Building a city in vitro
The Experiment and the Simulation Model

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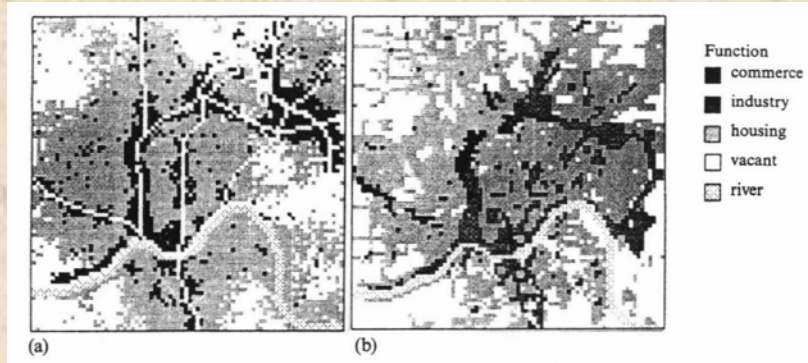
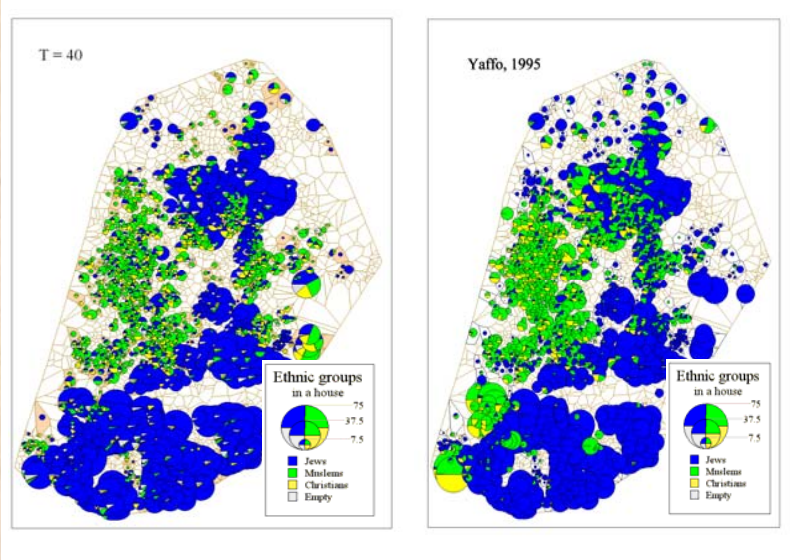
High Resolution Urban Modeling

Urban system as a collective of geographic objects - two types of models:

- Cellular Automata models - Formalization of infrastructure change using cell transition rules



- Agent Based Models – Explicit implementation of human behavior.



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Two formulations of urban dynamics

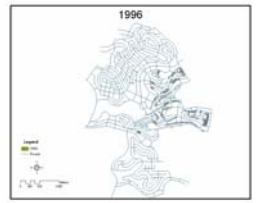
Formally, we have to distinguish between two situations

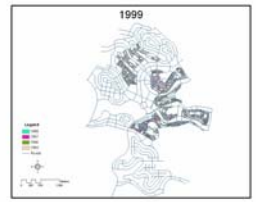
- Dynamics without memory - systems dynamics is a *first-order recursion process:*

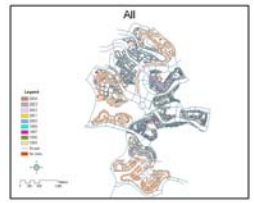
$$X_{t+1} = f(X_t, E_t)$$

- First-order recursion is insufficient for the adequate description of the urban system dynamics and object's automation rules should be extended to include the object's and system's history:

$$X_{t+1} = f(X_t, E_t, X_{t-1}, E_{t-1}\ X_{t-2}, E_{t-2}, \ldots)$$







The objective of my research is to distinguish between the two situations.
I do that on the base of experiments , in which participants build artificial city on the floor…

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City Games

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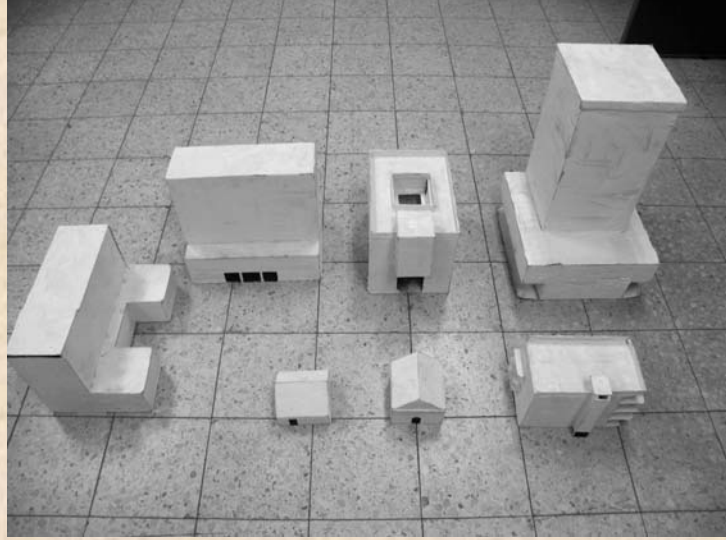
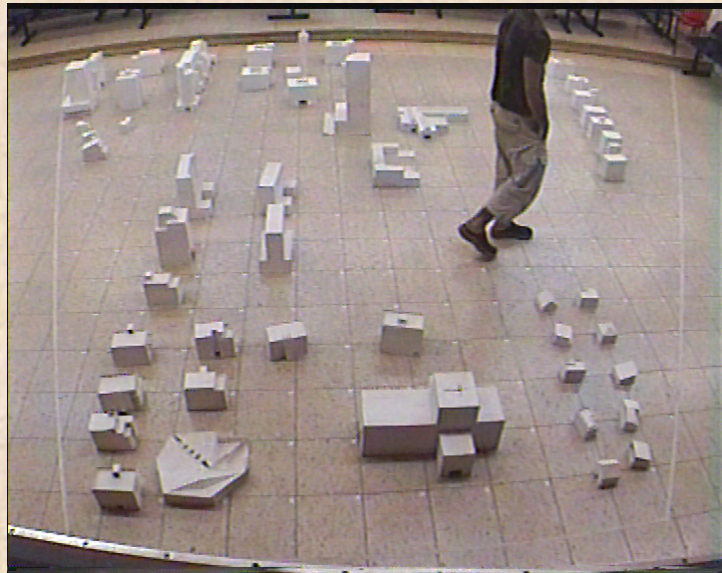
Description of the experiments



- 30 undergraduate students of geography were asked to build a ‘city’ using 52 mock-ups (developed by J.Portugali (1996)).
- The experiments were conducted with collaboration of H. Casakin
- Mock-ups represent real buildings at a 1:100 scale and resemble different urban functions.
- Each participant builds the city once, locating one mock-up at a time on the floor
- During a time step, the participant selects a building , claim its urban function, and then locates it on the floor.



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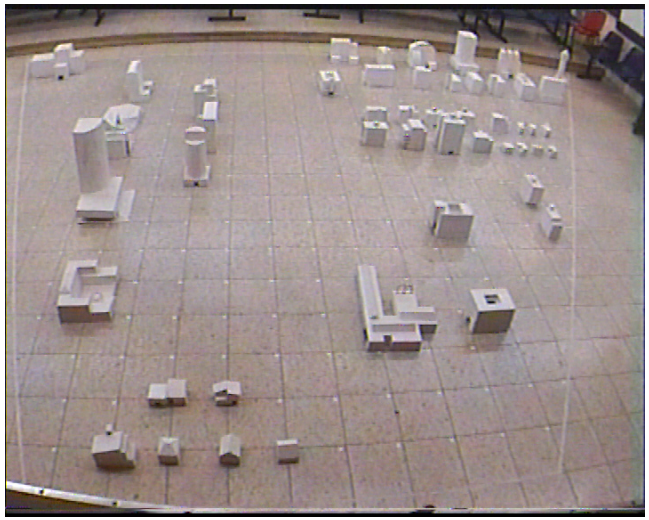
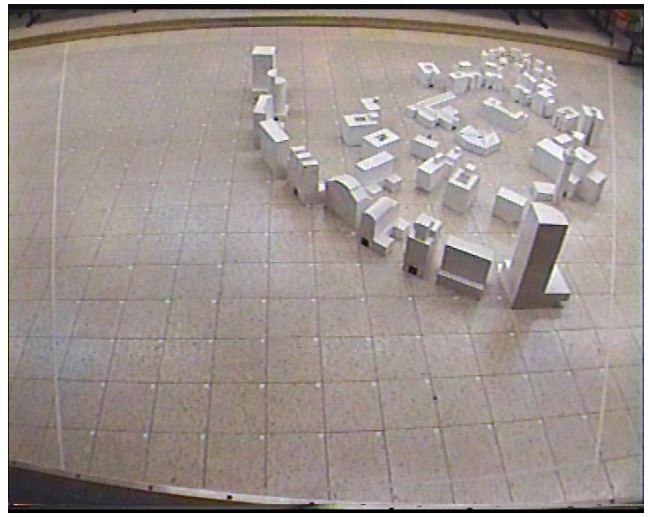
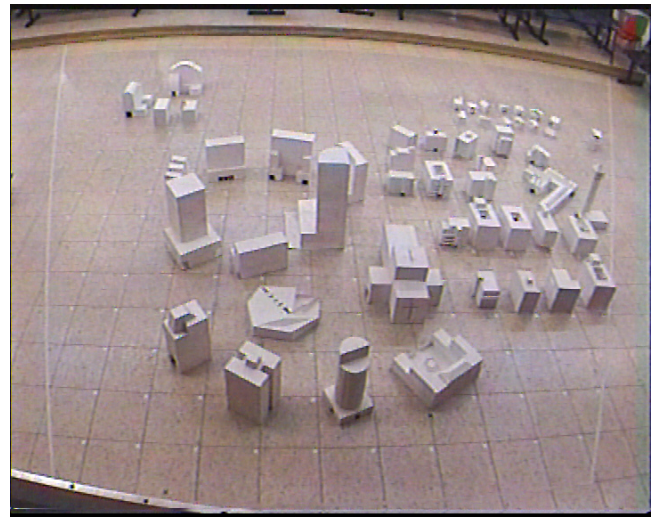
Four typical city patterns built in the experiments





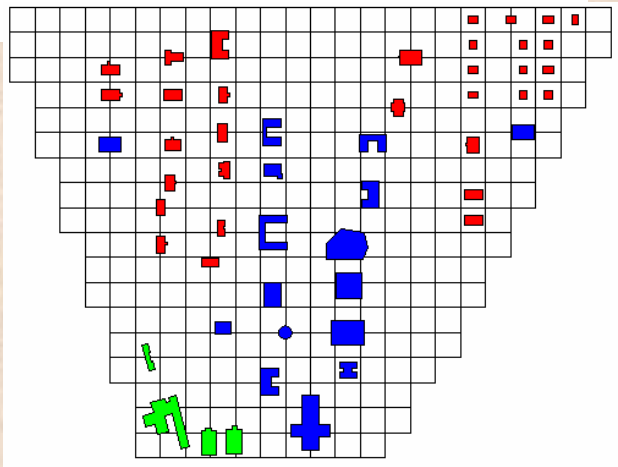


Mapping The Experiments

At each time step the following properties were recorded for the located building :

- Identifier
- Position
- Orientation

Buildings were further represented as features of a GIS layer, thus enabling spatial analysis of the results



Iteration	BuildingID	Cell1	Cell2	Cell3	Orientation	Angle	Building_Type
1	1	6	0	0	180	0	1
2	57	7	0	0	180	0	1
3	28	4	5	0	180	0	1
4	13	47	0	0	225	0	3
5	30	20	45	46	135	0	3
6	38	71	0	0	225	0	2b
7	17	93	114	0	45	0	2b
8	50	11	0	0	180	0	1a
9	54	10	0	0	180	0	1a
10	44	9	0	0	180	0	1a
11	41	9	0	0	180	0	1a
12	4	193	0	0	315	0	4b
13	8	256	0	0	135	0	4c
14	21	271	283	0	45	0	4c
15	5	191	209	0	315	0	3
16	23	37	13	0	270	0	1
17	40	36	0	0	180	0	1a
18	29	35	0	0	180	0	1a
19	53	34	0	0	180	0	1a

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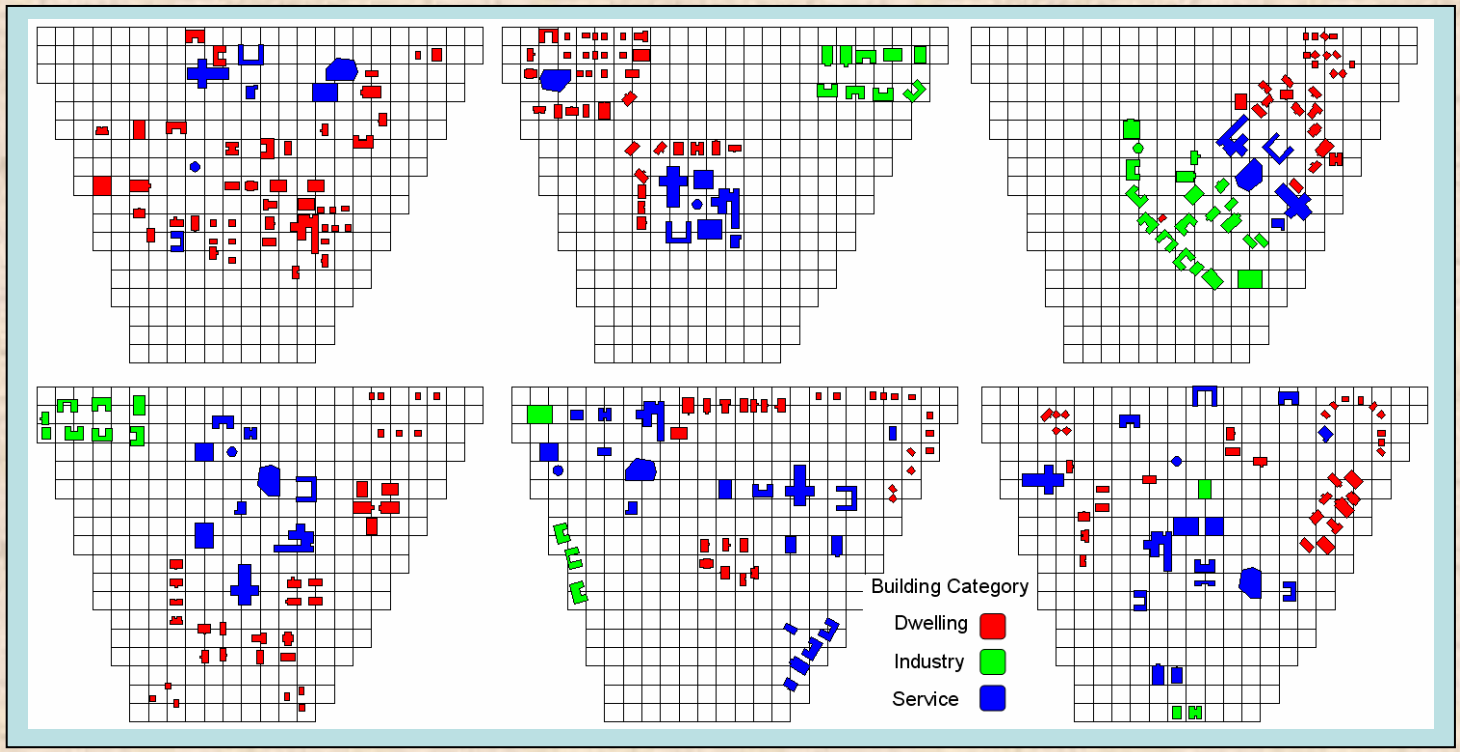
Six typical city maps



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A constant set of shared first-order recursive rules as the null hypothesis

We test whether a constant set of shred first-order recursive rules are sufficient for successful simulation of participants decisions.

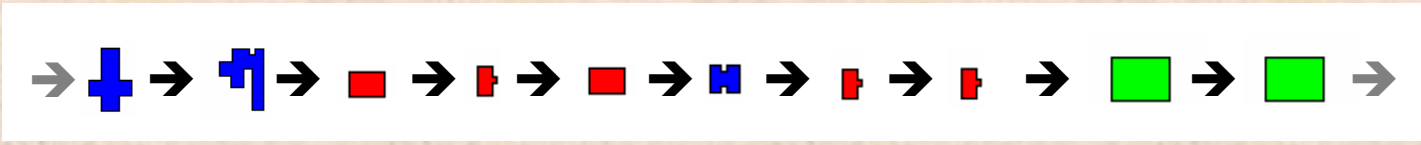
The rules have the following characteristics:

- Used to model all participants decisions
- Remain unchanged throughout the game
- Depends exclusively on the current state of the game.

Analysis of the experiments

Choice of building's urban function – is it a Markov chain?

To verify Markov view of the urban function choice. we have to analyze the pairs of consecutive choices ($F_{t-1} \rightarrow F_t$) .



F_{t-1} \ F_t	Dwelling	Industry	Service
Dwelling	743 (570.8)	54 (115.1)	135 (246.1)
Industry	52 (115.1)	93 (23.2)	43 (49.6)
Service	142 (251.1)	42 (50.6)	226 (108.3)

The data is strongly in favor of the dependence of F_t on F_{t-1} ($\chi 2$ = 556.6, $p<0.001$), with contingency coefficient C = 0.52. We can thus say that the behavior is at least Markov. Is it more complex?

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Choice of building's Location

We describe a buildings' location using:

- its distance to the *nearest buildings* of the three functional types in $\mathbf{pattern_{t-1}}$

- The *angle* ϕ between the building and its nearest neighbor of the same type.

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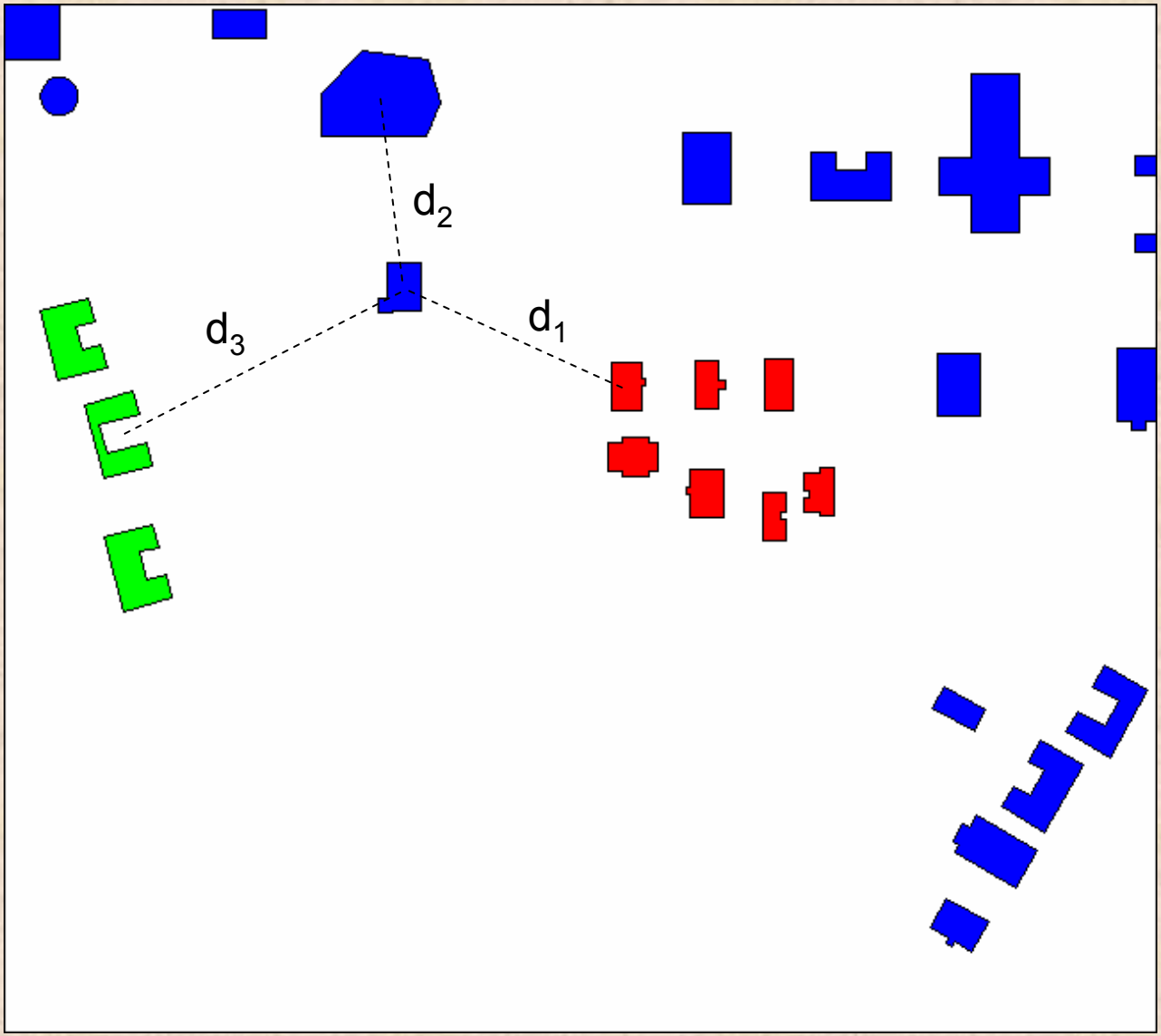
Distances from a given building to its three nearest neighbors



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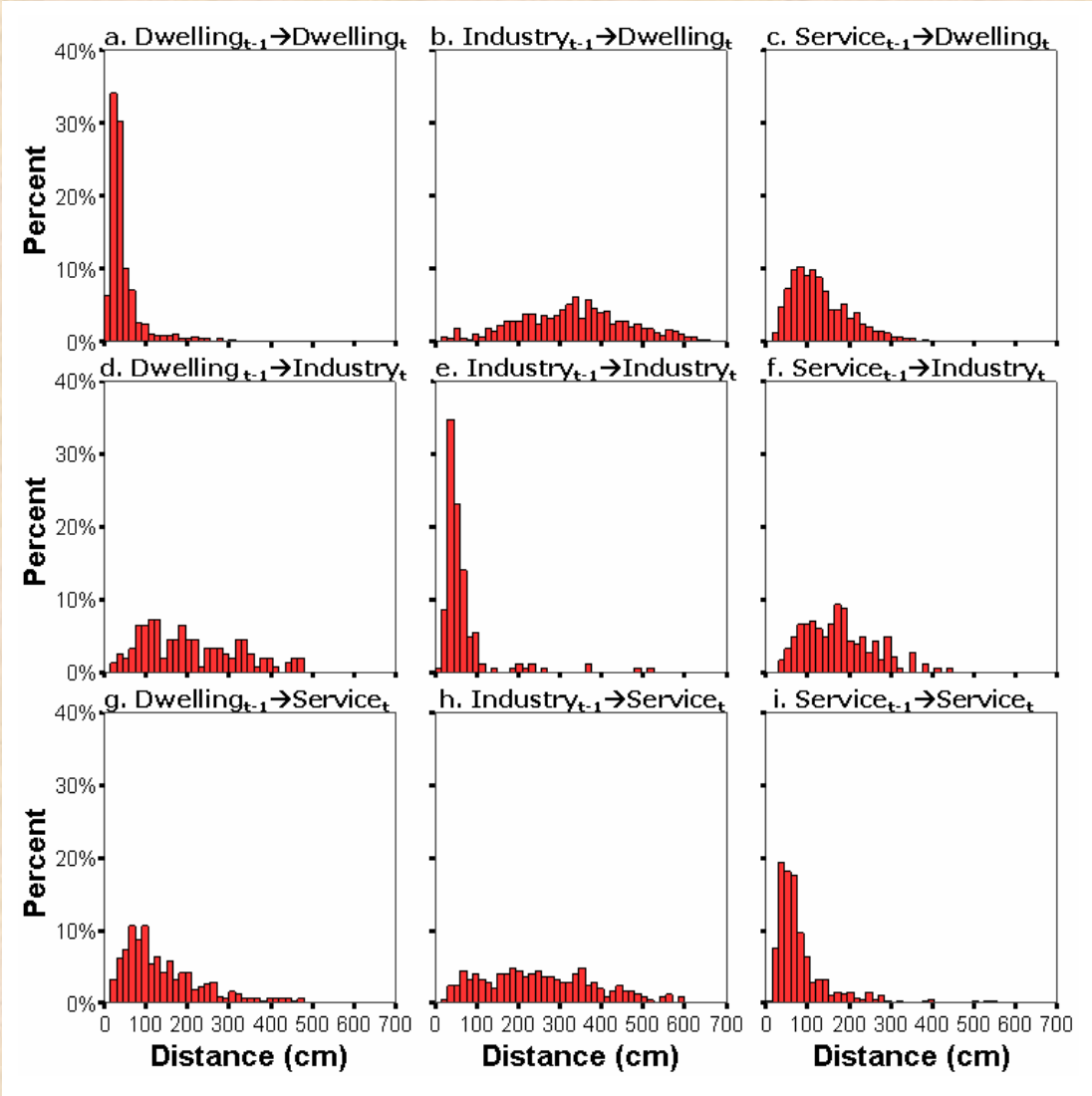
Distributions of distances between nearest neighbors for 52 steps



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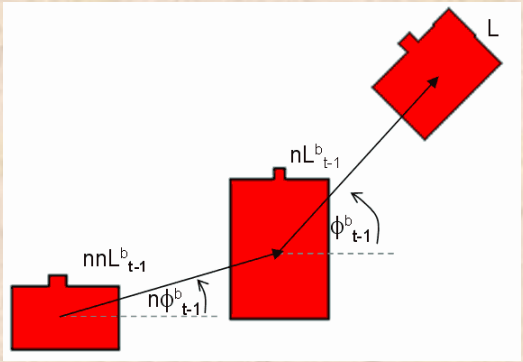
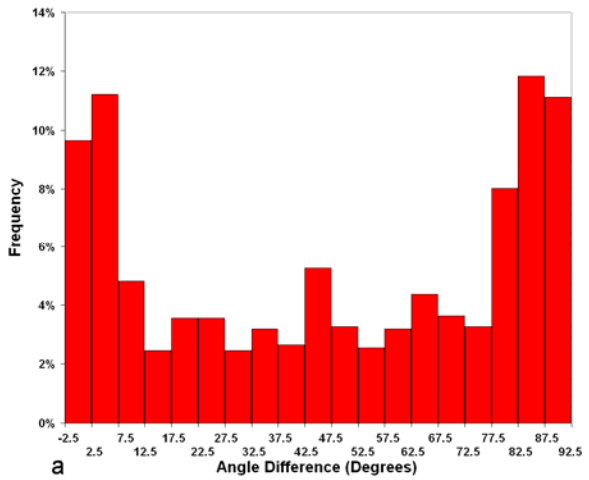
The distribution of direction differences of vectors connecting closest pairs

- The angle choice reflects the participants tendency to arrange buildings in an street like pattern.

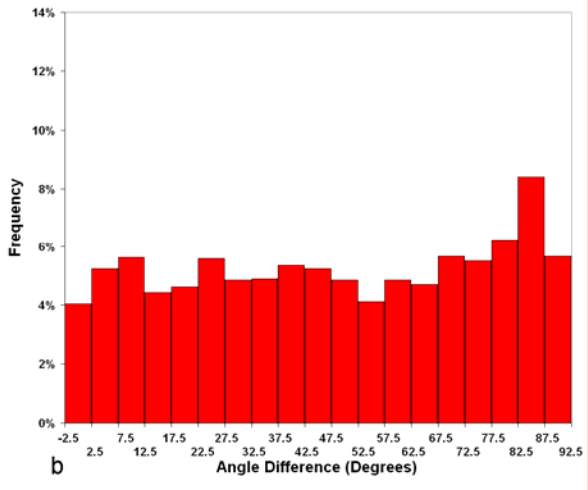


Distribution of the angle Φ

Distances below 70cm



Remaining cases



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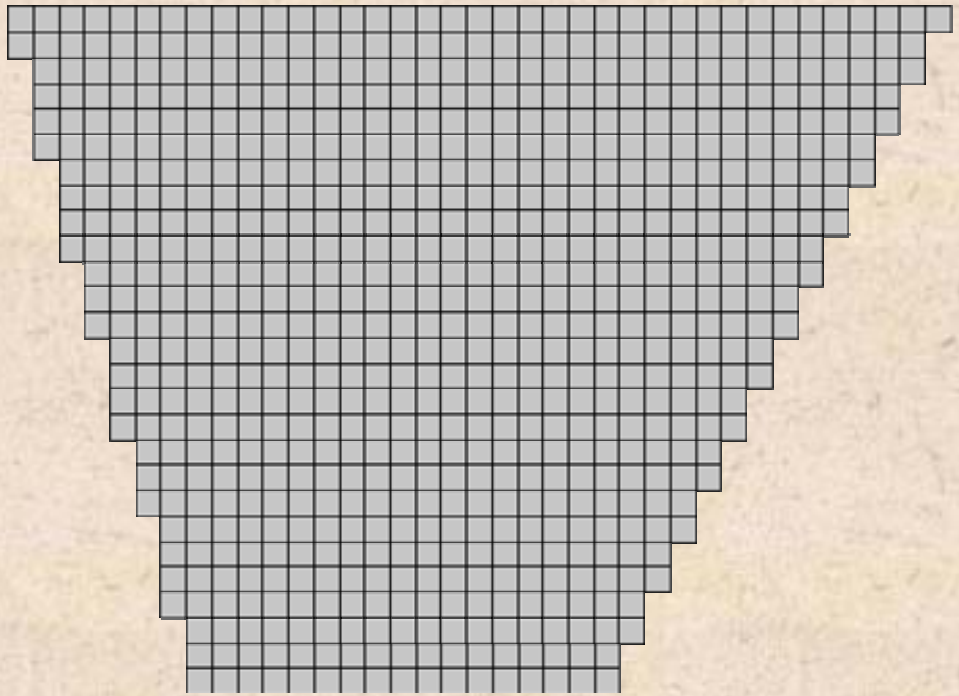
Simulation model of participant’s behavior

Representation of space

•We represent the city space as a trapezoid of cells, each of 20x20cm size, the same as the average size of mock-up foundation.
•Only a single building can populate a given cell



Building's Function Choice Model

Choice of the initial building's function

Building function	Probability to choose at **t = 0**
Dwelling	0.300
Industry	0.067
Service	0.630

Type of the F_t as determined by F_{t-1}

F_{t-1} \ F_t	**Dwelling**	**Industry**	**Service**
Dwelling	0.797	0.058	0.145
Industry	0.277	0.496	0.229
Service	0.346	0.102	0.551

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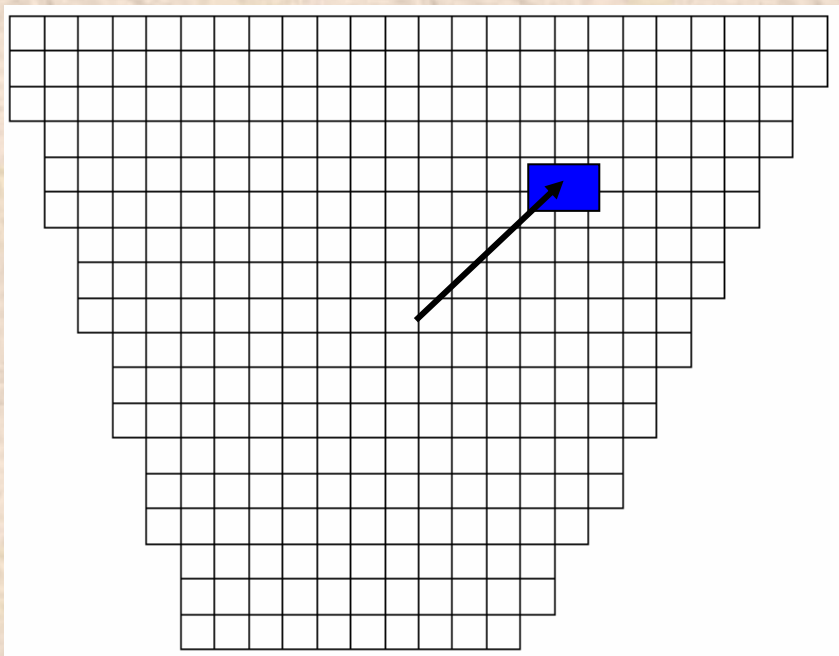
Locating the first building

- We use the center of the trapezoid as a reference point for locating the first building.

- Depending on its functional type, the first building is located according to the distance to the trapezoid center estimated on the base of 30 first steps



Distance from the trapezoid center (cm)	Probability to locate first building at the given distance		
	Dwelling	Industry	Service
0 – 25	0.00	0.00	0.50
25 – 75	0.22	0.00	0.30
75 – 175	0.22	0.00	0.05
175 – 275	0.33	0.50	0.05
above 275	0.22	0.50	0.10

Modeling building location

- For each empty cell, calculate three distance potentials based on the type of building and $Pattern_{t-1}$.
- For each empty cell, calculate angular potential based on $Pattern_{t-1}$.
- The product of the three distance potentials and the angular potential is calculated, and the resulting values are normalized
- A location is selected according to the normalized value of utility.

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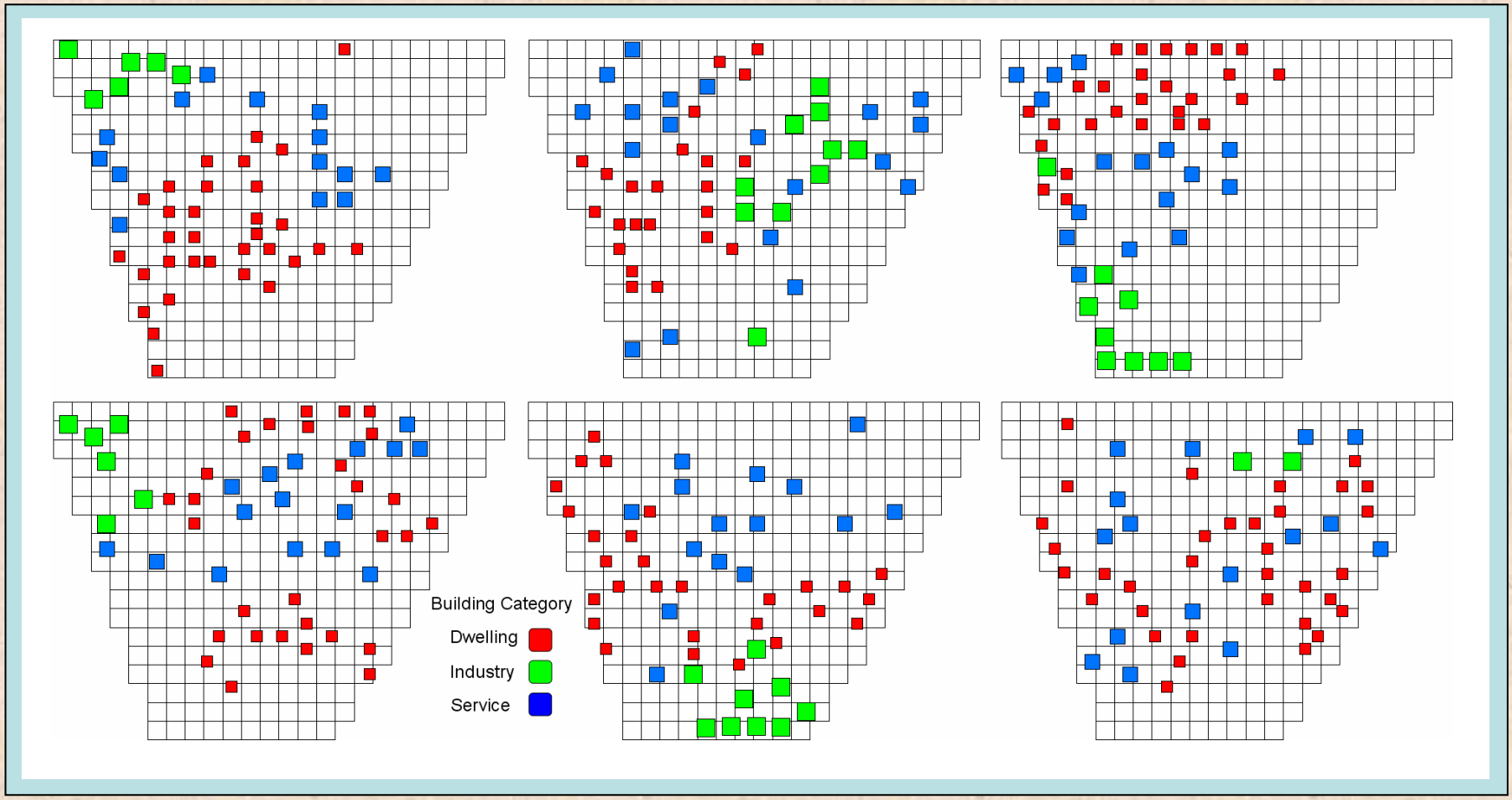
An example of six model generated patterns



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Evaluation of model results

To evaluate the model, we generated 500 city patterns of 52 buildings and additional 500 pattern produced by a “reduced model” and constructed distributions of the distances between each building and its nearest neighbor.

Based on the distributions, the means and STDs of the nearest-neighbor index for the two model and the experiments were calculated

	Nearest neighbors distance constructed in					
	Experiment		Model		Reduced model	
Pair	Mean	STD	Mean	STD	Mean	STD
$Dwelling_{t-1}$ → $Dwelling_t$	30[a]	6[b]	43	4	51	8
$Dwelling_{t-1}$ → $Industry_t$	184[a]	97[b]	153	64	50	14
$Dwelling_{t-1}$ → $Service_t$	112[a]	56[b]	85	19	50	11
$Service_{t-1}$ → $Dwelling_t$	104	41[b]	106	24	80	19
$Service_{t-1}$ → $Industry_t$	131	63[b]	120	46	81	30
$Service_{t-1}$ → $Service_t$	61	14	62	15	84	25
$Industry_{t-1}$ → $Dwelling_t$	280[a]	97[b]	258	59	132	55
$Industry_{t-1}$ → $Industry_t$	58	32	65	37	140	74
$Industry_{t-1}$ → $Service_t$	212	63	196	58	131	55

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Evaluation of model results

•The Mean values of the nearest-neighbor indices obtained in the reduced model significantly differs from the experiments and from the model.

•In half of the cases, the differences between the experimental and model means are insignificant.

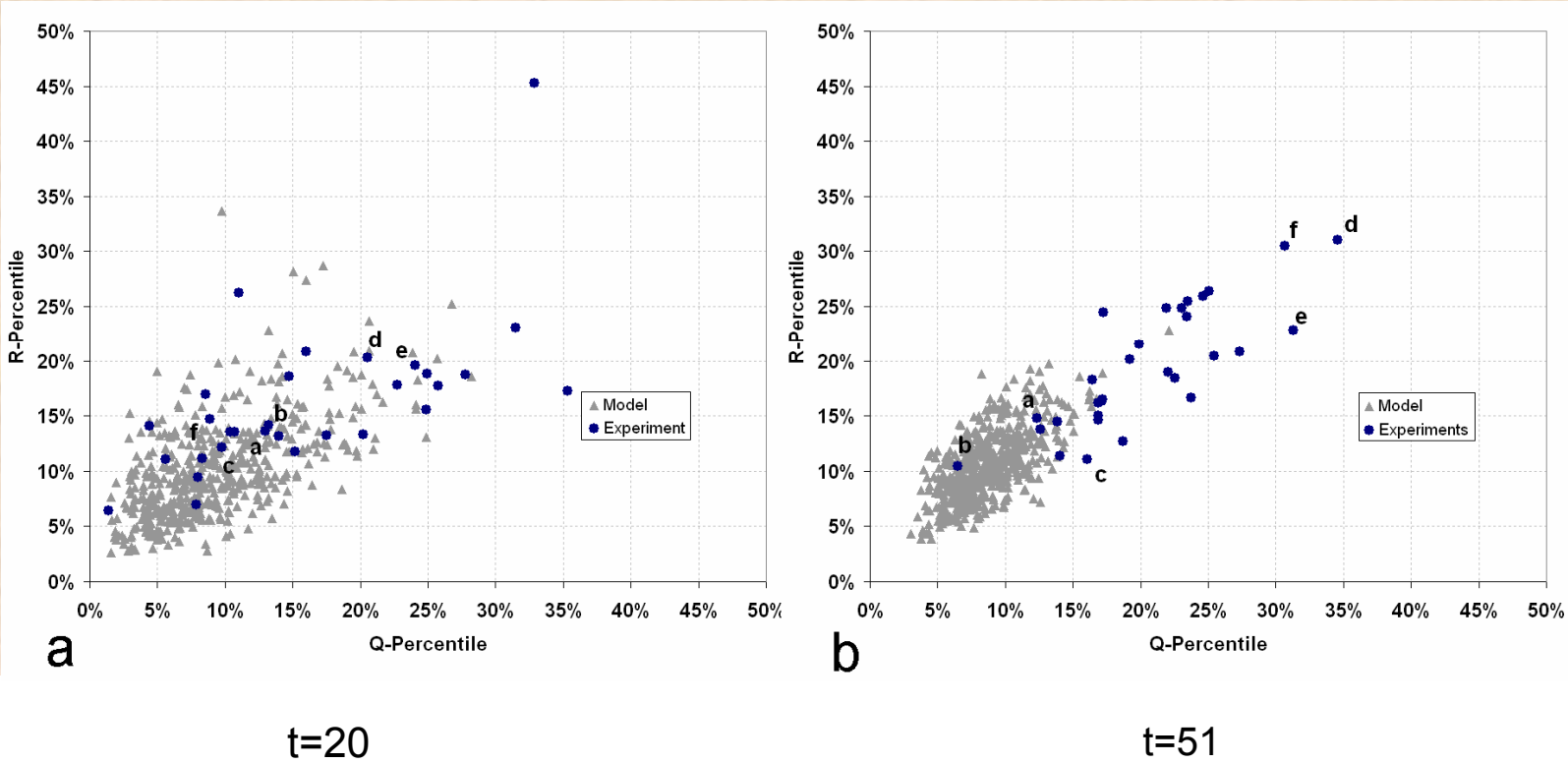
•In all cases excluding one, the differences between experimental and model means are less than 20%

But some disagreements between the model and the game patterns do exist:

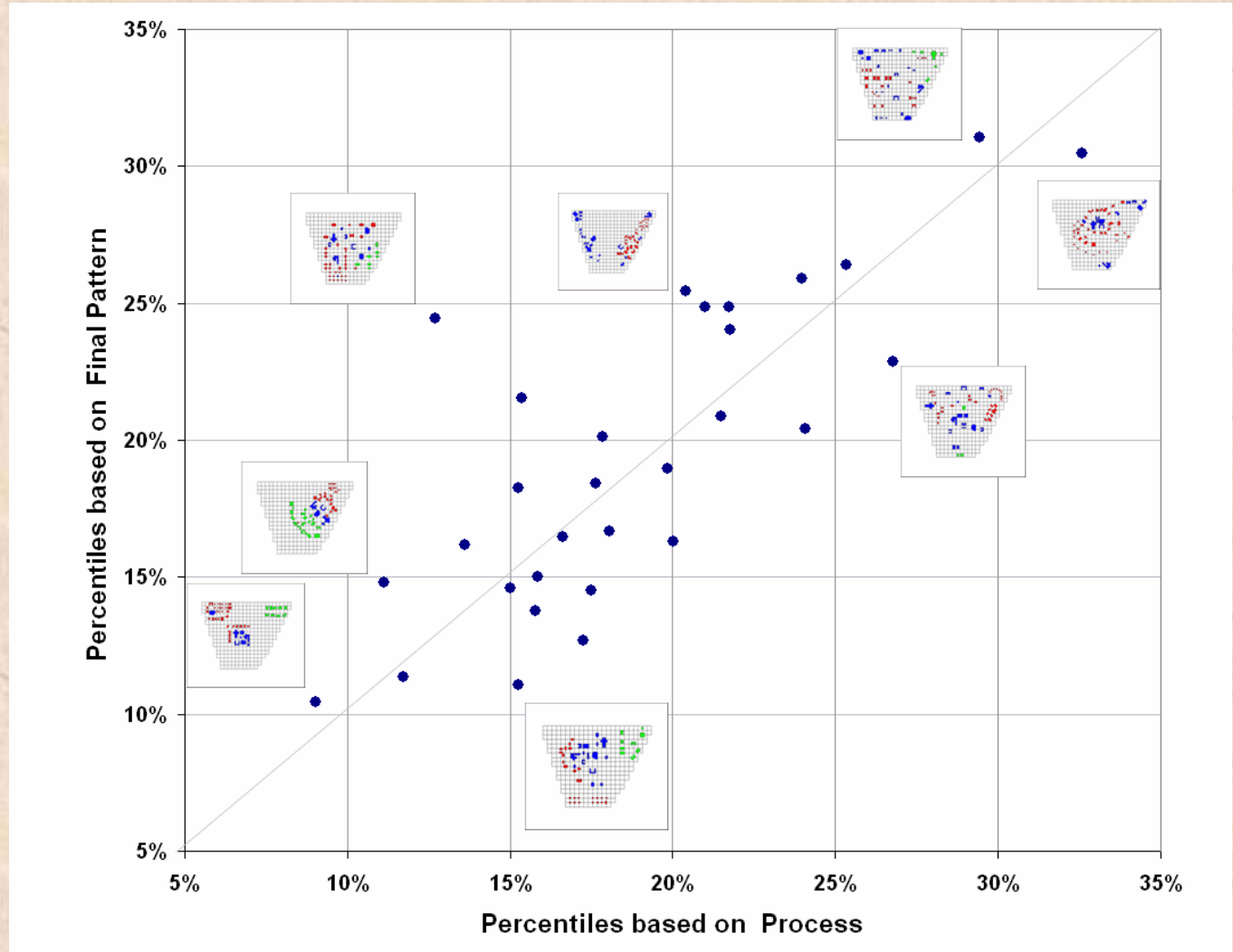
•The test for the hypothesis regarding the Markov chain as the model of choice of mock-up functional type resulted in significant $\chi 2$ values for three-step and four-step histories.

•In almost all cases, the model nearest-neighbor index varies less for the model patterns than for those obtained in the experiments.

Scatterplot (Q,R) at t=20 and t=52



What are the patterns of a model-like participant?



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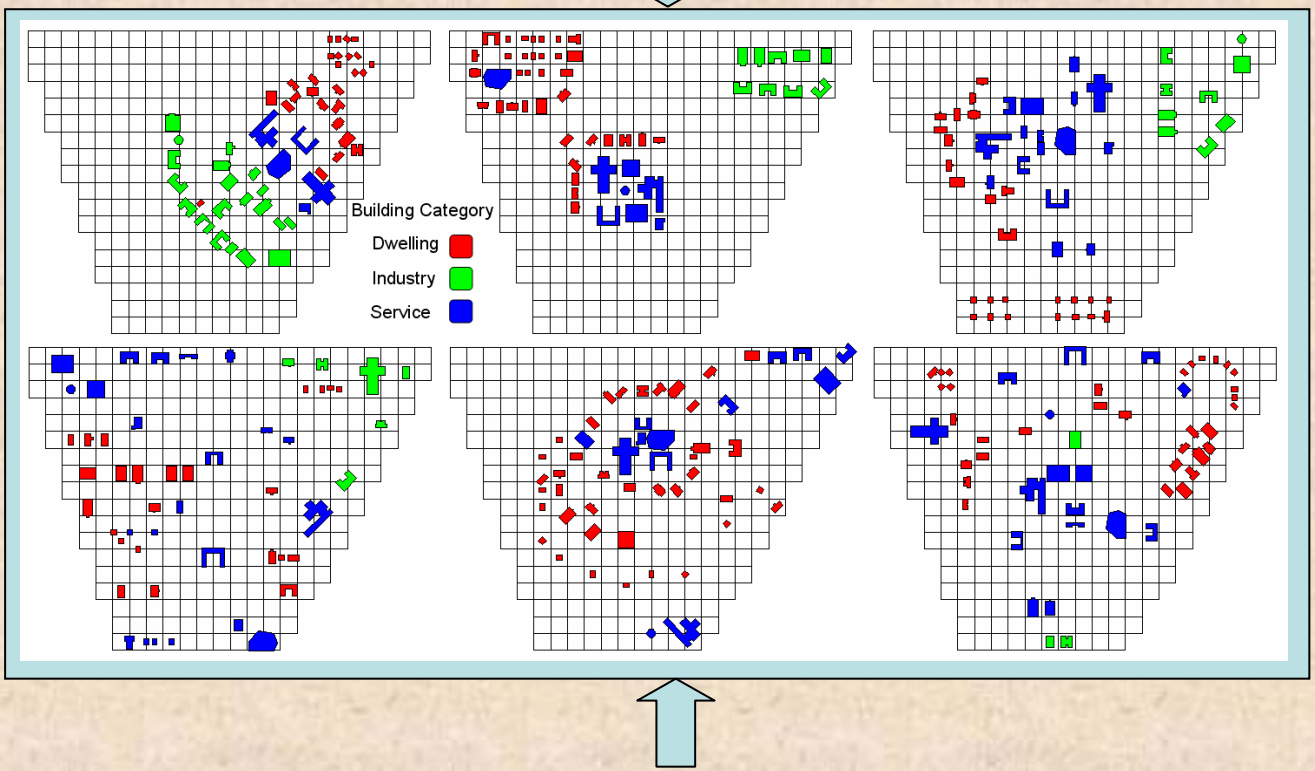
What are the patterns of a model-like participant?

Participants who followed the first-order recursion model



Participants who deviated from the first-order recursion model

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Conclusions

•The game experiments favor the idea of a shared set of rules that can be formally considered as first-order time independent recursion for representing the behavior of the majority of game participants.

•With the increase in pattern complexity, the behavior of some participants tends to deviate from the behavior generated in the model.

•The behavior of some participants tends to deviate from the behavior generated by the model. For some it results in disorganized patterns; for others the patterns remain organized despite behavior that differs from that characterizing the majority

•Studying 30 cities on the floor is the first step. Experimental study of decision-making process of the real developers and planners is necessary.

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A Skyline based ‘City Game’ Platform.

Developed by A.Roz and J.Portugali.