic, biologic, psychologic, cognitive, emotional, behavior attributes, social, and cultural) and social/organization factors (structural, functional, operational, and organizational attitudes and policies)[17] also influence stair use. The key task in using the framework to design buildings that promote stair use is to determine the key factors that influence the general population of a workplace. This study's purpose was to investigate the relationship between stair use and the physical environmental features within 10 academic buildings and identify the key physical environmental variables associated with voluntary stair use in these buildings.

Design

This study used a cross-sectional design to examine which physical environmental features (independent variables) were associated with stair use (dependent variable) within a sample of 10 academic buildings. Stair use was defined as the relative percentage of all vertical travel attributed to each stair within its own building. Physical environmental variables were identified based on the thematic-cognitive framework and the presence and variability of features within the buildings. These variables were operationalized quantitatively using spatial measures or by developing indices to measure qualitative attributes. The study used a series of bivariate linear regressions to examine the relationship between stair use and each of the 18 independent variables identified. The analysis then used a stepwise multiple linear regression technique to identify the key variables that best explained stair use in the 10 buildings.

Sample

Ten three- or four-story academic program buildings on the campuses of two universities containing a total of 38 stairs and 12 elevators were chosen based on optimizing the variations within the design of stairs, elevators, and the building layouts. Academic buildings were chosen to control for variance within the possible personal and social organizational factors while optimizing variation of building environments. Such buildings have a generally young adult population that moves within their buildings at multiple times during the common workday between sedentary activities. The 10 buildings provided a sample with wide variance in stair use both among the buildings (40% to 85% of travel by stair within the building), as well as the frequency of use among individual stairs (0.1% to 76.7% of the building's vertical travel attributed to the stair).

The study was conducted under the approval of the Georgia Institute of Technology Institutional Review Board and the Ryerson University Office for Research Services Review Board.

Measures

This study measured 18 independent variables of the physical environment that operationalized the themes of the framework. Appeal was categorized by two constructs: stair appeal and setting appeal. Stair appeal assessed the appeal of the stair as an object. It was operationalized by an index that ranked the articulation (form and finishes) of each stair by the level in which they differed from minimum construction and finishes practices of emergency exit stairs. All stairs in the study were categorized as either a basic stair (value = 1), having minimal articulation and finishes; an enhanced stair (value = 2), having some increased appeal through upgraded finishes or stair form; or an articulated stair (value = 3) that has distinctiveness in the form, finishes, and elements of the stair.

Setting appeal evaluated the appeal of the view from the stair. It was operationalized by an index that ranked the composition of the setting of the view visible from each stair. All settings visible from the stair were categorized as either: no view outside of stairwell (value = 0); view of interior wall of adjacent space or exterior wall of building or adjacent building only (value = 1); view of streetscape including view of exterior buildings and vehicular traffic (value = 2); or view of interior and exterior people-oriented spaces and scenic landscapes (value = 3). Evaluations of stairs for both of these indices were conducted through photo analysis by a panel of three architects.

Comfort was defined by three constructs: gait compatibility, exertion compatibility, and social-operational compatibility. Gait compatibility addressed the human stepping movement. Three alternative variables were initially measured for this construct: the horizontal metric depth of the tread; the height of the riser, and the ratio of the metric dimensions of the depth of tread to the height of the riser. Although building codes generally permit riser heights from 6 to 8 inches, there was little variance in riser height within buildings in this sample. Seventy-four percent of the stairs in the 10 buildings had risers of 7 inches. In light of this, only tread depth and riser/tread ratio were used.

Exertion compatibility addressed the effort required to climb stairs between rest points. It was operationalized by the maximum number of risers between landings on the stair flight. However, there was also little variance in the values for this variable in this sample as most stairs had landings (after approximately 12 risers) at the midpoint of the floor levels. Therefore, riser height and the number of risers between landings were not included in the statistic analysis.

Social-operational compatibility addressed the dimensional capacity of stairs to accommodate socially engaged groups of people. This required that people have the ability to remain engaged in conversation while on the stair. This variable was operationalized by the metric width of the stair flight.

Three constructs of convenience were investigated in this study: proximity, distribution, and accessibility. Proximity addressed the immediacy of stairs to important places within the building. This study examined two measures of proximity: the distance between a stair and the elevator, and the distance between a stair and the building's entrance. These metric distances were extracted from the building's digital architectural plans (Figure 2, Plan 2a).

Distribution variables addressed the location of stairs in relation to where people perform activities throughout the building. Two alternative measures for distribution were considered in this study. An effective area for each stair was determined by calculating the floor area that is closest in walking distance to each stair on the floor plan (Figure 2, Plan 2b). This measure is most relevant when there is a relatively uniform distribution of people throughout the plan but would also be useful during design phases when furniture arrangements have yet to be made. An alternative method of measuring distribution examined in this study was the occupant load of the effective area of each stair. This variable measured the number of seating stations within each effective area. In an existing building, this method would provide a more accurate account of the distribution of sedentary people in a building.

Accessibility addressed the effort required to move among the stair and both exterior and interior spaces through the building. An index for physical accessibility was developed that recognized three possible levels of accessibility: limited accessibility, which is no or limited accessibility between stair and adjacent spaces or exterior (value = 1); selective accessibility, which requires a key or pass card for entry (value = 2); open accessibility, which is unrestricted access (value = 3).

Legibility was defined by three constructs: visibility, imageability, and intelligibility. Visibility addressed the extent to which a stair can be seen from other interior spaces within the building and was measured by the area of a stair's isovist (Figure 2, Plan 2c). In this study, the stair and elevator isovists were determined as the area in which the stairwell or cab is visible when the door of the stair or elevator is open.

Imageability meant that the purpose of the stair is communicated to potential users through its distinctive expression and form. Stair type, a bino-

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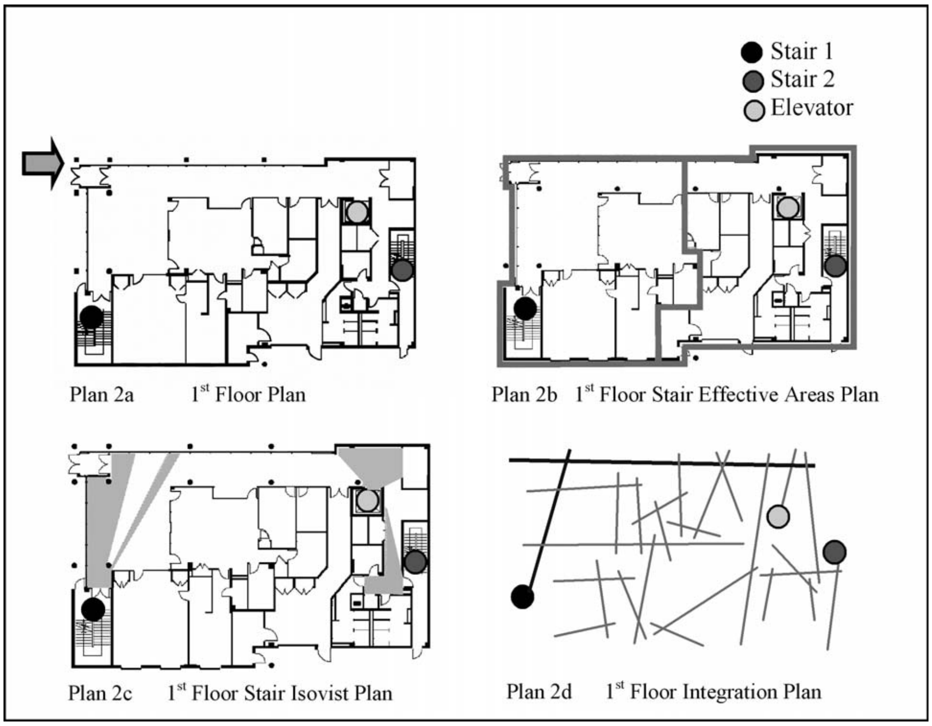
Figure 2
Graphic Representations of Spatial Variables of Stair Use



mial variable that classified stairs by their architectural distinctiveness, operationalized imageability. Stairs were identified as either a grand stair, one whose distinctiveness in form and finishes (compared with other stairs in the building) expresses its purpose as a means of general vertical circulation use (value = 1) or as an other stair (value = 0). While somewhat similar, this binomial measure differs from stair appeal, as it did not differentiate among the different levels of effort made to articulate the stair form and finishes.

Intelligibility addressed how well a person can understand the global structure of an environment from a sense of its local properties. This study operationalized intelligibility by the number of turns required to travel between entry of stair (a local attribute of the building) and two different points of global reference within the building: the most integrated path (MIP) and the building entrance. MIP is a space syntax technique developed as a means to analyze patterns of human relationships in terms of domain, movement, access, control, and hierarchy of spaces within a system such as a building or urban environment.[18,19] These techniques use a topologic basis for understanding culture and behavior by reducing the complexity of the built environment into discrete spatial units that provides a means to measure the movement patterns of a building system from the way spaces are linked together.

Integration plans that represent the measure of the global relationship between the lines of pedestrian travel in a building to each other were used in this study. Integration plans are generated from the abstraction of the arrangement of functional spaces on a building floor plan. This technique first requires the division of all rooms on a floor plan into the smallest number of convex polygons, which creates a spatial representation called convex map. The structure of movement within a building layout is mapped by laying down the fewest and longest straight lines that pass though at least one threshold between two adjacent convex spaces. This intersection of straight lines mapped over the existing spatial arrangement is called an axial map. Axial maps allow for the translating of relationships into mathematic relations. One such relation is the measure of integration, which is determined for each space by calculating the average depth of the intersection of each axial line from all other axial line intersections on the plan. This creates an integration plan, which represents the relative values of integration for each axial line. In the integration plan (Figure 2, Plan 2d), the darkest grey axial lines indicate the 10% most integrated paths within the building, which is referred to as the MIP. Research identifies this global measure of the structure of an environment as a consistent indicator of the most frequent paths that people travel within urban and building systems.[19]

Intelligibility was measured as the number of turns required by the traveler from the local element of stair entry (either the staircase's doorway or the first step in the case of open staircases) to the closest segment of the MIP. In addition to integration, this study speculated that in academic buildings where most building users would have developed a relational to global level of understanding of their buildings, they would have developed a cognitive map of the building available to them at the moment of building entry. The relationship between the number of turns required to travel between the stair entry and the building's closest entrance provided another measure of intelligibility of the stair within the building.

Safety was categorized by two constructs: maintenance and natural surveillance. Maintenance addressed the degree to which the stair's physical condition may increase a user's perceived risk of injury or exposure to criminal activity within the stair environment. A maintenance index was created for this study on the basis of cleanliness, operational wear, and intentional damage. Each factor was assessed on an ordinal scale from 0 to 3 (0 = the stair was nonoperational due to its condition; 3 = the stair was in excellent condition). Natural surveillance was operationalized by the minimum level of illumination (in footcandles) measured on the treads and landings of the stairs.

Stair use, the dependent variable of this study, was measured as the percentage of total vertical travel (both stair and elevator use) attributed to each stair within its building. To measure stair and elevator use, which reflected everyday natural stair use in a sample of academic buildings, data collection was only conducted during selected weeks of the academic term, avoiding the first or last week of the term or weeks during which extraordinary events might occur. These time restraints and the available inventory of buildings on the two campuses limited the data sample to 10 buildings. Vertical circulation within each building was measured for a total of 40 hours, for an 8-hour period each day over five consecutive workdays. Vertical circulation was measured using active infrared monitors, strapped securely to the underside of the stair handrail of the most used flight of each stair or on the interior sidewall guardrails located as close to the doors of the elevator as possible. In pretests, the monitoring equipment had a 96.8% average accuracy (in comparison to visual count) in measuring the number of people traveling on stairs. The average accuracy of the monitoring equipment in the elevators was 93.8%.

RESULTS

The results of a series of bivariate regression analyses (Table 1) identified 10 variables with a statistically significant relationship with stair use. Nine of these 10 variables operationalized the constructs of convenience and legibility. These spatial variables include the relational level variables such as travel distances from stair to nearest entrance and the elevator, effective area or occupant load of each stair, accessibility of each stair, area of stair isovist, and variables related to the global structure of the building such as the number of turns required for travel from the stair to the closest entrance and the MIP. Stair width and stair type were the only local-level variables that indicated a significant relationship with stair use. Stair type was the only nonspatial variable among the independent variables associated with stair use.

Table 1

Bivariate Regression Analysis between Stair Use and Selected Physical Environmental Variables

Physical Environmental Variables	Adjusted R^2
Convenience	
Proximity	
Travel distance between stair and nearest entrance	0.088*
Travel distance between stair and elevator	0.153**
Distribution	
% of total building occupant load	0.276***
% of total building area	0.247***
Accessibility	
Physical accessibility	0.127*
Legibility	
Visibility	
Average area of stair isovist	0.310***
Imageability	
Stair type	0.317***
Intelligibility	
Number of turns from closest entrance	0.164**
Number of turns from most integrated path	0.174**
Appeal	
Setting appeal	
Views	0.013
Stair appeal	
Stair articulation	0.057
Comfort	
Gait compatibility	
Riser height (insufficient variance in this sample for consideration)	
Tread depth	0.018
Tread/riser ratio	−0.002
Exertion compatibility	
Number of risers between landings (insufficient variance in this sample for consideration)	
Social operational compatibility	
Stair width	0.148**
Safety	
Maintenance	
Maintenance level	−0.020
Natural surveillance	
Minimum illumination	−0.024

* Significant at 0.05.
** Significant at 0.01.
*** Significant at 0.001.

A multivariable regression analysis was used to explore the relationship between stair use and the spatial variables identified in the bivariate regression analysis. This analysis indicated that three of the measures, the percentage of building area attributed to each stair, area of stair isovist, and average number of turns from the MIP, explained 53% of stair use (adjusted $R^2 = .531$, $p < .0001$) in these 10 buildings. A note of caution needs to be attached to these statistic findings though. As data on stairs within different buildings are inherently clustered, a multilevel regression analysis would generally be the recommended method of analysis. However, multilevel regression analysis requires a fairly large sample within each cluster, which was not possible within the limits of this data sample. To address this issue, campus- and building-level factors were investigated to confirm that there was no significant relationship among building-level variables and both building-level and individual stair use values. These variables included

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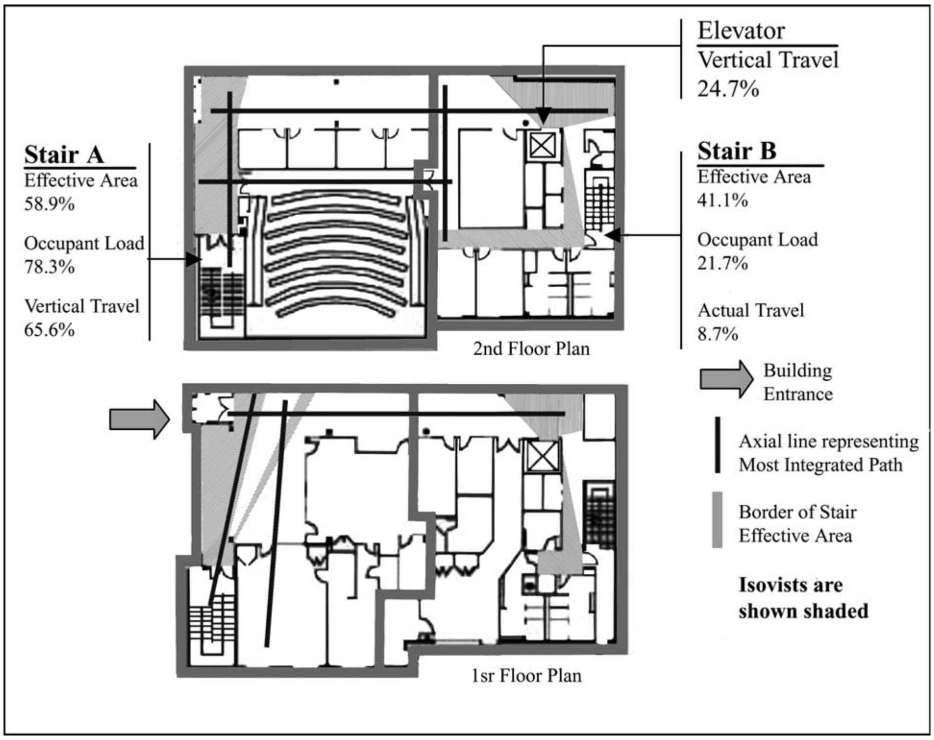
campus location, building height, building area, number of floors, number of stairs within the buildings, elevator speed, elevator capacity, and number of elevators.

Colinearity among variables also plays an important role in understanding the results of the statistic analysis. As expected, there was a high level of colinearity between the two alternative measures of distribution, effective area and occupant load. Many of the spatial variables displayed minor colinearity, which was not extraordinary when one considers that most key elements of variables such as entrance, stairs, elevators, and corridors are traditionally related to each other within a building. The three key variables presented from the multivariate analysis had the lowest colinearity between each other.

Figure 3
Composite Graphic Map of Key Spatial Variables



DISCUSSION

These results reflect the importance played by spatial characteristics of stair placement and building design that support the convenience and legibility of stair use relative to the movement structure of the building. The analysis indicated that there was generally little statistic evidence of the influence within the constructs of appeal, comfort, and safety on stair use within this data sample. The only variable of these constructs found related to stair use was stair width, which operationalized the compatibility of stairs to accommodate travel within social groups.

These results are consistent within a social-ecologic perspective, as this primarily student population might be expected to give social comfort a higher priority in their route choice decision making rather than other comfort and safety factors. The statistic analysis supports the earlier premise that populations that possess relational to global knowledge of their environment may place greater emphasis on relational (spatial) attributes of their building for their decision making in comparison to local attributes such as the attractiveness of a stair. Indeed, there were many appealing stairs with pleasing views within the buildings of this study that had low stair use likely due to their visual, distributive, and relational remoteness from the more frequently used paths of movement through the building. In addition, many of the best-used stairs in the study were convenient and visible but not among the most aesthetically appealing. This suggests that a well-placed stair has more impact on stair use than a well-dressed stair.

The spatial characteristics of the eight key spatial variables of convenience and legibility provided another means to cross-validate the results of the bivariate regression analysis through the translation of their spatial attributes into graphic representations on building plans. This method provided a structure for examining how the spatial variables work collectively to augment, complement, or efface each other within building case studies. Analysis of the 10 buildings revealed a spatial logic related to the key spatial variables of convenience, legibility, and stair use. The seven buildings with the highest overall stair use (60% or more vertical circulation by stairs) optimized the arrangement of spatial variables in the placement of stairs within their floor plans.

In the example illustrated in Figure 3, it is apparent from the overlaying of the spatial measures onto the floor plans that Stair A has superior values for the spatial attributes of each individual measure identified in this study. In this case, there is no overlap between the spatial areas or paths among Stair A, Stair B, and the Elevator that results in little competition for use. In other buildings in this study, the values for individual spatial variables were also consistent with ordinal frequencies of stair use even when there was more overlap of the spatial measures (such as the isovists of two stairs, making both visible from one position on the floor area) between stairs and elevators within the building layout. Future study is warranted on the spatial characteristics of stair use. A graphic analysis may provide a means of addressing the colinearity among the spatial variables through the examination of composite spatial configurations or spatial structures composed of multiple related elements that exist in buildings with high stair use.

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SO WHAT? Implications for Practitioners and Researchers

This study provides evidence that stair placement plays an important role in promoting stair use in buildings. Stairs that attracted the most use in their buildings had spatial characteristics that support the convenience and legibility of stairs relative to the movement structure through the building. This study has two main implications for increasing stair use in buildings. First, architects should consider how they may build in the potential for high stair use by locating stairs that are convenient and legible within the spatial organization of the building. Second, building managers may design interventions to remediate spatial deficiencies such as the lack of stair visibility or intelligibility.

This study employed a social-ecologic approach to develop operational definitions, quantitative measures for statistic and graphic analyses of the features of buildings associated with stair use within buildings. This study revealed the importance of the spatial relationship among stairs and other spaces within a building that operationalize the convenience and legibility of stairs in explaining stair use.

As a foundational study in this approach to stair use, this study provides multiple directions for future research. One direction is the refinement of the spatial measures of stair use. For example, additional consideration of the properties of isovists such as the shape and directional orientation of the visual field was identified for future study. Another direction for future research is to validate these findings using larger data samples and within other types of workplace domains with older, less healthy populations where the attributes of appeal, comfort, and safety may have different levels of influence. While this study avoided addressing the issue of causality, future research is warranted on the role that the spatial variables and other variables may play as mediators or moderators of stair use in buildings. However, the association of the key spatial variables with stair use does suggest that the promotion of stair use in workplaces requires a specific effort to program the spatial attributes that facilitate convenience and legibility of stairs into the building during the design phase.

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