Economics of Spatial Configuration: A Conceptual Framework for Tenanting Decision of Shopping Malls

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Abstract—A shopping mall is an agglomeration of discrete tenant stores with varied capacities of rental payment. The complexity of mall management lies in fulfilling the profit maximizing objective of the individual tenant stores and the mall as a whole. This two-step objective of profit maximization is attained through tenant-mix decision. Tenant stores of suitable size and rental payment should be placed in a shopping mall to generate maximum profit for that store and to earn maximum revenue for the shopping mall at the same time. The location and area allocation decisions are essentially spatial but no parameters of spatial configuration are used in predicting the tenanting decision. The mall management handles this decision in a subjective and generalized way. Only spatial variable acknowledged in retail literature is metric distance which predicts the most significant variable for tenanting decision, foot fall. Syntactical analysis of spatial configuration in the field of built environment on the other hand attempted to predict movement and foot fall within a built space. The results of studies in these two disciplines are end in themselves. The findings from one discipline do not help decision making in another. This research attempts to bridge the gap between retail management and syntactical analysis of space and attempts to include spatial parameters in taking strategic decisions.

Keywords: Agent based simulation (ABS), Metric mean shortest path angle (MMSPA), Tenant-mix, Through vision (TV), Visibility Graph Analysis (VGA).

INTRODUCTION

A shopping mall is an agglomeration of different stores, with varied rental payment potential, managed by an individual operator. Maximization of profit is the objective of the individual tenant stores as well as for the entire shopping mall. Tenant mix is the methodology adopted by mall management professionals to meet the dual objective. Research results in the field of retail management (Garg & Steyn, 2014 and Yiu & Xu, 2012) ventured to develop an "ultimate tenant mix" as a potential tool. The earlier researches on tenant-mix resorted to inter-store externality in explaining the agglomeration of stores (Benjamin , 1992; Eppli & Shilling, 1995 and Pashigan & Gould, 1998) without focussing on spatial configuration. These findings are case specific and non-generalizable. The leasing decisions within an organized shopping mall consist of selection of right mix of stores, space allocation, rent determination and location (Dawson, 1983). These should be finalized at an initial phase of development (Guy, 1994 and Beyard & O'Mara, 1999). This paper explores the economic potential of spatial configuration in a shopping mall and proposes a conceptual framework for designing tenant-mix relying on the configuration of the built space.

In reality, the design of a shopping mall involves complexities and requires input from a diverse group of professionals. The designer works on the concept and accommodates the requirements within an aesthetically appealing spatial envelope. The built space is converted into an efficient shopping mall with the help of retail and mall management professionals. Locating stores and allocating areas are spatial parameters (e.g. Roulac, 1996). Nevertheless, spaial configuration is not fully explotd in taking tenanting decisions; they are taken on a rule-of-thumb. Retail resaerchers (Carter & Haloupek, 2002; Carter & Vandell, 2005 and Ingene & Ghosh, 1990) acknowledged metric distance as the only spatial vaiable in determining tenant mix as it exhibits high correlationship with foot-fall. Space syntax analysis, on the other hand provides the spatial logic behind movement (which results in footfalls or gate counts at different places) through quantifying configuration and relating that with gate counts. The gap between the two approaches (retail management and architecture) needs to be bridged for a logical tenanting decision making framework. Gate counts can be used for predicting profit function of a store and the syntactic values of configuration can be used to analyse and predict footfalls or gate counts. It is possible to develop a tenanting decision making framework relying on those findings, where the layout of the mall and data regarding stores for occupation are available, under conditions of maximising profit of the tenant stores and maximising revenue earning for the developer.

LITERATURE REVIEW

SIGNIFICANCE OF TENANT MIX

McCollum, 1988 defined tenant-mix as a collection of different stores with varying capacities of rental payment within a shopping mall such that they help in achieving financial viability of the mall besides maximizing their own profits. Maximization of revenue from a shopping mall therefore relies on the efficiency of the tenant-mix decisions (Brown, 1992; Garg & Steyn, 2014). Research findings also suggest that tenant-mix impact selection of malls (Bellenger, *et al.,* 1977), stimulate repeat purchase behaviour (Stoltman*, et al.,* 1991) create imageability (Finn & Louviere, 1996) and finally affect customer gratification (e.g. Abghari & Hanzaee, 2011). The benefit of agglomeration is measured through store externalities by Wheaton (1999). This externality is the positive or negative impact on each other due to proximity.

CONFIGURATIONAL STUDIES ON SHOPPING MALLS AND THE SIGNIFICANCE OF MOVEMENT

Brown, 1991 and Sim & Way, 1989 focused on movement of customers or foot-fall as another important factor in influencing tenanting decisions. They adopted bid-rent in explaining tenanting decision relying on customer footfall. Carter & Vandell (2005) and Eckert & West (2008) explained internal configuration of shopping malls in terms of footfall. These studies relied on the inverse relationship between footfall and metric distance. Carter & Vandell (2005) adopted metric distance measure from Carter and Haloupek (2000) as a deciding factor and assumed in their model the maximum foot fall near the center of the mall with gradual decline to a minimum at the two ends. The studies, which considered the potential of footfall in projecting tenanting decisions, considered the theories of urban structure, i.e., central place theory (Christaller, 1966), bid-rent theory by Alonso (1964) in a 'closed city' form. Nevertheless, the methodology is applicable for a linear mall with entry point in Centre and is not sufficient for accommodating complexities in modern mall configurations.

MOVEMENT AND THE SIGNIFICANCE OF VISIBILITY MEASURES AND AGENT BASED SIMULATION

Retail literature, which relied on urban spatial structure, espouses the supremacy of footfall in tenanting decision making (e.g. Brown, 1999; Carter & Vandell, 2005) necessitating prediction of movement. Measuring navigation has always been critical in architectural and planning studies and is done through several methods. Unlike other methods, space syntax method is based on quantification of spatial configuration for understanding social encounters and co-presence. Research results for indoor movement (Haq & Zimring, 2003; Hölscher, *et al.,* 2012) established the efficacy of syntactic measures in predicting movement. Research findings of Hillier (1996) and Turner, *et al.* (2001) corroborated that syntactic values are better predictors of movement compared to the metric measures.

Among other syntactic measures visibility measures exhibit better results in predicting indoor movement (Ittelson, 1973, Appleton, 1975; Desyllas & Duxbury, 2001; Turner & Penn, 1999, Parvin, *et al.* 2007) and verified for artificial organisms (Yeap & Jefferies, 1999) and established a strong relationship between visibility and accessibility. The Visibility Graph Analysis (VGA) is a widely used tool (Batty,

et al., 1998; Turner & Penn, 1999; Turner, 2001; Turner, *et al.,* 2001; Desyllas & Duxbury, 2001) in studying movement relying on inter-visibility and is a good predictor of movement and accessibility (Turner & Penn, 1999; Desyllas & Duxbury, 2001; Parvin, *et al.* 2007). VGA is conducted on a plan diagram by overlaying a grid of points. The analysis yields several visual and metric measures of center points of those grids. Two measures of VGA have been identified for explaining navigation and prediction of gate counts: through vision (TV) and metric mean shortest path angle (MMSPA). TV is the line of inter-visibility between two vantage points (Turner *et al.,* 2001) and corresponds well with human movement (Peponis, et al., 1990; Haq, 2003; Conroy Dalton, 2003; Saito, *et al.,* 2017). MMSPA measure is selected for 'realistic' notion to movement (Turner, 2001) over metric distance, which is the traditional spatial variable in retail research (Carter & Vandell, 2005).

Turner & Penn (2002) recommended agent based simulation with visibility information. Agents or automata were used in these researches as proxy for pedestrians with the accessibility of visual information from VGA which is equivalent to vision. Therefore, by providing vision, the agents simulate a human movement around a built environment (Conroy, 2001). The agent based simulation results correlates well with actual human movement (Turner & Penn, 2002 and Turner, 2003).

METHOD

The basic research objective is to exploit the potential of configuration of built environment of a shopping mall to influence tenant-mix decisions. Therefore, the total revenue earning from a shopping mall has to be stated in terms of parameters of built environment. This is approached by a two-step methodology. Traditional bid-rent function is used to establish the total revenue function and the visual configurational analysis is adopted to establish the relationship between gate counts or foot-fall at a particular location in terms of spatial configurational parameters.

Bid Rent Analysis

The bid-rent analysis in its classical form establishes the relationship between profitability of a store based on its location. The objective of a store in a shopping mall just like "firms in (the) city" (Carter & Vandell, 2005) is to maximize profit. The profit function of a store in a mall is stated as (Deb, 2019):

$\pi = V - C - R$ (1)

Where π = profit, V = Revenue, C = Cost and R= total rent

So, $V = p.q$

Where, p = Average unit price of commodities and q = total sales quantity for an accounting period

The total sales quantity (q) again depends on the number of buyers and the amount of average purchase:

$q = N_b.a$

Where N_b = number of buyers
a = Average sales quantity per buyer

N_b, again, depends on the gate counts or footfalls and conversion rate of the store, i.e., number of buyers/ total gate counts:

$N_b = g^k.c$
g = gate counts or foot fall
c = conversion

k is a constant that ranges between $0 < k < \infty$. It is essentially inter store externality. For convenience of calculation, we will further assume that there is no inter-store externality or, $k = 1$.

Total sales quantity, q can be expressed as:

$q = a.g.c$

Conversion rate increases with increase of store area but at a decreasing rate. Carter & Vandell, 2005 showed the decreasing pattern from a dataset of Urban Land Institute, 1993 and that can be expressed mathematically as (Deb, 2019):

$$\frac{\partial f(A)}{\partial A} > 0,$$

$$\text{but } \frac{\partial^2 f(A)}{\partial A} > 0$$

Therefore,

$c = f(A). A$

Where, A = store area
$f(A)$ = rate of conversion as a function of area

The conversion factor increases at a decreasing rate with increase in area. Therefore conversion factor can be expressed mathematically as:

$f(A).A = \alpha.A^\beta$

Where α, β are store specific constants:

$0 < \alpha \leq 1$ for conversion
$0 < \beta < 1$ considering decreasing returns to scale

Cost component again can be expanded into different sub components:

C_F = Fixed cost

C_O = Operating Cost, function of sales quantity

C_M = Maintenance cost, function of store area

r = Rent per unit area

Expanding the classical bid-rent model, the profit of the store is denoted in following equation 2.

$$\pi_i = p_i.a_i.f_i(A_i).A_i.g_i - [C_{Oi}.[a_i f_i(A_i).A_i.g_i] + r_i.A_i + CF_i + CM_i.A_i] \qquad (2)$$

To relate rent and gate counts when other store specific variables remain constants, the above equation 2 has to be solved under the condition of maximizing profit

VGA and Agent Based Simulation

Virtual built space is adopted for analyzing foot fall (Reffat, 2008; Yan & Kalay, 2004) as it is a proven methodology for modeling human behavior (e.g. Franz, et al., 2005; Orellana &Al Sayed, 2013; Boustila, *et al.,* 2016). Four typologies are (e.g. Verdil, 2009) common for shopping mall layouts depending on the arrangement of circulation axes: Cartesian system, dumb-bell, branch or tree system and the hybrid system combining the elements of the other systems. Hypothetical layouts of equal leasable area have been prepared for the first three typologies. The Cartesian follows a grid network with one or more major arteries. Dumb-bell system has predominant central axis and two or more attractive spaces. The tree system, on the other hand, has a strong major axis with branching smaller axes from it. The hybrid one is eliminated from the analysis for presence of property of any two or all of the typologies. Three different mall typologies as identified earlier were created in drawing exchange format (*.dxf) considering equal total leasable and common circulation area (Figure 1). The layouts show mall interior public spaces without focusing on individual shop interiors.
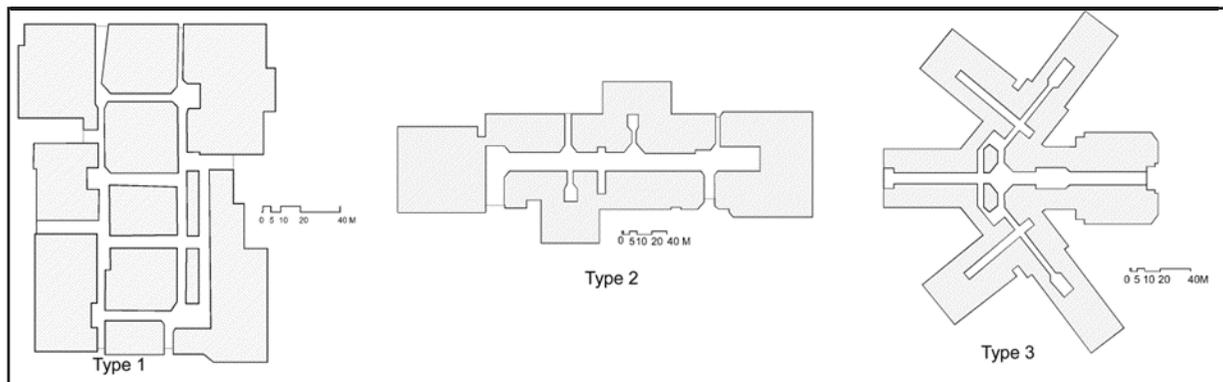
Fig. 1: Three Mall Typologies of Equal Leasable and Movement Area. From left, Type 1 (Cartesian), Type 2 (Dumbbell), and Type 3 (Tree)

The depthmap X software tool (Turner, 2007; Varoudis, 2012) has been used for VGA and agent based simulation in this paper for the above mentioned layouts by filling the layouts with grids (300X300 mm^2). The VGA generates values of TV and MMSPA for center point of every grid. The agents were released randomly from any random starting points within the layout following a standard movement rule (Turner, 2007). The standard movement rule of Turner (2007) recommended 170^0 field of vision for agents and three steps are considered before any turn. The agent release rate is fixed at 0.1 per timestep. The results of the simulation with standard movement rules correlates well with natural movement patterns in built spaces (Al_Sayed & Turner, 2012). The simulation result is done for 500 agents for all the above cases. The simulation generates gate counts for every center point of the grids along with values of through Vision (TV) and Metric mean Shortest Path Angle (MMSPA) value among others.

EXPERIMENT AND RESULT

The relationship between Gate Counts and Total Rent from a store

The profit earned from a store in a shopping mall can be derived from the bid-rent equation. By suppressing the

subscripts of the profit function of a store as expressed in equation (2) for ease of calculation it becomes:

$$\pi = p,a,f(A),A,g - C_0,a,f(A).A.g - r,A - C_F - C_M.A \quad (3)$$

For maximization of profit function, the first -order derivative of equation 3 with respect to A has to be zero, or,

$$\frac{d\pi}{dA} = a.f(A).A.g[\,p - C_O] - r - C_M +$$

$$A.[a.g.\frac{df}{dA}(p - C_o)\,] \quad (4)$$

Again, in a condition of perfect competition, profits are negated by increment in rent, so that π=0. The Equation (3) yields:

$$\pi = 0 = a.f(A).A.g[p - C_O] - r.A - C_F - C_M.A \,(5)$$

From the simultaneous equations 4 and 5, we can solve for optimum store area (A*):

$$A^* = \left[\frac{C_F}{a.g.(p - C_O).\alpha.(1 - \beta)}\right]^{\frac{1}{\beta}} \quad (6)$$

And optimal rent r^*

$$r^* = C_F \frac{\beta}{1 - \beta}.[a.g.(p - C_O).\alpha.\frac{1 - \beta}{C_F}]^{\frac{1}{\beta}} - C_M$$

$$r^* = C_F \frac{\beta}{1 - \beta}./A^* - C_M \quad (7)$$

The total revenue from a store will be area multiplied by rent:

$$R = C_F \left(\frac{\beta}{1 - \beta}\right) - C_M.(\frac{C_F}{a.g.(p - C_O).\alpha.(1 - \beta)})^{\frac{1}{\beta}} \quad (8)$$

Total optimum revenue generated from a store under the condition of profit maximization can therefore be presented in terms of gate counts or foot fall under condition of ceteris paribus.

Figure 2 expresses the relationship between optimum revenue generated from a store in a shopping mall in terms of generated foot-fall at that store when other factors remain constants. It is clear from the mathematical expressions that, at g=0 the profit function becomes undetermined and the same happens for value of g at f'(g)=0. Total possible foot-fall depends on the locational characteristics of the mall. Therefore, the points beyond that value of footfall are unattainable. It is clear from the visual analysis of the graph shown in Figure 2 that, the optimum total revenue falls drastically beyond a particular foot-fall value. That point can be designated as critical and any values lower than that would fail to achieve maximum profit.

GATE COUNTS AS A FUNCTION OF SPATIAL VARIABLES

After analyzing the layouts with Depthmap x software, VGA yields values for TV and MMSPA for center points of
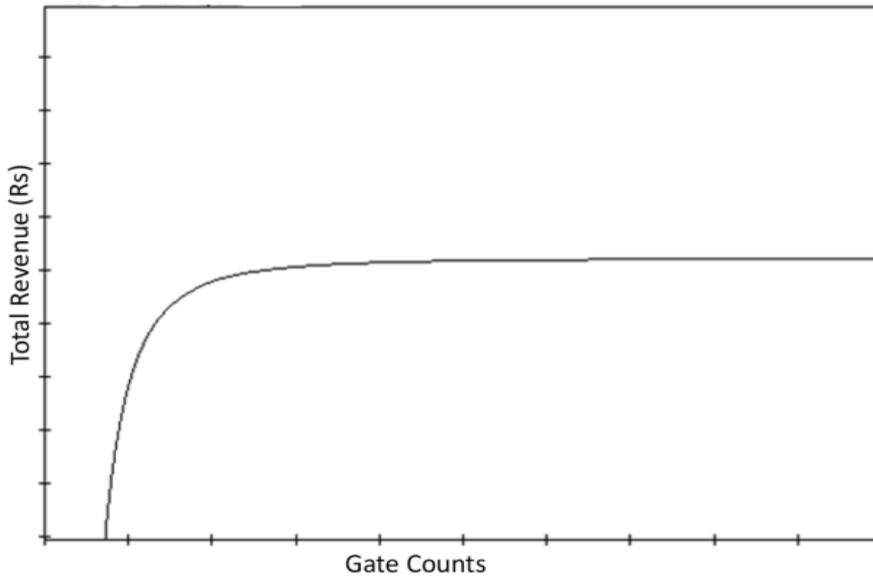

Fig. 2: Total Optimum Total Revenue from a Store with Respect to Foot Falls or Gate Counts under Condition of Ceteris Paribus from Equation 8

grids superimposed on the common area of circulation of the malls. Agent based simulation on the other hand generates foot fall or gate count values at those points of the corresponding layouts.

Figure 3 shows the scatter plot of gate count values from the simulations in terms of MMSPA and TV values for three mall typologies identified earlier. The scatter plot clearly exhibits that, gate count varies directly with TV values and inversely with MMSPA values for all the cases. The corresponding correlation coefficients are also significant. From the two

sets of relationships it is inferred that gate-count is exhibited as a function of TV/MMSPA irrespective of the shopping mall typology. A transpose of square root of TV/MMSPA provides the best fit relationships (Figure 4) with gate counts where adjusted r^2 values for all three typologies yield satisfactory values (Chin, 1998; Hair, *et al.,* 2011) (Type 1: $r^2= 0.61$, Type 2: $r^2= 0.70$, Type 3: $r^2= 0.54$).

The constant and coefficient are highly significant ($p<0.001$) and the gate count or footfall can be expressed through spatial configuration variables as
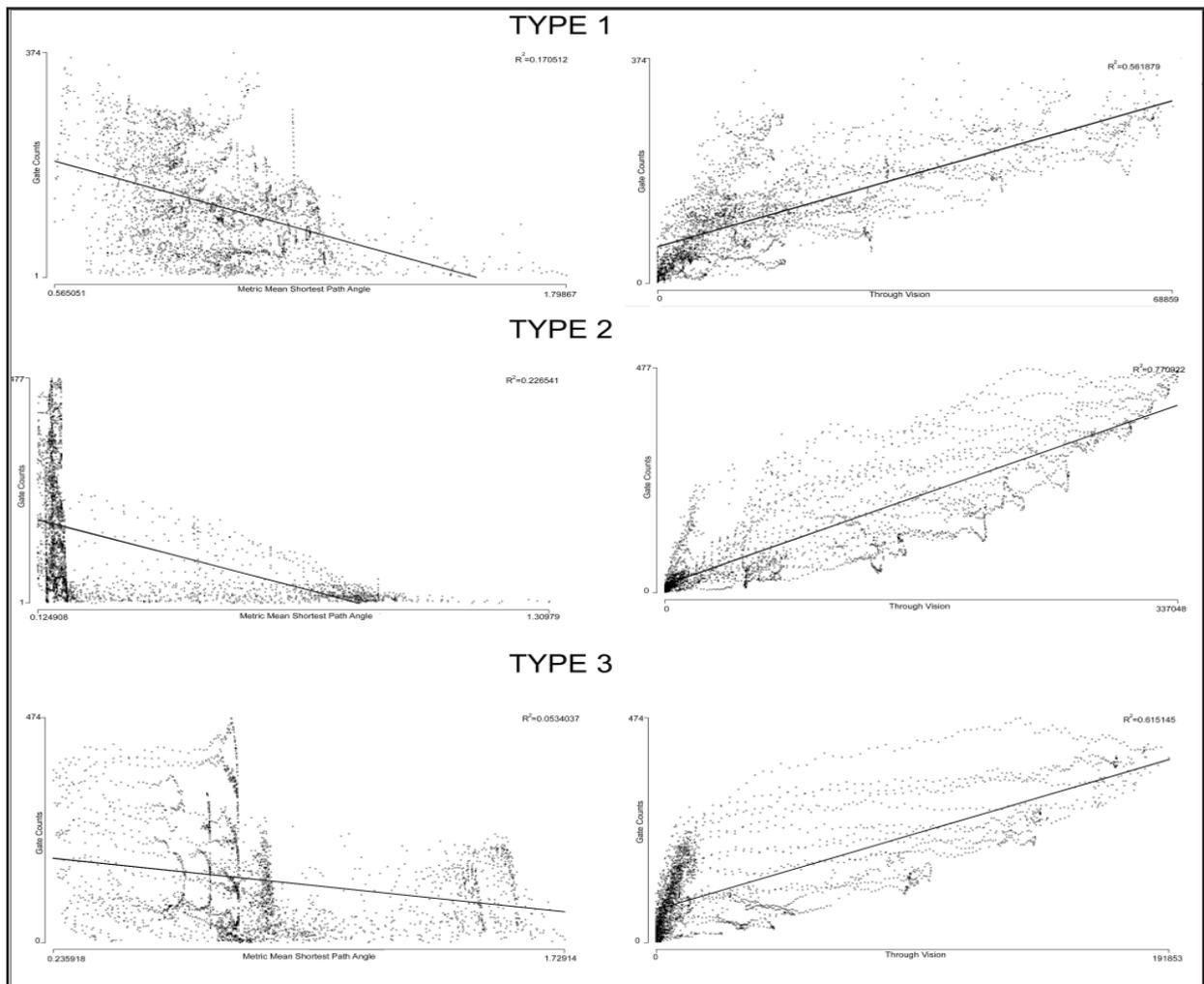
Fig. 3: Scatter Plot of Gate Count Values from the Agent Based Simulations in Terms of MMSPA and TV Values for the Three Mall Typologies Shown in Figure 1
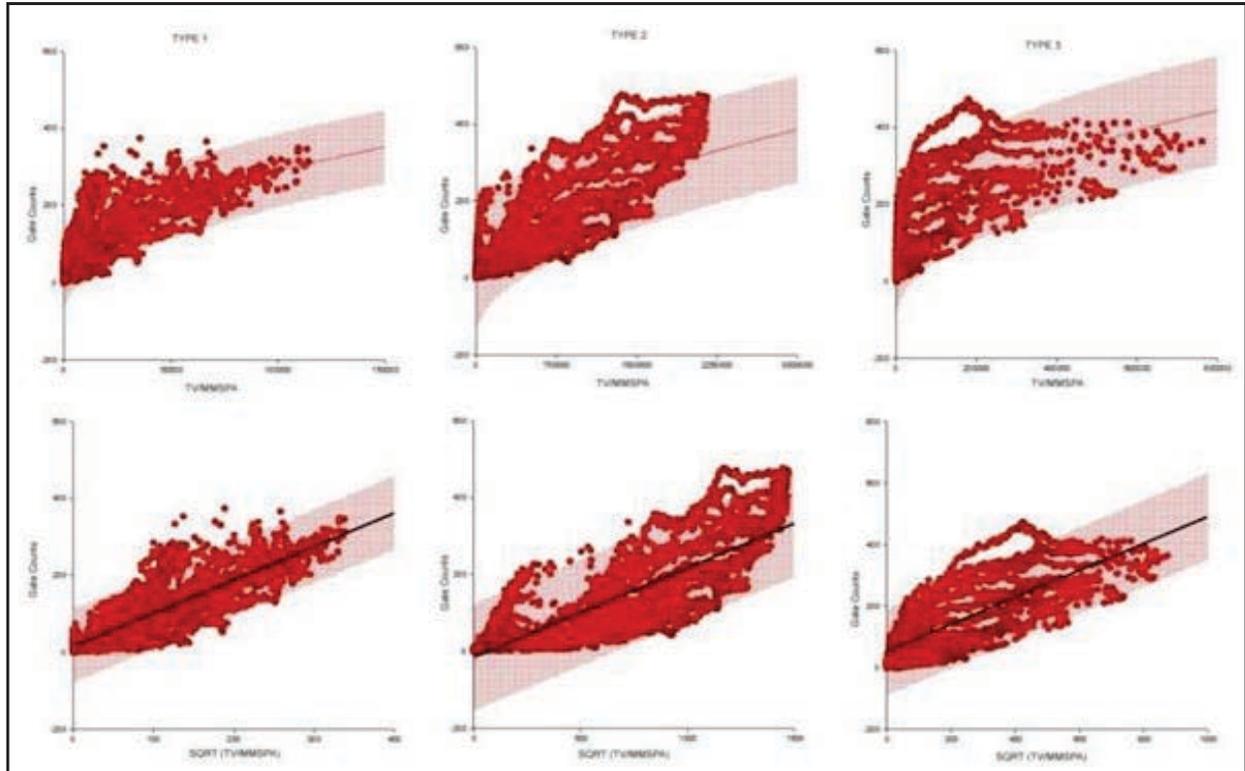
Fig. 4: Model Fit Analysis for the Relationship between Gate Counts and TV/MMSPA without (Above) and with Transpose (Below)

$$g = \gamma \sqrt{\frac{TV}{MMSPA}} + \delta$$

(γ= coefficient and δ= constant)

Eq. (9)

The gate count or foot-fall can therefore be expressed in terms of a simple functional relationship of configurational variables. The superiority of built environment in generating movement and resultant foot fall can therefore be easily established. Substituting the value of g in equation 8 will express revenue generation of a store in terms of spatial configurational variables.

FINDINGS

The revenue generation from a store of a shopping mall can be demonstrated in terms of foot fall and that, in turn, can be conveyed in terms of variables specifying configuration of built environment, TV and MMSPA. Undoubtedly, the revenue generation can be explained in terms of spatial configurational variables. Built environment is therefore not only an end in itself rather a potential tool for determining economic performance. The methodology adopted for visibility graph analysis makes the concept of strategic decision making difficult for implementation in practical cases. For operational effectiveness, the internal public spaces of the mall are decomposed in minimum possible non-overlapping convex spaces. The average values of configurational variables (TV and MMSPA) are considered for predicting foot fall in those convex spaces. The mechanism of decomposition of non-overlapping convex spaces is shown in Figure 5.

A conceptual framework can therefore be formulated for maximization of revenue for a shopping mall. A system is considered to have different number of zones. TV and MMSPA values for all the grid points will vary but δ and γ will remain same for the configuration. The process will start from the area of maximum gate counts. Best possible combinations of store type variables will be selected to maximize the revenue till the available leasable area around that convex space is allotted for lease. The process

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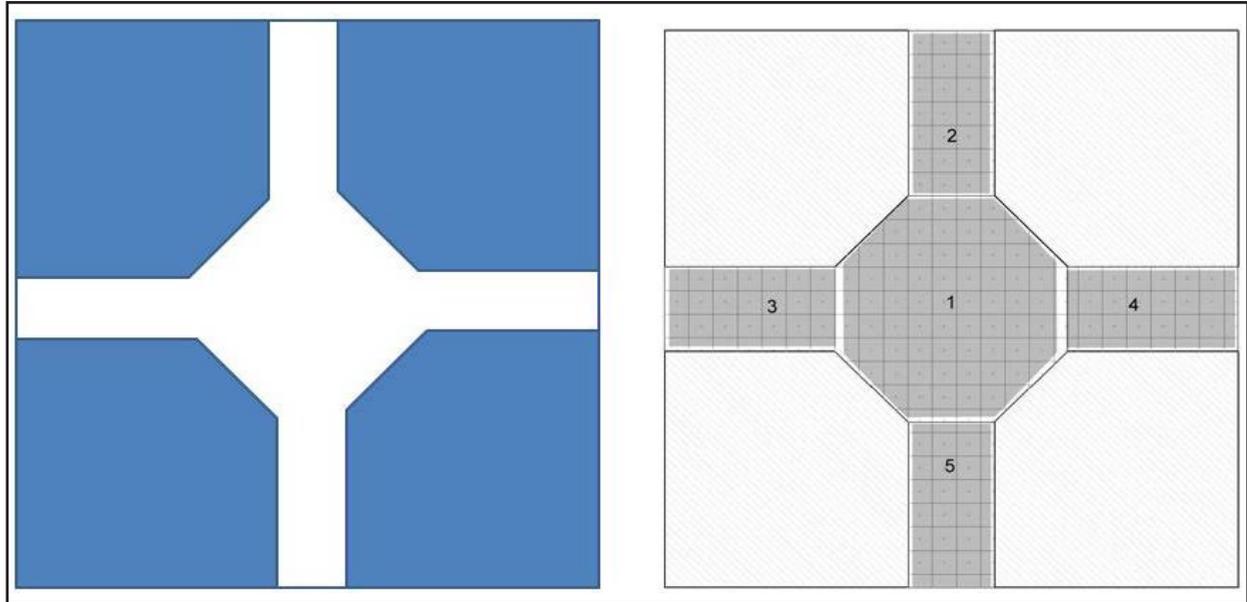
Fig. 5: The Mechanism of Decomposition of Internal Public Spaces of a Shopping Mall (Left: shown in white) in Convex Spaces Containing Different Number of Grids for Visibility Graph Analysis (Right)
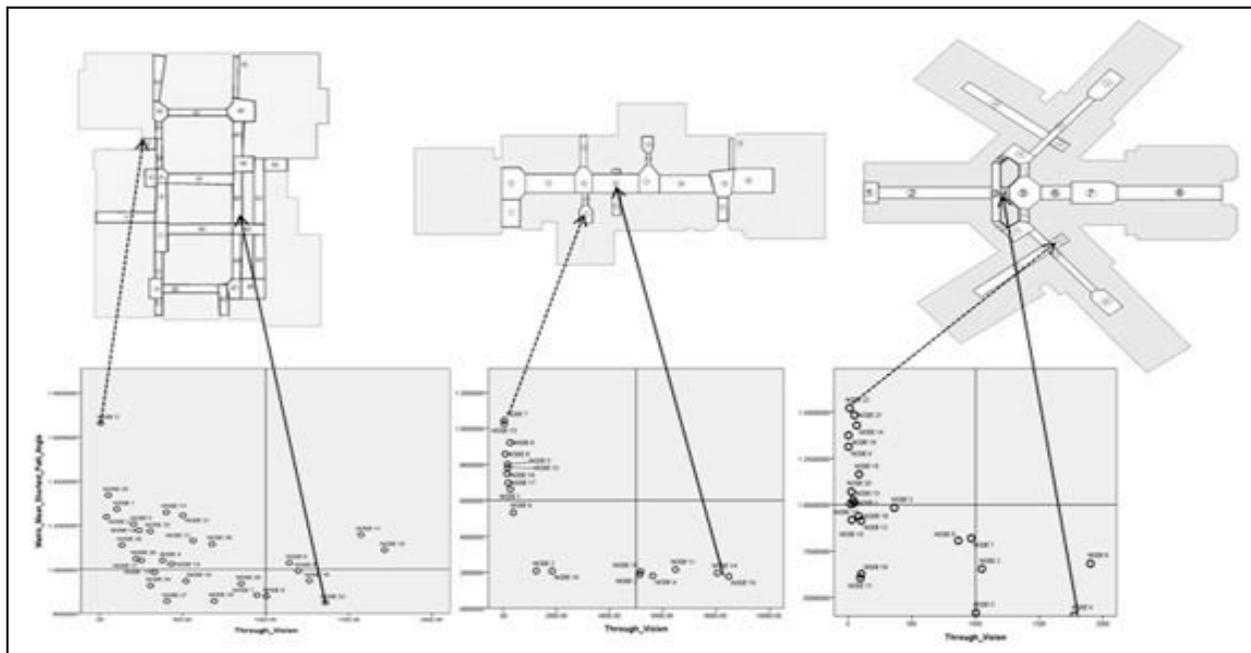
Fig. 6: The Highest and Lowest Foot Fall Convex Spaces for the Three Mall Typologies.

is repeated till the entire leasable area is occupied following the order of convex spaces in descending order of foot falls. The convex spaces with highest and lowest foot fall values for the three mall typologies are shown in Figure 6.

The iteration process of tenanting decision making will start from the convex space of highest foot-fall and will end at the lowest. The store specific variable values have to be ascertained at each convex space to allocate stores

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around them. Tenant-mix will therefore depend on spatial configurational variables.

CONCLUSIONS

Current practices in the field of mall management treat tenanting decision making on a purely subjective manner. The location and area allocation decisions undoubtedly have spatial implications but the knowledge of built environment is mostly ignored in designing tenant-mix. Retail management acknowledged the importance of foot-fall in maximizing profit. On the other hand, researches in the field of architecture identify syntactical measures in influencing movement within a built environment. This research tries to bridge the gap between the two disciplines through integrating profitability of a shopping mall in terms of spatial configurational variables. Classical bid-rent analysis is resorted to establish the relationship between total revenue generation from a store in terms of gate-count or footfall. Foot fall, in turn, are expressed, in terms of spatial configurational variables, TV and MMSPA. TV is nonmetric or syntactic measure of configuration and MMSPA is a metric measure of configuration. This is another improvement from the retail research wisdom where metric distance is the only spatial variable considered for tenant –mix design. The optimum revenue from a shopping mall can be ascertained from the knowledge of spatial configuration variables. Space design is, therefore, not isolated from the decision making process rather an integral tool for influencing economic decisions like design of tenant mixes. The research result can be used as an evaluation tool for existing shopping mall as well as a generative tool for designing tenant-mix for greenfield ones.

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