SUSTAINABLE DESIGN FOR A CENTRE OF VOCATIONAL TRAINING. A PETRI NET APPROACH

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ABSTRACT
The management, design, and redesign of educative centers are performed usually by means of criteria that do not consider in detail the social, environmental, and financial impact of the daily activities in the institution. This fact may move away the design and management processes from daily reality, which can provide with a huge amount of data to be considered by human decision makers. The purpose of this paper is to describe a decision support system for the managers of a vocational training center that may help them make the best decisions for improving the effectiveness of the educative process. This tool arises as a combination of the Life Cycle Assessment methodology and the simulation of a Petri net model of the educative institution.

Keywords: vocational training, Petri nets, decision support system, life cycle assessment.

1. INTRODUCTION

Nowadays, the design and redesign of new educative centers require taking into consideration topics such as sustainability, efficient use of the different resources, for example energy, recycling, and waste management. This trend is based in a broad social concern on these aspects, in exigent national regulations and international agreements, as well in common sense, due to the high cost and limited availability of resources and restrictions in the elimination of wastes.

Different approaches are followed by designers, architects, and engineers, when designing educative centers. Among them, it is possible to let experts to advise them, such as commercial executives from specialized companies, to implement technologies that are familiar to the designers making them confident, to improve or modify in a more or less extent previous designs, etc.

Nevertheless, a sustainable design, where a large number of alternatives, technologies, and variables have to be considered, should lead to the best solution, achieved not only from strategic considerations but also from the day-to-day management, based on operational decisions. Only with such an approach, it is possible to include the level of detail in the future operation of decisions that a fine design should take into consideration for avoiding errors that will arise when the construction of the building has finished and the educative activities begin (Latorre and Jiménez, 2012).

In the next section, the life cycle assessment will be introduced as a methodology to achieve the sustainable design of an educative institution. Section 3 deals with the main characteristics of a vocational training center. The following section presents the formalism chosen for the representation of the model of the educative center: the Petri nets. Section 5 discusses the model developed by the paradigm of the Petri nets of the educative center. The next section describe the simulation-based methodology for the decision support system to the design of the educative center. The paper continues with a section describing the conclusions of the research performed so far. The last section lists the bibliography referenced in this paper.

2. LIFE CICLE ASSESSMENT

LCA or Life Cycle Assessment is a tool to evaluate how human activities impact on the environment. In consists on a methodology which comprises the complete life cycle of a product, process or service, what is called the "cradle to grave" approach (Curran, 1996). In fact, the application of the LCA requires a complete study from the raw materials requirement and the energy needs, to the return of the materials to the earth (EPA, 2006).

The LCA methodology has experienced a significant growth in the last decades. Its success has led to the standardization of LCA, such as ISO 14044, (Baumann and Tilman, 2004). Nowadays, LCA is considered as one of the most consolidated tools for the analysis of the environmental profile of products, processes, and services, as well as an interesting methodology for achieving sustainability goals in a certain institution (Hertwich, 2005).

The methodology of the LCA can be applied to the analysis of the activities of an institution, such as a vocational training center. In order to achieve this objective it focuses on the energetic efficiency and the evaluation of the environmental impact.

The choice of a vocational training center, among other institutions, is based in the fact that this kind of educative center is very influential on society, with regard to the development of environmentally-friendly activities, since they contribute notably to the education and the attitudes of new generations of citizens. In particular, present and future professionals and experts in many activities belonging to the industrial, agricultural, and service sectors are trained in this type of educative institution (Otero et al., 2012a).

The application of the LCA lists the inputs and outputs of resources and waste, providing with a precise vision of the advantages and drawbacks of the decision-making process in the development of products, processes, or services, from a point of view of environmental impact.

The LCA is a systematic methodology composed of four stages: (Jiménez et al., 2012)

a) Definition of the objectives and scope of the analysis.

b) Analysis of the inventory (ICV). Input resources and output waste are identified and quantified for the significant activities.

c) Impact assessment (EICV). The effects on the environment and society of the use of resources and generation of waste is evaluated.

d) Interpretation of the results and proposals for improvement.

3. VOCATIONAL TRAINING SCHOOLS

A vocational training school in Spain consists of an educative institution, where the students enroll non-compulsory education courses for becoming technicians in diverse sectors. These courses belong to the initial vocational training, while other courses are offered in the same institutions to unemployed people, to help them to find a job, as well as to workers, with the purpose of improving their knowledge, performance at their workplace, and their employability.

The initial courses of vocational training are classified into medium degrees and higher degrees, being the first ones a terminal way, which offer the graduates a qualification for their professional practice.

However, graduates of medium degrees of vocational training can enroll a course of higher degree of vocational training if they pass an examination that is organized once a year for this purpose.

Higher degrees provide the graduates a professional qualification as higher technicians. Moreover, they may continue their studies in the university.

The duration of the cycles of vocational training depends on the specialty and varies from one year in the educative center and three months of professional practice in a company to one year and seven months in the educative institution and three months of professional practices in a company.

The range of specialties of the courses is very wide and includes industrial subjects, such as mechanics, maintenance, electricity, and electronics, or other more related to the sector of services, such as configuration of networks of computers, hairdressing, commerce, marketing, assistant of nurse, sports, etc.

Sustainability in the design and management of a vocational training center has a special impact in society due to the fact that these institutions are the places where lots of citizens and future professionals are educated and trained for serving the society where they will perform their activities and which has invested in their education.

The design of a center, which is a model in the management of resources and wastes, will teach the students how to perform professional activities respecting the environment and the society, as well as to assess in their context the scarcity and cost of the available resources and the subsequent rational use of them (Otero et al., 2012b).

4. FORMALISM FOR THE MODEL

For this purpose, a very powerful approach consists of developing a model of the educative institution in process of being designed. The activity performed in a vocational training center corresponds to a large number of individuals, such as students, teachers, administrative staff, members of the management board, and external services. Some of these individuals act in parallel and converge with others to synchronize and compete for limited resources.

Regarding the previous characteristics that the model of the system should comply with, an appropriate formalism to be considered in this process is the paradigm of the Petri nets. This formalism allows representing the model of a discrete event system with a double representation: a graphical one and a matrix-based one. Moreover, this formalism presents a large body of knowledge and a number of available tools and techniques for validation, verification, structural and performance analysis, as well as for simulation and optimization (Silva, 1993).

Definition. A Petri net system is a 5-tuple $R = (P, T, \text{pre}, \text{post}, \mathbf{m}_0)$ such that:

i) P is a non-empty set of places.
ii) T is a non-empty set of transitions and $P \cap T = \emptyset$.
iii) pre and post are functions that associate a weight to the directed arcs between the elements of the sets P and T, in the following way:
iv) pre: $P \times T \rightarrow \mathbb{N}^*$ and post: $T \times P \rightarrow \mathbb{N}^*$, where $\mathbb{N}^*$ is the set of natural numbers, excluding zero.
v) $\mathbf{m}_0$ is the initial marking, such that $\mathbf{m}_0$: $P \rightarrow \mathbb{N}^*$.

□

5. MODEL OF THE VOCATIONAL TRAINING

The model of the educative center should be able to represent all the possible alternative configurations or scenarios for the vocational training center.

These scenarios can vary according to the decisions made by the different actors taking part in the educative process (students, teachers, members of the managing board, administrative staff, maintenance staff, families, etc).

Choosing the best scenario implies selecting the best sequence of decisions made by the actors; hence, the methodology developed to make the mentioned choice, described in this paper, can be used as a decision support system for the managing staff of the educative institution. This tool can be used to get advice in a complex environment for decision making as is an educative institution, where the number of actors can totalize more than a thousand people.

As it has been mentioned, the decision support system should choose a scenario for the educative center. For this reason it is a vital stage in the application of the methodology to define with precision the way to measure the "goodness" or quality of a given scenario.

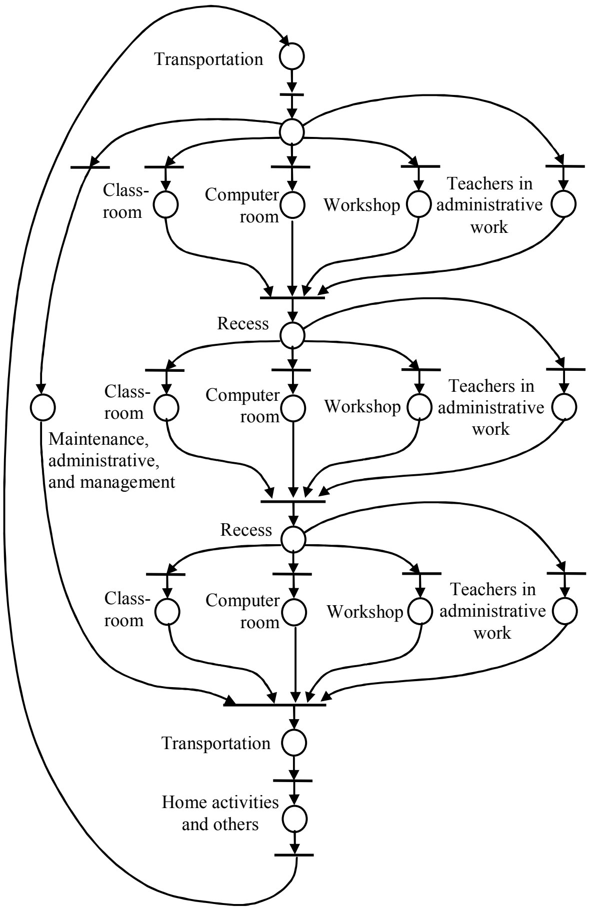

Figure 1: Petri net model of a vocational training center

In order to achieve this objective, it is convenient to have in mind the main objectives of the educative institution or, at least, the objectives where the decision support system should focus. These objectives may be to lead the educative institution to its highest social impact, by using the smallest financial resources, and reducing at a minimum the environmental impact.

The present methodology quantifies the contribution of every individual achievement to the global objective and integrates these assessments in the model of the system.

Subsequently, the model is set up with a specific scenario which has been made correspond to a given sequence of decisions of the different actors belonging to the educative community. The choice of a given scenario can be performed randomly or by means of a technique to search in the solution space of the problem that is being solved.

The following step consists of performing a simulation of the Petri net model of the system by adjusting the desired duration of the educative activities to be simulated (from a day to a year could be common choices). During the simulation, a parameter that measures the quality of the considered scenario is constantly updated by the educative activities simulated and the previous quantification that measure the contribution of each activity to the global objective of the center.

Once a simulation has been completed, and its quality parameter calculated, another scenario should be simulated. When a number large enough of scenarios have been simulated, it is possible to choose the one associated to the highest quality parameter. This scenario would be the one proposed to the managing staff of the educative institution, together with the appropriate decisions related to it.

A model of the system, appropriated to the described methodology, is presented in the following paragraphs and figures. In this model, the actors are represented by means of individual tokens of the current marking of the system, while actions performed by the actors are associated to the places of the net. The firing of a transition leading to a place, which is associated to a given educative action, updates the quality parameter of the simulated scenario.

In figure 1, it has been represented a low-detailed model of an educative center, where the main daily activities of the educative process have been made explicit.

For the development of the model, some assumptions have been made. Among them, the educative activities are organized in three daily period of classes separated among them by means of two breaks. This schedule affects the activities of students and teachers. Nevertheless, the rest of the staff, that is to say the managing staff, administrative staff, and maintenance staff follow a different timetable.

According to the developed model, the activities of the actors belonging to the educative community are classified into three groups:

a) Transportation to and from the educative center.
b) Activities in the educative institution.
c) Activities out of the educative center.

In the first group, the transportation of the actors to the educative center at the beginning of the workday and from this institution at the end of the workday are considered. Statistical information particular to a given educative center should be included in the model to evaluate the impact of this activity, considering the percentage of actors that use public transport, shared cars, non-shared cars, motorcycles, bicycles, etc. It is also important to know the distance covered by the actors, as well as if the displacements are performed in urban areas with dense traffic, rural areas, etc.

The second group of activities, the ones developed in the educative institution, is presented in the model as the type of activities performed by students and teachers in different spaces, such as conventional classes, classes with Internet and a network of computers, and workshops, with professional equipment for practices of vocational training.

Moreover, teachers can have time, free of classes, to perform administrative work, such as preparing and correcting exams, preparing the classes, meeting with parents of students, meeting with other teachers, doing paperwork, etc.

The activities of the management, administrative and maintenance staff are represented together by the same single place in the Petri net model.

The third group of activities corresponds to the ones performed by the actors outside the educative center. They can be related or not with the educative process and are performed in the period of time from the end of the transportation of the actors from the center of vocational training to the beginning of the transportation to the educative institution at the beginning of the following day of work.

In order to simulate the educative process with a higher level of detail, for calculating the value of the quality parameter with a high accuracy, it is convenient to refine the model by expanding the different activities considered in the Petri net model of figure 1 into more specific tasks.

According to this idea, in figure 2, it has been represented in a bit more level of detail, the activities performed in a class developed in a conventional classroom, in a classroom with a network of computers, or in a workshop.

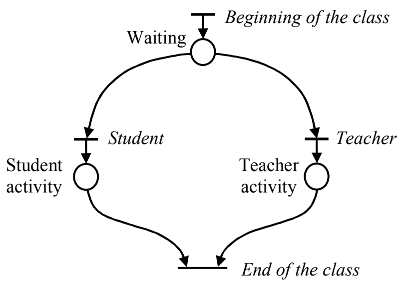

Figure 2: Tasks developed during a class.

In fact, the purpose of the Petri net presented in figure 2 is to split the tasks developed during a class into two groups: the ones performed by the teacher or teachers and the ones performed by the students. In fact, the mentioned Petri net corresponds to the places of the model depicted in figure 1 labeled "classroom", "computer room" and "workshop".

A further step in detailing the educative activities that correspond to a class will lead to two Petri net models. One of them corresponds to the tasks of the teacher and the other one the tasks performed by the students.

According to this idea, the Petri net model of the activities performed by a teacher in a class developed in a workshop has been represented in figure 3. The tasks developed by a teacher in a conventional classroom or in a computer room are similar and in general more restricted, due to a limitation in the available educative material and equipment, than the ones carried out in a workshop. For this reason the formers will not be detailed in this document.

Figure 3 shows a place representing the teacher waiting for the next task in the class to begin. From this place, the teacher can take the decision of beginning an explanation, helping the students individually or in small groups, while the other students perform a given educative task, correcting exercises or performing a brief task which can lead to significant influence in the social, financial, and environmental impact of the class: turning on/off the heating or the lighting.

Moreover, an explanation by the teacher can be developed using different technologies, implying diverse environmental impacts. The teacher can use a conventional blackboard, a projector and a computer presentation, or the explanation can be developed using professional equipment such as industrial machinery, chemical devices, or electrical systems.

It has to be said that more activities than the ones presented in figure 3 can be performed by a teacher during a class. However, the ones included in the model have been considered by the authors as the most representative ones, since they can be the most common ones and the environmental impacts can be significant.

Furthermore, the model of the educative institution developed for constructing the decision support system described in this paper should be detailed enough to allow the calculation of the quality parameter of a given configuration of the educative center with an appropriate accuracy but it should not be too large, since it might compromise the effectiveness of the methodology for requiring too much computer resources such as computing time to provide a suggestion of adequate decisions in a reasonable amount of time.

In the same way as it has been described for the activities performed by a teacher during a class, the place labeled "Student activity" in the Petri net model depicted in figure 2 can be expanded as it can be seen in figure 4. In this figure 4, there is a place with a conflict. In this place, labeled "Student waiting", a student and the teacher, with the limitations imposed by the will and enthusiasm of the student, can choose the following task to be performed by the student.

Among the educative tasks that can be performed by the students, the model includes the use of ink and paper, writing notes or solving exercises, the use of a computer, the use of professional equipment or not using anything but their brains by paying attention to an explanation or by studying from a book.

Some of the potential tasks of the student can be against the rules of the class leading to a loss of time. Among them, only one, loosing time by using a smartphone, has been considered in the model, since in recent times it has become a very common, and difficult to control, activity of the students. Moreover, on a large scale, the social impact, and even the environmental and financial impact can be significant for the educative institution and the families of the students.

The rest of the places of the Petri net model depicted in figure 1, not expanded so far in this paper, can be detailed in the same way as the previously mentioned ones.

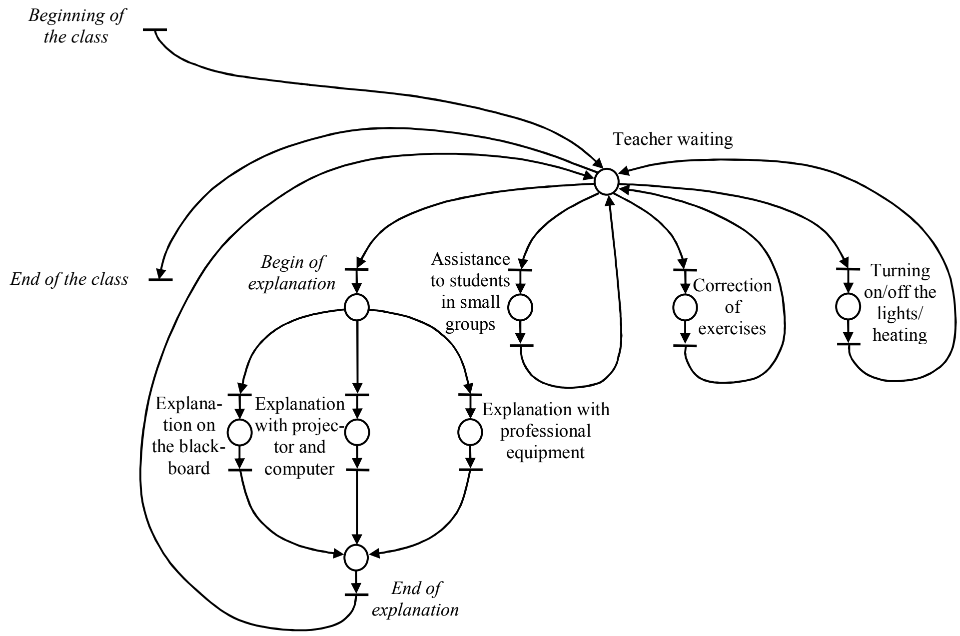

Figure 3: tasks developed by a teacher during a class in a workshop.

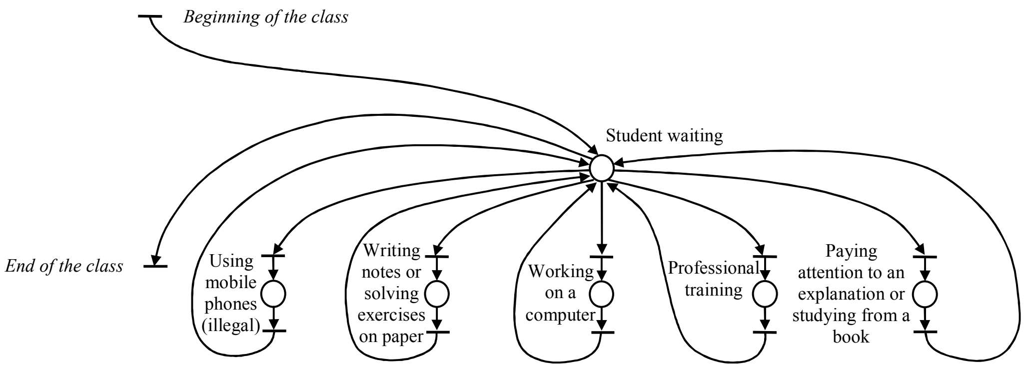

Figure 4: Activities of the students during a class in a workshop.

6. SIMULATION

The process of design of an educative institution based on a Petri net model can be supported very efficiently by means of simulation.

This methodology can be used in a variety of manners. One of the most common ways of using simulation is the technique called “what-if”. According to it, it is possible to choose a diversity of scenarios for determining which one of them is the best option for solving a problem such as the design of a system. Simulation is then applied to mimic the evolution of the real system under every chosen scenario.

The comparison of the simulations is performed generally by means of quantitative assessments. In this methodology, the scenarios to be tested by means of simulation can be chosen manually, requiring highly trained and costly experts or automatically, using an algorithm to choose the most promising options from a pool of feasible solutions (Latorre et al., 2013).

In case that an automatic procedure is chosen for the selection of the scenarios to be tested by means of simulation and an objective function is defined to quantify the quality of every one of them, the methodology belongs to the category of optimization. In this methodology, the diverse choices performed in the process of design of a vocational training center represent different feasible solutions for the stated problem.

The quantification of the quality of a given scenario for the educative center is usually performed by means of an objective function. In case there are several competing objectives simultaneously, a multiobjective function can be constructed. The influence of the different objectives in the quality of the simulated solution can also be quantified in the multiobjective function by means of weighing coefficients.

The quantification of the environmental impact of a certain scenario is performed by combining the simulation of the evolution of the Petri net model with the methodology of the LCA.

In particular, the second stage in the application of the LCA, the analysis of the inventory, requires that every single activity considered in the model of the system is analyzed to quantify the consumed resources and generated waste. This information can be stored together with the Petri net model. The simulation of the model allow the addition of the contribution of every single activity to the total amount of resources and waste that correspond to the educative process.

Furthermore, the third stage in the application of the LCA consists of the impact assessment. The effects on the environment and society of the use of resources and generation of waste are evaluated for every single action represented in the Petri net model. The simulation process allows calculating the global effects of the educative process for any scenario involved in the simulation.

7. CONCLUSIONS

The efficient design of a vocational training center has been the subject of the research line presented in this paper. The main objective aimed with this paper has been to present a methodology to build up a decision support system, appropriate for the managing staff of the educative center.

It has been described the procedure to build up a detailed model of the system by using the paradigm of the Petri nets. This model allows a quantitative representation of the educative institution able to perform a numerical analysis of the evolution of the educative process.

Furthermore, it has been shown that the LCA, a reputed methodology for the analysis of the environmental impact of human activities, can be applied in conjunction with the Petri net model, in order to provide with a flexible tool for simulating the behavior of the educative institution on a daily basis for a variable amount of time.

The resulting decision support system may perform a simulation of a selection of a predetermined set of configurations of the educative institution and calculate the corresponding environmental impact of every one of them, compare the results and determine the best one of them. Moreover, the decision support system can provide with the sequence of decisions of the managing staff that lead to the most successful configuration.

In the following stages of the research, the methodology will be applied to a diversity of centers of vocational training in order to refine the model of the system, increase its versatility, and test it as decision support tool.

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