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ARTÍCULOS

SPATIAL SELF-ORGANIZATION AND THE PRODUTION OF THE CITY

RESUMEN

La producción del espacio urbano es considerada una actividad de busqueda de lucros, llevada a cabo por muchos agentes que están constantemente tratando de obtener la mejor valoración de mercado posible y las mejores características espaciales para aumentar las ganancias obtenidas. Los urbanizadores actuan localmente, es decir, pueden escoger sus ubicaciones por toda la ciudad, a pesar de no tener una previsión perfecta. Diferentes ubicaciones urbanas propician diferentes tipos de urbanización, tal es el caso de los diversos modelos habitacionales, comerciales, industriales, no obstante que cada ubicación podría tener mas de un tipo de edificación.Cuanto mas estructurada es la ciudad, mas restringida es la selección de este tipo; por el contrario, en áreas escasamente ocupadas el grado de libertad e imprevisibilidad es mayor. Los urbanistas compiten entre sí por ubicaciones donde el precio de la tierra sea menor; de hecho, la tierra es considerada el componente individual mas importante en la urbanización, en el sentido de que es la única cuyo precio puede variar y con esto, alterar el precio del bien final. Los urbanistas "inventan" contantemente nuevas ubicaciones comprando tierras baratas, invirtiendo en ellas y vendiendo el espacio edificado resultante a precios mayores. Tan pronto como un urbanizador descubre una nueva ubicación, es seguido por otros, lo que motiva que el precio de la tierra se eleve y la ganancia desaparezca. El desarrollo urbano resultante es irregular y generalmente imprevisible; sin embargo, las áreas urbanas pueden ser valoradas tomando en cuenta su estabilidad, o su resistencia a cambiar.

ABSTRACT

Production of urban space is assumed to be a rent seeking activity, carried out by many developers who are constantly trying to get the best possible assessment of market and spatial features in order to better produce profit. Developers act locally, that is, they can choose their locations from all over the city, although they do not have a perfect foresight. Different urban locations prompt different types of development, e. g. several housing, commercial, industrial types, although each location can support more than one type development. The more structured the city is, the narrower is the type choice; on the contrary, in areas scarcely occupied the degree of freedom and unpredictability is larger. Developers compete to each other for locations where the land price is lower; in fact land is considered the single most important component of the development, in the sense that it is the only one whose price can vary and hence affect the price of the final good. Developers "invent" new locations constantly, by buying cheap land, investing on it and selling the resulting built space at higher prices. As soon as a developer discover a new location, others follow, making the land price to rise and the advantage to disappear. The resulting urban development is uneven and generally unpredictable; however, urban areas can be assessed from the point of view of its stability, or its resistance to change.

PALABRAS CLAVE: CONFIGURACIÓN ESPACIAL; MODELACIÓN URBANA; USO DE LA TIERRA; FORMA URBANA.

KEY WORDS: SPATIAL CONFIGURATION; URBAN MODELLING; LAND USE; URBAN FORM.

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1/ INTRODUCTION

The city has been preferably looked at by modellers from the point of view of demand (Echenique, 1994). This is not due to eventual operational facilities only, but involves deeper theoretical implications. To consider the urban space a result of social demand is the same as to take it as a by-product of an abstract productive process. The Lowry model (Lowry, 1964), for instance, is clearly the case of a society which pre-exists in the abstract space with its laws and processes, and that eventually comes down to earth by means of a pre-elaborated model of town. Urban space has no role in such a social process, apart from fulfil the static need of accommodating people and machines.

Quite different view is exercised by social scientists such as Lefebvre (1970), Harvey (1985), Soja (1989), Dendrinos (1992), among many others, for whom the urban space can be either an instrument for process implementation or objective for production or even better, both things at same time. As a production objective it can be able to represent the social process and to make the whole productive system to survive, as Harvey suggests; as a process instrument it can express and embrace much of the social system control, as Lefebvre says.

These approaches *conform* complex and interactive cities that definitely are part of the productive process, which is actually built up and developed in its real and material form together with and in interaction to the urban space. As far as the specific urban development is concerned, city growth is *the* productive process itself. Without denying the role of social demand, they suggest the possibility of describing the city growth as a relatively autonomous productive process. Another fundamental difference between the two approaches seems to be the basic order underlying the development process: demand models start from a previously established model of society, that is, an ordered society whose members act according to known patterns. The city proposed by those referred social scientists seems to be much more complex,

suggesting that social actors perform their moves guided by heuristic knowledge.

This paper reports an attempt to build up a urban space production model, based on earlier, simpler configurational models (Krafta, 1994). A production model deals with city growth, expressed by accretion of buildings and public open spaces around, between and over existing ones. In this sense, it should be rigorously a morphological model, and as such, should be responsive to the fundamental question of how and in what extent existing city restricts and orients spatial growth. An appropriate answer would include consideration to:

i. how new building types can be distributed around in the city;
ii. under what circumstances existing building types can be replaced by others, and
iii. when new areas can be incorporated into the city fabric.

For the basic question, the problem is to relate the development process to initial conditions strongly imposed by existing city: production of new space is inevitable, although it will only happen where local conditions are favourable. The specification of such a favourable conditions should, at their time, explain the other questions and give the model operationality. The paper will approach each one sequentially, starting from the general theory down to more particular problems. Following that, it will describe the model specification and implementation, as well as a discussion about results and further research. Three stages can be distinguished in the research: a first one, in which a simple production model, simulating the behaviour of urban developers, is structured, a second one, where more complex spatial variables are introduced, and a third one in which new social agents are considered. The first stage has been accomplished earlier, and its first results are reported in Krafta (1994); the second stage is now operational and its theoretical configuration is reported in this paper; the third stage is under way and deals with urban expansion (peripheral growth) and the rise of new built form types within the urban fabric.

2/ GENERAL THEORY

The first impression from a close observation of fast growing cities' dynamics is of chaos. In effect, all sorts of spatial events take place simultaneously without an apparent relation to each other. Pockets of rapid development occurs in unexpected places, just to be abandoned well before the area is fully occupied; newly urbanised areas are incorporated to the city, although they can stay unused for years; inner areas can be virtually abandoned despite their good location and stock quality. Assuming that all those events are not to be found random, relative location and built form should interact in a complex way. Good locations can be the cause for sharp wave of development, as well as of built form decline; in the same way, built form can contain effects of development and at the same time entail causes of it. Thus, in these two central variables of morphological change, cause and effect seem to coalesce.

Foundation for a general theory of urban form change can be devised in three important works, Harvey's contribution on the theory of uneven development (Harvey, 1985), Wheaton's work on urban durable but replaceable capital (Wheaton, 1982), and Dendrinos' one on city dynamics. Uneven development depicts urban fragmentation; durable capital describes urban reconstruction. For the former, creation of new locations is seen as a source of excess profit, that is to say, developers invent new locations in order to raise their profit rates, and by continuously searching for unexplored sites, they spread the city. Competition ensures that each spatial initiative is followed by others, causing the actual loss of locational advantages and the need for a new one. For the later, urban sprawl beyond a certain distance may turn inner city redevelopment viable. Built form ageing and obsolescence, combined with locational advantages, on the one hand, and urbanisation costs / peripheral location on the other can reach a balance favourable to inner city redevelopment. Dendrinos (1992) give to interdependencies a central role in socio-spatial dynamics. Interdependencies among socio-spatial stocks include, among other types, economic, social, demographic, cultural and political elements. These interdependencies are, among other things, spatio-temporal forces of attraction or repulsion among regions, nations, urban areas or other spatial units. Their effect is flow of various stocks among spatial units, in time. Following this, the result of socio-spatial dynamics is instability.

Focusing on built form (BF) stocks production, types of interdependencies, leading to spatial disparities, such as suggested by Harvey, as well as to "productive destruction", as mentioned by Wheaton, can be identified. In an earlier exercise, Krafta (1994) suggested a potential model straightly derived from uneven development theory, which central mechanism lays on the confrontation between two attraction / repulsion forces. On the one side, centrifugal force is found in the continuous search for new sites that allow excess profit through location promotion. It drives to complete spreading. On the other side, attraction force is found in the market competition that drives developers to share the development of newly discovered locations, up to the point that their initial locational advantages turn into disadvantages. This force leads to micro aggregations. Both forces acting together generate a configuration based on fast but limited growing isles of development, continuously emerging in the urban fabric.

The short-term dynamics above described —buildings being erected in different parts of the city— is complemented by longer term one caused by time. Building ageing causes decreasing value of existing stocks; any urban site becomes more vulnerable to renewal as time goes by. In this way, the model should include short-term spatial changes as well as vintage effects.

The potential model is formalised by the following expressions:[1]

$$D P_i = L_i K_i - B i \alpha_i + L (C^{max} - C_i), i \varepsilon I \tag{1}$$

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where

DP_i = potential of an individual land plot
L_i = land area in *"P"*
k_i = urban regulation (ratio between land area and buildable area)
B_i = built area in *"P"*
α_i = devaluation rate determined by building age
C^{max} = maximal centrality in the system
c_i = centrality of plot i

The development potential of site, or space I aggregated over all plots is:

$$DP_i = \sum_i DP_i, \, i \, \varepsilon \, I \qquad (2)$$

where

DP_i = potential of a space of the system, containing several land plots

The relative development potential of site I over all sites in the system is:

$$PR_i = DP_i / \sum_i DP_i \qquad (3)$$

where

PR_i = relative potential

The potential model simulates a system in which spatial distribution of discrete accretions of BF units, exogenously quantified[2], is made according to probabilities determined by:

i) the difference between the cost of demolishing existing structures / building up new ones, and the value of the new commodity, and
ii) the difference between the cost of land before the development and its (higher) value included in the new commodity.

The first one is directly affected by time, as buildings loose value as time goes by, the second one is affected by sites' actual locations, in relation to all BF units and locations in the system, that determine their cost, prior the development, and the system's best location, that determine the market value of the new commodity.

In this sense, the model, being of the automata type, is responsive to spatial as well as temporal changes; any discrete addition to its BF alters locational privileges throughout the system and consequently affects the variable described in "ii" above; every new time iteration in the system alters the actual stock's value and affects the "i" variable. The model is recursive over previously determined units of time. To each one, the model allocates the corresponding BF units and calculates all changes in locational differentiation and stocks depreciation.

The model proved able to simulate urban configurational changes, under conditions of relatively BF homogeneity and

1/ For an extensive demonstration of model's structure, see Krafta (1994).

2/ Quantities of built form accretion must be told to the model.

intra-urban limited areas. The first restriction was necessary for avoiding the theoretical problem of diverse BF types being driven by different logic and competing with each other; the second one, to prevent a radical disintegration of the existing city. Despite these limitations, which will be addressed in this paper, the most important achievements of this theory seems to be:

i. The inclusion of the notion of instability in a formalised urban model. Conditions for urban development are constantly changing inside it; each new BF is a factor for the next one to occur; the system never tends to equilibrium;

ii. The inclusion of existing city as the strongest determinant of further development.

City, to this extent, is represented as a probability field for rent seeking development initiatives. Production of new buildings occurs out of inner urban process, in which profit perspectives are stronger than demand requirements. Observation of existing spatial configuration importance on future developments tends to meet the slaving principle (Dendrinos, 1992) by which slower —moving variables slave or determine the behaviour of faster— moving components.

iii. The inclusion of configurational interdependencies. The same locational factor generating attraction can produce repulsion, depending on the relative effect of discrete changes on the aggregate system. Spatial units, once rated *inappropriate* for development, can turn into *appropriated* through changes in the systems in space-time.

These points considered, and looked at from the viewpoint of the most basic urban space production references, the theory still looks robust. Nevertheless, the resulting model requires further development, in order to gain realistic applications. First of all, specifications on BF should be considered, as different types may require slightly different conditions to occur. Changes in BF classification raise the issue of typological succession. Building up inside the city implies, in most of

cases, BF replacement, for which, Wheaton (1982) has already reported some parameters. These are density and cost-per-unit; a BF gives place to other of same cost only if the density is considerable increased; otherwise, a BF is replaced by other of same density only if its unit cost is considerably increased. The original model, moreover, introduced a variable of depreciation, by which BF units change their actual value with time. These mechanisms should be revised. Finally the problem of outwards urban growth should be addressed as a necessary dialectic contraposition to inner growth.

3/ SPATIAL CHARACTERISTICS AND BUILDING TYPES

Disaggregation is possible along three dimensions: spatial, temporal and sectoral— the sectoral dimension being a breakdown by social stock type (Dendrinos, 1992). The potential model described above considers fine grain spatial disaggregation; it also is open to equally detailed temporal one, although no sectoral disaggregation was exercised. Sectoral disaggregation of BF stocks is possible by various means; a classification according to building use types seems the best for this case, because uses can be associated to relative locations more easily. Moreover use types are the most common classification used in urban data records. In this sense, a first, still coarse disaggregation could be obtained by identifying residential, commercial, office and industry building types; finer classification would detail them into many more.

Whichever BF types are chosen, each one will enter the system through its particular behaviour, in spatial, temporal and sectoral terms. Spatial terms are expressed by preferences and reactions to locational privileges, while temporal terms are so by means of devaluation rates. Sectoral behaviour suggests type priority, prevalence and in the limit, BF type substitution. To this extent, a measure of sectoral performance, expressing such typological hierarchy should be included.

From the moment that more than one BF type is assumed, the model is supposed to distinguish and process each one

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separately; that is to say, more than one BF type implies in more than one allocation procedure. To the breaking down of BF in basic types, it would follow an allocation procedure that simulates sequentially the distribution of residential, commercial / office and industry, each one being allocated according to its own logic, taking available places from the system, and hence restricting the distribution of the following one.

In most general terms, every BF allocation decision is bounded by the two basic forces previously identified in the original model. Whatever the BF type is, its allocation surely will be a rent seeking decision, oriented towards the best difference between costs and final value, as well as by land excess profit. However, each BF type will also have just some locational alternatives, that is to say, not all locations in the spatial system will be available, not only because some are actually occupied, but because some will not be suitable for that particular BF type. The bundle of two forces, initially identified, is enriched by a third one, which selects suitable locations among existing ones. While the two original forces are equally defined for every BF type, the third one is unstable, as far as its inner components, weights and direction are concerned, and definable only for each one of the considered BF types.

The third force, now incorporated to the bundle of forces acting on BF allocation, can be named *spatial opportunity*, as it does express a true selection of opportunities the spatial system offers to the various BF types. The concept of spatial opportunity, usually defined as the spatial relation of a residential location to a system of service locations (Arentze et al, 1994), needs a little adaptation for this case, in which it will represent the relation of a urban site to a set of spatial features that gives support to a particular BF type allocation. Each BF type will be responsive to certain spatial features; every system's location can be evaluated in terms of their accessibility to them and the measure of it will express the location's spatial opportunity for that particular BF type allocation.

Considering, for instance, a coarse sectoral disaggregation, residential BF units would be positively responsive to

environmental qualities, such as good landscape, as well as neighbourhood qualities such as privacy or existing BF quality. Whether a finer disaggregation is taken, diverse housing types will arise, increasing the number of aspects to be considered (transport, school facilities, etc.) and restricting the locational choices for worse off types. In the same way, other BF types would be affected by particular aspects of urban configuration. Commercial / service ones, for instance, would be responsive to public transport routes, pre-existing shopping facilities of various kinds, neighbourhood rent level, etc. There will be very demanding built form types, like high rent housing types, for which only a few locational alternatives will be available; on the other hand, other types will necessarily require less and will have more alternatives.

Within the fundamental relationship between value, or price and cost of a projected development, the two initially defined forces are acting generally in the same way for every BF type: it always will drive the allocation of a new discrete BF unit according to the profit maximisation statement of the model. However, the third force now introduced in the bundle will restrict the geographical dominion in which the model operates for each BF type. In effect, for each BF type, the spatial realm of allocation will be different. Perhaps there will be many overlapping and nesting situations, where a location's spatial opportunity will suit many BF types; nevertheless, particular requirements for particular BF types are present.

The spatial opportunity, acting as a selective force increasing the probabilities of certain sites to be developed through the allocation of particular BF types, gives way to a new modelling problem which is the inclusion of a sequential procedure of BF allocation. In effect, a group of BF types, requiring diverse, specific spatial conditions to be implemented, requires a step-by-step allocation. Consequently, the modelling complement of sectoral disaggregation and spatial opportunity inclusion is the sequential allocation process.

In this way, three new developments are proposed for the original model in this section:

i. sectoral BF disaggregation, allowing as many BF types to emerge as necessary to describe the system's variety;

ii. a possibly defined sequence of BF allocation. This sequence could start from the residential type (and within it, from higher to lower rent level sub-types), followed by commercial and office types, and finish with industrial and warehouse ones. This first hypothesis follows the notion that residential types are the actual stuff cities are made of; nevertheless, the sequence could be other, perhaps defined after a more objective principle, to be defined in the next sections;

iii. a defined bundle of three forces acting on each type, in which two attraction / repulsion vectors are primarily defined from the model basic assumptions (centrality and buildability), and an attraction force, defined as spatial opportunity to particular features of the system, according to each BF type.

It is important to note that BF disaggregation can be performed through the introduction of as many built form types as the modeller wishes, provided that each type accepted in the system should be defined in terms of its bundle of acting forces.

4/ TYPOLOGICAL SUCCESSION AND URBAN GROWTH

The problem of how BF types are actually replaced by others is straightforwardly taken on by two of the already suggested new model's mechanisms. Firstly, the sectoral disaggregation of BF, which introduces several different types, and also prompts the use of differential profit rates, is included. From the moment that each BF type is associated to a particular profitability, a competition among types is established. Old BF types will be replaced in space by new, probably different ones, according to the relationship between costs and opportunities incorporated in each urban location. The principle of profitability, whose parameters are usually available for any city, could define the sequence of the model's BF allocation procedure.

Secondly, the spatial opportunity, particularly defined for each BF type, is introduced. It has been suggested in the previous section that the spatial opportunity is an attraction force, measuring the spatial relationship of each location to a system of particular positive characteristics, such as environmental quality, proximity to parks, schools and transport, or whatever could be of interest to residents. However, this measure could also weight negative characteristics, such as bad neighbourhood quality, proximity to undesirable urban activities or equipment. In general terms, a matrix of spatial characteristics can be assigned to the system's spaces, each one differently parameterised according to each particular BF type requirement. In this sense, spatial opportunity force classifies and chooses locations according to each BF type spatial requirement. The use of such a matrix, as illustrated in table 1, does enable the modeller to pick up objective land use definers to proceed with the spatial opportunity computation, and through it, to map up spatial realms for each BF type. Table 1 includes a number of parameters that would adjust each attribute's incidence on the opportunity being measured.

Two decision making procedures can be devised: the algorithmic and the heuristic one. The former is operated in terms exhaustive search and implies that all agents will have a comprehensive view of the system; the later will operate on more selective way, considering limited view of the spatial systems, although the agents will have a more structured and hierarchised decision process.
In order to allow the city to grow outside the limits of existing urbanisation, and to occupy eventual room left inside the existing fabric, it is necessary to define, firstly, how non urban land, so highly aggregated space, can be described in a system in which public space is finely disaggregated. It is not possible to foresee a site's future design layout, nevertheless, it is possible to include in the system a "theoretical" space unit, holding the main characteristics of the entire site: its conectivity to existing city, land area and eventual particular feature that could affect its spatial opportunity. Secondly, it is necessary to assume urbanisation costs. These are similar to costs of devaluating eventual existing buildings, in the sense that it is a factor affecting production costs, and be incorporated to the system in the same way. It is also impossible to foresee the possible size of chunks of land to be urbanised, however the previously existing property limits can be used as indicative of it

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TABLE 1

	SPACE	ATRIB 1	a 1	ATRIB 2	a 2	ATRIB 3	a 3	ATRIB 4	a 4	ATRIB 5	a 5	ATRIB ...
MATRIX OF THE TYPE USED IN THE SPATIAL OPPORTUNITY REPRESENTATION	1											
	2											
	n											

Note: Attributes would vary according to the system being investigated; parameters a would vary according to the built form type being simulated. In this way, applying the parameter as a multiplier, the value "0" would switch off the corresponding attribute, value "1" would include the attribute with its original weight, value "2" would emphasise the attribute.

This section has explored two more aspects of the model's theoretical foundation, in which the questions on typological succession and urban expansion are focused and their inclusion are solved within the method generally underlined in the model. In general terms, the original model's structure, which admitted a bundle of two forces acting on the BF allocation, has been enlarged with the inclusion of one more acting force, named spatial opportunity. This force allowed the BF to be disaggregated into as many types as desired; for each type a particular definition of spatial opportunity significant components assures a realistic configuration of the resulting force acting on the type allocation.

The three forces, always in the origin of every BF type allocation, act as a probability system, increasing or decreasing the potential of every location in the spatial system to be targeted in the development process, according to changing conditions in space/ time. Sectoral disaggregation of BF has allowed the typological competition and succession to take place in the system, apart from permitting the simulated city to grow outwards as well as inwards.

5/ MODEL SPECIFICATION AND IMPLEMENTATION

The development potential of a site is given by the relation between the expected value of an eventual development and the overall cost of it. The larger the difference between value and cost,

the higher its potential is. This assertion is consistent with the supply-side approach of the theory, in the sense that capital will be invested in space production if opportunities given by sites with high potential to generate profits exist. At the same time, it in not opposed to a possible demand-side approach, to the extent that the expected value of any development will be affected by demand:

$$DP_i = V_i - C_i \qquad (4)$$

where
DP_i = development potential
V_i = value of development
C_i = costs

In general terms, a development expected value is related to the size of the structure possibly buildable on the site. Considering different BF types, the value is also affected by each type's specific profit rate. For most cities controlled by regulatory plans, Brazilian cities included, the value would be expressed by:

$$V_i = (L_i k_i) T_i \qquad (5)$$

where
L = land area
k = floor/land areas planning ratio

T = profit rate

The k parameter could be replaced by a function of cost/density relationship, in which every new development is affected by the pre-existing ones. In this case a new field of variability could be introduced, bringing the technologic aspects of built environment in. The respective cost is affected by the eventually existing structures to be devaluated and by the expected excess profit made on the land transaction. The corresponding expression is:

$$C_i = (B_i \alpha) - Li (c_{max} - c_i)$$ (6)

where
B = built area to be devaluated
L = land area
α = devaluation parameter expressing age/vintage effects
c = system's relative centrality measure, expressing locational privileges
c_{max} = refers to the maximum centrality value attained by the system
c_i = is the centrality value in i

The equation (4), rewritten in accordance with (5) and (6) is very similar to the original model. The new equation includes a component - T - affecting V_r, due to sectoral disaggregation of BF.

5.1. The Measure of Spatial Opportunity

A measure of spatial opportunity is proposed by Krafta (1997). In this model, spatial opportunity is defined as the relative position of residential areas to a system's service locations. The spatial system is disaggregated into a number of discrete public space units, each one labelled as R (residential) and/or S (service). Service locations are weighted according to their particular attributes of size and variety. Shortest paths linking each R location to every S location are searched. Spatial opportunity of a R location in relation to a S location is obtained by dividing the figure expressing the attributes of S by the corresponding shortest path length[3]. Spatial opportunity of a R location in relation to the system's S locations is then obtained by computing all the partial figures assigned to R.

A similar procedure is proposed for this case. Spatial opportunity of a site, related to a particular BF type, could be defined as its relative position to a set of spatial features which affects that BF type implementation. Given the system of public space units, each of them is assigned with a series of attributes —from topography to neighbourhood characteristics, from environmental quality to service level. These attributes will be differently regarded for each BF type's spatial opportunity calculation; some of them will be included, some will be discarded, some of them could even be negative, that is to say, a feature that jeopardises the BF type implementation.

The model can be formalised by the expression:

$$SO_i = A_i + \sum_j^n \frac{A_j}{l_{ij}}$$ (8)

3/ Each discrete space belonging to the shortest path is counted as a length unit, consequently, the shortest path length equals the number of discrete spaces belonging t it.

where
SO_i = spatial opportunity of i
A_i = attribute of i
A_j = attribute of j
l_{ij} = length of the shortest path between i and j

A spatial opportunity model working in this way accounts for each discrete space's proximity to spatial elements of the system that could affect the chances a particular BF type has to be developed. The spatial opportunity of a particular location in a system, in relation to a determined BF type, is related to the size and relative position of every other location's attributes which could affect the allocation of that BF type. The model's results are real numbers that can be relativized to vary within a previously defined interval. Applied as a classifier, it delimitates the spatial sub-system in which a particular BF type will be allocated.

5.2. The Measure of Centrality

Centrality, defined in Krafta (1994), is a measure of morphological differentiation. The urban space is described as a system of public space and BF discrete units holding relative positions and adjacencies one to another. Public space units are loaded with different quantities of BF units, each pair of them are reachable from each other through identifiable routes. Spaces falling in those routes are considered central to that pair of spaces. By computing all pairs of spaces and the corresponding shortest paths, it is obtained an overall measure of centrality, which constitutes each space's morphological characteristic. The measure of centrality has proved consistently correlated to various indicators of activity level, such as pedestrian and vehicle flows, concentration of commercial activities, etc., and can be taken as a locational qualifier.

Centrality is expressed by:

$$C_k = \sum_{\substack{i,j \\ i<j}}^{n} t_{ij}(k); \quad t_{ij}(k) = \frac{b_i b_j}{p} q \qquad (9)$$

where
C_k = centrality index of space k
k = space belonging to the shortest path between i and
t = unit of tension between i and j, obtained by distributing the product of BG units of i by the ones in j, among all spaces which fall on the i-j shortest path
b = BF in i and j
p = number of spaces included in all shortest paths between i and j
q = number of times space k falls in the shortest paths between i and j
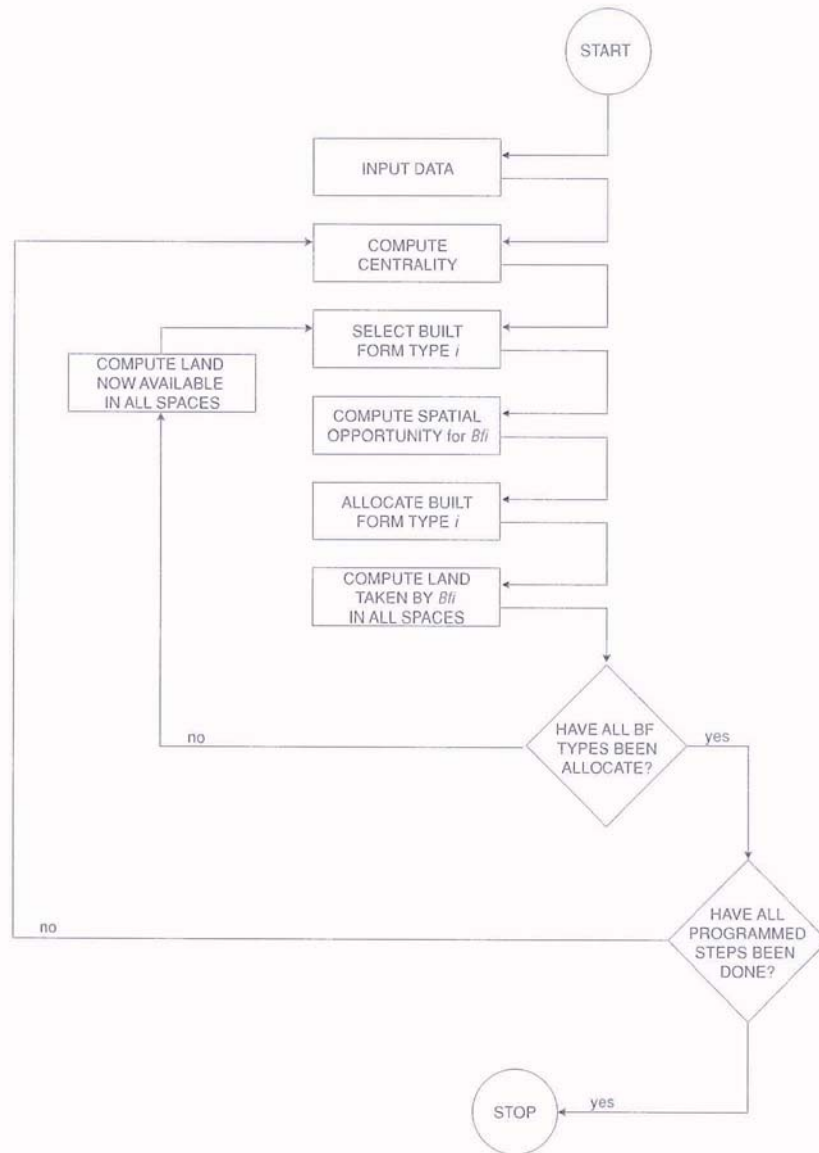
5.3. MODEL'S IMPLEMENTATION

The computer program developed in order to allocate BF units according to space potentialities benefits from pre-existing algorithms, which calculate respectively centrality and spatial opportunity. Basically, the program proceeds a recursive operation, firstly calculating centrality and spatial opportunity measures, then allocating BF units in the spatial system, then recalculating centrality and spatial opportunity measures. Each complete cycle is called a step, temporally defined. Hence, inside the overall simulation time there will be several steps. The case study reported in this paper had a simulation time of ten years and a step of two, so that the algorithm was called up five times. The main reason for having the time split in steps is that after each one the morphological measures are always recalculated and consequently the spatial conditions for BF allocation change for the next interaction.

5.3.1. Spatial Opportunity and Centrality Measurement Routines

Being a measure of qualified accessibility, the algorithm starts up by identifying the shortest paths' length between all pairs of labelled spaces in the system, one way. The second procedure does the calculation of attributes, asking for the appropriate parameters which will activate, disactivate, emphasise or play down particular spatial features each space unit has, according to each BF type

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FIGURE 1

**GENERAL MODEL´S
FLOW CHART**

START

INPUT DATA

COMPUTE
CENTRALITY

SELECT BUILT
FORM TYPE *i*

COMPUTE LAND
NOW AVAILABLE
IN ALL SPACES

COMPUTE SPATIAL
OPPORTUNITY for *Bfi*

ALLOCATE BUILT
FORM TYPE *i*

COMPUTE LAND
TAKEN BY *Bfi*
IN ALL SPACES

HAVE ALL BF
TYPES BEEN
ALLOCATE?

no

yes

HAVE ALL
PROGRAMMED
STEPS BEEN
DONE?

no

STOP

yes

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requirement. Having space attributes and shortest paths identified and calculated, the algorithm proceeds the simple calculation of the measure, according to the equation (8). Application of spatial opportunity results prior to the potential model itself will define the sub-system within which each BF type will be allocated.

Similarly to the previous algorithm, the centrality one works as a qualified accessibility measure. identifying quantitatively how central is each system's space for each BF unit to be reachable from every other one, within a previously specified range. In order to do that, the algorithm finds out all shortest routes between an unordered pair of spaces, computes the number of elementary "units of centrality" generated by the given pair of spaces (this is obtained by multiplying the number of BF units in i by the number of BFs in j) and distributes equal fractions of that product to every space falling in those shortest routes. Finally, after processing all possible pairs of spaces in the system, it sums up all partial centrality assignments for every space, as suggested by equation (9).

5.3.2. Routine for Potential Calculation

The algorithm for potential proceeds a double nested loop; within the inner one, all spaces are tested against requirements of all BF types, sequentially and cumulatively. In this way, it starts off from the first BF type, for which all spaces are checked out; once the allocation is complete, a new BF type is taken, for which the potential calculation will consider the previous allocation, and so on until all BF types are allocated. The sequence of BF types allocation is defined, for the time being, by the operator, based on profitability. It could also be worked out from within the model itself, for which a specific calculation should be set up. The criterion of profitability makes the most profitable building types to be erected first, taking the land required, either vacant or occupied by other building types, according the BF type´spatial opportunity measure. Subsequent, less profitable types, could face restrictions for implementation, since land is finite. The outer loop, defined by the simulation step, is performed after all building types´allocation is worked out. This is the moment in that spatial opportunity and

centrality routines are called upon to measure the spatial change caused by the previous allocation.

6/ THE TOWN OF BENTO GONÇALVES CASE STUDY

The Bento Gonçalves planning authority has been reviewing the city's master plan and offered the chance of testing the simulation model. Bento Gonçalves is a small hilly town in South Brazil, with some 80,000 inhabitants. The master plan has a strong regulatory content, restricting the occupation and use of land through zoning as well as building regulations. A more flexible set of controls has been discussed, and the model was used to help the investigation into probable urban development unfolding, derived from those new controls.

6.1. Case Description

The existing urban system was disaggregated into 661 discrete public spaces and some 20,000 BF units. These were also classified into four categories: low density housing, high-density housing, commercial/service and industry units. The simulation was set to ten years (1995 - 2005 periods) and two-year steps. Spatial opportunity was calculated for each BF type, considering only a few attributes in each case, for the sake of simplicity. In this way, industry was assumed to be responsive to location of regional roads and rail; low density housing to environmental (topography, landscape, privacy) qualities, commercial/service to previous commercial uses, district rent levels and transport facilities; high density housing to transport and commercial facilities. Centrality was calculated through the usual procedure. The potential model run five times, set for the current planning regulations on land occupation and use. A second simulation was performed with proposed planning controls, as well as with slightly different grid configuration.

Growth rates were kept constant at the level observed for the last couple of years, for all BF types. The model allocated BF increments to most spaces in the system; this was expected because the town is still largely low density, whereas its actual building regulations

do allow densities far higher than the existing ones. The spatial distribution of BF units varied largely, however. Fifty one (7.7%) spaces had no increments at all; sixty eight (10.3%) increased in only one BF unit, while others gained large number of new buildings. The distribution of various BF types were considered:

a) accurate for low density housing types, which were allocated preferably in the southern areas of the town, were the best sites are;

b) accurate for commercial/service types, which were allocated within the actual city centre, that is still able to accommodate them, as well as in some extensions. Both types confirmed the tendency currently verified in the local urban dynamics;

c) inaccurate for industry, as the present trend was not entirely confirmed by the simulation;

d) coherent, in general terms, with the observed trend, although some new development areas are not easily predicted.

For the cases in which the simulation did not follow the trend that local planners empirically observe, these results can be found affected by inaccurate spatial opportunity definition. Industry types have effectively been located by the regional roads, although several small-scale factories have occurred in other parts of the town. Unexpected industrial locations have also occurred for historical reasons, as the land could be bought long ago, belong to the family, etc.

Considering that local planners were interested in preserving the southern areas of the city at very low densities, due to environmental reasons, and also in extending the city centre towards the West, a new simulation was performed, considering this time diverse planning regulations. The result displayed satisfactory configuration. A third test was exercised, in which a redundant railroad that crosses the town right in the middle was assumed to be converted into urban road. New links with existing streets were considered: the result showed important changes in the city structure in short as well as long term periods.

7/ FINAL OBSERVATIONS

7.1. Model's features

A model for urban BF development simulation is proposed. In order to be efficient it had to consider BF disaggregation not only in the spatial dimension, but also in sectoral terms too, as the later would allow the modeller to identify and project the different BF types that the general urban BF is made of. Sectoral disaggregation has brought a new force to the bundle acting on BF development. It has been identified as the spatial opportunity to particular spatial, as well as behavioural aspects of urban systems each BF type is responsive to.

The model, that was originally conceived as a "one loop" algorithm, had to be rewritten as a "nested double loop" one. The first recursive procedure, used to deal with the variable *time*, was complemented with a second one, designed to handle the several *built form type allocations*. With the model designed as such, an experiment was carried out, in which four BF types were successively allocated. The results show that the model is able to recognise and combine the effects of the three forces admitted into the theory and to produce simulations considered plausible, if compared to observed trends. They also show the model's ability to simulate small BF variations: within an overall BF growth of 775630 m^2 over 10 years, the model allocated quantities as small as 66.53 m^2, that is, one built form unit of the smaller type.

The inclusion of the spatial opportunity force, based on diverse system's attributes, suggests that the model is suitable to run in a GIS environment, where spatially defined attributes can be extensively and efficiently handled. This articulation is being studied, aiming to provide not only a model's structured input but also a graphic display of results.

Proposed as a urban space production theory, the corresponding model has assumed that every and all spatial development are ruled by that same rent seeking logic. This may not be entirely true, particularly for industrial and some sort of commercial

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buildings. In effect, buildings housing productive activities would tend to included in a larger rent seeking equation, in which the eventual profit coming from real estate is just a part of it. This would partially explain the model's shortcomings reported above. Built form types not adequately simulated by the model would be better predicted by demand models.

The next step will surely include the consideration of new social agents. In effect, the model, as it is now, simulating only the action of urban developers, reduces the universe of interaction and consequently the range of possible outcomes. Users of space should be introduced in the model in order to accomplish the necessary plurality of interests and viewpoints of the whole process.

7.2. Emerging theoretical aspects

It is interesting to note that the model seems to deal with three basic and simple driving forces which do not act in a straight cause-effect way. In effect, the differential land value which act primarily as a spreading vector does not result necessarily in a concentric ring shape city form; the competition among developers does not end up in a continuous decreasing density gradient; additionally, regard to local spatial features increases the role of existing city over its futures. In fact the model implies continuous interaction between initial states and changing forces; in this way, the forces drive to change by means of triggering inner local processes and not as direct causes of spatial change.

Perspective for further development implies: a) a new measure of (local) spatial differentiation which will offer the allocation procedure a much more varied set of possibilitities; b) a learning capability that will benefit from "a", above, and c) a device that generates new types, as the system evolves from lower to higher levels of complexity (number of entities). All of these perspectives have emerged from discussion following the Paris workshop on self-organization.

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