A Visualization Framework for Synthesizing Spatial Impacts from Multiple Site Factors

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Abstract

This paper presents the development of a modelling framework for synthesizing and visualizing the spatial impacts of multiple factors with respect to the project site in architectural and urban design. In design practice, collecting and processing the information about the project site is critical to the final outcome of the design proposal. Given the complexity observed in our built-up environment, the information that architects need to process and respond to is enormous in terms of magnitude and variety. The proposed modelling framework aims to quantify the spatial impacts of various site factors on a consistent basis. The significance of this research lies in synthesizing the impacts from multiple factors through a digital interface. The three-dimensional form of data representation within the digital context may inspire schematic thoughts of architects. By adjusting the parameterization of each factor, architects can prioritize the design issues and explore a wide spectrum of design schemes.

Keywords: site analysis; spatial analysis; visualization; architectural design

1. Introduction

The formation of design schemes is bound up with the collecting and processing of information. Given the increasing complexity observed in our built-up environment, the amount of information that architects need to process and respond to is enormous in terms of magnitude and variety. How such intangible information is processed and then transformed into formative concepts is undoubtedly a subjective matter, and actually represents the originality of architects.

For a certain project site, the physical and social impacts of the surrounding contexts are critical to the formation of the design scheme. Original design solutions are often developed through the analysis of the surrounding contexts. The site information usually includes environmental and social factors that are location-specific and varying in terms of presenting format. In design practice, it is the architects who synthesize the varying types of site information, the process of which is hardly transferable among individuals.

In this paper we explore a new visualizing tool that may help designers better understand the spatial impacts of the surrounding contexts. The proposed tool provides a digital interface to synthesize the spatial effects of multiple impact factors. Architects can thus obtain a holistic view of the possible interactions between the site and its surrounding contexts, which may eventually inspire new thoughts of design.

We structure the paper as follows. Chapter 2 introduces the hypothesis and the formulations for quantifying the impact of different factor types. In Chapter 3, we present the visualization results for a series of archetypal project scenarios. Finally, we summarize the findings and implications for design practice in Chapter 4.

2. Model Formulations

2.1 Hypothetical Site

To facilitate the discussion on model formulations, we first introduce a hypothetical project site (Fig.1.). The hypothetical site is rectangular, 120m x 80m. We devise two types of impact factors. First, environmental factors. We assume that the road on the west is an urban artery road, which generates traffic noise to the site. There are existing buildings of varying height along the site periphery. The building height is represented by the number of floors and a uniform 3.5 meters per floor is assumed to calculate the building height. Existing buildings will block the direct daylight thus may cause shading issues against the site.

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The second type of factors are social factors. A public green field is assumed on the southwest of the site, representing natural amenities. Along the site periphery, there is one "annoying" street on the north and one "pleasant" street on the east, which exerts a repulsive and attractive force to the site, respectively. The possible reason for the street being "annoying" in the neighborhood may be unhygienic street conditions or high crime rates; the street may be "pleasant" because of the pedestrian-friendly street settings or business varieties.

2.2 Model Setting

We follow an agent-based approach to model the spatial impacts of the surrounding factors. We first deploy a three-dimensional analyzing grid (Fig.2.) over the project site. Each cubic unit within the 3D grid represents a spatial agent that would act to the impact factors. The vertical height of the grid may refer to the planning regulation on building height, and the spatial granularity of the grid (i.e. the density of the spatial agents) is subject to the scale of the project.

The next step is to define the action rules of the spatial agents. Specifically, there are two actions that the spatial agents may take depending on the type of impacts.

Action 1: Move

To embody the intangible impacts upon spatial agents, we assume that an impact factor would exert influence upon the space in the form of a virtual force (either attraction or repulsion). Driven by the virtual force, spatial agents depart from their original positions. The direction of movement is defined along the vector directing from the factor location to the spatial agent. In addition, stronger impacts would result in further moving distance away from the original position, whilst a distance decay effect between the agent and the factor location would discount the impacts. We allow the overlapping of spatial agents during the movement.

Action 2: Disappear

A spatial agent would disappear when certain conditions are met. In the case of daylight shading, we assume that the spatial agent would disappear if the total solar exposure time at the specific position is under user-specified threshold. In practical terms, it implies that the space is not suitable for residential use due to lack of direct daylight. The agent disappearing action can also be used to represent other regulatory rules, such as the building drawback requirements from adjacent street or the site boundary.

2.3 Impact Factors

(1) Solar factor

To model the solar exposure, we first develop an algorithm to calculate the sun position for any given date, time and location on earth. With this component, we can simulate the daylight shading cast by existing buildings along the site, thus obtain the daylight exposure time for each spatial agent. For residential use, the minimum length of daylight exposure is informed by the relevant planning regulations. Similar formulations can also be used to calculate the potential of solar power utilization on site.

In this paper, we assume that the minimum solar exposure time for the hypothetical site is one hour. The spatial agents that cannot meet this condition would thus disappear from the grid, indicating that the represented location is not suitable for residential use. In this test, the length of solar exposure is measured on the winter solstice day (22nd December), which marks the shortest daytime and the longest night time of the year.

The test result for solar shading is presented in Fig.4. and Fig.5. The spatial agents in black color indicate that the daylight access at the represented location does not meet the a priori requirement. The agents in white color denote that the location has satisfactory access to daylight. The model can also provide some basic
statistics of the shading conditions on site (see the right of Fig.4., 20 out of 648 spatial agents have inadequate solar access). In Fig.5., some of the black agents have disappeared from the grid.

(2) Noise factor

In traffic engineering, there has been extensive research on traffic noise prediction models, which predicts vehicle sound pressure level \( (L_p) \) at the roadside. These models are generally expressed as functions of traffic volume, speed and distance (Steele, 2001). In this study, a simplified prediction model is applied to predict the 50 percentile sound pressure level of traffic noise (Johnson and Saunders, 1968).

\[
L_{50} = 3.5 + 10 \times \log \left( V \frac{S^2}{D} \right) \text{ dB(A)}
\]

\( V \): traffic volume in vehicles per hour  
\( S \): mean vehicle speed in mph  
\( D \): distance from the traffic lane, in feet  
\( \text{dB (A)} \): decibel with an A frequency weighting

Based on this prediction model, the \( L_{50} \) sound pressure on each spatial agent will be calculated. The spatial agent would then react to the traffic noise by moving away to reduce the negative impacts.

To make the model representation realistic, we further define a minimum threshold for perceived sound pressure. If the perceived sound pressure for a given spatial agent is lower than the threshold, the agent would not execute the move action. In terms of the minimum threshold of traffic noise, we refer to the 'World Health Organization's Noise Criteria' (Møller, 1980; WHO, 2009), and define a sound pressure level of 45 dB (A) for daytime indoor living environment as the threshold of "complete intelligibility". The spatial agents would relocate to reduce the negative impacts if the perceived \( L_{50} \) sound pressure level is above 45 dB(A). Otherwise the agents would remain their original locations.

A visualized noise impact on site is shown in Fig.6 (we only present the affected agents while the unmove.d agents are hidden). The color and the size of the agents represent the extent of being affected. Specifically, larger size, warmer color and the longer moving distance implies stronger impact from the traffic noise. Due to the proximity to the noise source, the area near the northwest corner is vulnerable to traffic noise. Designers may consider setting up an outdoor space as a buffer zone or change function plan to mitigate the traffic noise.

(3) Social factors

Compared with the extensive accomplishments in evaluating the environmental impacts, methods for quantifying the spatial impacts of social factors are quite limited in existing literature. Consequently the real challenge for this experiment lies in how to quantify the spatial impacts of the social factors. Inspired by the spatial interaction models in the urban modelling realm (Wilson, 1971; Hansen, 1959), a gravity model is proposed to measure the effects of social factors. This method originates from the law of universal gravitation in physics, which refers to the fact that the attractive force between two objects is proportional to the product of their masses and inversely proportional to the square of the distance between them. Due to the merit of simplification, a gravity model has been widely used in social sciences.

We thus propose a similar equation to represent the spatial impacts of the social factors as follows:

\[
F = K \times \frac{C}{r^\pi}
\]

\( F \): attractive or repulsive force  
\( K \): attraction constant, \( K=1 \)  
\( C \): factor's impact capability  
\( r \): distance between the spatial agent and the factor  
\( \pi \): distance decay parameter

As an analogy of the gravity law, we assume that the attraction or repulsion force imposed on spatial agents is proportional to the factor's impact capability \( C \) and in inverse proportion with a distance decay function \( r^\pi \). A larger \( \pi \) value indicates that the factor's impact applies only to a limited catchment area and would decay rapidly as the distance from the factor increases. On the contrary, a smaller \( \pi \) implies that the factor has a wider impact catchment. Note that the values of \( C \) and the coefficient \( \pi \) is a local matter. Designers are able to change the parameterization according to
different design considerations and priorities. In this paper, we consider three types of social factors, i.e. natural amenities represented by the nearby park, one pleasant street and one annoying street. We will discuss each of the social factors in turn.

To demonstrate the positive role of natural amenities, we assume a park to the southwest of the hypothetical site. To calculate the distance between the hypothetic site and the park, we use Euclidean distance instead of network distance. We present the model result with different $\pi$ values in Fig.7. It shows that, with the increase of the distance decay coefficient (from 1.1 to 1.5), the spatial impact of the park diminishes quickly, implying that only the space close to the park (southwest corner) would benefit from the natural amenity. As a further extension, the distance function $r^\pi$ can be substituted with an index for landscape visibility, such that the visual aspect of the landscape can be considered in plan and elevation design.

The street condition is a vital factor in neighborhood design. In order to demonstrate both the positive and negative impact of streets, we assume one pleasant street and one annoying street, respectively. A gravity-based model is applied to quantify the attractive or repulsive effects of the respective street. The modeled impacts of the streets are presented in Fig.8. (comparing different parameter settings).

### 3. Multiple-factor Tests

To demonstrate the interaction of multiple impact factors, we design two site scenarios with different combinations of parameter values. The purpose of the scenario analysis is to demonstrate how different parameter settings may generate distinct model results. The scenario results are presented in Figs.9. and 10.

#### Table 1. Scenario Design

| Factor       | Parameter 1 | Parameter 2 |
|--------------|-------------|-------------|
| Park         | Impact Capacity: 3.0 | Distance decay: 1.0 |
| Pleasant street | Impact Capacity: 2.5 | Distance decay: 1.5 |
| Solar shading | Measured on 12th December | Min. solar exposure: 1 hour |
| Traffic noise | Traffic volume: 800 cars/h | Average vehicle speed: 30 mph |
| Annoying street | Impact Capacity: 4.0 | Distance decay: 1.5 |

| Scenario 2 | Park         | Impact Capacity: 3.0 | Distance decay: 1.0 |
|------------|-------------|----------------------|---------------------|
| Pleasant street | Impact Capacity: 2.5 | Distance decay: 1.0 |
| Solar shading | Measured on 12th December | Min. solar exposure: 1 hour |
| Traffic noise | Traffic volume: 500 cars/h | Average vehicle speed: 30 mph |
| Annoying street | Impact Capacity: 6.0 | Distance decay: 1.5 |

Compared with Scenario 1, Scenario 2 assumes that the distance decay coefficient for the pleasant street is reduced from 1.5 to 1.0, implying improved accessibility. In addition, the traffic noise is mitigated by controlling the traffic volume of the adjacent road. The impact capacity of the annoying street is also increased, in order to highlight the possible negative impacts to the design scheme.

For designers the distinct feature of this visualization framework is the interactive depiction of how factors of different types may affect the spatial configuration of the site. The synthesized impacts from multiple factors can be interpreted in a heuristic manner. First, the impact catchment of the traffic noise to the site is visualized with delimited boundary. It informs designers to which extent the traffic noise may affect the site, such that appropriate design strategies can be devised to mitigate the negative impacts. Second, the potential attraction from the pleasant street and the park sheds a new light on site plan and building layout. For example, a pedestrian-oriented entrance can be set close to the pleasant street, which not only increases business exposure of the site with more people flow, but may also create new urban public space that enhances the vitality of the area as a whole. Third, the visualized impacts of daylight shading and the annoying street could better inform the design of on-site open space, in the sense that both the environmental and social wellbeing of site users can be considered.
We should note that the above interpretations are for demonstration purpose only, and are not definitive. It is at the discretion of the designers in terms of how such diagrams could be interpreted and transcribed into design language.

4. Conclusions
This paper presents the development of a modelling framework for synthesizing and visualizing the spatial impacts of multiple site factors in architectural and urban design. Rather than deterministically seeking for an optimum solution in design, the purpose of devising an open-end visualization tool is to aid designers by synthesizing the multifaceted site information on a consistent basis. Moreover this design tool does not violate the independence and originality of designers. It opens up a dialogue between designers and the digital reference: within the analytical context, the initial design idea is enlightened by the three-dimensional form of data and is subject to further refining. By adjusting the value of key parameters, designers can prioritize the design agenda and explore a wide spectrum of design schemes.

As an outlook of this synthesizing experiment, we propose some directions of future research. First, more impact factors can be incorporated into the proposed framework. The inclusion of more factors would increase the number of parameters and complicates the interactions. To gain a better understanding of the synthetization, sensitivity tests on key model parameters are suggested. Second, interactive rules may be developed among the spatial agents, such that the agent may be able to respond to the behavior of adjacent agents. It implies a broad research area of applying rule-based agent modelling technique in architectural and urban design. Much remains to be done.

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Notes
1 It is also possible to differentiate the spatial agents according to the length of solar exposure, which may inform the design of outdoor space. Nonetheless we omit this extension and focus on the formulations of the theoretical model.
2 A stricter threshold, such as 40 dB (A), can be applied if vulnerable building users are involved in the project.

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