Analysis

Computation

Environment

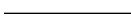# Computing Spatial Qualities For Architecture
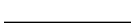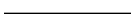
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COMPUTATIONAL REPRESENTATION OF SPATIAL QUALITIES CAN LEAD US TO A BETTER UNDERSTANDING OF HOW WE CONSTRUCT SPATIAL CONCEPTS. Analyses of spatial qualities can support architects in reasoning about the form of a configuration, helping them predict the consequences of a design.

In this paper we present three definitions (enclosure, viewfield, continuity) that describe experiential qualities of architectural spaces. Our project aims to provide computable definitions to these qualities to describe common spatial experiences that are implicitly understood by architects. The description, using familiar terms, reveals the analytical structure of spatial qualities that is based on the geometry of the physical elements.

We therefore introduce a graphic editor, Descriptor, that provides visualization of spatial qualities as the designer diagrams building elements. The system calculates perceived relationships (surrounded, visible, nearby, nearest) between a viewpoint and the architectural elements based on their geometric properties such as location and distance. The relationships are the components of the three qualities we define. We also present a use scenario to demonstrate how one might use our Descriptor system during early design.

Descriptor is an attempt to formalize descriptions of the spatial qualities to help beginners understand how to make design decisions. In the future, we plan to extend the set of qualities and add detailed attributes of the physical elements to the system.
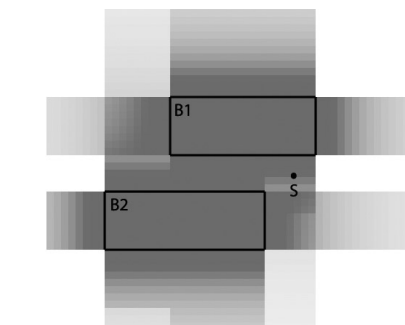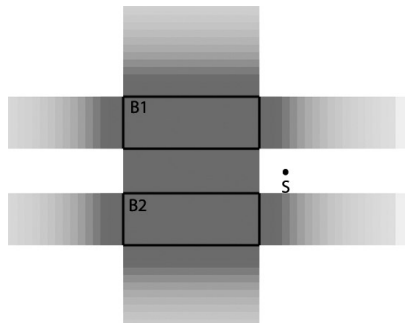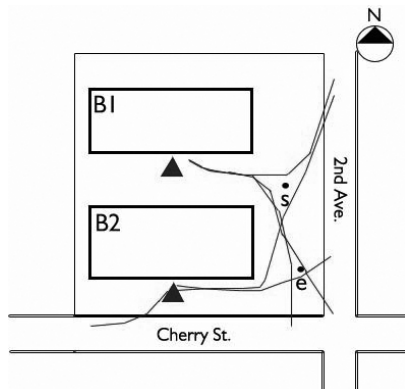
Representation

Spatial

## 1 Introduction

Architectural design is to determine the configuration of building elements and the space they bound. The configuration of built elements and space affects the perceptions and ultimately the behavior of people who use the building. A key component of architectural design expertise is anticipating how a configuration of built elements will affect people's experience.

Architects often describe information about the qualities that users experience in the built environment. For example, architects speak of space and place using terms such as enclosure, continuity, directionality, or privacy. These terms imply, to the architect, certain patterns of use and inhabitation. Some, for example, enclosure and privacy, make every-day sense to the lay person as well. Others, such as continuity and directionality, are jargon, meaningful only to architects or critics. These terms are vocabulary in a 'language of architectural qualities'. Our Descriptor project aims to provide computable definitions to these qualities to describe common spatial experiences that are implicitly understood by architects.
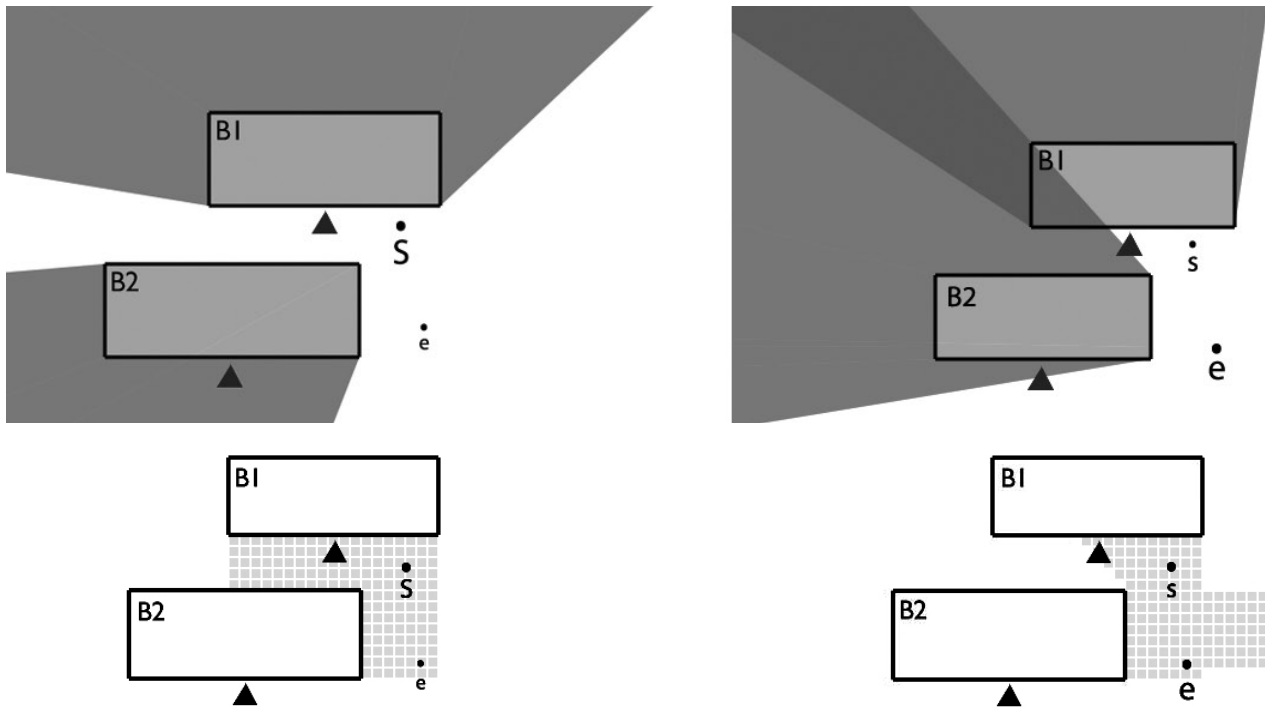
The Descriptor program attempts to compute and visualize spatial qualities by providing means to analyze the design. Learning to analyze built form is an important part of learning to design, as it offers a way to reflect on their action within the situation (Schön 1982). Computational representation of spatial qualities can lead us to a better understanding of how we construct spatial concepts. The understanding might increase the effectiveness of computer tools during a design process. Although the definitions of qualities are still provisional, we (or architects) might find it useful in relating a proposed set of design decisions to the ways that people are likely to use a building. Our language is well-defined in that from any given configuration of building components we can compute a map of the qualities of the space that they define. We suggest that our definitions are familiar to architects and can eventually be related to empirical studies of environment and human behavior.

## 2 Related Work On Modeling Spatial Qualities

Computation of spatial qualities is an attempt to put the representation of the spatial environment on a quantitative base. Reading architecture as a spatial field, rather than a collection of physical objects, can offer meaningful categories for evaluation of qualities of architecture from the building user's perspective. Analyses of spatial qualities can support the architect in reasoning about the form of the configuration, helping architects to predict the consequences of a design.

Much work has been done to provide methods to represent visual perceptual information of the environment into measurable attributes. In the early effort to make spatial qualities measurable, Benedikt presented an isovist model (Benedikt 1979). Isovist represents the field of the visually perceived space from a vantage point, often described as a set of points or a polygon. He proposed different measures of isovist, area (size), surface perimeter, occlusion (the proportion of the perimeter to the solid boundary of the environment), and skewness of the isovist polygon, addressing the relationship between the viewer and the immediate environment. Do and Gross compared methods of computing spatial qualities by analyzing enclosure and visual access from a floor plan. They calculated the number of walls to represent degree of enclosure, and the visible areas to represent openness and visual access, translating experiential qualities of architectural space into computable values (Do and Gross 1997). Widely referred to in the literature, *Space Syntax* presents a set of theories and methods to analyze the spatial configuration of architectural space (Hillier & Hanson 1989, Turner 2001). Spaces are broken down into components (nodes) and represented as graphs according to the relative connectivity and integration of the components. The integration value, the depth of the space, shows how much the space will likely be used or visited. The research on *Space Syntax* shows that translating geometrical attributes of building elements and the configurations into computable values helps architects and urban planners predict the social effects of their design.

A formal representation of spatial qualities can be utilized in knowledge-based systems. Kincaid proposed a mathematical model of territory (Kincaid 1997). Architectural el-

ements, when composed, produce an occupiable space, called territory. The shape of territory guides the user movement. Koile's prototype system (Koile 2001) illustrates how we can use descriptions of experiential qualities of architectural space for a knowledge-based system to evaluate physical form. Experiential qualities are inference rules in classifying physical characteristics of building elements. For example, a private space is hidden, and a hidden space has the characteristics such as 'connected by a circuitous path', 'not open to the front door', or 'on a different floor'. Koile's mapping structure shows a way to organize patterns of spatial qualities using properties of physical elements.

Computational models are used to predict human behavior within the built environment. Yan and Kalay modeled physical behaviors of virtual users (Yan & Kalay 2006). In relating geometric and behavioral models, cognitive factors of the virtual user function as the intermediate structure to link the models. The factors, such as previous knowledge about built environments, goals, social traits, or perception, explain different behaviors of the user (i.e. walking, sitting, standing). Therakomen's MouseHaus model of autonomous agents allows a user to create a 2D-virtual environment to explore pedestrian behavior in the urban space (Therakomen 2001). It focuses on local movement at the individual level of motivation, reaction, and reflection on the environment. Both studies demonstrate the virtual agent's experience as an important aspect of behavioral simulation.
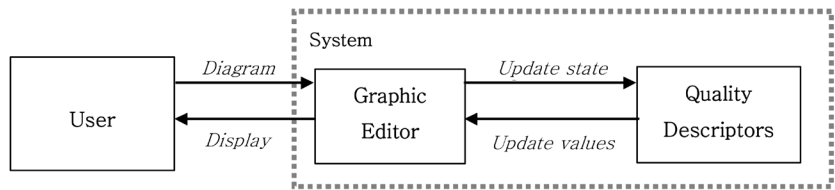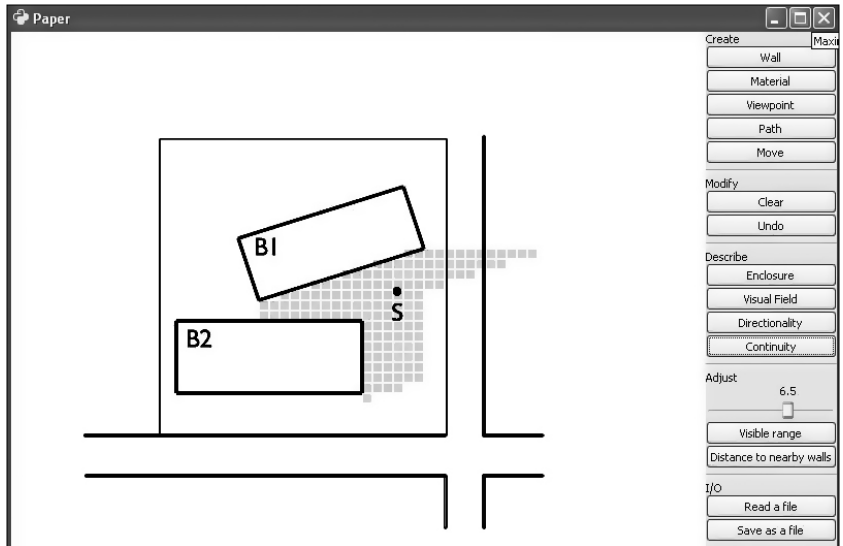
## 3 Definitions

People often prefer certain physical settings. A table at the corner of a cafeteria is more popular than the one at the center. The corner area is closer to the walls, thus, is more enclosed and less visible by others. Spatial qualities associate spatial experience with perception. In this paper, we define three qualities, enclosure, viewfield, and continuity, with the intention that, on one hand, formalizing these qualities can lead to predicting the behavior of building users, and on the other hand, a model of human behavior in buildings can be expressed in language that architects find familiar and appropriate.

### 3.1 ENCLOSURE

We define *enclosure* as how much a location is surrounded by architectural elements. The degree of enclosure is proportional to the inverse distance of an element from the location, represented as a scalar.

Enclosure is a function of a location P(x, y) and the set of visible walls from the location.



FIGURE 3. VIEWFIELD FROM TWO DIFFERENT VIEWPOINTS, FROM POINT S (TOP LEFT) AND POINT E (TOP RIGHT). WHITE INDICATES THE VISIBLE REGION; SHADED INDICATES THE INVISIBLE.

FIGURE 4. CONTINUITY AT TWO LOCATIONS: AT POINT S (BOTTOM-LEFT) AND E (BOTTOM RIGHT). E IS CONTINUOUS TO THE ENTRANCE OF BUILDING B1.

Total degree of enclosure at point P ($E_P$) is the sum of inverse distances ($d_i$) of visible walls from P, normalized as a percentage (0 to 100).

$$E_P = \sum 1/d_i$$

### 3.2 VIEWFIELD (ISOVIST VIEWSHED)

Following Benedikt (1979) we define *viewfield* as the visible area from a viewer's position within a field, represented as a polygon.

To define the shape of a viewfield, a line to each endpoint of each wall from a single viewpoint P is extended to the field boundary. The area on the opposite side of the wall from P is removed from the field. When there are multiple walls, the visible regions can be calculated by subtracting all invisible regions from the field. We define the visible region V as the shape of the remaining area. It is described as a boundary, a sequence of points forming a polygon.

$$V_{total} = [\text{a list of points of the polygon boundary}]$$

### 3.3 CONTINUITY

Cullen (1961) defines *continuity* as "a simple way to show how one type of space is directly linked to another by the physical elements." When a physical element creates a small field to move along, such as a fence or a sidewalk, continuity indicates whether a viewer is within the field. It suggests a path and an uninterrupted view within the object's field.

Continuity is a Boolean value, determining whether two mutually visible locations, P1 and P2, share a physical element e within the range of view. Two functions, mutually_visible and within_field are used to calculate the relationships between the two points and between the element and the point.

$$C (P1, P2) = \text{and (mutually\_visible (P1, P2), within\_field (e, P1), within\_field (e, P2))}$$

## 4  Use Scenario

The following scenario demonstrates how one might use our prototype Descriptor system during early design. The tool provides visualization of spatial qualities as the designer moves building elements.

An architect begins siting. He wants to arrange the building in order to place an outdoor seating area (Figure 1). Location s indicates a possible seating area. People approach to

**FIGURE 5.** A SCREENSHOT OF THE PROGRAM, SHOWING CONTINUITY AT S WITHIN A NEW CONFIGURATION.

**FIGURE 6.** STRUCTURE OF THE PROGRAM.
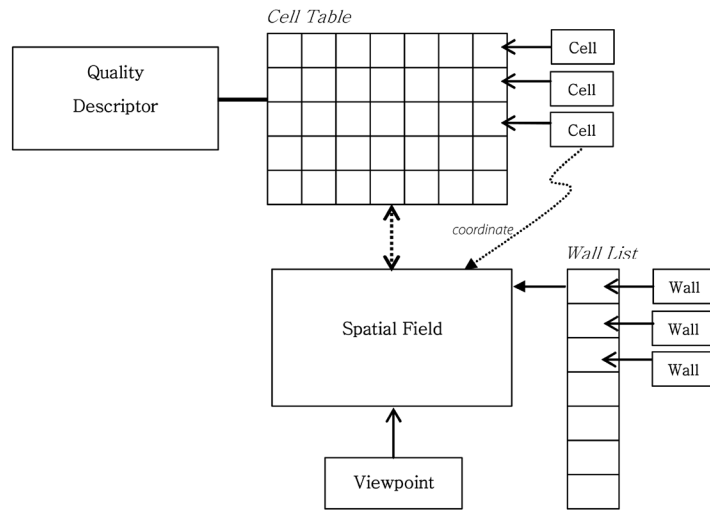
the buildings from the corner of the site, indicated as point e. Then they pass location s to enter B1. Point e is the entry point to the site, close to the intersection of two streets. Arrows indicate entrances of buildings, freehand lines, paths from the streets.

He uses our program to check how enclosed point s is. Darker color shows higher enclosure (Figure 2). The white region in figure 2 shows that the enclosure at point s changes when he moves B1 to the right.

Now the architect confirms the view at s by checking the viewfield the program draws. (Figure 3) Point s is visible from e. (Figure 3, Left) He infers that position s will give enough view, from the size of the viewfield. He also thinks, from the enclosure he previously checked, that the new configuration will give people a secure feeling. He moves the viewpoint to point e. The entrance of B1 is visible from e. (Figure 3. Right)

The walls of the buildings will affect how people will move within the site. The architect now wants to see whether s is connected to the rest of the area. He checks continuity at two locations s and e. (Figure 4) Providing a seating area at s (along the wall) seems reasonable. It is visually open, enclosed, and connected to the movement flow.

However the configuration seems a bit rigid. He rotates B1 (Figure 5). Now B1 is closer to the street, and the region where continuity value is true the area where people will likely move is different.

Finally, generating an alternative, our architect will repeat the process on different configurations. When finished, he will save the building outlines, and move on to room assignment inside the building outlines.

## 5 Implementation

### 5.1 THE SYSTEM

The demonstration system, Descriptor, is a graphic editor that measures spatial qualities from a drawing. The program calculates the values of a quality for every (10x10 pixel) cell on request, stores the values, and displays those using different intensities of colors. Qualities can be overlapped on top of a diagram and continuously updated as the user adjusts it. The user can draw a path to see varying shapes of the map of qualities as the viewpoint moves. Figure 6 illustrates the basic structure of the program.

### 5.2 COMPONENTS AND DATA STRUCTURE

The program has two main components: graphic editor, and quality descriptors. The graphic editor provides a single drawing space with simple functions. Each quality descriptor is an object, represented as a two dimensional table to store a list of cell objects. A cell represents the value of the (specific) quality at the position (x, y). Figure 7 shows the data structure of a descriptor object in relation to the wall object.

**FIGURE 7.** DATA STRUCTURE OF A DESCRIPTOR OBJECT IN RELATION TO THE WALL OBJECT.

### 5.3 QUALITY DESCRIPTORS

Quality descriptors have methods to measure perceived relationships (surrounded, visible,

nearby, nearest) between a viewpoint and the architectural elements based on the geometric properties (location, distance, angle) of the elements. The descriptors, enclosure, viewfield, continuity, are the terms to associate the type of spatial experiences to the computable relationships from a viewer's perspective.

## 6  Discussion and Future Work

During the design process an architect communicates using abstract descriptions of architectural space. Communication using abstract terms also happens when a group of designers and their clients are negotiating, or in design education when students lack previous knowledge to map spatial experiences of building users onto physical elements. Abstract qualities, e.g. continuous, come from the overall configuration of the elements, not just from the attributes of a single element. Designers infer the consequences of their design from physical elements and the relationships between them. The ability to map desired consequences to physical form is the hallmark of architectural expertise.

A problem of explaining qualities of architectural space is that there is no language (lingua franca) that describes spatial qualities. We intend to build a drawing environment that affords a certain level of description of the design. The description, using familiar terms, reveals the analytical structure of spatial qualities that is based on the geometry of the physical elements. We hope that the program help beginners understand the spatial qualities of buildings, by visualizing not exactly what people will see, but what they might perceive and what it might mean depends on the designer's own definition of qualities.[1] We believe the kind of structural thinking is a necessity for design education in addition to the architectural knowledge one can acquire from real experience.

We plan to extend the set of qualities[2] and add detailed attributes of the physical elements, color, material, and light to serve the function of a movement simulator. Since the vertical dimension matters for an accurate analysis, we may consider supporting three dimensional constructions of built objects to achieve accurate prediction of the physical configuration.

1.  Visible range is currently user-adjustable. All definitions will become user-adjustable in future implementation.

2.  A quality is a stand-alone class, designed for future extension to allow a richer vocabulary, for example 'isolated' or 'reachable'.

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