Methodology

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Where We Walk Is What We See: Foundational Concepts and Analytical Techniques of Space Syntax

Saif Haq, BArch, MS, PhD[1]

Abstract

The most difficult issue in writing a methods paper on Space Syntax is that it is not simply a method. It is a theory on which a methodology has been built. In the 40 years since introduction, both its theory and its methods have advanced, including the creation and development of computerized software. Essentially Space Syntax investigates layouts, seen in plan drawings; but this is done from mature theoretical arguments about function in those spaces. While theories of society were at the genesis of Space Syntax, it has branched into cognition, transportation, economics, and so on, and has been used to investigate buildings, cities, and regions. In the last decade or so, Space Syntax has been used in different ways to investigate healthcare facilities. This article concentrates on explaining the analytical techniques of Space Syntax. The theoretical underpinnings are minimally described—just enough for the reader to understand the basis of the methods. All examples provided are based on the same hypothetical hospital floor layout for ease of comprehension and comparison. Also, all Space Syntax concepts are italicized for identification. Since the theoretical aspects are not treated in detail, the reader is advised to pay particular attention to the citations for advanced comprehension. This cannot be overemphasized.

Keywords

Space Syntax, layout analysis, spatial measures, evidence-based design, visibility–accessibility

Layout is a set of spaces that are arranged in a certain order to fulfill both programmatic and aesthetic needs of an architectural project. This is arguably one of the most important aspects of architecture and forms the basis of any building design (Corbusier, 1960). It is also the most enduring. Once developed, approved, and constructed, it is relatively hard to change. Modifications to layout involve changing door locations, demolishing walls, and constructing new partitions which is difficult, time consuming, and expensive, compared to changing furniture or wall paint. Layout is therefore a relatively invariable architectural aspect and the reason why architects should be very careful in its design.

[1] College of Architecture, Texas Tech University, Lubbock, USA

Corresponding Author:
Saif Haq, BArch, MS, PhD, College of Architecture, Texas Tech University, Box 42091, Lubbock 79409, USA.
Email: saif.haq@ttu.edu

Unfortunately, and quite surprising when we pause to think about it, layout is very difficult to describe or to quantify. Most often, we speak of it as if we see the layout from the sky and describe floor plate shapes such as "rectangular," "circular," "H-shaped," and so on (Shepley & Davis, 2003) or assume X-ray birdeyes and use very general descriptors based on presumed corridor layout, such as "radial," "racetrack," "double corridor," "single corridor," and so on (Trites, Galbraith, Leckwart, & Sturdavant, 1969; Trites, Galbraith, Sturdavant, & Leckwart, 1970). Often, we use distribution of nursing stations (i.e., centralized, decentralized, or hybrid) as plan variables (Trzpuc & Martin, 2010; Zborowsky, Bunker-Heilmich, Morelli, & O'Neill, 2010). Other times, we simply use area measures (square feet, etc.) as descriptors of plans. Yet humans as peripatetic users of buildings experience spaces in a diachronic and two-dimensional manner, moving from one space to the other, through doors or other designed openings, and getting new visual information with every change of position. In other words, where we walk is what we see and where we have walked is how we understand the environment. Where we walk *to* is a function of what we walk *through*, that is, doorways and openings, and these are all predetermined by the designer. Space Syntax is the theory that recognizes the multifaceted significance of these experiences and has developed a robust methodology to measure layouts from this point of view (Hillier, 1996; Hillier & Hanson, 1984). Essentially this technique evaluates unit spaces based on their permeable connections, directly to adjacent spaces and to all other spaces in that layout through a number of intermediate spaces. This is done with a premise that such a relational analysis of unit spaces in a layout will be related to some human or organizational function (Peponis, 2012; Peponis, Hadjinikolaou, Livieratos, & Fatouros, 1989). Since this methodology requires complex numerical analyses, subsequent researchers have developed several computer programs that examine digital drawings and produce quantitative variables of unit spaces within it. A word of caution at this point is necessary, with the increase of availability and user-friendliness of Space Syntax software, it has become easy to analyze layouts. However, a thorough understanding of its theoretical underpinnings is necessary to make sure that the analysis is correct and that the results are properly interpreted. This is the purpose of this article. It begins with a very brief description of the core assumptions of Space Syntax, explains its original methods of analysis, and then moves to later developments. The tone is very basic, and no assumptions are made about Space Syntax knowledge of the reader. For convenience, a large number of explanatory diagrams are included, and they are all different analysis of the same hypothetical hospital plan or a subsection. They are provided for easy comprehension of concepts and comparison of different spatial units and methodologies. All analyses were done by using the software DepthmapX (Version X). A close inspection of the drawings in conjunction with the text will be helpful and strongly suggested. This article concludes with concise descriptions of recently developed composite Syntax variables that were tested in healthcare buildings and some suggestions for healthcare research.

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Space Syntax: Core Assumptions and Analysis Method

At this point, it might be useful to closely examine the diachronic experience of moving through a set of built spaces. For this demonstration, we will only consider a small section containing four spaces depicted as A, B, C, and D that are indicated by the dotted boundary in Figure 1. From outside this set of spaces (marked with an X), one may enter only to space A. From this location, one has a choice, either to room B or C. Entrance to room D is only available from room C and not

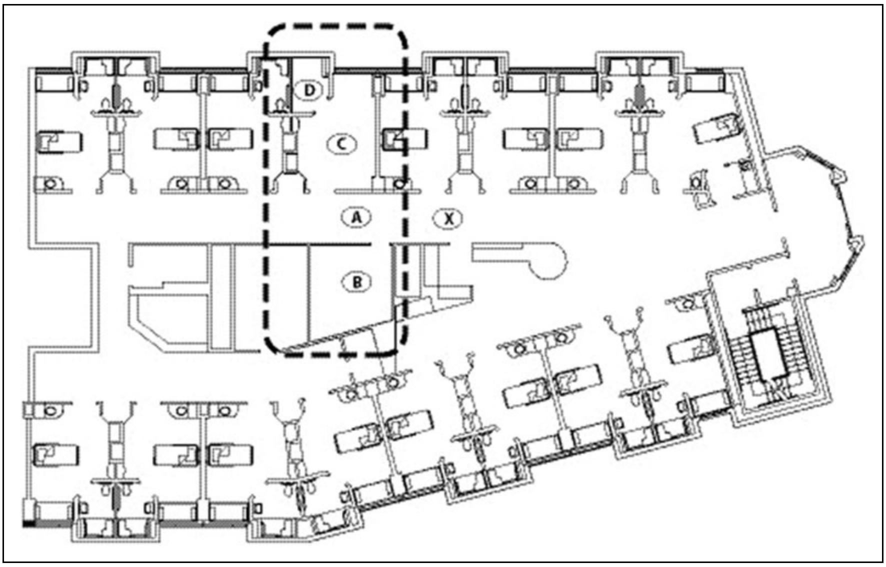

Figure 1. Hypothetical nursing floor plan that will be used as the base layout for all analyses in this article.

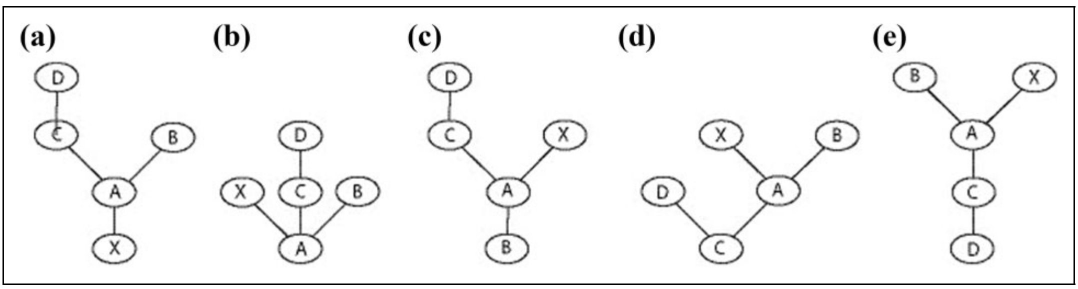

Figure 2. (a–e) Justified graphs starting from spaces X, A, B C, and D, showing their relationships to all other spaces in the smaller area in Figure 1.

from anywhere else. These are not complex concepts and are easily understood. The reader should note that the description of travel included starting from outside this set of spaces and reaching *all* the four spaces in this layout. This travel is very specific and determined by the plan itself. The movement described above can be illustrated by a "justified graph" as shown in Figure 2a. While this is a very basic concept of Space Syntax, it has been useful to some healthcare researchers (Zadeh, Shepley, & Waggener, 2012). Similarly, movement starting from A, B, C, and D is shown in Figure 2b–e. Collectively, the five diagrams (Figure 2a–e) indicate four different sets of relationships between all the spaces in one layout. From some spaces, all other spaces seem to be "closer" (i.e., from A, as seen in Figure 2b) or far away and only accessible through secondary or tertiary spaces (as from D, see Figure 2e). Considering the four diagrams in a simultaneous manner, we can think of this unique property that considers the relationship of all spaces to all other spaces. This causes some spaces to be closer to all others and some to be "farther" from all others on an average. This is a complex property and is a function of both the origin space and all other spaces included in the analysis. Hillier and Hanson (1984) calls this property of closeness *integration* and its opposite farness *segregation*. They have developed mathematical equations to calculate the numerical *integration* values of each space. In addition to the numerical values, most

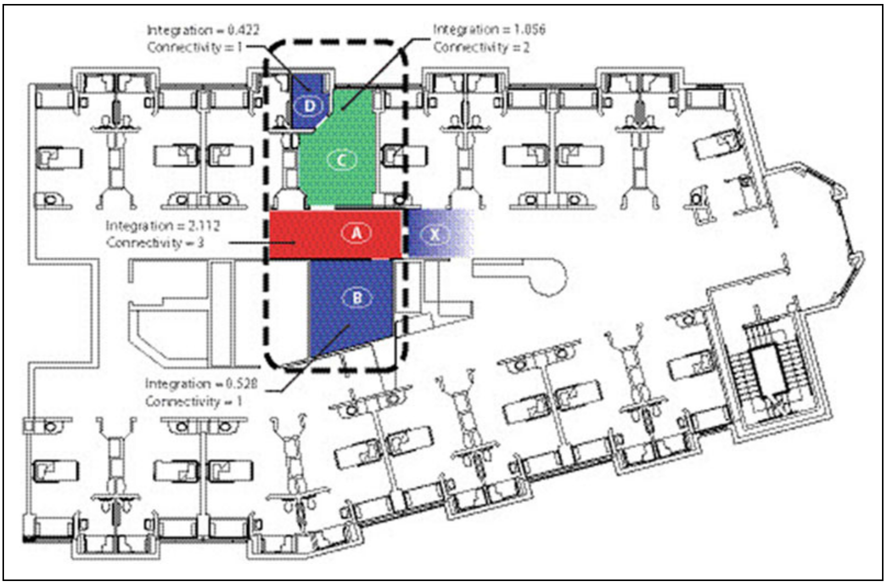

Figure 3. Each space considered in Space Syntax analysis receives its own integration value. These are color coded in the layout and their numerical values indicated (intelligibility = 0.973).

software produce color-coded versions of plans, where integration values are most often depicted from warmer (red) colors to cooler (blue) ones, corresponding to higher to lower values (see Figure 3, *integration* values of spaces are noted for convenience).

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The idea of considering relations between spaces in any layout and deriving complex variables for each space (and the plan itself) is the basic concept of Space Syntax methodology. At the same time, it must be emphasized that this analysis has a very robust theoretical arguments behind it (Hillier & Hanson, 1984). Some of the variables typically used are described below.

Connectivity is the number of direct connections to other spaces. For example, the *connectivity* values of spaces C and D in Figure 1 are 2 and 1, respectively.

Step depth is a distance measure between two unit spaces. It measures how far away each space is from an origin space. In the example, space A is two *step depths* away from D (easily seen in Figure 2e and can also be discerned in Figure 2a–d).

Integration represents the average distance of one space from all other spaces in a layout. In general, it indicates how close the origin space is to all other spaces or how easy it is to reach a space from all other spaces in that layout. Hillier and Hanson (1984) developed the equation to calculate this. It includes a method of "normalizing" the values by comparing with an "ideal" diamond-shaped grid. This allows comparison of *integration* values between layouts of different dimensions and different spaces. For example, *integration* values of C and D are, respectively, 1.056 and 0.422 (see Figure 3).

While *integration* and *connectivity* are measures of each unit space, *intelligibility* is the variable for the entire layout. It is measured by the correlation coefficient between *connectivity* and *integration* of all the spaces in that layout. Essentially, it indicates the ease of understanding the entire layout from what can be observed within individual spaces. For the convenience of the reader *intelligibility*, value is shown in almost all the examples demonstrated by the figures. For example, the *intelligibility* of the partial plan in Figures 1 and 3 is 0.973.

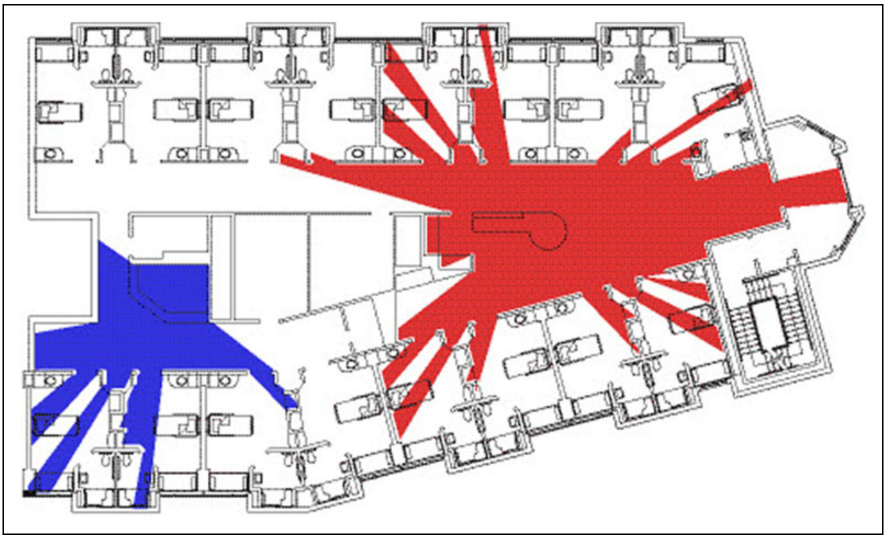

Figure 4. 360° isovist drawn from the two nursing stations in the plan.

Another measure of space called *isovist* has also become important in Space Syntax literature, especially when the concepts of accessibility and visibility are conceptually separated. Defined by Benedikt (1979), an *isovist* is everything that can be visible from one vantage point, provided that the observer has 360° vision. Figure 4 shows *isovists* from two nursing stations on the floor. While this is a simple concept, it has had great repercussions, as we will show later.

Concepts of "Space" in Space Syntax

Let us leave the methodology of calculating variables and focus on the definition of unit spaces in Space Syntax. In the analysis described above, each room was considered one unit space. Since rooms can vary greatly in size and shape (and in open-plan buildings, even the identification of rooms might be an issue), such a spatial unit would obviously be inadequate and lack a rigorous definition—something crucial for scientific exactness. Thus, there is a need for stricter definition of spatial units.

One such unit developed was a *convex space*. This is a space where all points in its periphery would be visible from all points inside it. In Space Syntax analysis, a beginning task might be the reduction of all rooms into a set of *convex spaces*. The other spatial unit that became ubiquitous and perhaps synonymous with Space Syntax is an *axial line*. Hillier (1999) defines it is the longest line that can be drawn through a set of maximum convex spaces, and the map containing the longest and fewest lines is called an *axial map* (see Figure 5a). With these lines as units, one may run an analysis using the same methodology described earlier, that is, considering the connections of each line to adjacent ones, and to others through intermediate ones, and end up with *connectivity* and *integration*, values of each line, and *intelligibility* value of the axial map.

The concept of *axial lines* may be extended to depict both *accessibility and visibility*. For example, when we examine a layout more closely, especially with windows and furniture in place, we can draw axial lines with higher sophistication, that is, going around furniture in the case of accessibility (Figure 5a and b) and looking over them and through windows in the case of visibility (Figure 5c). Obviously, with different numbers of spaces and different connection patterns, these would yield different *axial maps* with different Syntax values (cf. Figure 5b and c).

If we take the idea of generating axial lines further (for both accessibility and visibility), at least theoretically, we can imagine a very large

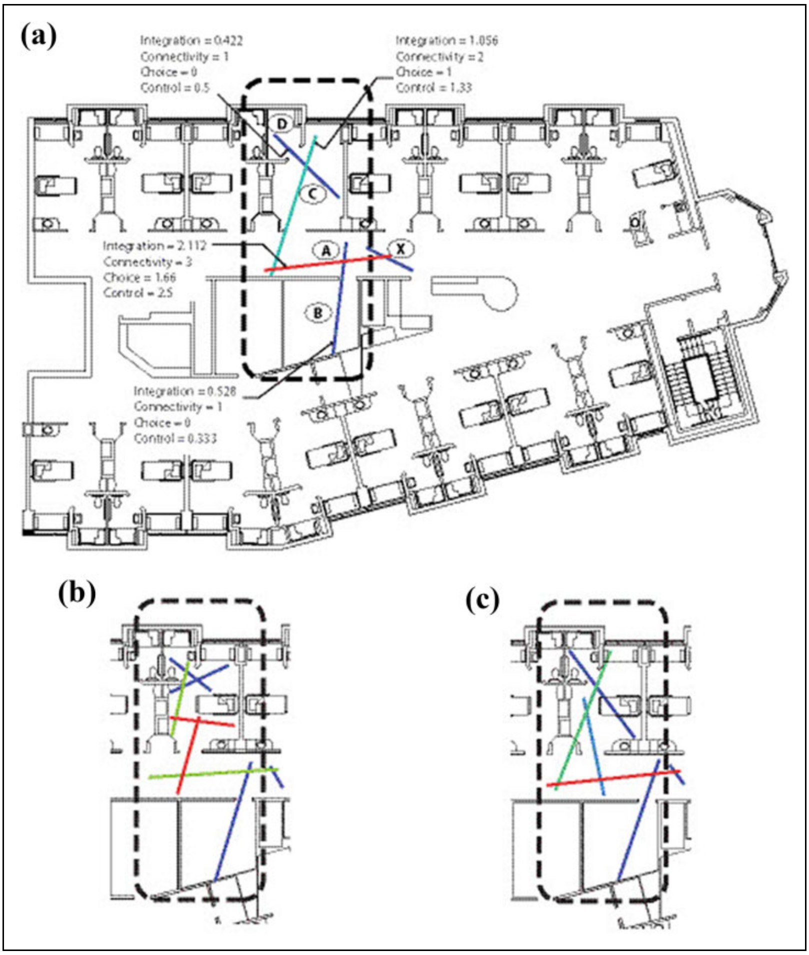

Figure 5. (a) Basic axial lines represent possibilities of access. Syntax analysis of axial lines depicting accessibility is shown here with unit values indicated (intelligibility = 0.973), (b) accessibility that considers going around furniture is depicted with axial lines. Color distribution indicates *integration* values, (c) visibility that considers looking over low furnitures and through windows (nurses stations in this case). Color distribution indicates *integration* values, (d) computer-generated diagram showing all the possible accessibility lines. Colors represent *integration* values (intelligibility = 0.747). A different axial map will be generated if visibility was considered, (e) computer-generated diagram that shows fewest lines of accessibility. Colors represent *integration* values (intelligibility = 0.734). A different axial map will be generated if visibility was considered, and (f) manually drawn accessibility lines. These can be carefully controlled by the researcher to make sure that the axial map responds to the research question. Colors represent *integration* values (intelligibility = 0.639).

number of possible lines. Figure 5d shows an accessibility map of the entire floor plan with all possible lines drawn. Since its beginning, Space Syntax theory has advocated for "longest and fewest" lines (Hillier, 1999) for inclusion in an axial map. Therefore, this all-line map must be reduced to minimum lines, and the software can automatically do this (see Figure 5e). A word of caution is relevant here. Automated generation of lines might be useful from the point of objectivity, yet they may not be adequate or appropriate to respond to a specific research question. As such, it may be easier to generate lines manually to respond properly to the research question being investigated. Figure 5f shows a manually generated axial map that might be more appropriate to respond to research questions where independent variables are corridors, rooms, toilets, or access to

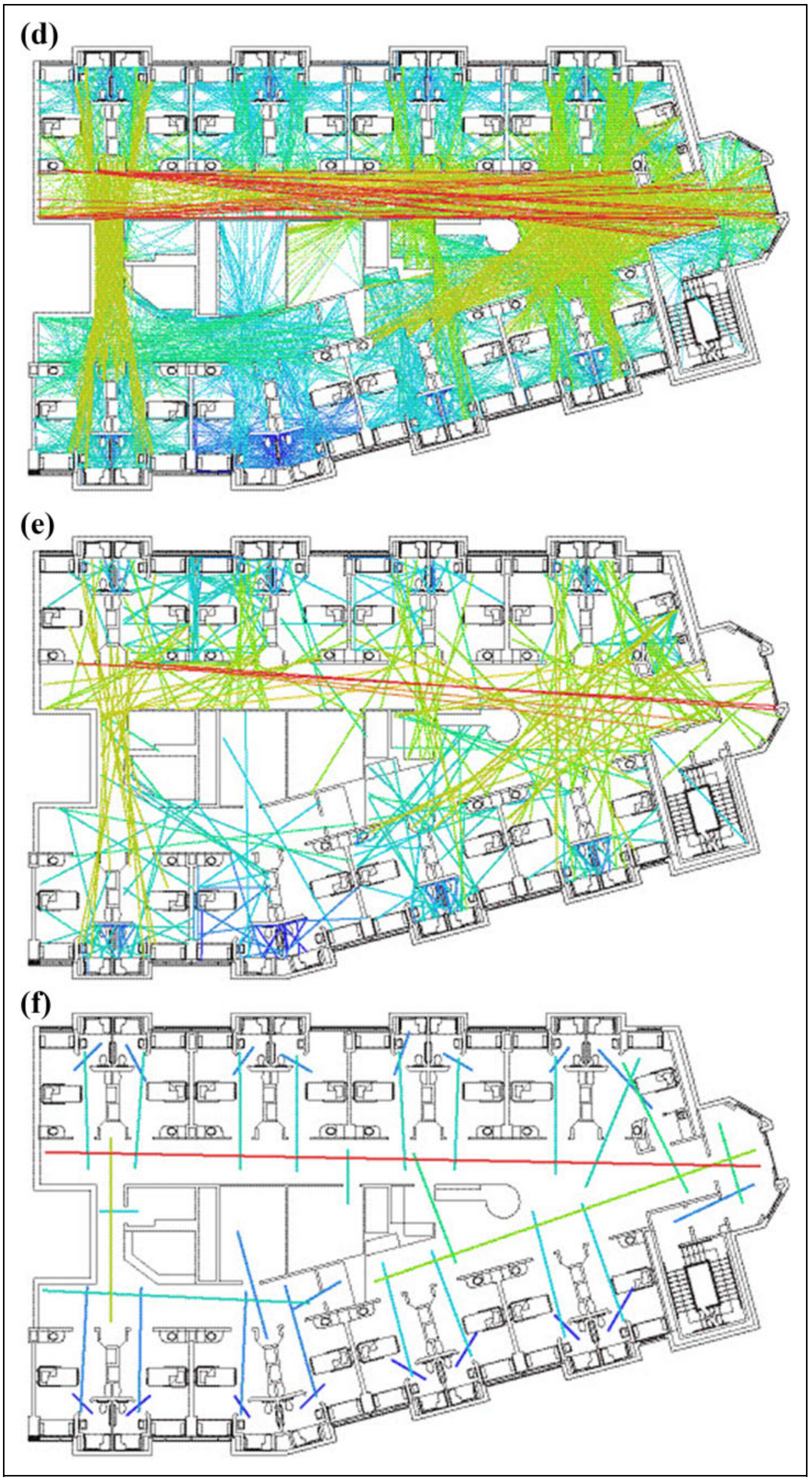

Figure 5. (continued).

Figure 6. Accessibility pattern shown with segmented lines. Colors represent *integration* values (intelligibility = 0.023).

these rooms. As necessary with any manual work in research, one needs to understand the research question very well, so that the map created is not "biased" by any preconceptions.

Later, as theoretical discussions became sharper and other factors such as cognition (Dalton, 2003; Haq, 1999; Penn, 2001) were included in Space Syntax discussions, a new spatial unit called *segmented lines* was developed. In this case, all the lines are considered segmented at their intersections with other lines. In such a condition, the length of each line is reduced at their segments and so the total number of lines in the plan increases. The *segmented lines* can then be analyzed according to the Syntax methods and the variables calculated (see Figure 6). *Segmented lines* are useful because they put variables to small sections of the plan, and so the environment can be studied in a finer detail.

A single tile of a grid was the third kind of spatial unit that was introduced in response to discussions of perception (Gibson, 1979) and visibility (Benedikt, 1979). One may imagine laying a grid of any dimension on a plan (e.g., a one foot by one-foot grid in Figure 7a–d) and then using each tile as a spatial unit to create an analysis based on the same methodology described earlier. In this case, each tile will be connected to adjacent ones and to others farther away through intermediate tiles. In this way, *connectivity* and *integration* can be determined; and the plan will obtain an *intelligibility* score. In addition, similar to the discussion above, one may consider furniture and/or windows to model accessibility (Figure 7a and c) or visibility (Figure 7b and d). Needless to say, a grid-based analysis will produce a very fine-grained distribution of environmental variables.

Figures 3 and 5–7 show the output of the same methodology applied to four different spatial units: rooms, lines, segregated lines, and tiles. Distribution of those spatial units can be based on accessibility or visibility. The visual outputs depict the distribution of *integration* and *segregation* values with the range of high and low values shown from warm (red) to cool (blue) colors. While these diagrams are suggestive, one must remember that numerical values are the basis of these colors and are much more relevant to research where there is a need to quantify the layout as predictor variables. It is also necessary to keep in mind is that the values generated belong to the unit space considered—room, line, segregated line, or tile. Thus, one unit, regardless of its dimension, will have one value. For example, a line may be a few miles long (as in an urban

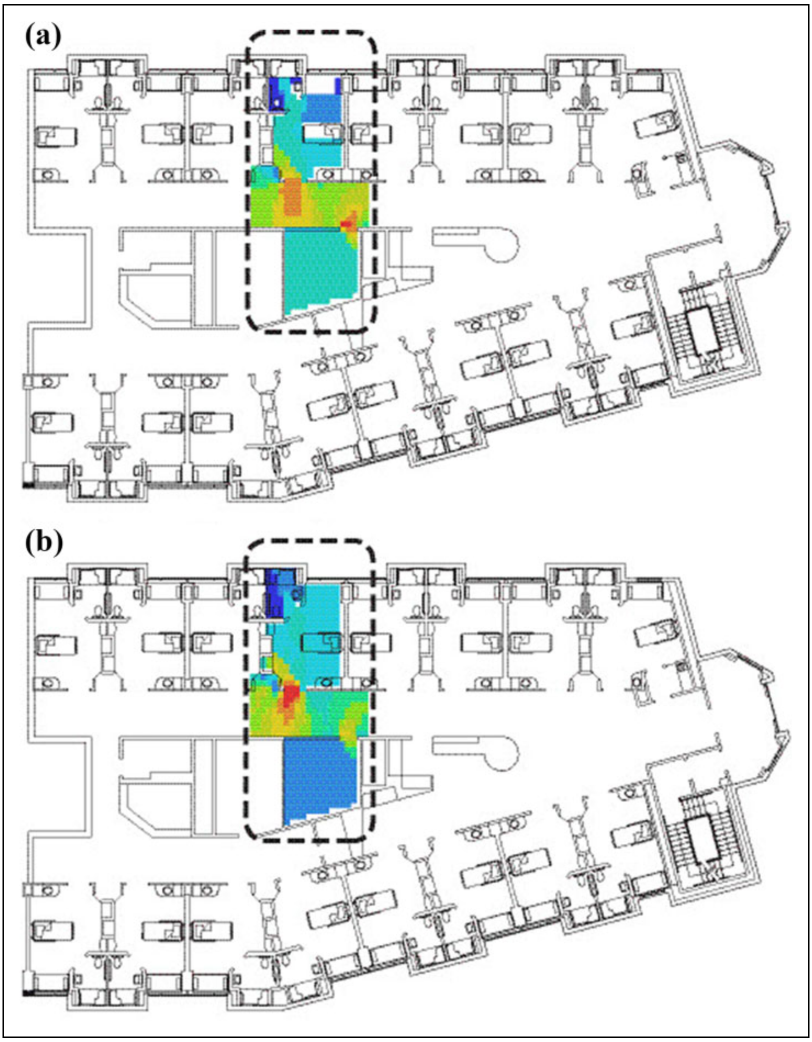

Figure 7. (a) Accessibility pattern of partial area using a "tile" as a spatial unit (colors represent *integration* values), (b) visibility pattern of partial area using a "tile" as a spatial unit (colors represent *integration* values), (c) accessibility pattern determined by using a "tile" as a spatial unit. Colors represent *integration* values (intelligibility = 0.795), (d) visibility pattern determined by using a "tile" as a spatial unit. Colors represent *integration* values (intelligibility = 0.742), and (e) accessibility pattern at a distance 3 (integration-3) determined by using a "tile" as a spatial unit. Colors represent integration values (intelligibility = 0.789).

setting), yet an axial analysis will provide the same value to its entire length.

Concepts of Distance Units and Distance Settings in Space Syntax Analysis

The idea of distance is the third factor to keep in mind along with analytical techniques and concepts of unit space. This is understood in two ways. First is the distance considerations between unit spaces, that is, how to measure the distance between them. The second is the distance to which Space Syntax analysis is carried out, that is, the distance at which the counting for analysis stops. Earlier in this article, "connections" between each space were the distance units considered; either a direct connection

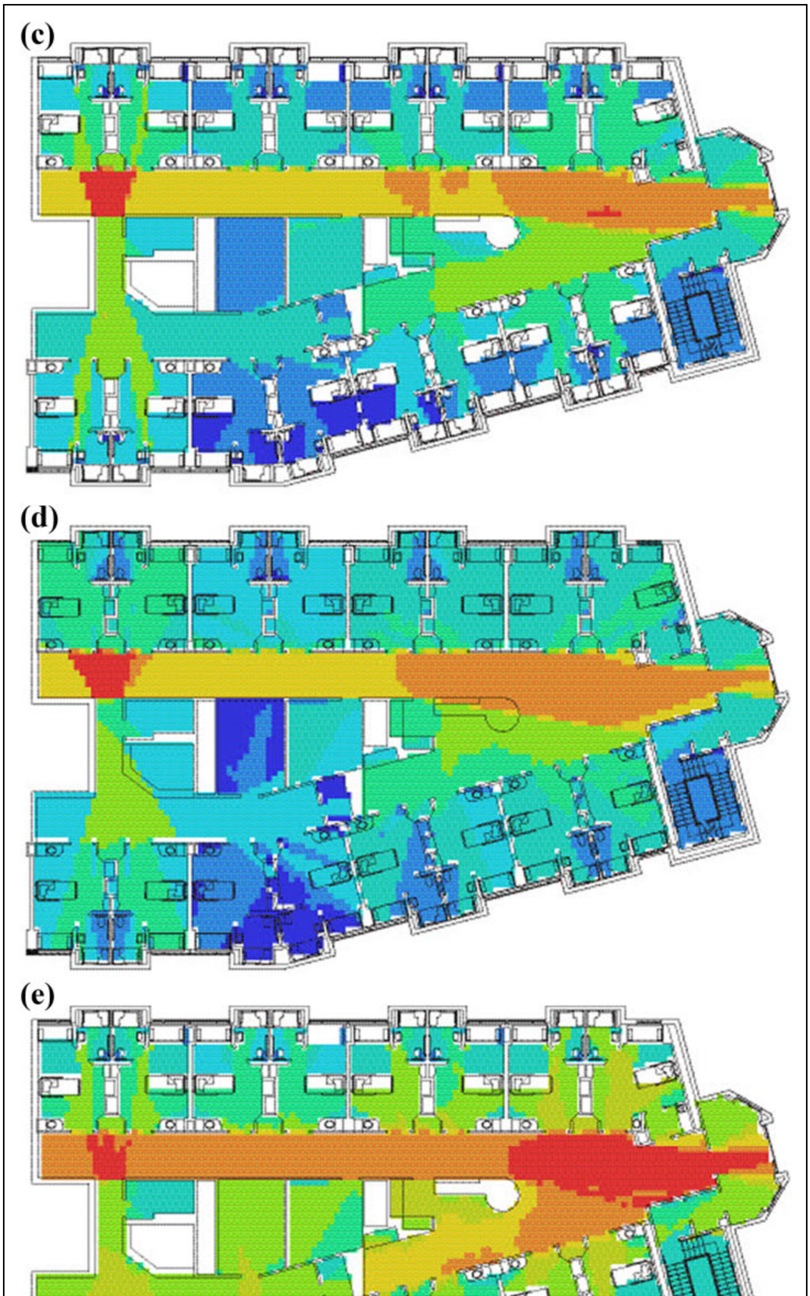

Figure 7. (continued).

to adjacent spaces or indirect connections through intermediate spaces to those far away. In this case, two adjacent spaces are one "step" away from each other, and those further away are two or more "steps" or connection distance (see Figure 2a–e). This is essentially a topological aspect and was the original distance unit of Space Syntax. Later researchers have introduced metric and angular distance units. Metric distance unit considers the length between the center point of lines and angular distance unit considers angles between them. These have been applied to axial and segmented lines and used mostly to study large urban areas (Al-Sayed, Turner, Hillier, Iida, & Penn, 2014).

Setting the distance for Space Syntax analysis is a different matter. It is where the software will stop counting connections to get values for unit spaces. In the previous sections of this article, each space's "connection" to all other spaces in the layout was taken into account to compute *integration* values. Since connections of all spaces to all other spaces provided the basis for calculating *integration* values, the distance considered for analysis is "all spaces," usually denoted with the letter "n"; that is, *integration-n*. Figure 5d and e maps the *integration-n* values of *axial lines* and Figure 7c and d maps *integration-n* values of one foot by one-foot tiles. This distance setting for calculation can also be set to a lesser value. For example, one may consider the connections of each space to others at a distance of a few connections only. For this illustration, let us consider three connections or three steps away. In such a case, *integration* calculation will consider the relationship of each space to only those connected through two intermediate ones, and so the values will be different. These are termed *integration-3* values. It should be noted that the software can calculate *integration* value at any distance—3, 4, 5, and so on. However, *integration-3* is most prevalent in literature, especially when considering pedestrians in an urban area. Figure 7e shows *integration-3* analysis of the accessibility in our demonstration plan using tiles as unit spaces. Similarly, when distance-setting units are metric or geometric (angular), a specific metric distance or a specific angle can be preset for Syntax analysis. Some publications use the term "radii" or "reach" to refer to distance settings as explained in this article.

To reiterate, distance units refer to how relationships between unit spaces are measured by connections, distances, or angles. On the other hand, distance settings relate to how far the relationships between spaces will be considered to calculate *integration* values.

Recent Developments

Over time, Space Syntax became more interdisciplinary and involved researchers who were well versed in software coding and scripting. As new ideas of layout variables were developed, they could be quickly scripted into software for easy calculation. These had two implications: First, some variables identified in early literature were reexamined for consequence, and second, a new set of layout variables were identified. The variables that made a comeback are described below.

Choice measures the condition of "betweenness" of a unit space, that is, the possibility of it being placed at the shortest path connecting spaces in that layout (Hillier & Iida, 2005; Varoudis, Law, Karimi, Hillier, & Penn, 2013). Thus, it captures how often a space may be used in journeys from all spaces to all other spaces. *Choice* has been found to be useful for axial analysis.

Control measures the degree to which a unit space controls access to its immediate neighbors, taking into account the number of alternate connections that each neighboring unit spaces have (Al-Sayed et al., 2014). It can be used in both axial and grid analysis (Figure 5a indicates both *choice* and *control* values for different unit lines).

The second implication came from development of composite variables that extended Space Syntax traditional measures. In this article, we will introduce three that were developed for healthcare facilities research.

Peatross (2001) was interested in "behavioral normalization" of residents in restrictive settings. For her investigation, she selected Alzheimer care units and youth detention centers and argued that the visibility properties of spaces, that is, "awareness field" that includes both properties within the space and visibly beyond (foreground and background) will be an important predictor of space occupation and animated behavior. To measure this quality, she proposed a composite variable called *animated isovist*, which included both the *convex space* and all the *isovists* that can be drawn from all points within it. Thus, an *animated isovist* measures the property that is "synchronously visible to a peripatetic observer in a convex space" (p. 537). This new property was found to be useful in describing the behavior of both staff and residents in her six experimental settings.

Lu, Peponis, and Zimring (2009) have argued that a generic "from all spaces to all other spaces" analysis treat each unit space equally and does not distinguish areas of perceptual or behavioral significance. Based on this hypothesis, they overlapped layout variables with programmatic information (areas of significance) and developed a hybrid measure that they called *targeted visibility index*. In their empirical work, they found that this is correlated with density of nursing staff and locations where they interacted with one another. In a later study, Hadi and Zimring (2016) used this composite variable to investigate the impact of corridor width and unit shape of intensive care units on their visibility characteristics.

In a different study, Ossmann (2016) considered the twin concepts of patient surveillance and organizational awareness in hospital care units. She hypothesized that stationary nurses would choose such locations to position themselves because they needed to simultaneously survey their assigned patients and maintain a situational awareness of the floor. To investigate this, she proposed another composite variable called *isovist connectivity*. This is a combination of *isovist* and *connectivity* values and defined as the average connectivity of all the points in the *isovist* of that location (p. 43). Using this measure of patient rooms and comparing them to mortality rates (as an indicator of nurse surveillance), she found that patients in higher *isovist connectivity* spaces indeed experienced lower odds of death, compared to patients in rooms of low values.

What Does Syntax Analysis Mean for Healthcare Research?

The analytical technique explained in this article is simply a computer algorithm that produces values for unit spaces based on the relationship of each space to all other spaces in a plan. In other words, Syntax analyses evaluate the plan with information contained solely in the plan itself. It has no basis for including information about function, organization, cognition, behavior, surveillance, and so on, in any way. These are not built into the analyses. With quick availability of user-friendly software, it has become easy to analyze without understanding. This must be avoided at all costs.

Syntax analyses evaluate the plan with information contained solely in the plan itself.

Researchers who are serious about using Space Syntax is forced to carefully examine the details of a layout—usually from the point of view of visibility and accessibility of the immersed peripatetic observer. Thus, location and distribution of doors, dimensions of furniture (including height), and window locations have to be taken into account (see e.g., Figure 5b and c). Such a close analysis of the plan is an important benefit by itself and may lead to the development of very specific and additional research questions. Certainly, inclusion of detailed plans in the published paper is an added benefit to architects and designers.

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In Space Syntax, "considerations of human function are built into the foundation of descriptive models" (Peponis, 2012). In other words, the theory and methods are in tandem and separating the two is never advisable. In this article, we have gone against our own advice and have focused the discussion on analytical techniques only. We reiterate that a good understanding of the theoretical basis is crucial for the researcher who wants to use Space Syntax. Healthcare researchers need to develop sharp theories about functions and hypothesize about environmental properties that may influence them. If those properties are based on space and their interconnections, then Space Syntax methodologies can be adapted for analyses.

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Space Syntax develops in two ways. First is a series of correlational studies that investigate dependent variables outside of layout. Since correlational studies are suggestive only, a very strong theoretical argument and many replication studies in different settings are necessary to generalize and predict. The second development is new (and often composite) variables. This requires robust theoretical arguments and computer scripting skills. Additionally these new variables have to be tested and verified. Once that is done, a series of replication studies are necessary for external application of the results. As Syntax is being applied to healthcare facilities research, we see both trends. While traditional analyses applications have the support of more than 40 years of literature, newly developed composite variables do not. More experiments would provide validity to the results obtained. This should be kept in mind.

The many kinds of unit spaces described above have hopefully highlighted the point that the researcher has a wide choice of selecting the shape and dimensions of unit spaces for analysis. This also means that collecting dependent variables for these small areas (especially for correlational studies) should be carefully considered. Thus, creative and technologically based data collection techniques must be developed. Some suggestions are tablet computer–based data collection, video analysis, Radio Frequency Identification-based tracking, Global Positioning System (GPS) positioning, or drone monitoring. To assist in developing a research methodology in healthcare settings with Space Syntax, the reader is referred to recent reviews by Haq and Luo (2012) and Sadek and Shepley (2016).

A technique used in this article is analyzing the same plan in different ways. This serves the purpose of easy comparison. One thing to note is that depending on how the layout is analyzed, values of both unit areas and overall plan fluctuate. Yet the building has not changed. This should serve to remind the reader and future researchers that any analytical technique is only as good as its appropriateness to the research questions being investigated and its thoughtful application.

Concluding Remarks

Space Syntax has been around for more than 40 years and is constantly evolving. The favored research methodology so far has been correlational analysis. Based on repeated studies in many settings, we can now claim that Syntax may be used to predict movement densities, references for cognitive maps, areas of informal learning, patterns of organizational behavior, and collaboration locations (Peponis, 2012). In the last decade or so, its applications in healthcare settings have been promising. In an interesting manner, work in healthcare seems to follow the general pattern of Space Syntax development. Some researchers repeat existing studies to provide more confidence in the published results and for predictions based on those, while others take a hard look at the plan and depending on their focus propose new and often composite variables. We need to continue both trends. The first kind is necessary, so that enough studies are available to demonstrate converging results and support strong evidence-based design decisions.

Implications for Practice

- Since dedicated Space Syntax software can analyze vector drawings quickly, it is immediately useful to the practitioner. Layout proposals at different stages of design can be quickly evaluated, and changes made as needed and re-tested. Similarly, it can be a useful tool for Post Occupancy Evaluations to test the effect of layouts.
- Space Syntax provides numerical/quantitative measures of each defined space, and of entire layouts. Thus, it is useful for quantitative understanding.
- As evidence increases regarding the foretelling power of Space Syntax for various aspects of

improved efficiency within healthcare facilities, it can be used as predictive analytics where the potential effects of a design can be understood beforehand, changes made accordingly, and hypotheses developed for the research team.
- Finally, the beautiful diagrams produced by Space Syntax software can be used for both presentation and explanatory purposes.

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