A Fuzzy Cognitive Mapping Approach for Housing Affordability Policy Modeling

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Abstract: - Considering the Fuzzy Cognitive Map's potential to be used in the policy modeling, this paper applies Fuzzy Cognitive Map (FCM) in the field of housing, in order to help policy maker to decide the best policy in supporting the Housing Affordability.
FCMs are capable of participative process, mapping, analysis, modeling and scenarios in terms of significant events or factors, named concepts and their cause-effect relationships.
Our approach is based on examining the perceptions of different stakeholders groups on housing affordability policy issues, in order to facilitate the development of a comprehensive housing policy modeling. Within this process, we propose to quantify the subjective perceptions of the different stakeholder groups, using FCM methodology, generally known as suitable tool for livelihood analysis.
This paper presents a FCM approach used into FUPOL project (www.fupol.eu) financed by FP7 Program. The FUPOL project proposes a comprehensive new governance model to support the design of complex policies and their implementation, to further advance the research and development in simulation, urban policy process modeling, semantic analysis, visualization and integration of those technologies.

Key-Words: - Housing policy modeling, Housing Affordability Policy, Fuzzy Cognitive Map, subjective perceptions, FUPOL.

1 Introduction

1.1 Housing Affordability Policy Model

It is well known that local officials in city governments need to develop a comprehensive housing policy to guide their current and future housing–related decisions in the context of a specific community that often face different issues. Access to affordable housing is an essential prerequisite for any community based on humanitarian principles.

It is widely recognized the importance of the community perception. Local people and other stakeholders trust in the FCM scenario analysis process as being participants in the process and understand to relate the outputs generated by the FCM, with different goals that to be take in account:

-to provide guidance regarding the type, number and location to build across their service area in order to identify and design policy directions for affordable housing

-to help clients/households make relocation decisions, housing choice, etc.

-to assign production levels for affordable housing and construction technology requirements regarding housing projects development

-to optimize social impacts of affordable housing policy (social efficiency and equity measures)

-to generate promising forecasting models for use at municipal/regional-level planning models for allocations or subsidized housing across a large study area

-to better understand the nature of local housing markets

The Housing Affordability model includes stakeholder groups representing households, affordable housing providers (public housing authority, municipal housing administrators) and private housing builders.

Our research includes examining the perceptions of different stakeholders about housing affordability and facilitates the development of policy modeling based on the multi-step FCM analysis presented in detail in (Özesmi 2003).

1.2 Cognitive Maps and Fuzzy Cognitive Maps

Cognitive maps are qualitative models of a system, consisting of variables and the causal relationships between those variables. FCMs integrate the cognitive maps of accumulated experience and knowledge concerning the factors and the underlying causal relationships between factors of the modeled system. Kosko (1986) modified Axelrod's cognitive maps, which were binary, by applying fuzzy causal functions with real numbers in [−1, 1] to the connections.

Variables can be physical quantities that can be measured. The decision-makers' maps can be examined, compared as to their similarities and differences, and discussed (Özesmi 2003). If some groups perceive more relationships, they will have more options available to change things.

Based on experience and knowledge of the system under consideration, responsible person with design of the cognitive map, decides the important factors that affect a system and then draws causal relationships among them indicating the directions of the causal relationships with arrowheads, and the relative strength of the relationships with a number between −1 and 1. More simulations are done to learn how the model changes with changing strengths of relationships.

FCMs have a wide field of application, such as: modeling intelligent systems (Jang et al. 1997), decision analysis (Khan et al. 1999), graph behavior analysis (Hagiwara 1992), social systems modeling (Taber, 1991,1994), organizational behavior (Craiger and Coovert 1994), virtual worlds (Dickerson and Kosko 1994), supervisory systems modeling (Groumpos and Stylios 2000; Papageorgiou et al. 2004a), decision-making medical field (Papageorgiou et al. 2003b; Parsopoulos et al. 2004), (Papageorgiou et al. 2004b, 2004c), demographics models (Schneider et al. 1998), ecological systems modeling (Hobbs et al. 2002), (Özesmi 1999a, b).

Jean-Luc de (Kok 2000) is among the few people who applied FCM in the policy analysis to predict urbanization.

FCMs are designed by experts through an interactive procedure of knowledge acquisition (Hagiwara 1992; Stylios and Groumpos 2000).

2 Modeling Methodology

2.1 Description of Fuzzy Cognitive Maps (FCMs)

FCM are capable of modeling scenarios where nodes represent concepts, and edges represent causal links among the concepts.

One of the most useful aspects of the FCM is its potential for use in decision support as a prediction tool. Given an initial state of a system, a FCM can simulate its evolution over time to predict its future behavior where the system converges to a point of a certain state of balance.

In terms of the graphical representation FCM is a signed causal digraph with feedback which consists of the following components:

a) Nodes: to represent concepts Ci, i = 1 ... N, where N is the total number of concepts. Each concept/node indicates a characteristic or key factor of the system such as events, actions, and states. Each concept/node it is characterized by a value, Ai ∈ [0, 1], i = 1... N. The concepts/nodes are interconnected through weighted arcs, which significance the relations among them.

b) Edges/arcs: to represent causal links among the concepts.

c) Weights: to represent how much one node influence another. The weight Wij is analogous to the strength of the causal link between two concepts Ci and Cj .

The positive sign of Wij indicates a direct relation between the two concepts that means a positive causality, the negative sign of Wij indicates an indirect relation between the two concepts that expresses negative causality, and Wi =0 expresses no relation. Human knowledge and experience on the system determines the type and number of nodes, as well as the initial weights of the FCM.

d) Activation events at different moment t. The stimulated events can bring changes to certain concepts, edges, or even the overall of FCM.

2.2 Selection of Factors and Causal Relations

This subsection explains the factors used in the model of housing affordability to set later the causal relationships among the factors. Housing affordability policy means the ability to select the location and type of housing that a household can 'afford'. An affordable house, whether rented or owned, is commonly defined as house (including taxes, insurance, and utilities), which does not cost more than a fixed percent (for example30%) of the gross income of a household.

Housing affordability (to buy, rent or build) is affected in principal by *household incomes*, *housing costs*, *supply of housing*, and the *cost of borrowing money*.
Bigger income of a buyer gives him more affordability to acquire a house. *Costs of financing* influence the purchase transaction (include mortgage rate, length of the loan, points, and closing costs).
Home building benefits not only the *trades* but also *manufacturing*, *professional services*, and even *transportation*.
The increase and diversification of *job market* in neighborhood could influence the *household income* and therefore the housing affordability.
One of the key ways to bring housing costs down is to increase *housing density* if *land use* regulations allow.
Educational programs available to assist individuals for families in need of credit counseling can lead to homeownership and also teach them how to take care of themselves financially.
Thus, the relevant factors that will represent concepts in the cognition map, and the relationship between them for the field of housing affordability are grouped in the following categories: Population (Households income, Financial literacy of buyers, Offers of lenders, Community attitudes), Economic (Housing costs, Costs of financing, Costs to build houses, House building, Trades, Manufacturing, Professional services, Transportation, Job market, Demand for new housing), Social-political (Land use regulations, Public services for training and counseling, Educational programs, Local legislation), and Natural changes (Weather, Natural disasters).

2.3 Methodology for Stakeholders Interviews

Generally, the cognitive maps can be obtained in different ways: from questionnaires, by extraction from written texts, by drawing them from data that shows causal relationships or through interviews with people who draw them directly. The fuzzy cognitive mapping approach used in this study may provide insights into different housing scenarios where it is necessary to have the support of local stakeholders.
Here the purpose is to illustrate how to obtain the views of the different stakeholder groups, their differences and similarities about housing affordability. The municipality's officials have come to believe more in the usefulness of participatory processes as they have come to use these results as recommendations in order to support the process of developing a housing policy design.
Interviews have to be conducted with stakeholders belonging to different groups able to participate in the questioning process to find what is perceived as important factors/concepts in the domain of housing affordability. Examples of questions to be used in interviews, in order to design FCM for housing affordability:

a. Categories of questions

Q1: "Have you some experience in buying/renting/building a house in this city?"
Q2: "What are the most important, current housing affordability–related issues in your area of living?"
Q3: "What factors/concepts do you appreciate that make a house affordable?"
Q4: "Do you think that in the last years, in your area of living, the concept of housing affordability has been changed?"
Q5: "Regarding housing affordability, which kind of factors do you think have changed since you started coming here? (population, economic, legislative, natural, etc.)
Q6: "How identified changes did affect you to afford a house?"
Q7: "What were in your opinion the causes of change?"
Q8: "Regarding housing affordability, do you perceive there are some factors/concepts that are being influenced by others? Which are these important concepts in your opinion?"
Q9: "How do you think these perceived important concepts are being influenced by other concepts?"
Q10: "What are in your opinion the causal concepts that could impede a household to 'afford' a house, also meaning location and type?"
Q11: "What are in your opinion the concepts due to which a household could 'afford' a house, also meaning location and type?"

b. Customized guiding questions

During this part of interview process, a guiding question could be systematically asked for each of all indentified concepts, such as:
"Are there any concepts that affect the concept [X]?" and "Does this concept [X] affect any other concepts?" such as "Are there any concepts that affect the house costs?" and "Does the house costs affect any other concepts?"

c. Other Guiding questions

What if more people are coming to live in the city?	*What happens with:*
	- community attitudes? - level of population income?

	- jobs market? - demand of housing? - financial literacy of potential buyers or renters? - offers of lenders?
What if household's income decrease?	*What happens with:*
	- demand for new housing? - public services for training and counseling? - developers for low income households? - builder's profit? - lenders who offer low cost financing? - subsidizes social programs (for first time home buyers, to essential workers, for construction)?
What if costs of financing are increasing?	*What happens with:*
	- families in need of credit counseling? - educational programs available for families in need
What if increase houses building?	*What happens with:*
	- trade? - manufacturing? - professional services? - jobs market?
What if increase demand of houses for low income households?	*What happens with:*
	- developers offers? - offers of lenders? - housing costs? - cost of financing?

The interviewees are asked to list on the paper all concepts identified through previous answers, and to draw lines between them in order to represent the relationships/connections that link each of them.

Then, interviewees are asked to explain the relationships between the variables. They are asked to assign arrows to the lines for indicating their directions. For example, if the interviewee thinks that housing costs decrease housing affordability for buyers, then they would draw a line with the arrow pointing from housing costs to housing affordability for buyers.

Next, the interviewees are asked to label the lines with signs of positive, or negative. For example, if the interviewee thinks that increase housing costs cause substantially decrease of housing affordability for buyers, they will give a value of -1 to the connection.

"How affects these concepts each other (positively, negatively, feed-back mechanisms)? For this purpose, label the lines with signs of positive, or negative."

When conducting group interviews, group dynamics, which can lead to the exclusion of certain elements, have to be considered. Aggregation can also be used to reduce the complexity of large maps.

Independent of what kind of stakeholders are interviewed, there are qualitative concerns such as "what attributes of housing units and neighborhoods are important to me?" and quantitative concerns such as "what is the number of housing units in that development of a certain type of affordable housing?"

2.4 The methodology to assign linguistic weights to causality relationships

FCMs integrate the accumulated experience and knowledge concerning the underlying causal relationships amongst concepts.

After interviewees are asked to label the arrow lines with signs of positive or negative, they are questioned about perceived strengths of the relationship between concepts and are also individually asked to assign to each arc a linguistic weights, such as "strong", "weak", or "lack" "low", "medium", "high" etc. In this respect, the questions use different degrees of comparison to guide interviewees in assigning the corresponding linguistic weights, like in the next table 2.

The degree of causality among the concepts is qualitatively described by linguistic weight, subjective given by words.

Table 2 Question degrees and linguistic weights

	Linguistic weights					
	Question degrees					
Fuzzy weights	**How many?**	**How often?**	**How level?**	**How much?**	**How big?**	**How strong?**
1.00	all	always	highest	most	biggest	strongest
0.80	much more	very often	very high	very much	very big	very strong
0.70	more	often	high	more	big	strong
0.60	moderate	usually	medium	much	medium	moderately strong
0.50	some	some times	low	little	small	weak
0.40	fewer	a few times	very low	less	very small	very weak
0.20	a few	rare	lowest	least	smallest	weakest
0.00	none	none	none	none	none	lack

2.5. Drawing Fuzzy Cognitive Maps

2.5.1 Transformation of the linguistic weights into fuzzy sets

After the interviews, the Cognitive Maps are transformed into matrices in the form (Wij)ij (Khan and Quaddus 2004). The linguistic variables that describe each arc, for each interviewed are characterized by the fuzzy sets. The linguistic variables are combined, and the aggregated linguistic variable is transformed to a single linguistic weight, through the SUM technique (Lin and Lee 1996). Finally, the Center of Area (CoA) defuzzification method (Kosko 1992; Lin and Lee 1996) is used for the transformation of the linguistic weight to a numerical value within the range [−1, 1].

The concepts C_i (e.g housing costs) are listed on the vertical axis and C_j (e.g., housing affordability for buyers) on the horizontal axis to form a square matrix $(W_{ij})_{ij}$ where W_{ij} takes any value in the range −1 to 1, based on the cognitive maps. The element in the ith row and jth column of initial weight matrix $(W_{ij})_{ij}$ represents the strength of the causal link directed out of node C_i and into C_j. For example, W_{ij} =-1 is entered if there is a causal decrease from C_i to C_j (e.g., housing costs decreases housing affordability for buyers).

The new value of any concept is calculated based on the current values of all the concepts, which exert influences on it through causal links. This computation of a node's output is based on the combination of a summing operation followed by the use of a non-linear transformation function such as threshold function.

The value of a concept, C_i is derived by the transformation of the fuzzy values to numerical values. Since the values of the concepts, by definition, must lie within [0, 1], the chosen function f is regularly the sigmoid function.

To receive information on the dynamic behaviour of a FCM we have to calculate the influence one factor has on others over a number of iterations (the feedbacks between the concepts).

The computation of the C_j node's output is given by formula:

$$C_j(k+1) = f\left(C_j(k) + \sum_{\substack{i=1 \\ i\neq j}}^{n} C_i(k)W_{ij}\right)$$

where k is the iteration counter; and W_{ij} is the weight of the arc connecting concept C_i to concept C_j. After a number of iterations FCMs will either converge to a stabile state, implode (all factor values converge to zero), or explode (all factor values increase /decrease continuously) or show a cyclic stabilization.

Having assigned values to the concepts and weights, after a few iterations the FCM converges to a steady state. At each step, the value of a concept is influenced by the values of concepts–nodes connected to it, till the system would converge to a point and no further changes would take place. So, a FCM can simulate its evolution over time to predict its future behavior.

2.5.2 Graphical Representation

Bellow is presented graphical representations of cognition maps:

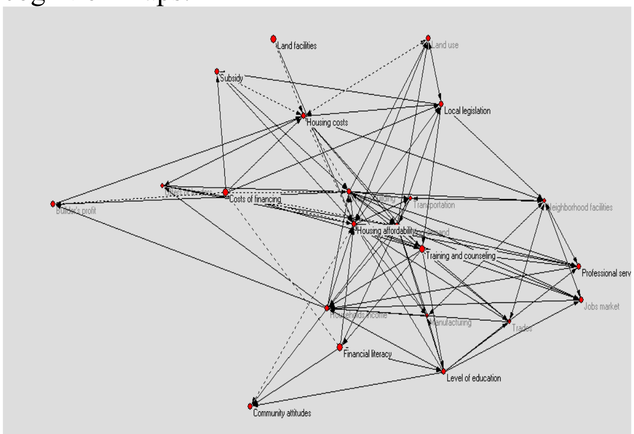

Fig. 3 Cognition map for Housing Affordability

The following figure is the graphical representation FCM for Housing Affordability, for 106 total numbers of connections corresponding to 22 nodes:

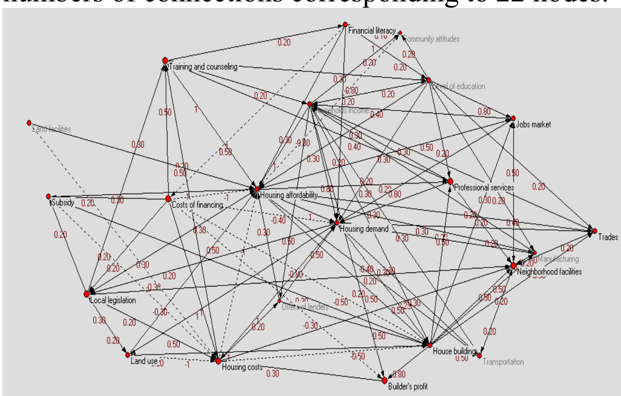

Fig.4 FCM for Housing Affordability

2.6 Computing Scenarios

Through policy option simulations, it is possible to determine which policies and combination of policies would increase the housing affordability, according to people perceptions.

In the scenario analyses, FCMs indicate the direction in which the system will move given certain changes in the driving variables.

Given an initial state of the system, represented by a set of arbitrary values of its concepts, a FCM can

evolve over time until a state of equilibrium, i.e. until it reaches the steady state. This steady state can be used to make different scenarios. Fine modifications of one or several factors in the equilibrium state will yield to different comportments of the system.
Two scenarios were imagined in our model: first, we diminish the Land use factor from 1 to 0.5, second we have increased the same factor to 0.7.
Comparing the second simulated scenario with the steady state, we've obtained the following conclusions listed in table 3, with the changes of the link strength:

Table 3 Results of the second simulated scenario

Positive Changes	strength (+)	Negative Changes	strength (-)
Offers of lenders	high change	Housing affordability	no change
Community attitudes	high change	Households income	medium change
Housing costs	no change	Level of education	low change
Costs of financing	low change	Financial literacy	low change
Neighborhood facilities	medium change	House building	high change
Subsidy	medium change	Trades	high change
		Manufacturing	high change
		Professional services	medium change
		Transportation	high change
		Jobs market	high change
		Housing demand	high change
		Builder's profit	medium change
		Local legislation	no change
		Training and counseling	medium change
		Subsidy	no change

The use of FCM modeling to simulate different housing polices scenarios offers a convenient way to experiment with policy alternatives.
As a tool to further develop various types of scenarios, FCM can be used in order to simulate how consumer behavior responds to house price and income declines while accounting for social impacts.

3 Conclusion

Considering the FCM's potential to be used in the policy modeling, this paper explores how FCM can be applied to housing affordability policy.
The advantage of such model is that it provides a better and more comprehensive understanding of citizen needs regarding housing affordability while it offers a way to involve stakeholders in participatory modeling.
Even the FCMs can be used initially to evaluate behavior of the system and his equilibrium states, for further quantitative predictions of system behavior over time, other simulation methods may follow the analyses for visualization and provide as a feedback to stakeholder.

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