2.2. Tools and Models for Understanding and Exploring Urban Spatial Dynamics

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Representing a real system in all its complexity in order to measure its possible evolutions, or to conceive development solutions that are adapted to it, is one of the challenges of current research in computer modelling. This approach, which is complementary to classical analytical methods, allows us to develop models whose dynamics are the result of the interactions between the computerised representations of the entities in the modelled system (players, institutions, environment, amenities, etc.). These models are then used as a support for a "virtual" experimental method – requiring simulations – where the resulting dynamics may be studied with all the necessary details and where interaction with the user is encouraged.

The objective of the workshop is to introduce the trainees to the methodologies of the computerised modelling of urban growth phenomena. By basing ourselves on a case study concerning the development of a part of the city of Cần Thơ (Mekong Delta) between 2000 and 2010, we shall address the following points: urban growth models; the methodological aspects of composing a set of (geographical, urban, social) data necessary for any type of modelling (GIS, satellite images, survey results); the construction of urban growth models in the GAMA modelling platform and their exploration through simulation in relation to the initial question. The trainees will be divided into work groups whose objective will be to enrich two of the models presented by incorporating new data and new rules. Each group is required to recapitulate the methodology presented during the first two sessions.

The day before the beginning of the workshop, the trainees meet with the trainers in order to install the software that will be necessary for the training.

Day 1, Thursday 24th

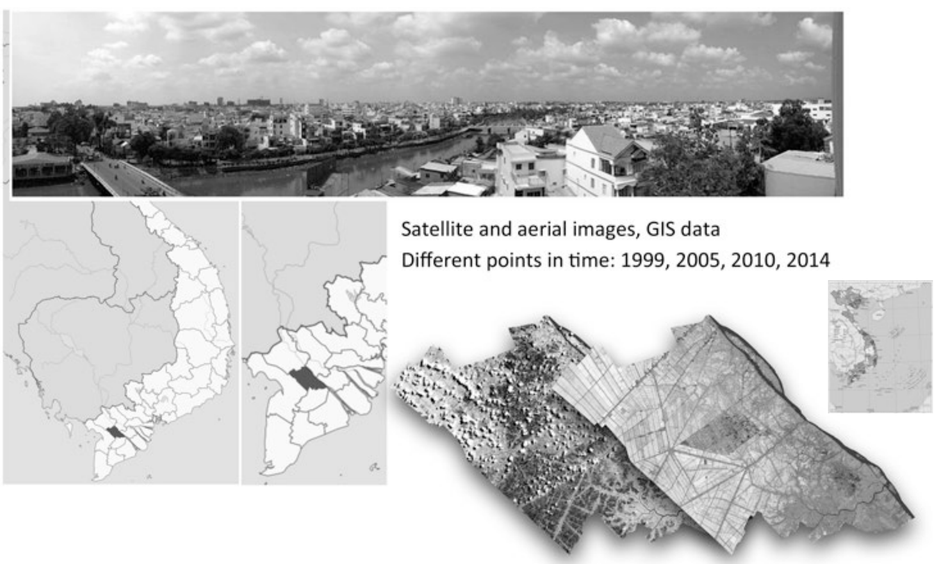
The first part of the workshop is devoted to the presentation of the trainees and trainers (cf. trainers' biographies and list of trainees inserted at the end of this chapter). During the round table, each trainee must introduce his/her neighbour stating his/her university or institute, current research and expectations of the training.

[Alexis Drogoul]

During the plenary sessions you saw a certain number of challenges raised by growing urbanisation throughout the world. In this workshop, we are going to place ourselves in the precise framework of deciders and developers. You are going to have to understand the dynamics of the urban system, anticipate and foresee future changes in these systems, and describe and assess them while at the same time exploring development policies.

We are going to mainly look at models of urban morphogenesis or indeed urban growth, that is to say models representing the evolution of the spatial impact of the city in its physical environment. In order to

Map 16 Example of Cần Thơ



Source: Author's construction.

understand this dynamic, we are going to build models that will need a large quantity of often heterogeneous data: satellite imagery, aerial photographs, surveys, field inquiries, etc. These data will be combined according to the given objective of the model in order to understand how the social, urban and environmental system develops.

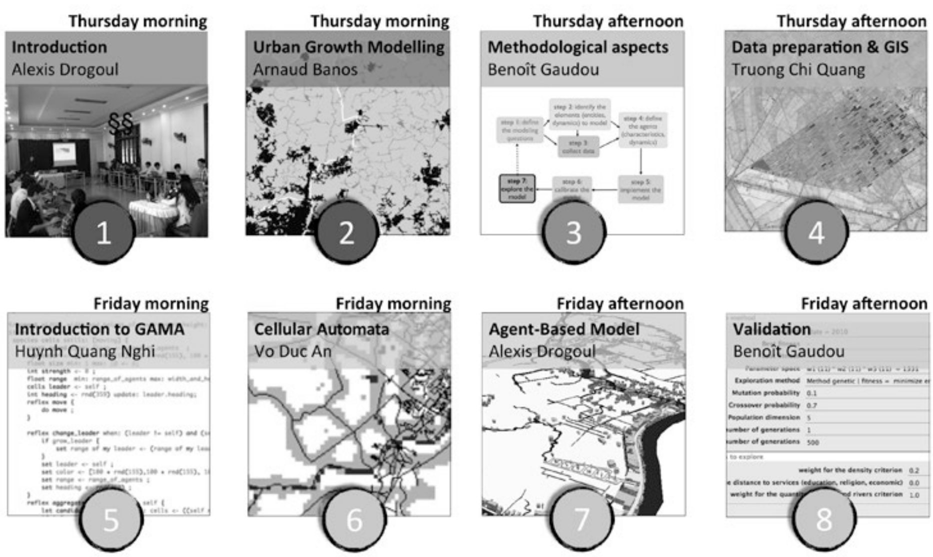
The training will throw light upon different methodological aspects and questions of research and application. We shall attempt to transfer know-how that, without making you autonomous, will make you aware of a methodological dimension used in certain urban development projects.

All these theoretical sessions, as well as the practical exercises, will use the same database created by the trainers and which concerns the city of Cần Thơ (*cf.* Map 16).

Cần Thơ is today the biggest city in the Mekong Delta and its dynamic has been one of the strongest over the last ten years. Furthermore, we have at hand a rich set of historical data about the city.

On a theoretical level, the training is organised as follows:

Diagram 19 Workshop Structure



Source: Author's construction.

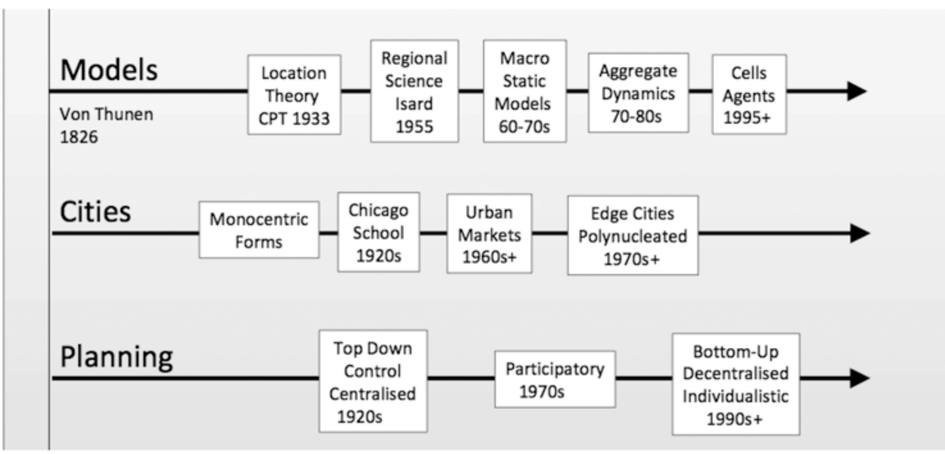
Arnaud Banos will first review different models of urban growth and focus on the questions and challenges surrounding these models. In the afternoon, Benoît Gaudou will deal with the methodological aspects of constructing a model, and then Trương Chí Quang will address the problem of collecting and processing data. Friday will be devoted to the modelling and simulation tool and to the presentation of two representative models of urban modelling – cellular automata and agent-based modelling using vector information. The last two days will be devoted to practical work in working groups – one trainer for four trainees; two oral presentations by group are planned before the final summary by two of you on Saturday.

2.2.1. Models of Urban Growth

[Arnaud Banos]

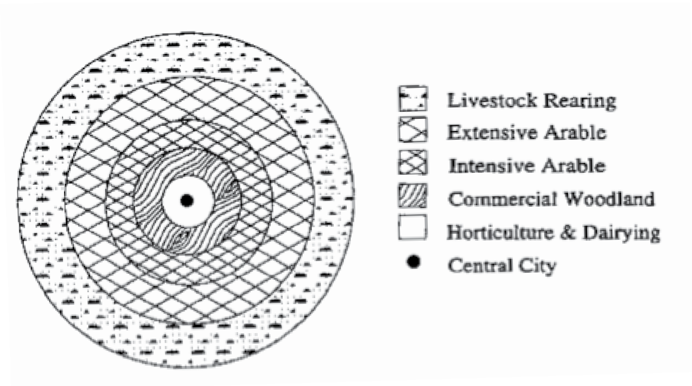
Urban modelling has a long history and its transformations have been linked to human progress and the way in which urban growth is planned. The model developed by Von Thunen is a fundamental one as it lies at the heart of spatial economics and urban geography.

Diagram 20 The Urban Modelling Timeline



Source: Batty, 2014.

Diagram 21 Von Thunen Model



Source: Von Thunen, 1842.

Von Thunen was a landowner who observed regularities in the way cities were organised in relation to the surrounding countryside. In the 19th century, cities were supplied by the countryside. Von Thunen put forward the idea of concentric circles of agricultural activity surrounding the city characterised by a progressive passage from intensive activities to extensive ones with wilderness lying at the city's farthest limits. At this period, the agricultural value of land was linked to its fertility. However, Von Thunen based his theory on the idea that land value depended on its distance from the marketplace. He defined a theoretical model from the following hypotheses:

Box 11 Construction of the Von Thunen Model

- *The city-countryside system is autonomous (isolated);*
- *The physical environment is flat (no natural obstacles);*
- *Soil quality and climatic conditions are homogeneous;*
- *Producers minimise distance-related costs;*
- *Producers maximise profits.*

P = *profit from a given crop on a market P*

Di = *distance from a point* i *to the market*

ß = *transport cost by distance unit*

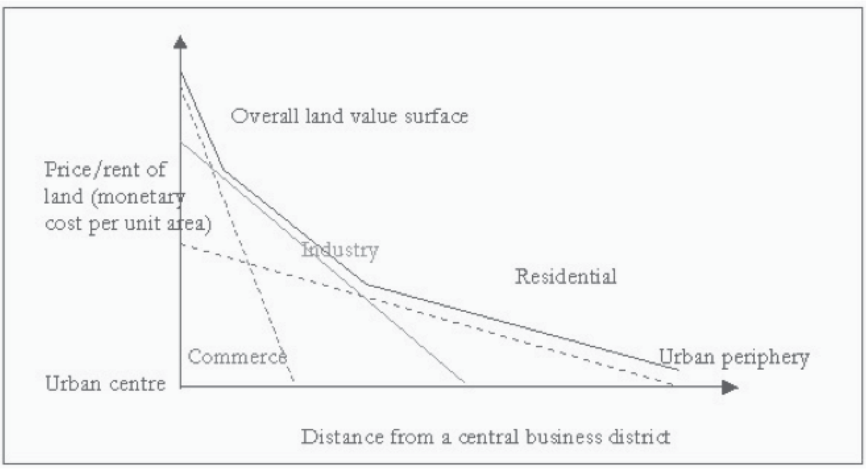
Ri = *rent of a crop at a point* i

Ri = P - ßDi

The model tells us that, at a given place, the land rent is a function of the profit from the produced crop minus the cost of transporting it to market. In concrete terms, this equation allows us to accurately predict land use according to distance from the city.

This model inspired the land rent theory of the Argentine economist Alonso that is still today the cornerstone of urban economics.

Graph 2 Alonso Bid-Rent

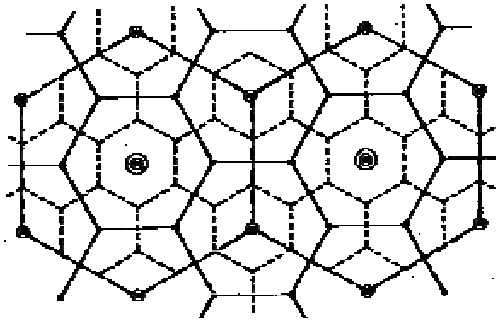


Source: Torrens, 2000.

The theory explains why monocentric, European cities are organised around a business centre that in turn is surrounded by industrial zones and then by residential ones. The notion of accessibility is essential: access time to the centre allows us to understand how the city is constructed and how it develops.

Walter Christaller, who further developed this issue, proposed a theory that concerns the domains of economics, geography and urban planning. Christaller demonstrated that the distribution of cities – small, medium or large – is not random as each urban entity corresponds to particular events; cities are independent and autonomous. How can we then explain that by a locally centred process, we can observe a macroscopic regularity in their spatial distribution? The Nobel Prize winner in economics, Paul Krugman, who is one of the most influential figures in economics in the world, considers that this is one of the most difficult research issues.

Diagram 22 Central Places Theory

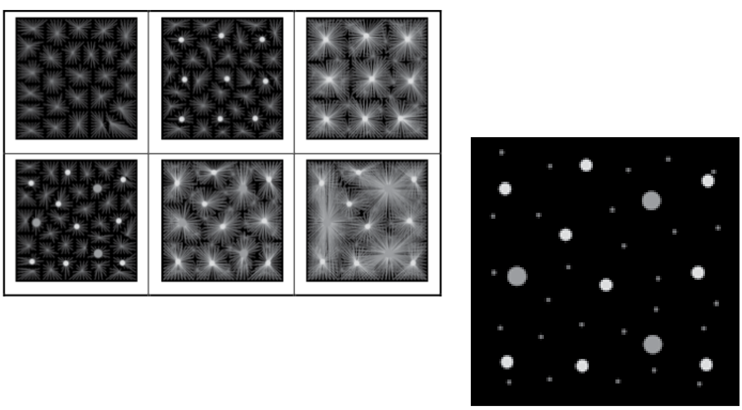


Source: Christaller, 1933.

Walter Christaller was inspired by Von Thunen: there is homogeneity of space; consumers all seek to buy at the lowest price; there is perfect competition. He also considers that the transport cost of goods is shouldered by the consumer – who often lives outside of the city. The cost of transport is thus included in the sale price. Christaller defines an urban hierarchy – if you live in a small city, you will purchase ordinary produce (vegetables, fruit, clothes, etc.), the rarer the product (or service), the bigger the city will be. For example, if you need administrative documents, you will go to a big city on which medium-size cities depend. Now the premises are laid out, the consequences are relatively simple: consumers will seek to minimise transport costs and prefer the nearest cities; producers will tend to spread out in a regular manner.

You can introduce all these hypotheses and behavioural rules into a multi-agent model:

Image 1 Central Places Theory 2



Source: Banos et al., *2011.*

Small cities will seek to position themselves so as to maximise profit; medium-size cities have a larger field of influence. Every city operates according to the Christaller Model. The surprising thing is that, in reality, cities do not position themselves so easily in relation to others: their location is the fruit of a long, historically rooted process. And yet, this regularity can be observed.

A considerable amount of research thus deals with the extremely regular division of cities and their distribution according to size.

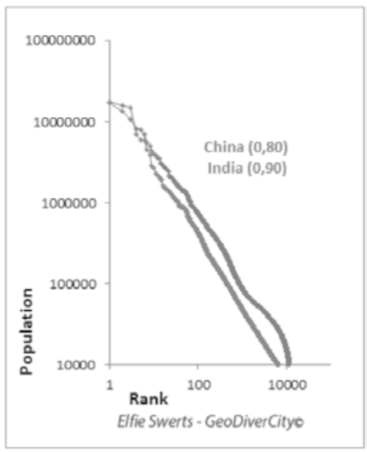
Graph 3 Zipf Law

$$f(P) = a \cdot P^{-\beta}$$

Where:

- *f(P) is the frequency of different city sizes P*
- *a is a constant of proportionality*
- *ß is the scaling parameter*

= Zipf law: ß = 2

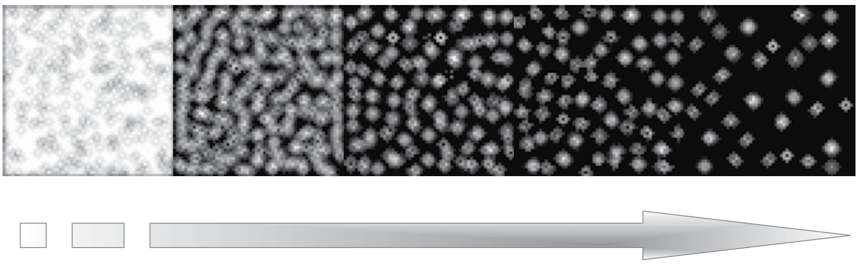


Source: http://geodivercity.parisgeo.cnrs.fr/blog/

The economist Zipf was the first to demonstrate that if you consider the population of a city in logarithmic scale and according to its rank, you will identify a statistical signature. In the case in point, all cities are organised according to a straight line whose exponent is often close to the value 2 (Zipf Law). The astonishing thing is that the behaviour of a city is linked to a unique context and yet you can observe regularities with signatures that are almost always identical.

Let us return to the model proposed by Paul Krugman. Let us imagine a simple, linear city that is composed of adjacent cells. At the outset, each cell possesses an identical number of enterprises. Each place presents a location interest for these enterprises that takes into account two opposing forces, one attraction, the other repulsion: by being close to each other, the enterprises can reduce certain costs (economies of scale) – a collective electric supply for enterprises will reduce expenses for example, but also attract more clients (the principle of commercial zones). However, if they are too near each other, they will also be in competition. The location dynamic is thus based on a subtle balance between these two forces, which are not symmetrical, as the force of repulsion diminishes more slowly than the force of attraction.

Image 2 Krugman Model: Results



Source: Author's construction.

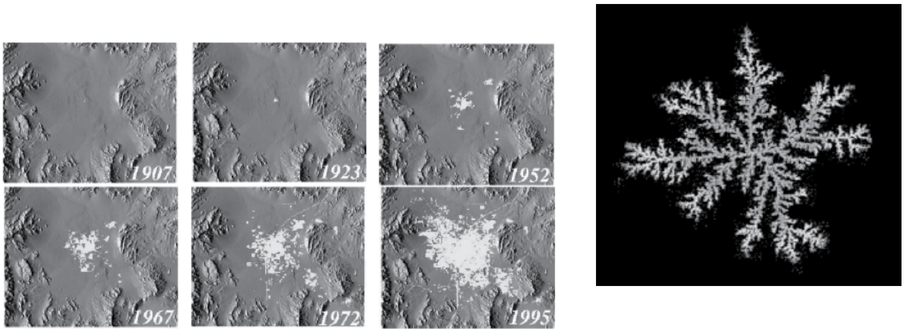
From an initial situation where all the enterprises are localised in a space, the trend is towards a grouping together. In this image, you can consider for example that they are commercial centres or cities:

- The commercial centres group together shops that benefit from economies of scale but, at the same time, it is in their interest that the other shops be sufficiently far away so as to avoid competition;
- Cities exist because economic players feel the need to be close in order to benefit from agglomeration economies while at the same time being far from other cities and competitive factors.

It is nevertheless difficult to speak about a model of urban growth by simply working on one city. This growth implies that the city is open to its environment and has relationships with other cities in the system – competitive but also cooperative relationships. It is a fundamental mechanism of economic growth.

On the other hand, models of morphogenesis liberate themselves from the context, and we only work on the urban form. Let us take a look at a category of models used in the 1980-90s.

Image 3 Diffusion-Limited Aggregation (DLA) Models

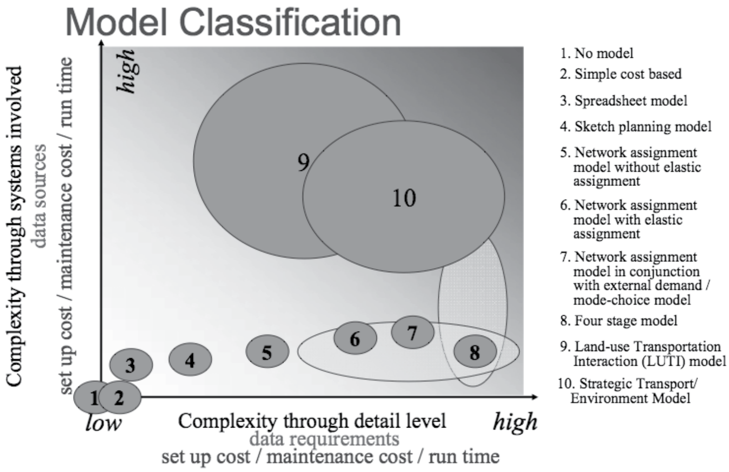


Source: Acevedo et al., *1997.*

These models are observation based. Let us take the case of the growth of the city of Las Vegas (United States). Only urban areas are considered. We are very far from the circular form of Von Thunen's monocentric city. The surface of the city is finite, and yet, if you seek to calculate its perimeter, it is infinite: we cannot calculate the distance around the city. How can we explain this particular type of geometry? The proposals, which were very fashionable in the 1970-80s, drew inspiration from crystallography, a discipline that studies the creation of crystals. By analogy, we can consider that the new arrivals are perhaps going to fall by chance upon a city being built and are going to settle there. The mechanism is thus individual: a random movement that leads to the creation of the surface of the developing city. The result is determined by the random process of the new arrivals (particles). If you apply this to urban genesis, this means that the cities are self-organised and that nobody decides anything at the collective level. The city is a group of individual decisions.

Let us now concentrate on the models of land use and transport that we are going to seek to develop during this workshop.

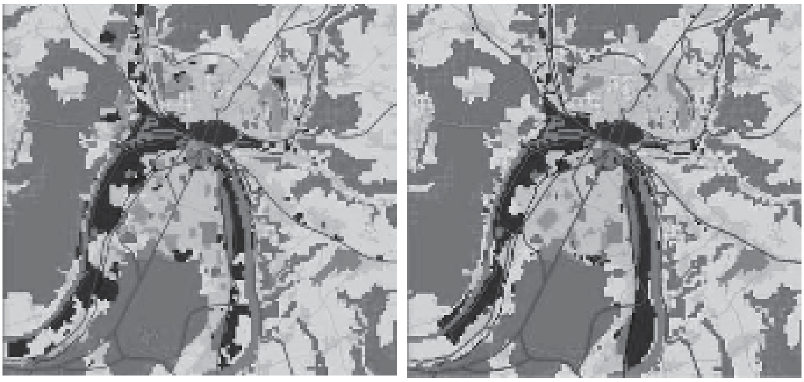
Graph 4 Land Use / Transport Models



Source: Emberger, 2005.

The work of a modeller consists in seeking to establish a link between a model that is the expression of one or several theories and the theories that are at the origin of the model. This graph presents a classification of the models that are currently most in use according to their complexity – level of details involved; number of sub-systems in the model. It is, for example, possible to construct a simple model that will calculate the generalised urban cost of any city by taking the variables of surface, average transport time and number of enterprises.

Image 4 Land Use Models, Cellular Automata

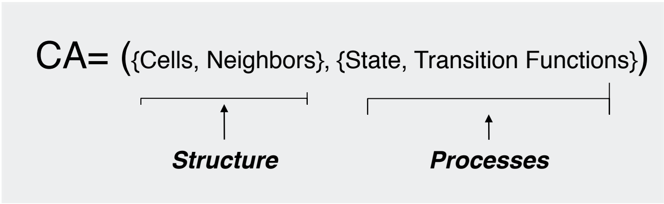


Real situation in 1994 — Situation simulated in 1994

Source: Langlois, 2008.

We are going to dissociate the evolution of the land use of transport and mobility, and then we shall superimpose the files. Often, land use models are based upon a formalism referred to as "cellular automata" that we shall examine this week. In the present case, it involves an application to the city of Rouen in Normandy (France).

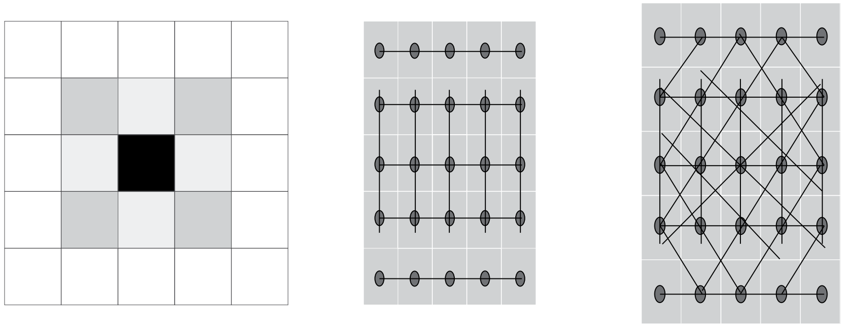
Diagram 23 Cellular Automata



Source: Moreno et al.*, 2009.*

Fundamentally, a cellular automaton combines a structure with processes. The structure corresponds to the cells and to a neighbourhood; each cell is defined in relation to its neighbourhood. The processes integrate the state of the cell. For example, a cell may be occupied by the forest, water or buildings. The transition functions give you the probability of a cell changing state – at a given moment T, a forest; at a given moment T+1 a building with a certain probability.

Diagram 24 Cellular Automata (2)



a. 2D Automata with definition of neighbors — b. Underlying Neighboring graph — c. Underlying Neighboring graph

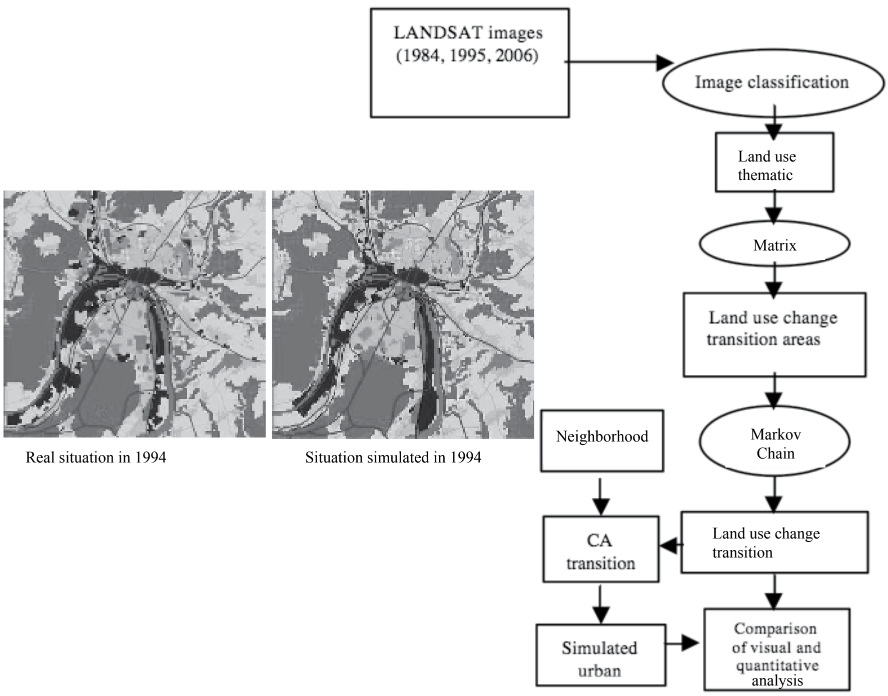
Source: Moreno, op. cit.

Each cell is characterised by a state. Here the state is the colour black and each cell is capable of identifying its neighbours. *"b"* is a representation of *"a"* with graphs. Each cell becomes a node and all the neighbouring nodes of the representation are linked. You then obtain the graph *"b"* or *"c"* in function of what you retain as a definition of neighbourhood.

Cellular automata have had a lot of success as they allow us to reproduce complex processes using simple rules – each cell changes its own state in a dynamic way in function of the state of the neighbouring cells. One of the most well-known examples in the "artificial life" domain is Conway's "Game of Life" which allows us to engender a large diversity of patterns according to very simple rules.

In an urban context, how can we explain that a cell will change state at a given moment? The most usual way of doing so is by using data, such as satellite images for example, in order to construct transition matrices.

Diagram 25 Example of Transition Matrices

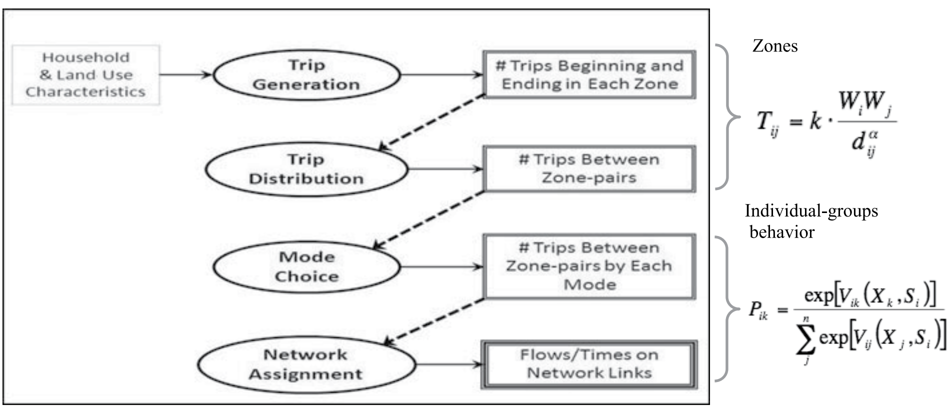


Source: Demirel et al., *2010; Langlois,* op. cit.

From classification, the number of land use class categories is limited. Then we define the (dynamic) changes for the cells in function of three Lansdat images (1984, 1995, 2006). A transition matrix is created – several thousand cells have a state at a given date and the transition matrix indicates a change of state with the probability of moving from a *forest* state to a *built-up* state, for example. We seek to reduce the combinations by using a statistical regularities model (Markov chains). This model identifies the transition probabilities in a huge system. We compare the predictions of the automata for the same dates. Contrary to Von Thunen's model, the approach focuses on data ("Data-Driven") and the model produced is capable, in certain configurations and over a short period of time, of producing accurate predictions. On the other hand, this model is not well adapted to explain how the city grows: learning takes place through a model that is not causal but which works on a base of statistical regularities. Conversely, the "Concept Driven or Theory Driven" models are more explanatory but, because of their more general character, they may have a weaker power of prediction – although this depends on how we define a "good" prediction.

Let us take a look at the mobility calculation associated with the evolution of urban growth. The easiest and most common way of doing this is to work on macroscopic models that will reason in the form of zones. Urban space is divided into the zones and the flows between these zones are estimated.

Diagram 26 Four Step Model



Source: Southworth, 1995.

The most widely used model throughout the world is the four-step one. We first seek to define the emission potential of each zone – for example, the number of people who live there – and its potential to attract (according to workplaces for example). On this basis, we introduce a "Trip distribution" stage that naturally depends on the emission and attraction potential of the zones. We then determine how individuals move around (transport mode) and their itineraries, which we shall allocate to the transport network ("Network Assignment"). A large number of equations come into play in the four-step model but these may be grouped together into two big families: macroscopic equations (cases of generating steps and distribution of flows) and equations that are linked to individual behaviour (cases of modal choice or itinerary, which often come under the category referred to as "discrete choice" models).

It should be noted that the macroscopic model subjacent to the generation/distribution of flows is inspired by Newtonian physics. The number of people moving (flow) between the zones *"i"* and *"j"* is thus a function of the "weight" of zones *"i"* and *"j"*. Furthermore, this number is inversely proportional to the distance that separates these two zones. We find here Newton's model of universal gravitation, on the basis of an analogy that continues to stimulate debates within the research community. Contrary to the physical model of Newtonian theory, which is a universal and explanatory (causal) one (the exponent of distance is constant), the flow generation model is a statistical model that is both descriptive (the "weight" of the zones is subject to indirect indicators such as their population for example) and relative (the distance exponent is adjusted to the data and varies between places and periods). However, the analogy on which it is based makes sense when we reason at a macroscopic level and this model often allows us to measure quite accurately flows between urban zones or cities within a system of cities.

On the other hand, it is necessary to introduce behaviours when we have to decide how individuals travel and through which points they will transit. These behaviours are indeed a lot more variable. The construction of a model therefore involves a series of simplifications – very similar to those mentioned in the models of Von Thunen or Christaller. For example, hypothesising that the agents are in a perfect information situation, are capable of comparing the "utility" of all possible alternatives and of systematically choosing that which will maximise their utility, allows us to express the model mathematically, in a compact and practical form. Generally speaking, if we assume that everyone is different, it becomes difficult to express (formalise) a model and even more so to resolve it using the tools we have at hand (mathematics for example). The advantage of agent-based models is that you can – to a certain extent – discard these assumptions. But you will see during the workshop that this possibility has both upstream and downstream constraints. Upstream because the idea that all individuals and their behaviours are different is debatable, especially in a specific and clearly defined context such as that of mobility. Furthermore, we should not lose sight of the fact that microscopic fluctuations may produce regularities at a macroscopic level, hence the dual necessity of asking the right questions beforehand. And downstream because a model composed of too large a number of parameters would quickly become too difficult to understand and control.

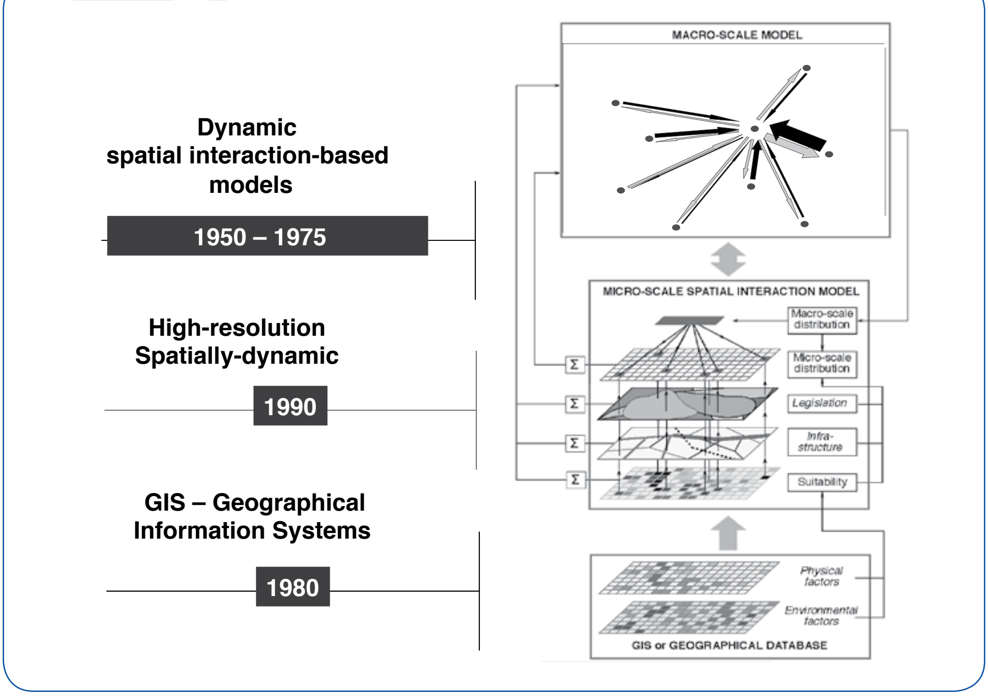
We should also note that the four-step model, in the version that I have just presented to you, is largely static. It lacks, for example, an essential piece of data: road traffic.

This piece of data is important, as you will include it during the group work phase. The interest of doing this is to draw up hypotheses and simplify the situation, for example: single lane routes; cars are not allowed to overtake; there are no accidents, etc. In this case, you can outline a model in a purely mathematical form. For a segment of road, you know the concentration – the number of vehicles at a given moment *"t"* – and the flow – the number of vehicles that pass through a segment during a given period. In simple cases, traffic theory tells us that there is a fundamental relationship between density and flow: if you increase the number of vehicles on the road, flow increases until it reaches a critical level that corresponds to the capacity of a segment of road; from this moment onward, each time you add a vehicle, the flow diminishes (congestion).

If we wish to come down to the level of the car, we observe the behaviour of each vehicle that takes into account the legal maximum speed limit and of the car it precedes, as in the NaSCh model – whether we place ourselves at the microscopic level of individual vehicles with specific behaviours, or at the macroscopic level where only the flow of the vehicle is considered.

At different periods, different formalisms have been used.

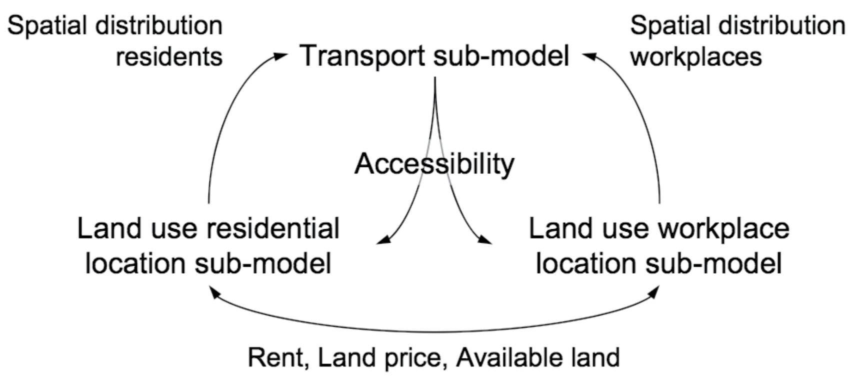
Diagram 27 Models Coupling



Source: Engelen, 2006.

This approach was typical of the 1950s-1960s. It corresponds to the introduction of geographic information systems (GIS) that allowed us to feed more accurate data into the models. We then coupled with rasterised information on the pixel level, which is linear for the road network.

Diagram 28 LUTI Models

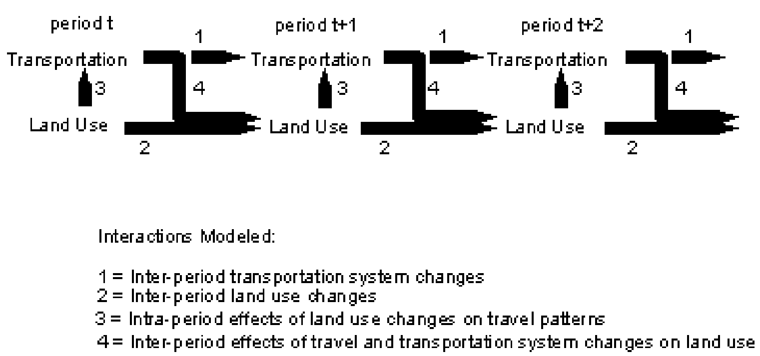


Source: Engelen, op, cit.

Here is a Land Use and Transport Interaction (LUTI). Everything is linked; there is no beginning or end. Accessibility is a major concept; all this evolves in relation to accessibility (distance, cost).

I shall finish with the key issue of the dynamics of coupling.

Diagram 29 Slow-Fast Dynamics



Source: Southworth, op. cit.

What should we begin with? Here is a typical graph that is supposed to tell you exactly how this functions in the preceding model. The periods are thus divided:

- Arrow 1: the period of change in the transport module;
- Arrow 2: the period of change in land use;
- Arrow 3: the impact period of land use changes on mobility;
- Arrow 4: the impact period of mobility on land use.

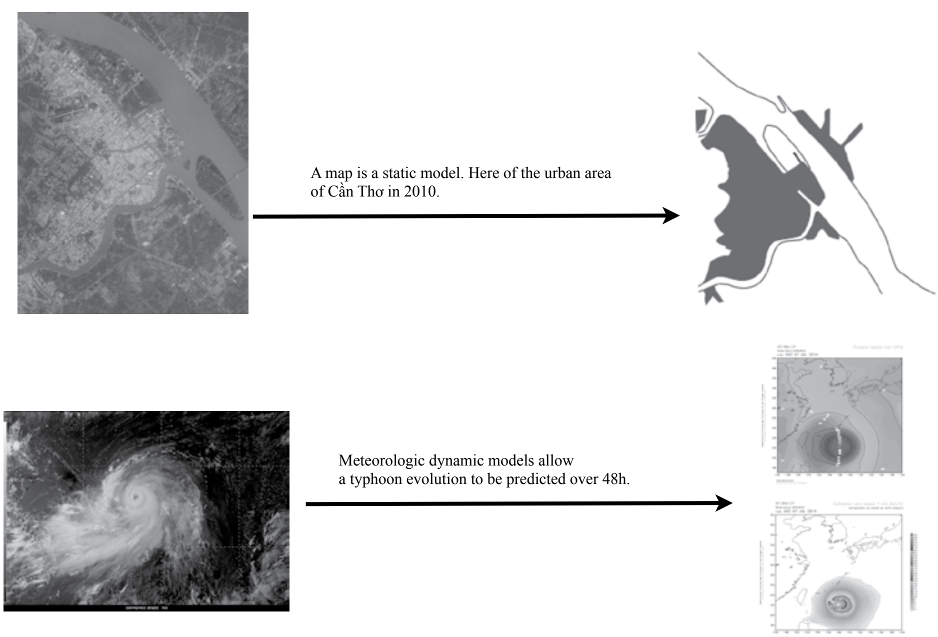
Land use has a rapid impact on mobility. If I take away buildings, this will have an immediate impact on mobility. On the other hand, the development of mobility has a longer impact on land use – individuals have to have difficulties moving about over a long period before eventually deciding to move house.

2.2.2. Case Study: Types of Question, Approach and Model

[Benoit Gaudou]

The first model is static (*cf.* Image 5); it represents a satellite image of the city of Cần Thơ – a vision at a given instant *T* of the urban state. The second example is a dynamic model – the description of the evolution in time of a phenomenon. It is illustrated by the typhoon that moved up towards Japan in July 2014. Dynamic models of the meteorological type allow predictions; they give the evolution of a system by simulation. Another principal objective of modelling is to provide support to a decision by testing different scenarios.

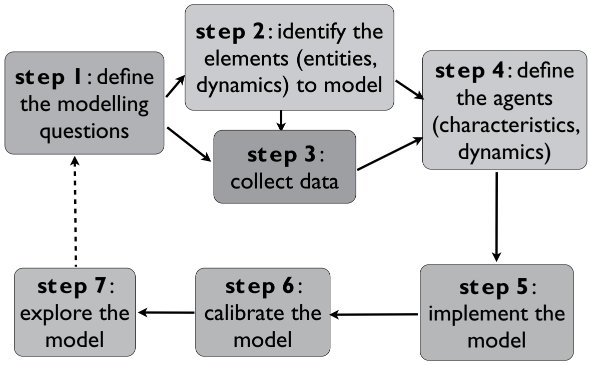
Image 5 Static and Dynamic Models



Source: Konings, 2012 ; http://lesbrindherbes.org/2014/07/06/l-enorme-typhon-neoguri-se-dirige-japon/

This diagram represents the different stages of modelling and simulation.

Diagram 30 Modelling is a Multi-Step Cycle



Source: Author's construction.

A model is defined by the question to which it is supposed to provide an answer. Our workshop is interested in models focused on the understanding of urban growth and its explanatory factors by taking the city of Cần Thơ as our subject. What are the mechanisms and rules that allow us to produce urban growth similar to real growth? A wide range of questions may be raised regarding the transformation of urban space: the adding and/or the elimination of roads, modifications in public and waterway transport, the impact of the construction of commercial centres, reflections about public service needs (hospitals, schools, hydrological networks, etc.), etc.

In terms of techniques, we are going to focus on agent-based modelling that allows us to: include spatial heterogeneity in a simple way, induce spatial data, describe the phenomena at the microscopic level that are going to generate macroscopic behaviour and, finally, carry out experiments with the help of scenarios.

We are going to identify at the same time important entities in the system and their dynamics. The entities are individual elements in the system and their state is characterised by variables or attributes. The dynamic, or process, is what allows us to modify the system: for example the actions attached to the entities – movements, interactions between agents or indeed, the dynamic of agents such as financial markets, flooding, etc.

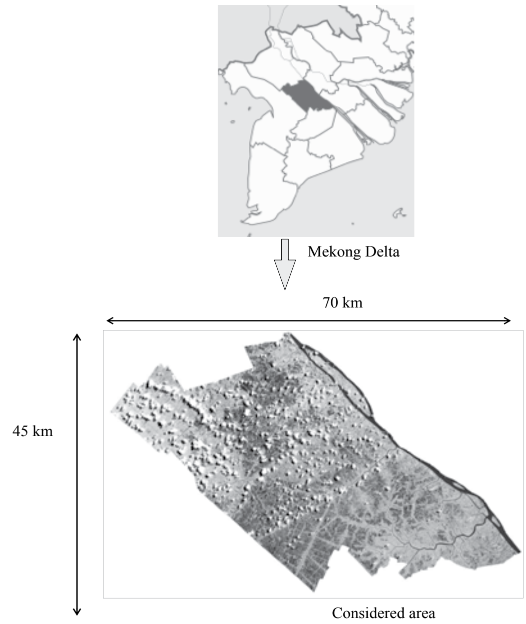
Image 6 Model 1: Entities, Dynamic and Scales

Spatial scale
Area that covers Cần Thơ city and the nearby suburbs

Time scale
Duration: 15 years from 1999 to 2014

Dynamic to take into account:
The construction of buildings

Entities to take into account:
- Buildings;
- Roads;
- Rivers.



Source: Author's construction.

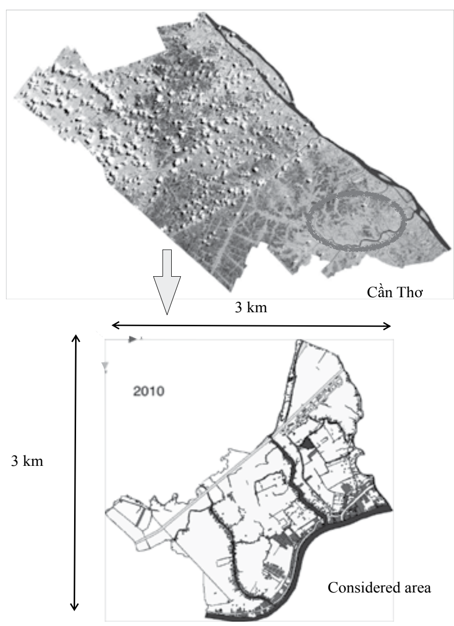
Image 7 Model 2: Entities, Dynamic and Scales

Spatial scale
The An Bình ward of Cần Thơ

Time scale
Duration: 5 years from 2005 to 2010

Dynamic to take into account:
The construction of buildings

Entities to take into account:
- Buildings
- Roads
- Rivers



Source: Author's construction.

In this first model (*cf.* Image 6), the spatial scale in which we are interested is the greater region surrounding Cần Thơ; the targeted dynamic is the appearance of new urban entities, new housing for example. For our purposes, the movement of entities is done by road or waterway. The considered temporal scale is fifteen years.

In the second model (*cf.* Image 7), instead of taking an interest in the urban growth of the entire city, we shall now consider the An Binh neighbourhood. The model is more precise, and at the same time examines the same dynamic.

The first stage is the constitution of a set of data, either through field inquiries with government agencies or by free access on Internet. For the city of Cần Thơ, the data come from the Department of Natural Resources and the Environment.

The following stage corresponds to the construction of a GIS. The data are going to undergo different transformations in order to homogenise the format, correct the attribute table, establish links between the different sources in order to produce new data, etc.

What are we going to include in the model? What are the agents that are defined in the system?

The definition of the type of agent depends a lot on the chosen scale and the question formulated. The implementation will be different, if observed at the level of the entire city, the neighbourhood or the household – it is possible to represent individually the inhabitants, the households or the entire house. For Cần Thơ, we are interested in the production of new buildings. These agents have for attribute a form, a position and a residential or commercial type. An agent represents a physical entity in the system. In the model, the buildings are the principal agents: it is on them that the dynamics and rules of urban expansion are described.

We are going to get close to the cellular automata type models presented by Arnaud Banos. Space is thus divided into grids in which each cell is an agent with, for example, an attribute of demographic density. Each agent combines a certain number of buildings.

Benoit Gaudou concludes his presentation on the issue of dynamics and the implementation of the model. For this, he presents three platforms: NetLogo, Repast and GAMA that will be used for the training. Calibration objectives are also addressed.
The end of the day is devoted to the methodological aspects for the constitution of a set of data. The following points are developed by Trương Chí Quang: introduction of GIS; raster and vector data; conversion of different data formats; etc.

Day 2, Friday 25th

[Alexis DROGOUL]

This day will be devoted to purely methodological aspects in which we shall take a look at the conception and implementation of these models in the GAMA platform. Our objective is not for you to become autonomous and experts in GAMA (!), but for you to become confident enough to tackle as a group the collective task of conceiving models and experimenting.

Huỳnh Quang Nghi presents the GAMA platform and introduces "GAMA Modeling Language" (GAML) that allows models to be written. A second section, developed by Vơ Đức Ân, introduces the cellular automata based model whose objective is to reproduce the urban development of the city of Cần Thơ for the 1999-2014 period. Some elements of presentation were developed in the 2012 edition of the JTD; we here refer the reader to preceding publications (Drogoul and Goudou, 2012; Drogoul et al.*, 2012). Finally, Alexis Drogoul sets out the different stages of construction presented the previous day by Benoît Goudou (cf. Diagram 30) in the framework of an exercise concerning the reproduction of the phenomenon of the densification of buildings in the An Binh district of Cần Thơ between 2005 and 2010.*

2.2.3. Brain-Storming

[Arnaud Banos]

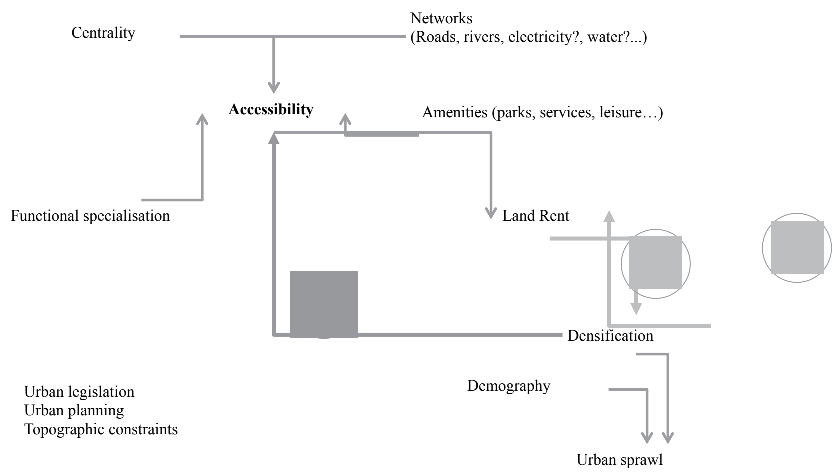
Let us take the time to clarify what we have seen this morning.

We asked the different groups to propose three examples of rules for the urban development of Cần Thơ. Your reflections can be summed up in simple words such as: centrality, networks, functional specialisation, land value, densification, etc. These words refer to fundamental concepts of urban planning. Urban legislation imposes constraints and the work of planning modifies and proposes new projects that are factors of urban dynamism. Furthermore, topographical constraints influence the transformation of the city.

How can we move from a general concept to a model? We have examined how to define simple rules and include them in GAMA. But this is not sufficient because a model is an intellectual construction and not simply a computerised or mathematical representation. It is important to establish this construction in order to feed the model as a mathematical or computerised concrete object.

Firstly, it is necessary to carry out the task of implementing a system of concepts.

Diagram 31 Conceptual Model



Source: Author's construction.

Your descriptions omitted the concept of accessibility that allows us to connect many other concepts. The notion of centrality is fundamentally a notion of accessibility. The idea of road networks or electricity networks, for example, is linked to the concept of accessibility. It is the same for parks and leisure areas or even functional specialisation – activity venues and commercial zones. We saw with the theory of Von Thunen and that of Alonso's land rent that accessibility is a central concept for explaining land value at a given moment. What counts is not only what is happening in a place but the way in which this place is accessible from the rest of the city.

Land rent leads to planning. All the economic players who seek to locate themselves in the city are in competition to settle in the best places in relation to their economic capacities. The land rent theory tells us that if the value of land was identical everywhere in a city, this city would not be dense. Land rent engenders the densification of the city and, in return, urban densification reinforces land rent as the players are in competition.

Densification also has an impact on accessibility through traffic; these two forces are opposed. Let us bear in mind Krugman's model and his forces of attraction and repulsion. Individuals are attracted to each other, to activity venues, the city centre and its networks. However, a force repulses them far from the city because of difficulties in accessibility. Within this mechanism, there is also a force of repulsion: competition *via* the market increases land rent and the economic players who are unable to assume the costs must distance themselves from the centre.

By adding relationships between these concepts, we construct a model of urban development based upon attraction and repulsion. But in order to obtain urban growth, we must include demography – a factor that is both endogenous and exogenous.

We now have to implement the model in GAMA in order to test its capacity to reproduce urban growth. We are going to place ourselves in the position of urban developers (use of cellular automata then vector models). We are confronted by three challenges: 1) introducing commercial spaces into the model so as to reproduce functional specialisation; 2) including mobility; 3) reproducing low population density areas.

Group work implies social interactions that are fundamental to research. It is necessary to express our ideas, be capable of listening and debating so as to arrive at something coherent. This is something that is absolutely central to the scientific method. One of the objectives of group work is thus to allow you to exchange ideas and listen to arguments in order to construct common proposals.

Benoit Gaudou concludes the day by talking about issues of simulation, the exploration of different parameters and the different solutions provided by a model within the framework of an example of urban growth. In relation to the preceding presentation, two projects are suggested:

- Use of the cellular automata model provided in order to observe the different results according to change in GIS data: modification of GIS data (adding and elimination of roads, bridges, etc.); simulation on the new data and with the original data (in GAMA); comparison of results and understanding of the impact of urban planning on urban growth;

- Use of the agent-based model provided in order to observe and understand the spatial growth of geographical units: adding of traffic density indicators in order to observe the impact of the phenomenon on development; adding of rules in order to construct commercial activities and observe their impact.

The technical character of the sessions developed during the rest of the week cannot be included in the simple framework of this publication. In order to specify their content, we invite the reader to contact the trainers of the team constituted by Alexis Drogoul and also refer him/her to the different research programmes described in the biographies at the end of this publication.

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Conférences & Séminaires

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July 2015

A Glance at Sustainable Urban Development

Methodological, Crosscutting and Operational Approaches

Regional Social Sciences Summer University
"Tam Đảo Summer School Week" (Đà Lạt, Việt Nam)
July 2014

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