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A Hybrid Expert System for the Estimation of the Environmental Impact of Urban Development

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Abstract

Aims: In this paper we present a prototype of a computational system, running on the web, for the estimation of environmental impact caused by urban development. The system represents and manipulates the expert knowledge of the environmental impact domain through the collaborative interaction of two important artificial intelligence techniques: expert systems and neural networks.
Methodology: We used an environmental impact estimation methodology based on three phases that are: the identification, characterization and evaluation of the environmental impact. Specifically, the system uses heuristic rules for the identification of environmental impacts; neural networks for the impacts characterization and decision algorithms for their evaluation.
Results: The main result of this work is a prototype of a computational platform, highly visual and interactive, that provides the user with a continuous availability of knowledge and procedures used by experts for the analysis and the assessment of environmental impacts. The user provides the system with previously recollected data of environmental scenarios, and the system produces estimations about the possible negative consequences entailed by a new urban project.
Conclusion: We represented and implemented the expert knowledge and procedures for the estimation of environmental impact. We discussed the design and implementation of a computational system that provides support to the estimation of environmental impacts generated by urban development. This estimation is very important because it allows proposing measures that reduce, eliminate or compensate significant environmental impacts.

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1 Introduction

Urban projects, such as dwellings development, schools, hospitals, etc. offer benefits to society, but their construction has some negative consequences for the environment, for example, the destruction of forest areas, the stock out of non-renewable resources or the increase of vehicular traffic [1]. Such changes can be studied for their planning and prevention through an automated and interactive representation of possible environmental scenarios caused by a particular urban development.

In the last two decades, different modelling approaches have been developed to deal with environmental impact assessment, from information systems —mainly Geographic Information Systems (GIS)— to artificial intelligence models —expert systems [2-6], artificial neural networks [7,8] and agent-based systems [9]. Accordingly, different computational tools for environmental impact assessment have been developed.

Multiple studies and techniques deal with the impact of sustainable development (due to transportation and economic systems) on the environment and vice-versa. The works [10-16] specifically talk about state of the art practices and the generation of such systems to highlight environmental impacts on urban development.

On the side of artificial intelligence models, expert systems have been widely used; we could cite the following works. Study [3] presents a rule-based expert system with backward chaining for environmental impact assessment. The expert system provides advice for hydropower development and river regulation projects. Work [4] proposes a rule-based expert system for the identification of environmental impact. The expert system takes data from a geographic information system to configure the knowledge base, the inference motor and the user interface. Study [6] presents an expert system for environmental compliance auditing. The expert system integrates Geographic Information System (GIS), Statistical and Database software packages for environmental compliance auditing. Work [2] describes a forward chaining hybrid expert systems for environmental and technological risk assessment and management tasks. The real time expert system uses simulation models, GIS and estimations derived from the forecasting models in its inference. As a final example, [5] presents an expert system that integrates environmental factors into the supplier selection process. The knowledge-based system employs both case-based reasoning and decision support components as part of its inference engine.

However, the vast majority of work carried out in analysis and assessment of environmental impact consists of theoretical proposals, rendering it very difficult to find a computational tool that provides the user with the support required to assess environmental impact produced by urban developments.

The problem we address is as follows: there is not a computational platform, in Mexico, that integrates the three main phases of the commonly used methodologies for the environmental impact estimation caused by urban projects, which are: identification, characterization and evaluation [1]. In order to provide a valuable support for the estimation of the environmental impact produced by urbanization project, we designed and constructed a computational platform prototype -a hybrid expert system-, based on expert knowledge. The tool provides results that allow valuating how the urban project will affect the environment, aiming to help planning modifications that minimize the destruction of natural factors.

Urban projects are not only limited to the construction of facilities providing services, such as schools, hospitals, malls and dwelling developments. There are also projects like construction of military areas, airports, conversion of abandoned industrial parks, railway stations, rehabilitation of marginal housing, and construction of new public transport models, among others. An urban project impacts not only the physical environment, but also the socioeconomic. In this first phase, we analyse the impact on the physical environment, also called natural environment, of urban dwellings projects.

The principal problems to be faced during the evaluation and diagnosis of the impact produced by urbanization projects in Mexico are the following: i) information is scattered and distributed in different sources, ii) it is required consulting with experts in the field, who are not always available, iii) there isn´t an integral computational tool in Mexico that helps with this work. The proposed computational platform implements the different activities involved in environmental impact assessment through the use of techniques such as expert systems [17], artificial neural networks [18] and numerical methods.

In section 2 we briefly explain the methodology for the study of the environmental impact in urban projects, and show how this methodology is implemented in a computational system. In section 3 we describe the Computational Platform for the Estimation of the Environmental Impact (CPEI). As a result of the expert knowledge acquisition related to environmental analysis domain, we obtained the representation, encoding and availability of such expertise in CPEI. The use of this expertise is exposed through some screenshots of CPEI in section 4. Discussion is in section 5. Finally conclusions and future work are presented in Section 6.

2 Methodology for the Study of the Environmental Impact of Urban Projects

In this section we present a summary of the activities involved when an environmental impact study of a given urban project is done [19]. The environmental impact estimation includes the following three aspects [1]:

Environmental impacts identification: consists of identifying the effects that the activities related to the urbanization project will have on the environment.
Environmental Impacts Characterization: it is a *qualitative* assessment of the environmental impact, in which the importance level of the identified impacts set is determined.
Environmental Impacts Evaluation: it is a *quantitative* assessment in which a numeric value is assigned to the impacts characterized as critical or severe.

As it was previously mentioned, the conceptualized computational system offers support to the identification, characterization and evaluation of environmental impact, making use of the knowledge, abilities and procedures applied by experts in environmental areas (see Fig. 1). We call this system Computational Platform for the Estimation of the Environmental Impact (CPEI), and it is available at http://eolo.cua.uam.mx:8080/SSICEIA/. The use of CPEI is intended for Mexican urban projects so it is in Spanish.

2.1 Identification of Negative Environmental Impacts

Negative environmental impacts have to do with pollution and/or territory occupation. In order to identify them, checklists are made to determine the effects that the project would have in each aspect on the list. There are four commonly used methodologies for making checklists: the simple listing, the descriptive, the scale, and the scale and weight. In this project, we used the simple list, consisting of a list of precedents, which serve to evaluate the aspects of the environment that will be affected. For this purpose, we based the lists on the SEMARNAT guide [20], considering 150 aspects. The questions in the checklists refer to activities that will be carried out when developing the urban project under analysis that impacts directly or indirectly the physical environment. Table 1 illustrates an example of the checklist used by the system. The user provides the answers to these questions and assigns one of 5 possible values.

Table 1. A checklist sample

a101. Permanent or temporary changes in land use, cover or topography including intermediates in the intensity of use?
a102. Work removing vegetation and / or soil?
a103. Creation of new land uses?
a104. Pre-construction work such as drilling or soil analysis?
a105. Construction work?
a106. Demolition work?

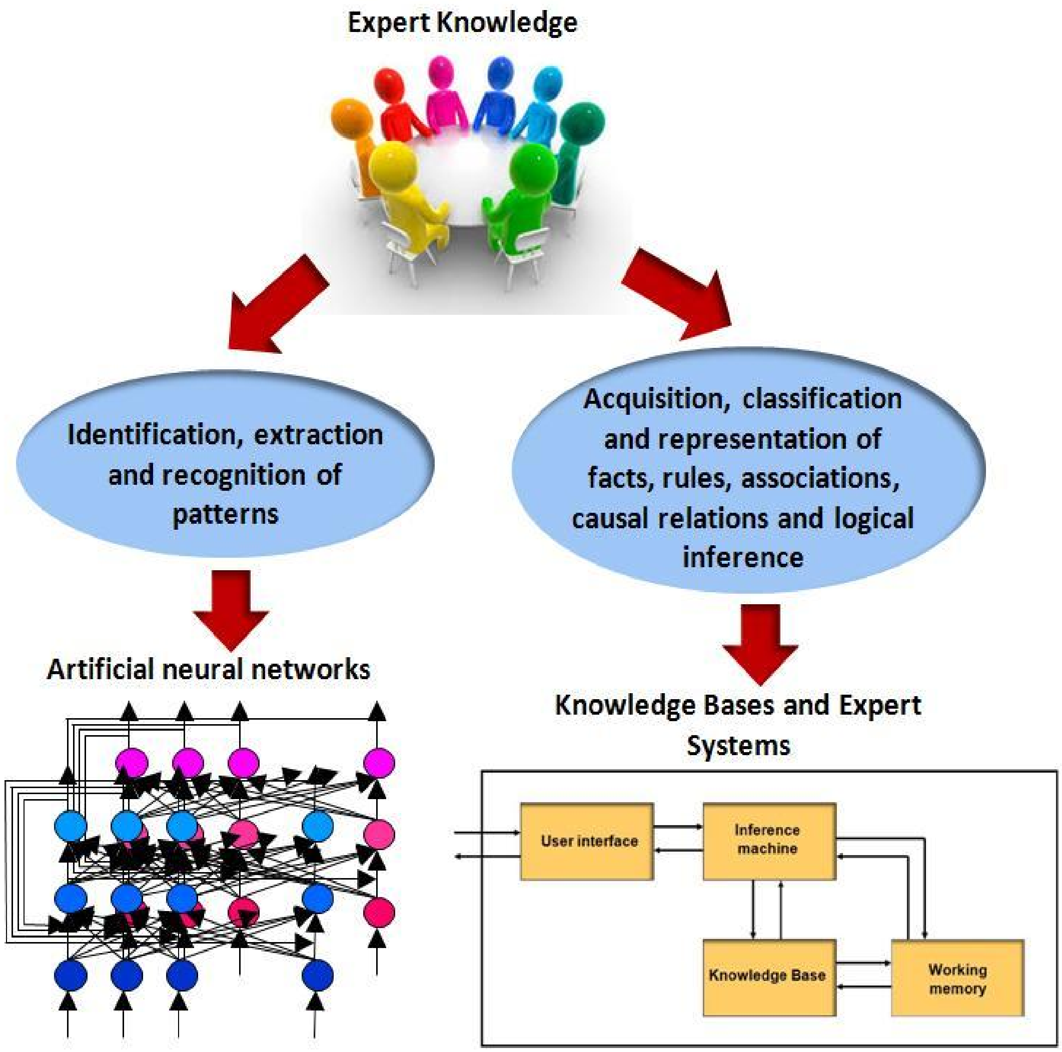

Fig. 1. Representation and manipulation of expert knowledge in environmental impact domain

Table 2 shows the importance levels used to qualify each question on the checklist.

Table 2. Importance levels in the environment

Value	Answer level
0	No, not significant
1	Little bit
2	Moderate
3	A lot
4	Excessive

The expert system CPEI gets preliminary conclusions based on the importance levels provided by the user for each one of the questions on the checklist. These conclusions are obtained with production rules (logical inferences) [17], which are coded in Prolog. Here we present an example of the required conditions for the system to reach the following conclusion: *The Project will make significant use of any natural resources, especially non-renewable or scarce resources*. Each Preliminary Conclusion (PC) has a code associated with it, in this case PC_2. The questions list that can lead to PC_2 is the following:

Will the project make use of lands, especially those non-urbanized or agricultural?
Will the project make use of water?
Will the project make use of mineral resources?
Will the project make use of forest resources?
Will the project make use of electricity or fuels?

It is worth noting that some questions have more importance than others. For example, if the use of water or of forest resources has an answer level greater than or equal to 3, then a high importance level is assigned to the PC_2 (level 4), although the other answers have a low level. Generally, production rules are responsible for assigning an importance level from 0 to 4 to each one of the preliminary conclusions. To do this assignment, the user must answer all the questions in the checklist. The system has 23 preliminary conclusions PC_1, PC_2,… PC_{23}. Each conclusion PC_n is associated with a list of questions that affect it and its production rule (as inferential knowledge representation structure), indicating in which extent each question affects it. In addition, there is a list of 17 final conclusions FC*n*. These final conclusions are obtained depending on the value assigned to the preliminary conclusions. Each final conclusion depends on one or more preliminary conclusions. With the final conclusions, we have an assessment of the impacts identified according to their attributes. Table 3 shows the example of a production rule of the system, which infers a partial conclusion, PC_2 in the example.

Table 3. Example of a production rule for getting a preliminary conclusion

PC_2. The project will have significant use of any natural resource, especially non-renewable or scare resources.	
Questions	**Production rule**
a202. Will the project make use of water? a204. Will the project make use of forest and/or timber resources?	If antecedent (index, Answ Level) and index == "a202" and Answ Level A202 >= 3 or antecedent (index, Answ Level) and index == "a204" and Answ Level A204 >= 3 Then Preliminary Conclusion (pc2, 4)

The identification phase ends with the obtaining of 17 final conclusions, which give information about the project impacts. Once the environmental impacts have been identified, we proceed to characterize them in order to determine how important each one of them is. The following section explains the way the system does this characterization.

2.2 Environmental Impact Characterization

In our project, the environmental impact characterization is treated as a pattern recognition and classification problem. For such effect, CPEI uses a back-propagation supervised neural network [21] with three layers: 17 neurons in the input layer (the 17 final conclusions of the identification phase); 17 neurons in the intermediate layer; and 4 in the output layer, which correspond to the 4 possible rating values of the impact importance. The configuration of this network is shown in Fig 2. The training phase of the neural network has a set of 60 training patterns of the type input/output, which were presented in an iterative way during 15,000 epochs or iterations.

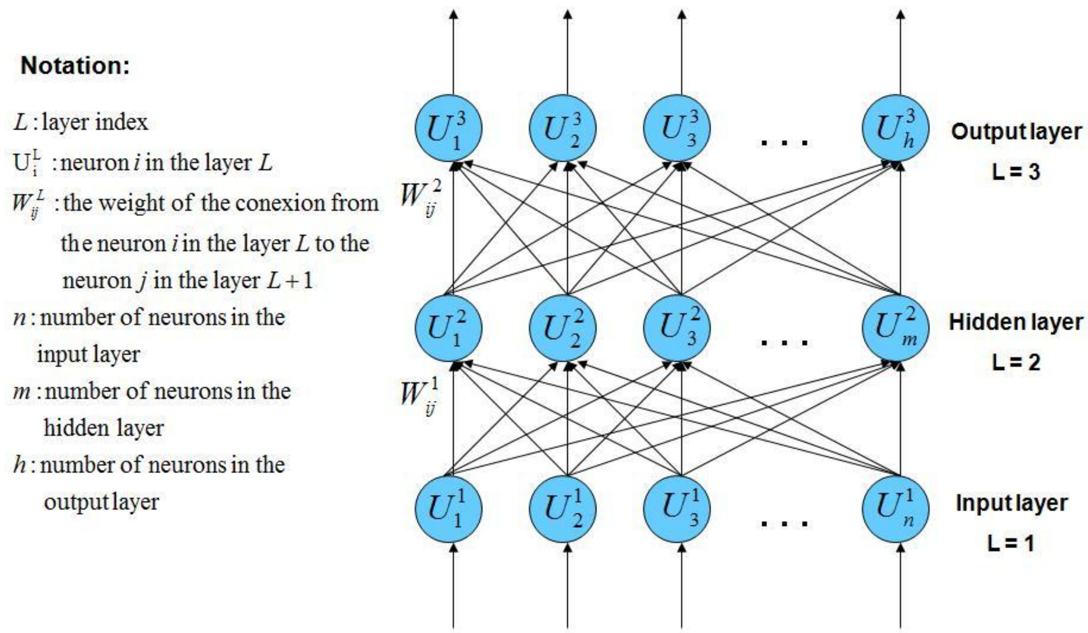

Fig. 2. Artificial neural network model used to treat the environmental impact characterization as a pattern classification problem

During the neural network training phase, the initial mean square error was 20.90, after 15,000 iterations it was reduced to 0.035. With this value, it was possible to get the best network performance during the answer phase, preventing the *overspecialization of the network* on the training. New patterns were presented to the network, which were not a part of the training sample, and the network answer was successful, because it classified correctly the given patterns. The qualitative values of the environmental impact are classified in the four categories described in Table 4, where the importance ranges, for each of the categories in which the neuronal network can classify, are defined. Notice that these are precisely the ranges defining the characteristics that must exhibit the training patterns.

2.3 Environmental Impact Evaluation

Leopold's matrix [22,23] is a method to evaluate environmental impacts. CPEI is based on this matrix to do quantitative assessment of the impacts. To make the evaluation, it is necessary to have the environmental impact characterization ready with its corresponding impact level. Only the impacts characterized as moderate, severe or critical are evaluated. In the first phase of the evaluation, a Leopold matrix is built. Its columns are the activities that affect the biotic factors (flora, fauna) and abiotic factors (water, soil, air) of the urban area where the project will take place; in rows project activities are included.

Table 4. Correspondence between the importance ranges and qualitative values

Importance value	Assessment
0 – 17	Irrelevant
18 – 34	Moderate
35 – 51	Severe
52 – 68	Critical

On the other hand, an importance level is given to each activity in the list. This level is the environmental impact rating, and it is given depending on the negative effect that the activity has on the environment.

The rating is on a scale from 1 to 10. In the second phase, a quotient that qualifies the interactions between activities and factors is determined. The numerator represents the activity importance level (previously given), and the denominator is the level in which the activity affects the environmental factor in the column, see example in Table 5. Finally, the sum of all these quotients produces a numerical value for each one of the activities of the project (Total column in Table 5), this value is the environmental impact of the activity.

Table 5. Leopold's matrix for CPEI

Activities during the project development	Air	Water	Soil	Flora	Fauna	Total
Water use	-0/0	-3/3	-1/2	-2/3	-2/2	-8/10
Emissions from production processes	-3/2	-2/3	-1/2	-3/2	-1/1	-10/10
Toxic waste	0/0	-1/3	-1/2	-1/2	-1/1	-4/8

3 The Development Process of the Computational Platform for the Estimation of the Environmental Impact (CPEI)

CPEI software was developed through the process called “Rational Unified Process” [24]. RUP is a hybrid model that aims at taking advantage of waterfall [25], evolutionary [26], and reusable components [27]. RUP is serial in time as the waterfall model. Seen at each phase, it is evolutionary, because the phases can be composed of multiple deliveries. This reduces risks and makes it somewhat flexible to changes in requirements. The reuse of components encouraged by this model, aims at reducing costs and development time. The use of Unified Modelling Language: UML [28] associated with RUP facilitates analysis and design of the system components. Their quality control procedures and control of changes contribute to the production of satisfactory software.

As said by Sommerville [29], “change is inevitable if software systems are to remain useful”, therefore, for implementing new requirements and bug fixing, we will use Sommerville’s spiral of evolution. The development of CPEI includes the recommended practices of software engineering, such as documentation, tests performance, error-reports elaboration [30] and software inspections [31]. CPEI web pages were built with Java Server Faces, Primefaces framework, and Java, using mysql database.

In order to help with the understanding of how CPEI works, we describe the system by means of the User Interface Transition Diagrams (UITD) [32]. An UITD describes interactions between the user and the system. Fig. 3 shows the login subsystem. The user must enter a correct user identification and password to enter the system. The user can also register first and then enter the home page.

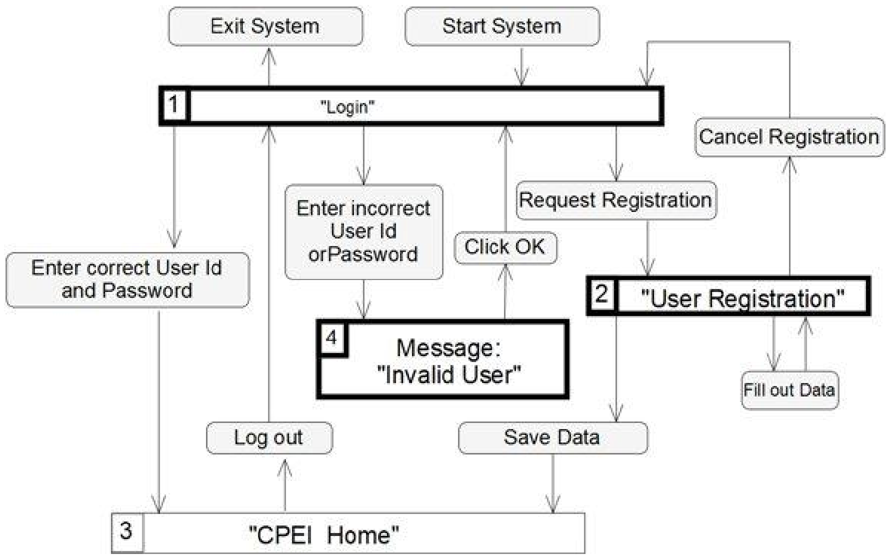

Fig. 3. System Login

The CPEI Home is described in Fig. 4. In the home page the user can track a current project, do an estimation of an urban project, and see environmental laws, the impact levels definition, related documents or already estimated projects.

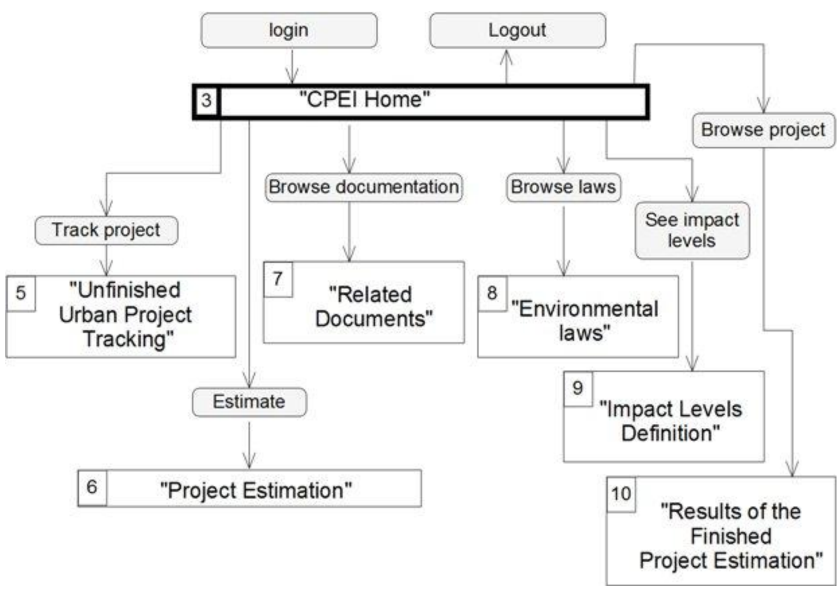

Fig. 4. CPEI Home

The three phases of the project estimation are carried out from the "Project Estimation" user interface shown in Fig. 5. First, the user must Identify the impacts in "Environmental impacts identification" user interface, which is described in Fig. 6. Once the impacts identification is done, the user can *Characterize* the urban project. The characterization done by the neural network is displayed in "Results of Environmental Impacts Characterization". Finally, once the characterization is done, the user selects *Evaluate* project, and the "Results of the Environmental Impact Evaluation" are displayed as a Leopold´s matrix.

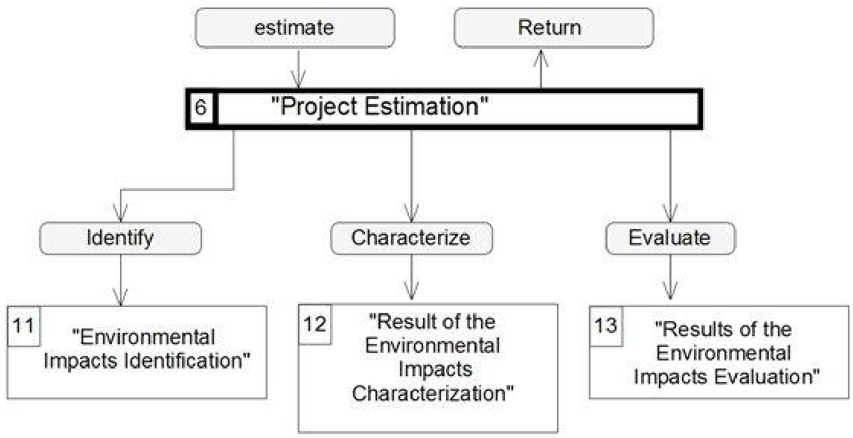

Fig. 5. Project Estimation

Identification is the first phase of the impact estimation process. Fig.6 shows the activities that the user can do during the identification phase. The project must be registered in the "Project Registration" user interface; also the project environment and the relationship project-environment must be registered before doing the environmental impact identification. For clarity, we do not detail the lower level user interfaces (14, 16, 17 and 18, in Fig. 6). The evaluation of the project-environment relationship is done by means of the checklist explained in section 2.1.

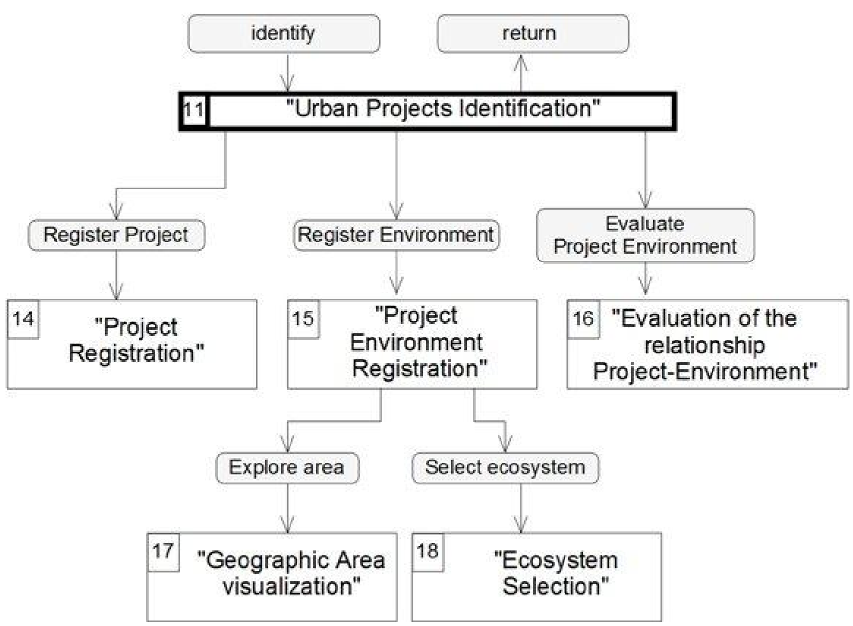

Fig. 6. Environmental Impact *identification*

4 Results

We extracted expert knowledge of the domain of the environmental analysis and then encoded that knowledge – using expert systems and neural networks techniques - so CPEI can process it. As a result, we have got the completely functional prototype of this hybrid expert system, which provides a qualitative and quantitative assessment of the impact generated by the urban project. We used an environmental impact estimation methodology based on the identification, characterization and evaluation of the environmental impact. We represented and implemented the expert knowledge for the estimation of environmental impact, with methods and techniques such as expert systems, artificial neural networks, numerical methods and calculation algorithms. The computational system was developed as a web application; its home page is shown in Fig. 7.

Fig. 7. CPEI's home page

We used, as a case study, an urbanization project in Mexico City. We set the objectives, methodology and the legal support. The evaluation of the project-environment relationship was done by means of a checklist like the one shown in Fig. 8. At this point the knowledge was acquired by giving an importance level to each of the environmental impacts. This information was given to the system by means of a check-list according to values of Table-2: No, Little bit ("*poco*"), Moderate ("*moderado*"), A lot ("*mucho*"), Excessive ("*excesivo*").

Once we entered and saved the importance value for each of the environmental impacts we proceeded to the second phase: the project characterization. In this step the qualitative values of the environmental impact were classified in the four categories described in Table 4: irrelevant ("irrelevante"), moderate ("moderado"), severe ("severo") and critical ("crítico"). Fig.9 shows the list of final conclusions as a result of the urban project identification. Fig. 9 is in turn part of the input for the characterization. In addition to the list of final conclusions in Fig. 9, the characterization phase requires as input the project length and the list of residuals that the project will produce.

Fig. 10 shows the characterization phase output according to our case study. The system characterized the case study project as moderate. The definition for moderate is: "At this level the effect on the environment does not require intensive remedial or protective practices. The return to the initial state of the environment does not require a long period of time ".

Evaluation is the third phase of the project estimation, in this phase the system uses the Leopold matrix to evaluate the urban project. Fig. 11 shows the Leopold matrix as a result of a case study.

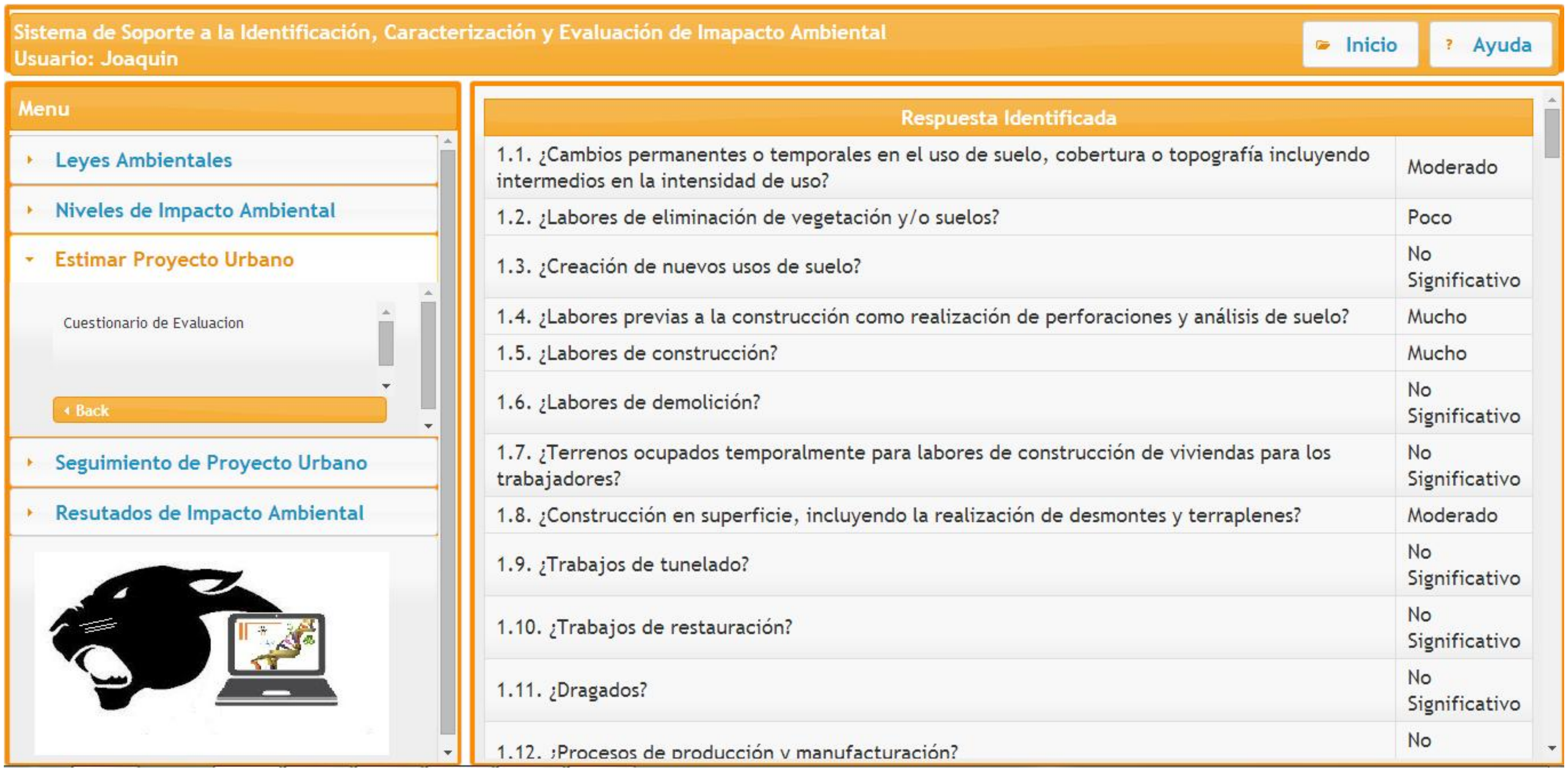

Fig. 8. Checklist (for the environmental impact *identification*)

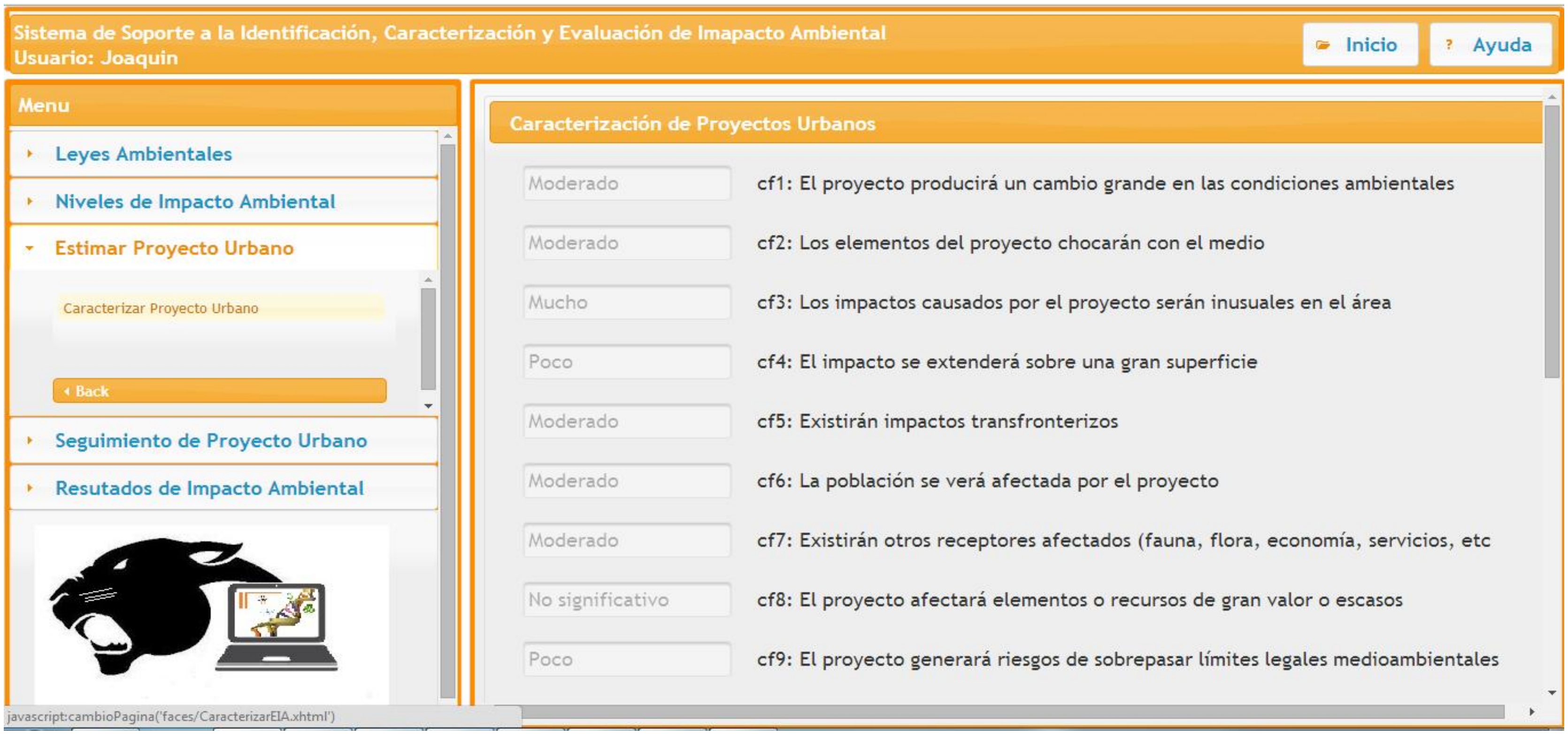

Fig. 9. Final Conclusions are the identification output and a characterization input

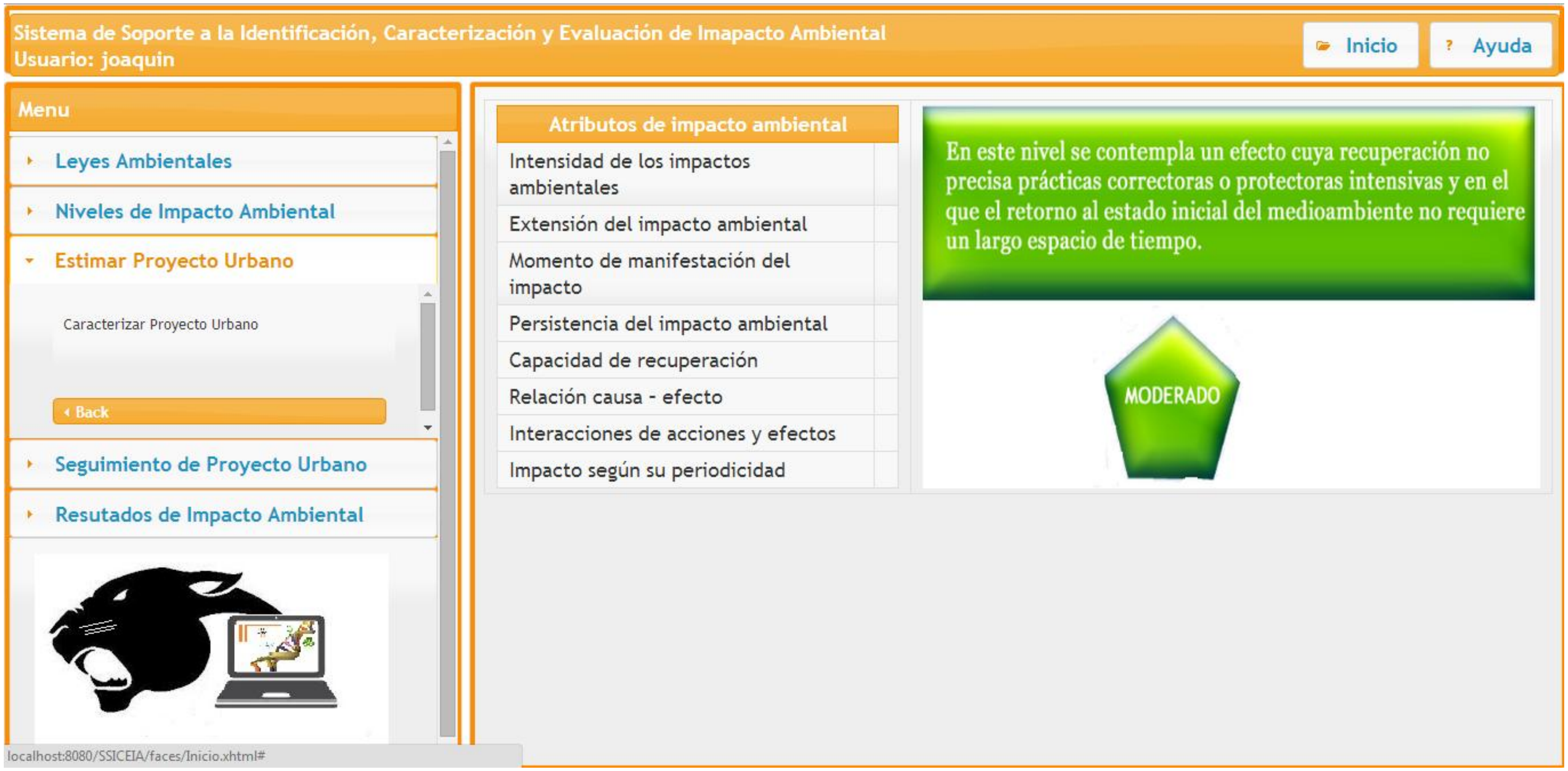

Fig. 10. Results of the environmental impact *characterization*

Fig. 11. Results of the environmental impact *evaluation*

5 Discussion

CPEI concentrates the experts' knowledge and uses it to provide a study of environmental impact assessment of an urbanization project. In addition, CPEI concentrates information storage that otherwise would be scattered in many places. It also helps projects by reducing the time it takes to get this analysis so that costs and delays may be reduced.

Unlike conventional methods, ANNs are able to model complex relationships between the input and output data. With the development and implementation of CPEI we confirmed that an ANN is able to classify the inputs even if this classification is very complex.

In order to take advantage of CPEI, it could be linked to the database of the Mexican government institutions that perform environmental impact studies.

6 Conclusion and Future Work

An urbanization project must undergo the study of its environmental impact before being approved, so as to evaluate the foreseeable effects on the population, flora, fauna, soil, air, water, climatic factors and landscape and material assets, including the artistic and archaeological heritage. The evaluation of these impacts is very important because it allows proposing measures that reduce, eliminate or compensate the significant environmental impacts.

In this work we have presented an interdisciplinary project that merges the environmental impact domain with the artificial intelligence techniques. The resulting computational system prototype provides support to the identification, characterization and evaluation of environmental impacts generated by urbanization projects. A crucial feature of this tool is the ideal representation, manipulation and permanent availability of the expert knowledge of the domain through expert systems techniques (identification phase), artificial neural networks (characterization phase) and algorithmic and numerical methods (evaluation phase). We are currently adjusting the system comparing it to real cases of studies to get an optimum answer.

We demonstrated, with a fully functional system, that neural networks and production rules are useful to get the required report of the environmental impact of urban projects estimation, according to the Article 8 of the Mexican General Law of Ecological Equilibrium.

Among the wide range of future development alternatives for the CPEI is the increase of analysis level in the checklist, the addition of methods different to the Leopold matrix for evaluating, and adding specialized methods to evaluate specific environmental impacts, such as pollution in air, water, soil, etc.

Competing Interests

Authors have declared that no competing interests exist.

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