Proceedings of the Ninth International Space Syntax Symposium
Edited by Y O Kim, H T Park and K W Seo, Seoul: Sejong University, 2013

A CONNECTIONIST APPROACH TO PEDESTRIANS MOVEMENT IN URBAN CENTRES

047

Décio Rigatti
Universidade Federal do Rio Grande do Sul
e-mail: driga2000@yahoo.com.br

Fábio Lúcio Zampieri
Universidade Federal da Fronteira Sul
e-mail: fabio.zampieri@uffs.edu.br

Vanessa Dorneles
Universidade Federal de Santa Catarina
e-mail: vgdorneles@gmail.com

Cláudio Mainieri de Ugalde
Universidade Federal do Rio Grande do Sul
e-mail: ugaldeclaudio@yahoo.com.br

Andrea da Costa Braga
Universidade Federal do Rio Grande do Sul
e-mail: andreabraga23@gmail.com

Abstract

Human beings have managed to prosper due to their capability to group on and live in society. Through thousands of years of evolution the humankind have developed their own logic to create and read city patterns. In order to understand how the people really interfere in those space patterns one proposes an urban neural network model for prediction and analysis of the pedestrian movement. The connectionist approach, which has an intrinsically complex nature, can better capture proper variables of the pedestrian movement phenomena in urban cores. The working model was applied in the same manner in two different cities, Santa Maria city and Florianópolis city with a correlation higher than 85% for both. Although, the variables seem to "explain" the movement differently on each case. One believes that this research can support the debate of this issue, and perhaps bettering the understanding of pedestrian mobility.

Keywords: *Pedestrian movement, Urban centres, Artificial Neural Networks, Space Syntax, Urban Models*

Theme: *Modelling and Methodology Developments*

1. INTRODUCTION

Human beings have managed to prosper due to their capability to self-organize and live in society. The evolution has allowed them to build large societies conceived as spatial clusters such as villages, towns, cities and other settlements. Through thousands of years of evolution the humankind have developed their own logic of shape the city and, consequently, to read the existent patterns of urban grid.

What defines the shape of urban space is the means how the agents self-organize themselves by the formation of an arrangement. These groups of individuals, on the other hand, interact among themselves with a greater or lesser degree of aggregation and/or segregation. The agents needs and the existent characteristics are inequitable and consequently generate tensions between the society and the urban space, lead to city changes through the specifically local intervention and, also, land use regulations, among other actions. Thus, the society expectations, related to the urban morphology performance, are the real determinations of the city spatial shape. Understanding the shape of the city one can comprehend the society that has created it (Holanda 2002).

Each individual has a degree of space interference, contributing with his own individual characteristic to the group and, consequently, changing the city. Collaborations are limited by simple social rules, written or not, thus, emerging complex global patterns in the city which are understood by for the moving people in the space. Castelfranchi (1998) supports the idea that one should not diminish the social actions as several individuals actions taken as a collection, because this way one can miss the real contribution of the joint social action, as the cooperation, the competition, the group formation, the organization, among others.

The social implication of the own space production reverberates in the society and the power relations among forces, which generate the urban space and seem to feed back. The city seems to be eternally incomplete, always in a construction and modification state. The relation between the construction of the space and the society condition the people's behaviour and can be explicated by urban grid characteristics by The Space Syntax theory and was described in this manner by Holanda (2002) "The Space Syntax focus efforts in aspects denominated co-presence looking for therefore, to understand how the architectonic space interferes in the way how the people walk, stop, meet each other, how space conceptualizes itself as creator and regulator of behaviour.

The social structure formed by several kinds of human actors involved, their relationships and the rules that govern them can directly influence the urban and social phenomena, such as the pedestrians movement. This is a phenomenon where the patterns emerge from the effects of the complex interactions among individuals due to their restrictions/facilities given by environment where they walk (Ormerod 2005).

In this study, one does not want to understand how dynamics of social groups and their relationship create social patterns found in the cities. One seems to realize how these patterns affect the formation, and consequently, the use of the urban public spaces and built environment by the repercussions of the social patterns in pedestrians movement. One does not want to know whether by walking the pedestrian uses simple cognitive process or not, if they plan to optimize their routes searching for the better way to find a destination. Merely, one wishes to discover how the pedestrians movement, the most basic human movement, can receive pressure by social groups, which build and modify their environment.

Therefore, the objective of this work is to evaluate the pedestrian behaviour from the use of the pedestrian facilities making a relation between the choice and the characteristics of the urban grid and, also, the sidewalk performance measure itself.

2. LITERATURE REVIEW

To understand the immanent logic in the pedestrians movement phenomena one needs to find a way to relate the space attributes where they are found and compare them. The model creation helps to understand this behaviour, because it allows easily visualization as the attributes variation can change the studied phenomenon.

2.1 Forecast models versus simulation models

The big question about urban models is: How knowledge can be acquired thought model? If urban grid is a product of a social group interaction, the model can learn how inhabitants behave reading these underlying patterns. To learn how movement pattern works it is not relevant because of the movement itself, but by its meaning to the city.

Currently, there are models able to explain pedestrians behaviour, or part of them, using well grounded theories, yet with different approach. One highlights here two major groups shaped by traditional models and another one, which are the next generation of urban models. The reductionism existing in the traditional models, where the goal is to simplify the studied phenomenon the most, using linear methods, which are completely different from the new modelling techniques, which seek to evaluate the phenomena by a bottom-up parallel approach.

The majority of traditional models about pedestrian use the linear regression techniques linking the theory with the study object to understand the pedestrian flow. According to Helbing et al. (2001) this methodology is not appropriated because the linear approach has low correlation capability in differentiated environments. Another problem of the traditional models is that the agents that affect the pedestrian flow are usually aggregated as a whole, assuming that one single kind of rational behaviour makes all the decisions to minimize the costs and maximize the benefits (Briassoulis 2008, 22).

The new pedestrian models use the complexity theory to create models of parallel processing, working with several elements of the model in the same time, doing their predictions over simulation. In this kind of model, several local rules emerge creating a global complex pattern. These methods do not search for the prediction of the phenomenon itself. The prediction is applied to hypothetic events that happen in the model simultaneously and allow understanding the role of the variables included in simulated scenarios. According to Johnson (2008, 525) “The only known approach to predicting future states of such systems is simulation”.

Therefore, the simulation is an indispensable tool to understand the complex social systems and, according to Briassoulis (2008, 19) “CS models employ simulation to articulate and reproduce sociospatial system characteristics such as self-organization, learning and adaptation through positive feedback, multiple equilibria, path dependence, and emergence.” In the new models the prediction is developed with qualification purpose and are defined to help understand the discussion structure, type scenarios “what if?” are made to evaluate possible future states.

According to Popper (1994, 166) the complex models are more necessary in social sciences, because on the contrary of the nature ones, they are not predictable with Newtonian explication and prediction methods of unique events by universal laws. Although recognizing that the world is complex, there are ways to capture social reality in a proper means. To build models require a simplification in an embracing condition to reduce the phenomenon without reducing their complexity (Briassoulis 2008). Though the complex system models, like the traditional type, where reductionism cannot be avoided, they can work with larger variable numbers, incomplete data and the several dimensions of sociospatial systems.

2.2 Connectionist approach

The Artificial Neural Nets (ANN) are a computational mode based upon biological neural nets of the brain. The first artificial model of a biological neuron came from a work of two researches, Warren McCulloch e Walter Pitts, in 1943, called: "A Logical Calculus of the Ideas Immanent in Nervous Activity". They are not algorithms and, also, not grounded in programs or specific rules. The ANN are composed by nodes, or artificial neurons, are disposed in one or more layers interlinking themselves by a large number of connections working almost always in an unidirectional way. To a greater efficiency of the model, each one of their connection is associated to "weights", storing knowledge and serving as pondering from each input received by the neurons forming the network. Thus, the ANNs assign to examples a relatively great importance:

> "In connectionist models there is only one level, that of the neurons and their weights. Instead of an 'active' program and 'passive' data, you have numerical weights that are dynamically adjusted through interaction. Instead of a program you have memory." (Cilliers 1998, 19)

Since early 1990, ANNs are introduced as an alternative to traditional modelling, achieving great results with less data samples. Tillema, Zuilekom, and Maarseveen (2006) compare a traditional gravitation model and another one, developed with Neural Networks to evaluate the trip distribution. The authors found that both of models have the same performance with plentiful number of data. Otherwise, when the data are limited, the neural network models always show the best results. Another featured fact was that the ANN was able to correct assign trip distribution decay, when the distance between generate poles are lesser, considering motorized transport. This study was important for considering a way to evaluate different methods, thereby creating a plausible comparison.

The difficulty generally found in the study of pedestrian movement is the option of using simple but limited theories over other ones, which are complex and nonlinear, but more suitable, due to their complexity level and the limitation degree in the understanding of the phenomenon pattern. The problem of pedestrian movement analysis by the models approach that explore the complexity, lies on lack of tools that simulate the pedestrian movement change from urban environmental alterations, which can validate such changes by real data analysis. The neural nets offer a means to solve these questions by a connectionist approach, i.e. where the variables behave like nodes in a widely connected network.

The interesting thing to work with ANN is the possibility of practical confirmation that certain complex phenomena can be explained by certain kinds of urban agents and / or spatial patterns. In the field of urban planning, constantly one seeks to associate phenomena and patterns to their causes, to intervene in space, improving conditions for users. Thus, the public administration can better negotiate with social groups if they know how the claimed modifications or proposals will materialize in the city by the appropriation of the remaining population. It is known that degraded areas where people do not enjoy staying or wandering, tend to get marginalized decreasing the value of land use and creating a social problem.

2.3 Model variables

In many cases the observations are mapped and the theory is expressed as a deduction. In artificial systems, the designers define which 'parts' and which 'whole' are presented in the simulated system and how they are configured. In this research one uses the variables found in the literature that have correlation with the studied phenomenon. However, the configuration of the resulting neural system will not be configured in any way, it will emerge by the interaction of connections among the artificial neurons and, also, due to error backpropagation algorithm, allowing neural net to learn the implicit rules of the studied system.

According to Briassoulis (2008), the complex social systems are still "black boxes" that need time and specialization to be understood and checked in comparison with the reality. In this point the ANN bring a wide advantage in contrast to other complex system methods, because they are trained and validated from real data. Furthermore, ANN have many types of analysis techniques that allow to understand the studied phenomenon and, even if not fully understood, can be evaluated and tested through the scenario creation 'what if?' that permits evaluation possibilities of future outlooks, but it does not isolate variables.

The methodology aims first to evaluate the role of pedestrian flow as a by-product of society and thus demonstrate these relationships. To do so one will use the methodology proposed by Zampieri (2006) with adaptations to fit the case study. The proposal is to create pedestrian flow models with the city data and to evaluate their performance through their coefficients of correlation and statistical errors. In short, this methodology acquires the syntactic variables from axial map jointly with the attractors area (m^2) linked to each sidewalk and, also, its quality, hence, each pathway can be compared together, regardless the studied system. Because all data are with the variables in the same unit, the sidewalk, they can be processed with any statistical method. The models used in this research, were developed with the methodology presented by Zampieri (2006) and employ spatial attributes related to space syntax (Hillier et al. 1993) and level-of-service of the sidewalks (Khisty 1994). The analyzed attributes work as inputs of the model and are processed by artificial neural networks using the mean of the pedestrian flow as the output. Each one of the models consists of 17 input variables, being 10 syntactic: (1) global integration (Rn), (2) local integration radius 3 (R3), (3) control, (4) connectivity, (5) depth, (6) constitutions, (7) residential attractors, (8) commercial attractors, (9) service attractors, and (10) another attractors; 7 of performance: (11) width (12) length (13), attractiveness (14) comfort (15) maintenance (16) security (17) public safety; and one output from each model: mean of pedestrian in movement. The input and output variables were related with the sidewalk (the basic unit of analysis).

The relation between the pedestrian movement and the urban configuration is described in several scientific works of space syntax. Even in early works of Hillier and Hanson (1984) it already becomes clear that the pedestrian movement is largely dependent on the spatial arrangements produced by the society. The space syntax establishes the relations between spatial structure and the social logic of the space. The pedestrian flow explained by urban form, called by Hillier et al. (1993, 32) natural movement "is literally a by-product of a research programme with different aims"; but to discovery this relation, they show somehow, that the pedestrian movement can be fundamental to understand the urban configuration.

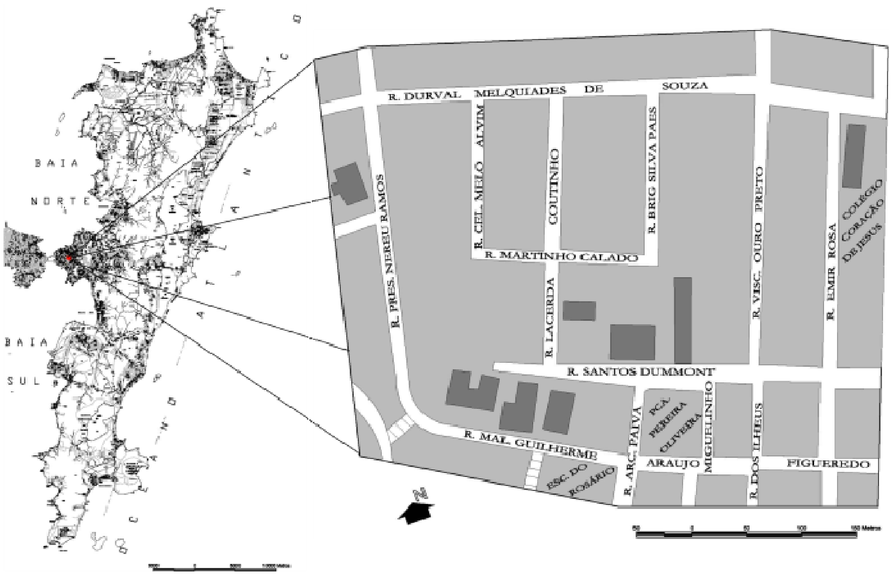
The level-of-service method is interesting by evaluate the local performance from each sidewalk. The pedestrian that moves through a city, also makes decisions based upon the physical characteristics of the path, chosen through the local information, the route that is most comfortable and safe. To evaluate these sidewalks, elements allow identifying how the movement is conditioned by local variables that emerge. This knowledge is passed on to other pedestrians through global patterns disseminated in the urban network.

3. CASE STUDY

To choose the areas study one does not consider as condition the size of the axial system, because according to the space syntax theory the global integration is normalized to enable the comparison among urban systems of different sizes (Hillier and Hanson 1984, 109-113).

In Santa Maria city, the research was made in 2004 and 2005 embracing 74 sidewalks in the central core of the city (figure 1a). Back in Florianópolis city, the research was made in 2008, using a central area with 52 sidewalks.

(a)

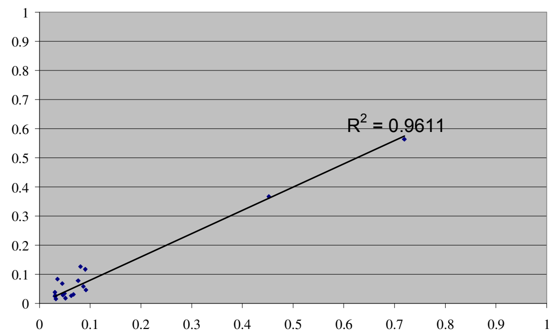


(b)

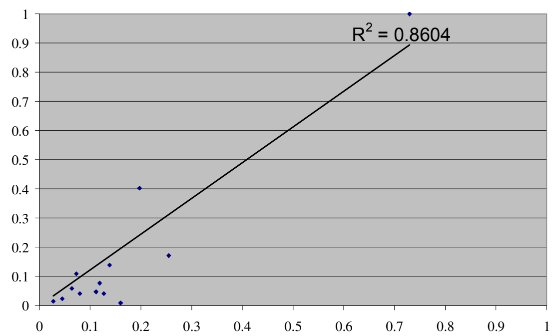
Figure 1: Study area, Santa Maria (a) and Florianópolis (b).

4. RESULTS

The data processing to create the models was conducted through a ANN software and lately by its reproduction in a spreadsheet to each city separately. The model was reproduced base upon the sigmoid function of neurons in a ANN and served to assess its internal structure, the coefficients of determination and the statistical errors. The results were considered satisfactory because the pedestrian model of Santa Maria city has presented a determination coefficient (R^2) of 0,9611 and a mean square error (MSE) of 0,002469; and the pedestrian model of Florianópolis city with R^2 de 0,8604 with a MSE of 0,012438. Both the coefficients of determination and the errors were acquired in the testing phase, i.e., with unknowing data by ANN. From de results, one can infer that the phenomenon could be partly explained by the variables used in the model. At this point it is worth to highlight that each model has its function directed only to the original city in which the field survey was conducted.



(a)



(b)

Figure 2: R^2 between real and simulated data to the models of Santa Maria (a) and Florianópolis (b).

4.1 Garson method

After the creation and evaluation of the models were run procedures to assess the variables performance, such as the weight method developed by Garson (1991) to obtain the magnitude order of the variables weight in the connection among the artificial neurons, and the sensibility method (Lek et al. 1996), in measure empirically how changing the variable values affecting the phenomenon.

When one uses the Garson (1991) method, all the variables, in both models, has presented performances in the same range and none of them has such a great importance that could explain the entire phenomenon itself.

Variable	Santa Maria-RS		Florianópolis-SC	
	Percentage	Ranking	Percentage	Ranking
Integration RN	6.0%	8	4.9%	13
Integration R3	5.2%	11	6.4%	5
Connectivity	7.7%	3	4.7%	16
Control	7.2%	5	6.4%	4
Depth	5.7%	9	8.6%	1
Constitution	5.1%	12	4.7%	15
Residential Attractors	5.3%	10	5.9%	9
Commercial Attractors	7.4%	11	6.4%	6
Service Attractors	3.7%	16	5.9%	10
Another Attractors	8.2%	1	4.7%	14
Width	7.9%	2	5.4%	11
Lenght	4.3%	15	7.4%	2
Attractiveness	5.0%	13	7.0%	3
Comfort	3.5%	17	4.6%	17
Maintenance	4.8%	14	6.0%	8
Security	6.8%	6	5.0%	12
Public safety	6.1%	7	6.1%	7

Figure 3: R^2 Importance of the variables to Santa Maria-RS and Florianópolis-SC in the Garson Method.

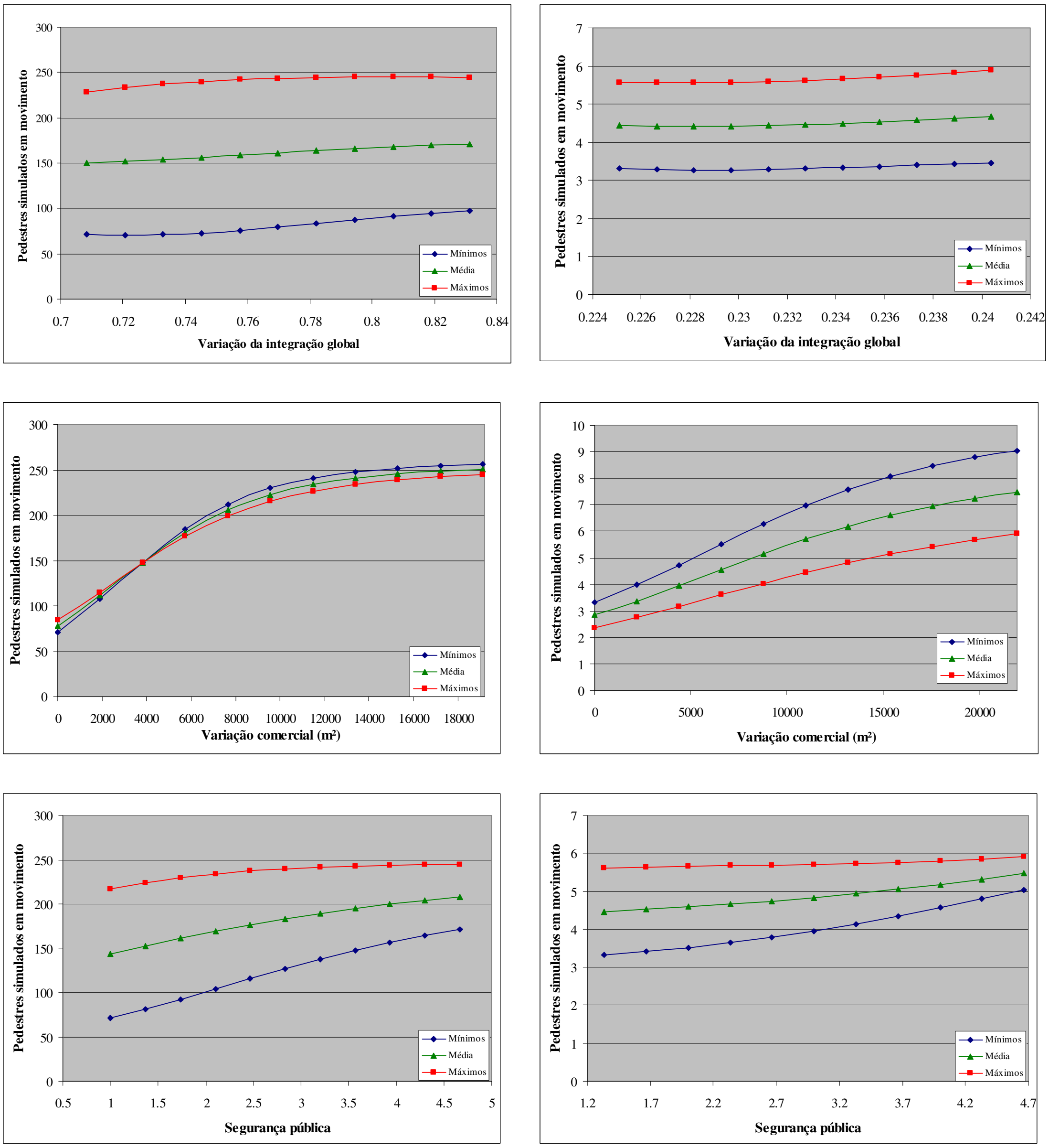
Nevertheless, these methods show no significant correlation between the variables of both cities. This evidences that wherever the generating social strength of the urban grid has been, operated in different way in each one of them. The complexity indicates that in certain way, the variables responsible for a phenomenon may be the same, but when employed with different arrangement may create different results. The patterns found in a phenomenon will be replicate differently, because each society is formed for unique forces, but based upon the same simple rules; as explains Hayek (2002, 56):

> "If I tell somebody that if he goes to my study he will find there a rug with a pattern made up of diamonds and meanders, he will have no difficulty in deciding "whether that predict was verified or falsified the result," even though I have said nothing about the arrangement, size, color, etc., of the elements from which the pattern of the rug is formed." (Hayek 2002, 59)

Thus, the movement pattern apparently could be explained by the variables used in the model, but in a different manner in each city.

4.2 Sensitivity analysis

After the use of Garson method one question still remains: what is the true participation of the variables to the pedestrian movement? To answer that question one can uses a method known as sensitivity analysis, which evaluates the answer given for each variable in three hypothetic systems. To do it, one sets the variables in arbitrary values (in this case, minimal, average, and maximum values), while the variables contribution that one wants to test is changed at regular intervals between the minimum and maximum values, for a total of eleven equally spaced values (Lek et al. 1996). This procedure was realized to each one of the 17 input variables, which resulted in majority in a similar performance. To demonstration purposes are presented three comparative graphs of space syntax variables – Global integration, land use – commercial attractors and performance measures – public safety.



(a) (b)

Figure 4: Graphs of sensitivity analysis of global integration, commercial attractors and public safety variables to Santa Maria-RS (a) and Florianópolis-SC (b).

Although the variable graphs in both cities do not show the same values, their pattern is very likely, revealing how the variables can structure the urban space and condition the pedestrian behaviour and, somehow, its movement. The cities are different; created by social structures that form spaces for themselves in a different way, so the product found, the pedestrian movement, is also different. However, as different as that social structures can be, the pedestrians seem to read the patterns of the urban space by the same simple rules, varying over them.

5. DISCUSSION

The pedestrians are social agents because in the same way they interfere and depend on each other and the social outcomes of the environment. Sociability implies two or more social agents that interact in the same environment and with a possibility to interfere in the action and the objectives of the other, either positive or negative way. Thus, even an individual has the power to ease the movement of the other, the possibility exists that a third person also intervenes, preventing any form of movement, by their action or a lack of them.

The interference and dependence create patterns that emerge of the system either individual know or not of their existence. These patterns or part of them, become known by the individuals through the reinforcement learning (trial and error) or understanding (the capability to learn with positive outcome of another individuals). From this process emerges the notion of transformation in the individual who set goals and objectives, passed through their actions to others in the group creating a social action. These new goals change the relationship types and strengthen the dependencies on individuals. According to Castelfranchi (1998, 1568) “Without the emergence of this self-organising (undecided and non-contractual) structure, social goals would never evolve or be derived”.

The capability of ANN to extrapolate the data and make correspondences using a smaller number of data has already been proven by several studies. However, the city of Santa Maria city, which is smaller and had more sidewalks assessed, presented a better result and with less statistical errors. On the other hand, Florianópolis city, which has a larger urban area and population, has showed greater errors and, probably if more sidewalks have been evaluated, probably error would diminish greatly. The next step is to evaluate a system similar to Santa Maria, but with a larger number of sidewalks. This study is already underway, and its results tend to corroborate the previous studies. The ultimate goal of the research is getting data from various cities to create a more general pedestrian model that can be applied to several distinct realities without such a long step of data collection.

ACKNOWLEDGE

We’d like to thank the financial support given for this research provided by CNPQ and FAPERGS fostering agency. Without their support this work could not be possible.

REFERENCES

Briassoulis, Helen. 2008. "Land-use policy and planning, theorizing, and modeling: lost in translation, found in complexity?" *Environment and Planning B: Planning and Design* 35:16-33.

Castelfranchi, Cristiano. 1998. "Modelling social action for AI agents." *Artificial Intelligence* 103(1-2):157-182. doi: http://dx.doi.org/10.1016/S0004-3702(98)00056-3.

Cilliers, Paul. 1998. *Complexity and Postmodernism: Understanding Complex Systems:* Taylor & Francis.

Garson, G. David. 1991. "Interpreting Neural-network Connection Weights." *AI Expert*: 47-51.

Hayek, Friedrich Von. 2002. "The theory of a complex phenomena." In *Readings in the philosophy of social science*, edited by Michael Martin and Lee C. McIntyre, 55-70. Cambridge, Massachusetts: MIT Press.

Helbing, Dirk., Péter Molnár, Illés J. Farkas, and Kai Bolay. 2001. "Self-organizing pedestrian movement." *Environment and Planning B: Planning & Design* 28:361-383.

Hillier, Bill, and Juliene Hanson. 1984. *The social logic of space*. Cambridge: Cambridge University Press.

Hillier, Bill., Alan Penn, Juliene Hanson, Tadeusz Grajewski, and Jinxi Xu. 1993. "Natural movement: or, configuration and attraction in urban pedestrian movement." *Environment and Planning B: Planning and Design* 20:29-66.

Holanda, Frederico De. 2002. *O espaço de exceção*. Brasília: Editora Universidade de Brasília.

Johnson, Jeffrey. 2008. "Science and policy in designing complex futures." *Futures* 40(6):520-536.

Khisty, Cristine Jotin. 1994. "Evaluation of Pedestrian Facilities: Beyond the Level of Service Concept." *Transportation Research Record* (1438):45-50.

Lek, Sovan., Marc Delacoste, Philippe Baran, Ioannis Dimopoulos, Jacques Lauga, and Stephane Aulagnier. 1996. "Application of neural networks to modelling nonlinear relationships in ecology." *Ecological Modelling* 90(1):39-52.

Ormerod, Paul. 2005. "Complexity and the limits to knowledge." *Futures* 37(7):721-728.

Popper, Karl Raymund. 1994. "Models, instruments and truth - the status of the rationality principle in social sciences." In *The myth of the framework : in defence of science and rationality*, edited by Karl R. Popper and Mark Amadeus Notturno, xiii, 229 p. London ; New York: Routledge.

Tillema, Frans., Kasper M. Van Zuilekom, and Martin F. A. M. Van Maarseveen. 2006. "Comparison of Neural Networks and Gravity Models in Trip Distribution." *Computer-Aided Civil and Infrastructure Engineering* 21:104–119.

Zampieri, Fábio Lúcio. 2006. *Modelo Estimativo de Movimento de Pedestres Baseado em Sintaxe Espacial, Medidas de Desempenho e Redes Neurais Artificiais*. Dissertação, PROPUR, UFRGS, Porto Alegre.