The city as object of human agency

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Keywords
Urban morphology, agent-based urban modelling, urban configuration

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Abstract
There seem to be three basic kinds of theories trying to provide explanations for the urban spatial process: the causal, the formal and the decisional. By these terms it is meant respectively theories based on cause-effect mechanisms linking the social and the spatial; theories that take some sort of spatial transformation mechanism of their own, which are triggered by the social; and finally theories that take agents' intertwining decisions as the mechanism of spatial change. Causal theories, being the oldest, are apparently the crudest, whilst the cutting edge multi-agent simulations seem more elaborate. However, the former have been able to expose basic and stable relationships between man and space, even though they have not been able to explain how individuals actually interpret and use such relationships to their own interest in different situations. The latter try to do precisely that, but very little spatial matter has as yet been included in the agents' decision-making process.

Our point is that fundamental spatial attributes of the city, such as accessibility, centrality, relative position, and polarity could be included as reasoning instruments in agent-based models. In order to do that, however, cause-effect relationships should not be taken as laws or principles to be obeyed, but as means to realise profit (and utility), subject to speculation, personal interpretation and relative short sighted decisions. The paper reviews part of the configurational theory and proposes a model of production and consumption of urban space, based on agents that make decisions on a spatial basis. The model is presented in a conceptual form, and its testing in a computer simulation is also described. In order to do that, we comment on the computational approach that was used in such simulation. Some early results of our experiments with this agent-based social simulation are also mentioned.

1. Introduction

This work aims at building upon some issues on *urban centrality* laid down by Hillier (2001a, 2001b) in his "Theory of the city as object" (from now on referred to as the Theory). This will be done, first, by discussing how such a theory seems to be set up, and second, by proposing new developments in some aspects of its structure.

By doing this, however, he must not forget other previous senses given to the word "centrality", specially the one developed by Krafta (1994, 1999), which will be also reviewed and criticised. The most relevant points to be developed are, first, whether centrality is a matter of fragmentation or polarisation; second, whether configurational principles, laws and patterns bear a value in themselves, and finally what sort of reading are they submitted to in the process of urban change. This will be carried out through a preliminary theoretical discussion and then the proposition of a model that is likely to simulate such a process. The paper describes ongoing research whose results are still preliminary; nevertheless, it has been developed on an arguably sound theoretical basis.

2. The theory of centrality

2.1 Centrality as a quality

Urban spatial dynamics have been approached in many ways. Because it is something artificial, man-made, it is said that its fundamental explanation rests on human free will and decision; because it is bound to the concreteness of built space, it could be taken as a cause-effect physical phenomenon; because its manifestation through space and time follows some patterns, it is said to be formal, perhaps. Most theories are, in fact, combinations of these approaches, where even though human decision, space and patterns are alternatively taken as cornerstones, all three are somehow concurrent. Hillier's Theory, despite the apparent intention to keep it spatial, does the same. The Theory is based on two explicit propositions and a third underlying one. Proposition 1*: built forms undermine centrality by fragmenting space*. Proposition 2: *social agents have a dual interpretation of spatial features: cultural and economic; each of them is associated with one particular spatial feature*. Underlying proposition: *agents are rational, do share the same unique rationality, and tend to apply it to city making*.

The Theory's so-called *principle of centrality* refers to an eventual breaking up effect caused by built forms when inserted into an existing system of at least two other built forms linked to each other by a straight path. This new built form would eventually break up that path, causing an increase of Universal Distance (UD). Now, the point in which the built form would do it is claimed to be relevant, as the nearer to either end, the smaller would be the universal distance increase. In other words, centrality would be off-centre or counter–intuitive in two ways: the more the city is filled up with buildings, the worse for centrality, and particularly so if those buildings are geometrically centred in relation to existing buildings. The demonstration is provided by the computation of universal distance in a row of cells linking two built form units in which one cell is obstructed by a built form, and indeed, the position of the obstructed cell is relevant to the UD figure. Further, if a new cell non-adjacent to that one is also obstructed, the UD figure goes higher. In a row with 7 cells, depending on the method of calculation, the UD figures go from 112 (empty), to 144 (for 1 cell obstructed), to 192 (for 2 cells obstructed), and to 220 (for 3 cells obstructed in such a way that the system has every other cell obstructed). However, from this point, if a further cell is obstructed, and this time it must be adjacent to one already obstructed, the UD figure falls to 180. The same occurs if one more cell is occupied (UD = 136). In an extreme situation, where all cells are obstructed, the UD figure returns to its original value of 112.

The exercises assume that built form units are successively placed on the path between two others, along it but in a way to obstruct the otherwise free route, so that the movement must go around, using other cells. In fact both propositions (to fill the path partially or totally) are unreal, in the sense that nobody would actually build on the road, bur rather off it. The assumed resulting movement (going around every obstacle, always returning to the original path) is also unreal. Nevertheless, even relying more on mathematical relations than on urban spatial particularities, they help to shed light on the relationships between open space and built forms.

The two experiments seem to suggest that: first, built forms can indeed fragment the system, causing the UD to increase, as well as it can mend it, pushing the UD down; second, they show that none of them can elucidate anything about centrality, in the sense that high or low UD figures do not reveal how the system's centrality really is. Universal distance is about size, or in other words, number of space units in the system. Universal distance is also about relative positions kept by those space units (obviously if we had a n-dimensional system in which every cell is adjacent to all others, its UD would be very low, regardless of the cell number), but the experiments do not deal with that, so they are unable to reveal the nature of urban centrality by themselves.

Thus, the question of what centrality is all about remains; classically, it has been dealt with in two ways: central is the point that is nearest to all others, and central is the point that falls most frequently in the way between others. The first case is classic **accessibility**, defined as the average of the distances from a certain point to all others within a given system (Ingram 1971). The second is **betweenness centrality**, from now on called simply *centrality*, defined as the weighted frequency a point falls in the shortest path between two others in a given system (Freeman 1977).

Adapted to spatial systems, **accessibility** can be measured by considering *distance* in terms of metric, topologic, time, or cost units, and *space units* as zones, axial lines, links, convex spaces, etc. Moreover, it can accept *parameters* as ways to weight distance decay, attractiveness or carrying capacity, giving way to different measures, such as relative asymmetry, weighted accessibility, Gaussian accessibility, etc. **Centrality** can be measured by computing the tension between every pair of space units; such a tension is a product of their attributes (e.g., number of built form units, built area, type of activity) whose value is distributed among all spaces that fall in the shortest path, or paths, between the considered pair of spaces. This way, fractions of the tension, assigned to central spaces, are a function of the path length, number of shortest paths, as well as to the loading of the pair of spaces linked by them. Centrality requires parameters for built form and activity weighting and can take different spatial descriptions (e.g., geometric, topologic, axial, convex). Detailed explanations of the centrality formalism and computation can be found in Krafta (1994, 1997a).

2.2 Centrality as a process

In the discussion above, what is at stake is how to differentiate spaces that are particularly placed in a system, by considering their attributes and relative positions. In any case, central are those spaces that hold a privileged position in relation to a distribution of spaces and space attributes, either in terms of proximity or strategic position and linkage. Nevertheless, centrality is still a state attribute of a system, that is, a characteristic of it in a given moment in time. The interest here is to investigate how could centrality be considered in a dynamic situation, and then we move to the second proposition.

Hillier's second proposition implies that *function follows configuration*; that is to say that basic land uses – residential and services – would de deployed in short and long lines respectively. Such a relationship had already been stated in Natural Movement (Hillier, 1993), in which a correlation "*integration _ higher pedestrian flows _ attractors location*" is taken as natural, in this order. In the Theory, the same correlation is considered in a simplified way (*long lines _ attractors location*). So, the dynamics, in principle, are quite simple and deterministic, steming from the road layout. Road layout evolution, however, would add complexity, in the sense that inclusion of new roads would modify the axial hierarchy and cause decline and emergence of centres. In general terms, it is assumed that social agents are able to read the spatial configuration (perfect sight) and act according to the principles of movement and rational activity.

Another approach is exercised in Krafta (1994, 1999), which is somewhat opposed to this. Considering the production of the city as a rent seeking activity, location privilege is seen as an additional cost, and avoided. This way, space producers would also read the spatial configuration, but choose their construction sites according to the principle of lowest land value, which would cause an effect of decentralisation. Central locations are the places of lowest profit realisation, hence the least preferred ones. In the process, of course, 'holes' of high location values would be filled up with new, high-value built form types. This approach differs from the previous one in that it considers built forms as part of the process of spatial differentiation, so that each new built form inclusion affects the entire centrality distribution, *increasing it*. Spaces that, in a certain moment, are chosen as places for built form insertion thanks to their "bad" position have their location value increased, and their chances to be chosen in a subsequent moment decrease by that very insertion. The result of such a process is an uneven sort of development. The aggregate result in the long run is not necessarily opposite to the one proposed in the Theory, but dynamically very different.

Both approaches do share, however, one issue, that is the underlying agent's perfect sight, or his illusion of it. Their logic, in the first case, say, functional, and the other economic, leave no room in the first case, and little room in the second, for uncertainty, social agents' misunderstandings, and conflicting reasoning. Hillier's theory suggests that spatial features do have values in themselves; integration is a positive value and all agents not only have the perception of it but also believe that they can benefit from it. Krafta's counterpart suggest that centrality is a relative value that would be beneficial, in general social and urban terms, if somehow distributed (and not concentrated) and, most relevant for this case, agents could have different perceptions of it, and at least one – the space producer – could even take it negatively. Nevertheless, the derived model of Potential/Centrality, being space-based, is unable to deal with simultaneous conflicting value perceptions.

Uncertainty and idiosyncratic behaviour has been treated statistically (entropy, random choice), mostly within deterministic models, so that it does not fundamentally affect the theories behind them**.** We now see it as a necessary part of the logical mechanism of models, and this is being tried out in this exercise of micro-simulation, which we discuss next.

3. The multi-agent space production model

The Multi-Agent Space Production (MASP) model is an attempt to overcome difficulties presented by space-based models, and to reach a better relationship between social and spatial domains. It is characterised by interaction between urban space producers and consumers. Space production is seen as a rent seeking activity in which agents try to maximise profits. Space consumption is utility guided, "utility" being a complex attribute. The proposed dynamics is an iterative process in which

Built Form Units (BFU) are allocated on a territory divided into cells, and social activities are allocated inside BFUs, alternately. Consumers decide their locations over the existing BFUs; producers decide on the location of their BFUs over a landscape of opportunities of rent generation and risk taking. Supply and demand affect each other.

Different agents have particular attributes; agents develop attitudes and preferences toward others, so that any decision will always be taken in an urban-like situation (current and expected state of the spatial system) as well as a social context. All agents' decisions generate externalities, that is, side effects (or other effects apart from the wished ones). Externalities affect agents' performance, positively or negatively, so that any action is likely to unbalance the system.

3.1 Agent definition

In principle, there are three types of agents: space producers (developers), residential-space consumers (residents), and service-space consumers (who provide services). **Developers** enter the system undifferentiated and achieve particularities in two ways: the building capacity, that grows along with each developer's success rate, and specialisation, that emerges from each one's preferences to built those BFU types that sell best. Success is measured by consumption. This way, the eventual sales success of one certain BFU type will cause a super-production of it in the next iteration, which could result in poor performance, and little production in the iteration after next. **Residential consumers** enter the system according to an income/population pyramid controlled externally. Manipulation of that pyramid by the operator will prompt the system to change quantities and proportions of residents' social classes. **Service consumers** enter the system automatically, as a function of population and wealth within the system. Basic service types will be previously declared, with corresponding population and wealth thresholds. A new service unit is admitted in the system when its type's threshold is reached; to exist in the system does not mean to be automatically allocated, as allocation will demand also a spatial requirement, as explained ahead.

3.2 Spatial base definition

At the present stage of development, the system's spatial base is a square grid of *n*X*n* undifferentiated cells. Every cell has the same building capacity and is related to each other through Von Newman adjacency, and extensions. It is expected that more realistic spatial bases could be manipulated later on. BFUs differ from each other in size and value. Sizes are previously determined and can be added up to fill a cell (e.g., sizes 1, 2, 4, 8, 16, 32, and 64, for a cell of size 64, so that a cell can contain all combinations of values that add up to 64). BFU values will be established as a function of land value (around 20%). Land value is assumed to be correlated to centrality values, whose computation will be explained next. Every value initially assigned to a BFU will be devaluated at every iteration according to two criteria: age and vacancy. Age is a fixed devaluation rate. Every BFU can be pulled down and replaced, according to a procedure described below.

3.3 General dynamics

Taking agents, cells, and BFUs as objects defined through attributes and relationships between each other, the process tries to allocate BFUs in the cellular base first, and then agents within BFUs. This is done iteratively, so that what happens in one space allocation constrains what happens in the subsequent agent allocation and so on. BFU allocation is done through the consideration of two factors: what the agent learned from previous iterations about consumption profiles, and how much risk it is willing to take in the next. The feedback factor helps the agent to choose BFU *types* to build; the feed forward one is concerned to his profit and defines the *location* of BFUs' in the next allocation. The most central locations, within the interval defined by the relationship land/type values, are the least profitable ones, but also the safe side; the worst locations are the opposite, and within these two limits a decision is made. The learning process is represented by a distribution of probabilities (of certain type of space to be occupied, of certain type of BFU to be built) that changes from iteration to iteration according to performance.

The second allocation will simulate consumption. First, residents are allocated, according to wealth priority. Their choice is also guided by two factors: spatial opportunity to services and neighbourhood quality. Similarly to developers, consumers also take risks, in the sense that neither services nor neighbourhood characteristics will be necessarily in place and fully configured in a growing system. So, residents will bet on possible future system states, represented in the decision process by an agglomeration factor (the choice tends to fall on places already inhabited by similar agents).

After each iteration, all residents evaluate their relative positions with respect to specific attributes, comparatively to other locations. All BFUs lose value with time; however, those that perform well (that is to say, have residential attributes and occupation rate stable or rising) will lose less than others with poor performance. This way, value, or price, is both a spatial and social attribute of BFUs.

Service consumers are allocated next. They appear in the system whenever the threshold and local rules are satisfied. The threshold refers to the total amount of consumers in the system; local rules refer to specific reach and consumer density within an area around the intended location, as well as location of other service units of the same type and other types. Local services (the ones with short reach and low consumer density) will interpret the presence of other service types as a boost (co-operation) and same type as obstacle (competition). Other services could adopt different rules (all co-operation, for instance). Services will also proceed with feedback; those with satisfactory performance remain, those with high performance grow, and those with poor performance decay and can disappear.

3.4 Feed forward procedures

Before the simulation starts, a measure of centrality in the empty cellular matrix is taken and considered as a proxy of land value structure. After every BFU allocation, centrality is calculated again, as configuration is affected by built form insertions. Developers read the land value structure as bands of opportunity for different built form types, each band defined by an upper value/lower risk and a lower value/higher risk limit. BFUs of each type will be placed somewhere in between such limits; the exact place is defined by each agent's belief on risk and profit making. Situations of high demand could encourage developers to go farther by taking risk, spreading the city faster. Beliefs are assigned to agents, and updated during the simulation, as a function of performance and market conditions.

Residential consumers read the built form distribution in terms of neighbourhood homogeneity and proximity to services. In the first rounds, there are no services and distribution is random, so that the wealthy ones will take the best places available and the others will try to become their neighbours, depending on the relationship between demand and supply, as well as on each one's budget limit, of course. Both homogeneity and spatial opportunity to services are measures derived from centrality (Krafta, 1997b). Residential consumers' attitudes towards other residents and to services are not the same: residents in the high-income end depend less on the availability of services in their vicinity, and are more sensitive to mixed neighbourhoods. Other residents will combine differently these two ingredients. Each resident's beliefs on the present and future environment configuration are also updated during simulation time. Even very stable areas can have their quality affected by the general development, and agents are responsive to discrete changes such as a service that goes away, newcomer residents, and so on.

Local service providers, the first service providers to appear in the system, guide their location search by a measure of convergence, that accounts for local consumer densities (centrality with respect to a specific radius and existing consumers inside that area). The measure of convergence is parameterised by BFU type, so that the services will follow consumers of high income. Service providers, as all other agents, are somewhat myopic; that is, they cannot see the system as a whole, let alone its configurational properties, or its future states; thus, they make decisions based on local evaluations and beliefs on their own ability to compete and make profit.

These forward factors of decision-making are clearly spatial, yet not aligned along a unique interpretative logic. Developers have a dissipative vision of the city, always acting on its fuzziness; high-income residents look for exclusiveness, but are constantly assaulted by poor neighbours and service providers. Low-income residents vitally depend on service proximity, but see them run away towards more powerful consumers. Local authorities want to pack everybody together, in order to maintain a certain minimum system efficiency; service providers, individually, depend on some agglomeration, so that they tend to form poles, tensions and centres spatially related to consumers. All of them should be allowed to make mistakes, learn, and change beliefs, goals and strategies.

3.5 Feedback procedures

Feedback procedures are also spatial measures that are taken as an expression of the system's behaviour. The measure of full centrality, as already mentioned, is assumed to represent the land value structure; measures of spatial opportunity and convergence are used to assess the system's behaviour, either as residential location privileges, or service competitiveness. Spatial opportunity and convergence are also configurational measures directly derived from centrality. As the system evolves, expectations on residential neighbouring qualities can be fulfilled or not, depending on the aggregate decisions made by many consumers in the previous iterations. Similarly, performance of services can be as their providers expected or not, depending on the decisions about location made by other service providers, as well as service consumers.

Decisions on location do have costs; that is, once made, they cannot be undone easily. Agents should remain in the location where they decided to establish themselves for a while, before moving somewhere else. Agents can also evict other agents from their locations, and this is done according to economic power: services take over residents, wealthy residents take over poor ones; however, poor residents can occupy and overcrowd higher types of built forms. This implies a form of organisation in which agents do not act alone, being able to structure collective actions.

4. The simulation environment

The model has been developed in a software system called MASSOC (Multi-Agent

Simulations for the Social Sciences). The main goal of MASSOC is to provide a framework for the creation of agent-based simulations without requiring too much experience in programming from users. In particular, it should allow for the design and implementation of cognitive agents. A Graphical User Interface (GUI) is provided which facilitates the specification of multi-agent environments, agents (their beliefs and plans), and multi-agent simulations; it also helps the management of libraries of these simulation components. From the information given by the user through the GUI, the system generates source codes for the interpreters of the language for programming cognitive agents and the language for the specification of multi-agent environments.

In our approach, the reasoning of agents is specified in AgentSpeak(XL) (Bordini *et al.* 2002), an extension of AgentSpeak(L) (Rao 1996), which is an abstract programming language for cognitive agents following the Belief-Desire-Intention (BDI) agent architecture. It is an elegant way of specifying reactive planning systems according to the BDI architecture, the most promising approach to the design of intelligent agents. The environments are specified in ELMS, a language we have designed for the description of multi-agent environments specifically. The development of an environment description language for our simulation platform was needed because when a multi-agent system is a (completely) computational system (i.e., not situated in the real world), this is an important level in the engineering of multi-agent systems which is not normally addressed in the literature, as environments are simply considered as “given”. The interaction among those components of a simulation (i.e., agent-agent, agent-environment, and the GUI for creating and controlling the simulations) has been implemented using the SACI toolkit (Hubner & Sichman 2000).

The MASSOC platform provides for straightforward implementation of multi-agent based simulations, with sophisticated cognitive agents. However, we still lack the means for specifying social structures explicitly (e.g., groups, organisations), which is very important for social simulations. To provide mechanisms for specifying such structures is part of our long-term objectives, which also include an attempt to reconcile cognition and emergence. This latter objective is inspired by Castelfranchi’s (2001) idea that only social simulation with cognitive agents will allow the study of agents’ minds with their individual choice and actions, as well as the emerging social structures, which co-evolve determining each other. In other words, we aim at providing the basic conditions for MASSOC to help in the study of a fundamental problem in the social sciences, the micro-macro link problem, which is of the greatest relevance in multi-agent systems as well.

4.1 Specifying agents

We give here only a short description of AgentSpeak(L); the reader should refer to the literature mentioned above for more details. An AgentSpeak(L) agent is created basically by the specification of a set of beliefs and a set of plans. Base beliefs are ground atoms in the usual form (as in Prolog); belief literals, as usual, are either belief atoms or negated belief atoms. The set of beliefs represents what an agent thinks to be true about the world. Plans can be described as sequences of steps the agent needs to execute in order to handle some perceived event. AgentSpeak(L) distinguishes two types of goals: achievement goals and test goals. Achievement goals are used when the agent needs to achieve a certain state of the world (by performing actions and achieving sub-goals). Test goals are used when the agent needs to test whether the associated predicate is a true belief, i.e., whether it can be unified with that agent's belief base (thus binding free variables in the body of plans).

Next, the notion of a triggering event is introduced. It is a very important concept in this language, as it is a triggering event that starts off the execution of plans. There are two types of triggering events: those related to the addition, and those related to deletion of mental attitudes, specifically beliefs and goals. Plans need to refer to the basic actions that an agent is able to perform on its environment. An AgentSpeak(L) plan has a head which is formed of a triggering event (the purpose of that plan) and a conjunction of belief literals forming a context that needs to be satisfied if the plan is to be executed (the context must be a logical consequence of that agent's belief base). A plan has also a body, which is a sequence of basic actions or (sub)goals that the agent has to achieve.

An agent is given by a tuple $<E, B, P, I, A, S_E, S_O, S_I>$, where E is a set of events, B is a set of beliefs, P is a set of plans, I is a set of intentions, and A is a set of actions. The selection function S_E selects an event from E, the selection function S_O selects an option or an applicable plan from a set of applicable plans, and S_I selects and intention from I. The selection functions are supposed to be agent-specific; intentions are particular courses of actions to which an agent has committed in order to achieve a particular goal. Each intention is a stack of plans. Events, which may start off the execution of plans, can be external, when originated from perception of the agent's environment, or internal, when generated from the agent's own execution of a plan.

AgentSpeak(XL) extends AgentSpeak(L) for improving that language in various ways, such as handling plan failure, belief addition and deletion in the bodies of plans, communication, and provides a new construct called internal actions which allow for the general extensibility of the language. One such extension aimed at the automatic generation of efficient intention selection function from high-level descriptions of relationships between plans and their scheduling criteria. The AgentSpeak(XL) interpreter is available as free software. The MASSOC platform is under development, but should also be made available as free software in the future.

4.2 Specifying environments

Agents are computational systems situated in some environment, and are capable of autonomous actions in this environment in order to meet their design objectives (Wooldridge 1999). Agents perceive and interact with each other via the environment, and they act upon it so that it reaches a certain state where agents' goals are achieved. Therefore, environment modelling is an important issue in the development of multi-agent societies. However, the multi-agent systems literature seldom considers this part of the engineering of agent societies. For that reason, the MASSOC platform includes a language designed for this purpose specifically. The language is called ELMS (which stands for Environment description Language for Multi-agent Simulations).

An environment description can be made by the specification of properties of the environment that is modelled as sets of *resources* – modelling the ordinary objects in the environment; *agents* – the properties needed for modelling their physical representation, which is visible to other agents in the environment; *actions* that each type of agent can perform in the environment, or that happen as *reactions* of objects towards actions performed (pro-actively) by agents; and the levels of *perception* available to each type of agent. Users also specify which of all those specified properties they wish to observe during simulation, and they have access to grid configuration options and control variables of the simulation. For more details about the language see (Bordini *et al.* 2003).

Note that an agent representation in the environment includes only its perceptible properties. The deliberation activities of an agent are not relevant, since they are internal to it, thus not observable to the other agents. Such internal reasoning of agents is what we specified with AgentSpeak(XL).

ELMS is still under development, and is, to the best of our knowledge, the only language for specifying multi-agent environments designed for the integration with a language for specifying cognitive agents. It is an expressible language that allows the specification of environments that are, from the point of view of the agents, inaccessible, non-deterministic, non-episodic, and dynamic; however, they have to be discrete. See (Russel and Norvig, 1995) for the definition of these terms used for the classification of environments.

4.3 MASSOC simulations

The graphical user interface (GUI) gives access to what we call the MASSOC Manager, which, besides facilitating simulations, integrates the various technologies used in the approach (the ELMS interpreter, the AgentSpeak(XL) interpreter, and SACI). Figure 1 gives a flavour of the MASSOC user interface. It has the style of a workplace, where one can create and edit agents, plans, and environments, which can then be used in defining a multi-agent simulation. Plans and agents follow the straightforward syntax of AgentSpeak(L), and the environment provides all necessary information for an ELMS environment. Figure 2 gives an overview of the functioning of the various parts of MASSOC that are controlled by the manager, and shows how they relate to each other. Through the GUI, the user defines the agents and the MASSOC manager generates the appropriate “ASPK Code”, which means an agent definition in the AgentSpeak(XL) language. Also defined through the GUI is the “ELMS Code” which is an environment description in the ELMS language. Once the environment and agent codes are prepared, the MASSOC manager starts the “Environment Controller” that, in turn, processes the ELMS specification, generating the appropriate data structures representing that environment. Then, the SACI society is created, through which the agents and the environment communicate. The agents connect themselves to the SACI society, so that through it they will receive the relevant perceptions and will send the actions they have chosen to perform on the environment. The connections between components of a simulation are shown in Figure 3.

In a simulation definition window of the user interface, the user determines the set of individual agents and the particular environment that is intended for a given simulation. From the environment definition, the MASSOC manager checks which types of agents can participate in the simulation, and allows the user to choose, for each of those types, the number of instances of individual agents that will be created. Each of these agents run an AgentSpeak(XL) interpreter with the source code generated by the manager. After the user has informed the intended environment and the instances of agents, the simulation can be started off. Agents can abort execution and new ones can be included by the user.

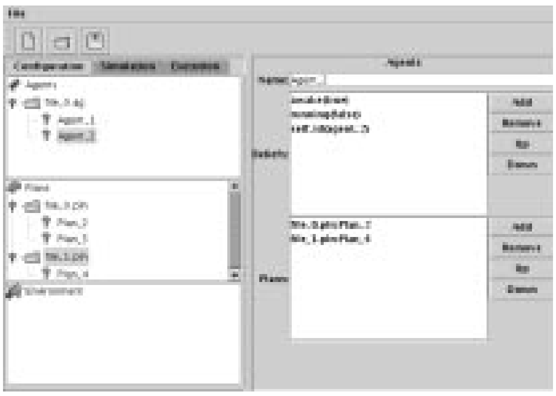

Figure1: The MASSOC manager GUI

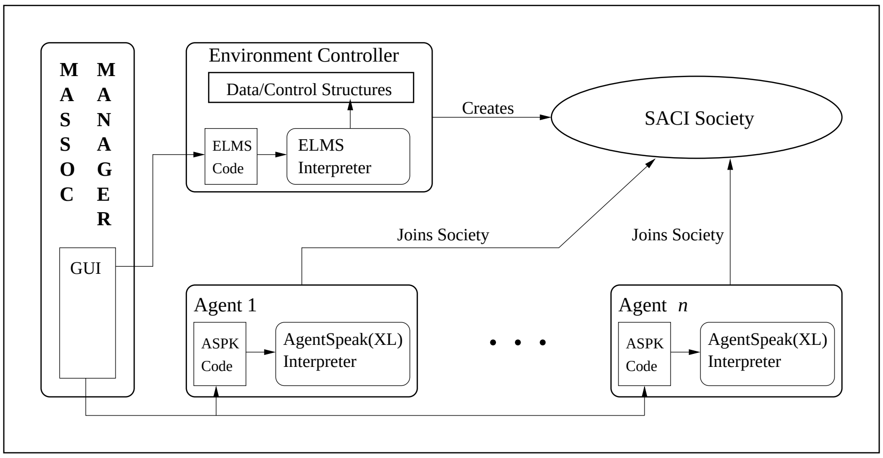

Figure 2: Creating a MASSOC simulation

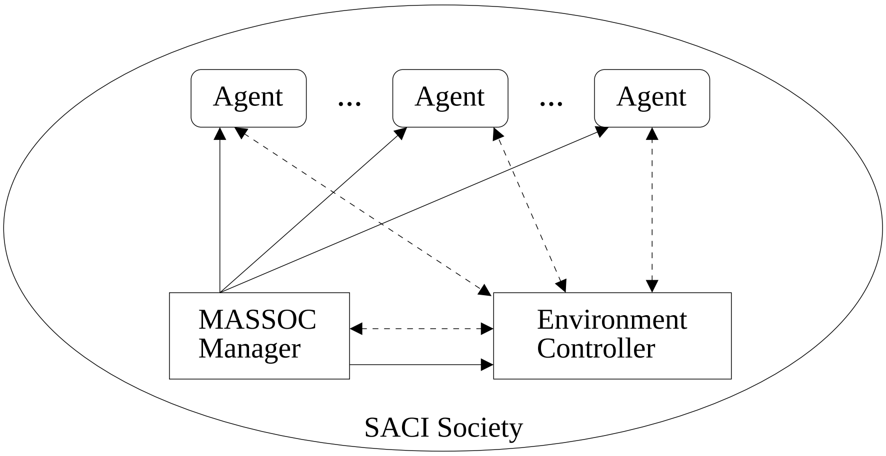

Figure 3: MASSOC components

5. Preliminary experiments

Both MASSOC and MASP are under construction; during experimentation we often find that new adjustments, corrections or improvements are necessary – also coping with misunderstanding between urban modellers and software developers is a major issue, as expected. An initial simulation, with only a few cells, agents, and iterations, has been carried out; its results are inconclusive, although encouraging in that they show a reasonable sequence of iterations, with some recognisable spatial/social patterns.

In this application, the behaviour of three types of agents interacting in an urban space is simulated. The production of space generates profits for the producers, and the consumers decide their location according to their preferences on neighbourhood. This is simulated by an iterative process where BFUs are allocated in a territory divided into plots of the same size. In the system, agents interact in a city in various ways, using a certain set of actions that they can perform in the environment. Agents make decisions based on the urban layout and the social context.

5.1 Agents

Developers: these are the agents that construct and sell BFUs. Constructions are made to obtain greater profits, thus increasing the construction capacity itself. Each time a BFU is bought, its value is credited to the developer agent. Initially, a number of developer agents are included in the system; new agents can be incorporated during simulation time.

Consumers of residential space: the main goal of agents of this type is to get a satisfactory location. They are divided into three social classes; each one has different goals to be fulfilled: *agents in class A* tend to live away from the agents of lower social classes (B and C) and all the service agents, as they do not need to live close to the services; *agents in class B* tend to live away from the agents of class C and be as close as possible to agents of class A, having no restrictions on service agents; *agents in class C* tend to be as close as possible to the service agents, and have no restrictions on other social classes.

Consumers of service space: they are categorised according to size and type of the service they offer. The size determines the radius of its influence in the system, whereas the type of service indicates what the agent actually provides to its area of influence. A "consumer of service space" agent being present in the simulation does not necessarily mean that it has a BFU allocated to it; to be allocated to a BFU, it is necessary that the system is ready to admit a new commercial agent, checking the total number of consumers and wealth of the entire the city, as well as finding satisfactory local conditions.

5.2 Environment

The environment (the city space in this simulation) is a regular square matrix of nXn plots, with no urban characteristics. Each plot has a fixed and equal edification capability. The constructed unit is created when a *developer* allocates a BFU of a certain size. Each BFU has a size, value and type associated. The maximum size of a BFU is the size of a plot, which in this case is composed of 64 basic units of land; its minimum size is one.

5.3 System implementation

This multi-agent system was implemented using the MASSOC approach, i.e., using AgentSpeak(XL) for the implementation of the cognitive agents, and ELMS for the description of the environment. The three main types of agents in the implemented simulation can be described by their plans, as follows.

Developer agents have plans for searching and choosing plots as their main characteristics. The choosing plan checks whether the agent's funds are enough for building a BFU in the system, and then the size and type of the BFU to be built is decided. The searching plan checks where is the most appropriate area for building the chosen type of BFU: if a commercial BFU is to be built, then choosing a plot with more residential consumers is probably best; if a residential BFU for the lower classes is to be built, then choosing a plot with more commercial agents is best; if it is a BFU for the higher classes, then the developer will search for a plot with few commercial agents.

The residential consumers have plans for searching plots, checking the neighbourhood, occupying and changing properties. Depending on its social class, the agent has different attitudes (as mentioned before). The searching plan checks if there is any BFU suitable for its social class available in the city. This plan chooses, in a random way, among the BFUs available for its class and activates the plan for neighbourhood checking. If the neighbourhood has no problems, then the agent will occupy the BFU. The plan for neighbourhood checking is defined according to the preferences of the agent's social class. Agents of class A and B are more demanding than those of class C, and because of that, after they occupy a property, they can activate the plan for changing residences when their neighbourhood is no longer appropriate for their class and the change is possible (e.g., they have enough funds for that).

The service space consumers have their behaviour based on plans for searching and checking BFUs. They are quite similar to the ones used by residential agents. A service agent searches for any available service BFU of its size, checks the wealth and consumers in the system, chooses a BFU with more residential neighbours and, if possible, occupies the BFU.

In this initial environment implementation, the city is a 4x4 matrix; that is, there are 16 plots (cells). Each grid cell stores the number of service and residential agents in that area, indicates if there is any BFU allocated in this plot (if the terrain is urbanised), the value of the space unit in this plot and the number of basic units available to the developer agents.

5.4 Some early results

A simulation was carried out where 55 agents were created in the system and distributed using a pyramidal distribution: 10 developers; 28 residential space consumers (16 class C, 8 class B, and 4 class A); 17 service space consumers (10 small, 5 medium, and 2 large) with no specific kind of service.

Preliminary result of the first complete simulation shows 20 consumer agents in BFUs, with 27 BFUs built by the developer agents. Figure 4 was created from the analysis of the output data of the MASSOC system after 400 simulation steps (note that an action can take several simulation steps to be performed). This is the average time for the simulation to stabilise.

In this first result we can observe class segregation to some extent, but as said before the results are still inconclusive. Also, we would have expected developer agents to have produced more BFUs than they did, as it seems that more BFUs of type A could have been sold.

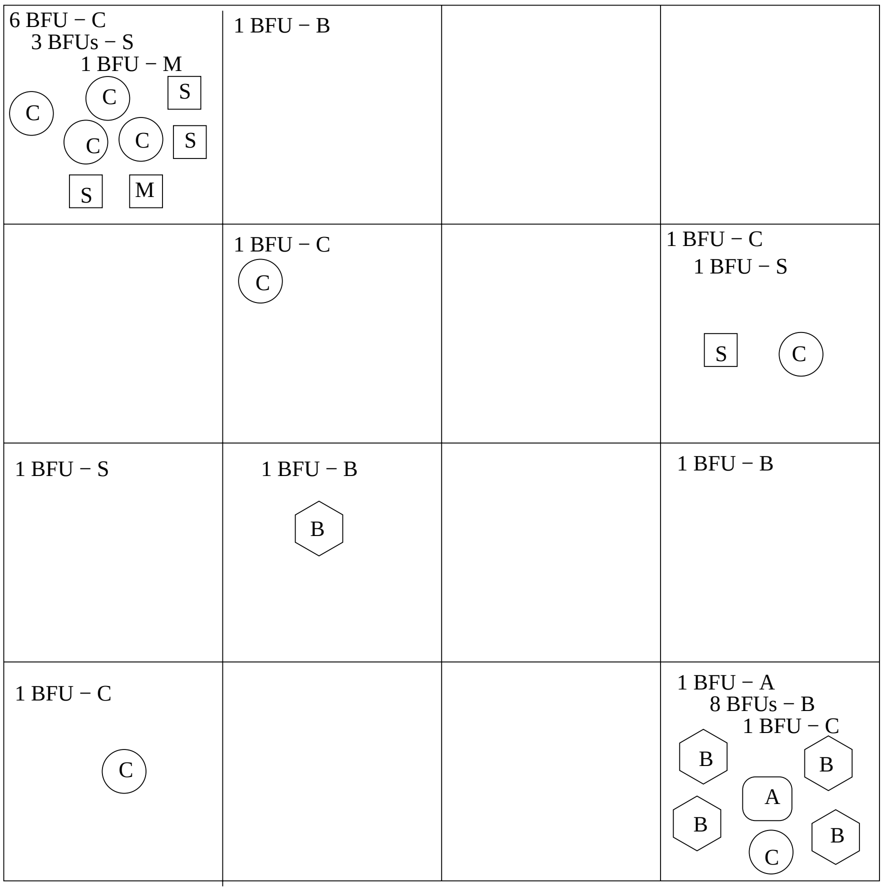

Figure 4: Final configuration of agents and BFUs in the city

6. Final remarks

The research tries to bring together two quite different goals that are, nonetheless, inter-dependent: an urban space production model and an agent-based social simulation system. The urban model, despite its own theoretical framework, benefits from the simulation system in the sense that the latter requires precise definition of agents, environment and interaction structure. The urban model has been built upon the assumptions that agents do have a feeling for spatial characteristics, and that they guide their actions by them. However, the model also assumes that different agents have different visions of space and different beliefs on how they affect them.

The model also assumes that centrality – a quality of positional hierarchy, regarding open public spaces, built forms and activities – can embody the essence of these spatial characteristics and therefore its measure can consist of a primary component for urban space production simulation. In fact, the model assumes that centrality, taken as an expression of spatial differentiation, or non-equilibrium, is the engine of urban dynamics.

Lefebvre pointed out (1970) that centrality is the strongest of urban characteristics, that centrality is everywhere, although it hardly can be defined and grasped. The model is aimed at investigating a way of defining centrality, to grasp it and to represent it both as a quality and as an urban change driver. Urban change, we know, is the battle for social appropriation itself; therefore, centrality is the battleground relief.

References

Bordini, R. H. et al., 2002, "AgentSpeak (XL): Efficient intention selection in BDI agents via decision-theoretic task scheduling", in C. Castelfranchi and W. L. Johnson (eds.), *Proceedings of the first international joint conference on autonomous agents and multi-agent systems*, New York, ACM Press

Bordini, R. H., Okuyama, F. Y., Oliveira, D., Drehmer, G. and Krafta, R., "The MASSOC approach to multi-agent based simulation", submitted

Castelfranchi, C., 2001, "The theory of social functions: challenges for computational social science and multi-agents learning", *Cognitive Systems Research*, Volume 2, pp. 5-38

Freeman, L., 1977, "A set of measures of Centrality based on betweenness", *Sociometry*, Volume 40

Hillier, B., 2001a, "A theory of the city as object*", Proceedings of the 3rd International Symposium on Space Syntax*, Atlanta 2001

Hillier, B., 2001b, "Centrality as a process", *Urban Design International*, Volume 4

Hillier, B. et al., 1993, "Natural movement: or configuration and attraction in urban space use", *Environ ment and Planning B*., Volume 20, 29-66, Pion, Brondesbury

Hubner, J. F. and Sichman, J. S., 2000, "Uma ferramenta para implementação e monitoração da comunicação entre agentes", in M. C. Monard and J. S. Sichman (eds.), *Proceedings of the 7th Ibero-American conference on AI*; http://www.lti.pcs.usp.br/saci

Ingram, D. R., 1971, "The concept of accessibility: a search for an operational form", *Regional Studies*, Volume 5

Krafta, R., 1994, "Modelling intraurban configurational development*", Environment and Planning B,* Volume 21

Krafta, R., 1997a, "Urban configurational complexity", *Proceedings of the 1st International Symposium on Space Syntax*, London, 1997

Krafta, R., 1997b, "Urban convergence: morphology and attraction", in H. Timmermans (ed.), *Decision Support Systems in Urban Planning*, London, E&FN Spon

Krafta, R., 1999, "Spatial self-organization and the production of the city", *Urbana,* Volume 24

Lefebvre, H., 1970, *Revolution urbaine*, Paris, Gallimard

Rao, A. S., 1996, "AgentSpeak(L): BDI agents speak out in a logic computable language", in W. van de Velde and J. Perram (eds.), *Proceedings of the 7th workshop on modelling autonomous agents in a multi-agent world*, London, Springer-Verlag

Russel, S. and Norvig, P., 1995, *Artificial intelligence: a modern approach*, Upper Saddle River N. J., Prentice Hall

Wooldridge, M., 1999, "Intelligent agents", in G. Weiss (ed.), *Multi-agent systems – a modern approach to distributed artificial intelligence*, MIT Press