METABOLISMO INDUSTRIAL INTELIGENTE EN EL PROYECTO DE PRODUCTOS SOSTENIBLES

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INTELLIGENT INDUSTRIAL METABOLISM IN THE SUSTAINABLE PRODUCTS PROJECT

ABSTRACT:
Industrial systems, in the current technological, legal and economic context, require the addition of more sustainable, flexible and intelligent processes, aimed at mitigating the global metabolic rift with proactive character from design phase. This work proposes the development and implementation of an ontology for knowledge of sustainability that supports intelligently the management of Industrial Metabolism, enabling the closure of material cycles in industrial ecosystems from eco-compatibility and efficiency. The proposal made is concreted in an application that meets the information requirements of design tasks in the domain of design materialization of Genomic Model of Eco-design and Eco-innovation (MGE2). The proposal is formulated under a brokering architecture of Intelligent Multi-agent Systems, which are used for integration of the ontology established under the perspective of the engineering life cycle of industrial products and processes. This approach supports engineers in design tasks oriented the closing of material cycles on the technosphere under toxicity and efficiency criteria. With regard to ontology the objective is to establish a transversal ontology of information that fosters collaborative work and a specific ontology to maintain individual autonomy, allowing decision making to ensure the sustainability of products and processes. The developed ontology is integrated into a Multi-agent System and applied in a case study.
Keywords: Sustainability, Eco-design, Ontology, Multi-agent Systems, Multi-agent Systems Projects, Intelligent Industrial Metabolism.

RESUMEN:
Los sistemas industriales en el actual contexto tecnológico, legal y económico, requieren de la incorporación de procesos más sostenibles, flexibles e inteligentes, orientados a mitigar la fractura metabólica planetaria con carácter proactivo desde la fase de diseño. El presente trabajo propone el desarrollo e implementación de una ontología para el conocimiento de la sostenibilidad que dé soporte inteligente a la gestión del Metabolismo Industrial (MI), posibilitando el cierre de ciclos de materiales en los ecosistemas industriales desde la ecocompatibilidad y eficiencia. La propuesta formulada se concreta en una aplicación que satisface los requerimientos de información de las tareas de concepción en el dominio de diseño de materialización del Modelo Genómico de Ecodiseño y Ecoinnovación (MGE2). Dicha propuesta se formula bajo una arquitectura de brokering de Sistemas Multiagente Inteligentes, que son empleados para la integración de la ontología establecida bajo la perspectiva de la ingeniería del ciclo de vida de productos y procesos industriales, dando soporte a los ingenieros en tareas de diseño orientadas al cierre de ciclos de materiales sobre la tecnosfera bajo criterios de toxicidad y eficiencia. En lo que se refiere a la ontología el objetivo es el establecimiento de una ontología de la información transversal que favorezca el trabajo cooperativo y una ontología específica que mantenga la autonomía individual, permitiendo la toma de decisiones que garantice la sostenibilidad de productos y procesos. La ontología desarrollada es integrada en un Sistema Multiagente y aplicada a un caso de estudio.

Palabras clave: Sostenibilidad, Ecodiseño, Ontología, Sistemas Multiagente, Proyectos de Sistemas Multiagente, Metabolismo Industrial Inteligente.

1. INTRODUCTION

Since its origins, the human society has been integrated in natural ecosystems, taking an active part of the same and immersed in their own biological cycles. The arrival of industrialization has led to a series of circumstances that have significantly altered this seamless integration between society and nature. As well the intensification of cultivation, the manufacture of synthetic materials, the indiscriminate use of fossil fuels, etc., have led to an imbalance in the harmony existing in the metabolism socio-environmental. Marx and Engels [1] were the first who tried the metabolism from a

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social conception in 1883, considering that the work was the activity through which regulated the metabolism between society and nature. The concept of metabolism was used to describe the exchange of matter and energy between society and nature, merrily of support for his criticism of the industrialization focused on the exploitation of wage labor [2] through this study, Marx [3] develops the well-known term of *metabolic rift* in the metabolic cycle of nutrients, making it clear that industrialization has interrupted the existing metabolism for centuries between society and nature. This fracture is a gap in the continuity of the metabolism, according to the natural laws of life.

However, currently, most of the productive systems have been developed from a linear conception of economy, consisting in the removal of natural resources, the use of the same for the production of goods and services, and the incorporation of the waste generated and resulting emissions to the environment with a pre-treatment under the approach end of pipe. However, this linear conception or shortages in the productive systems, represents a loss of economic value, environmental and social. In 1989, Frosh and Gallopoulos [4] introduced the idea that a way to minimize these impacts could be carried out by modeling the systems of production and consumption from a similar perspective on natural ecosystems, giving rise to the circular economy or the abundance. The main objective of this idea is to transform the linear relationship of the flows in the productive systems flows in closed-cycle that mimics the circular chains of natural ecosystems, providing an overall framework for ensuring that the industrial system will become sustainable, integrating it into the environment and not enabling it to operate beyond the capacity of reception of the planet and limit their extractions and returns to and from the nature. That is why the ultimate goal of industrial ecology is reuse, repair, recover, re-manufacture, or recycling products or take advantage by-products [5].

It is remarkable, from the perspective of the circular economy and its implementation under *cradle to cradle* (C2C), the lack in the majority of contexts of an agent that promotes a shared vision of the network of materials, water and energy that flows between the various producers with the purpose of cycle flows in the productive system. This determines the need of gathering local information on the requirements of by-products available or raw material, by providing such information in a networked platform that facilitates and expedites access to the various stakeholders in the cycle flows required for your manufacturing process. This is made possible by integrating tools that provide innovation and systems that support decision-making processes, allowing organizations to improve their competitiveness and functions, from a global, integrated perspective. Industrial ecology is presented as an appropriate framework for the implementation of strategies for optimization and efficiency in the consumption of resources [5], enabling the evolution of industrial systems from a reactive behavior, to a proactive.

The system of information required for the formation of a manufacturing system circular under C2C is of paramount importance, taking as a goal to the incorporation of sustainability does not involve an increase in the complexity in the management of companies. For this reason it has been proposed a *Multi-agent System* (MAS) pointing to the management of the cyclicity, efficiency and eco-toxicity of the industrial and urban ecosystems. Develop mechanisms to permit the establishment of the cooperative communication and strategies among agents, for the achievement of sustainability objectives, under a framework for joint action [6]. To this end, this work proposes an ontology of knowledge for sustainability, integrated in a MAS.

2. FRAMEWORK OF INTEGRATION OF THE INDUSTRIAL METABOLISM

In the evolution of the fields that arise from the approaches to study the problems of environmental sustainability arising from human activity, in analogy with the natural ecosystems, are the urban and industrial metabolism [7], which include, among others, the flows of material and energy used in buildings, infrastructure, transport, industrial processes, water, lighting or heat and it is converting the industrial system in a sustainable system, considering that in natural systems there are no waste since the processes of each agency contributions are necessary to the welfare of the entire system.

Each mode of production and reproduction of life that has developed the humanity on the planet, gives rise to a particular regime of organization of this metabolism socio-environmental. The same has been determined the 'rift' open metabolic in the relationship between human beings and the earth, in which the work and production as a condition of human existence poses a need natural and eternal to mediate in metabolism that occurs between man and nature, and must be designed with some criteria which take to the nature as a teacher, model, and mentor, in a way that determine a design integrated and sustainable eco-social metabolic processes both urban and industrial.

2.1. INDUSTRIAL METABOLISM

The *Industrial Metabolism* (IM) is defined as an analysis of the use of materials and energy on the part of the industry and the way in which these materials flows through the industrial systems for processing and subsequent disposal as waste [8]. This led to the understanding of the flow of materials, water and energy (and *stocks*) linked to human activity, since its initial removal to its inevitable reintegration in global biogeochemical cycles, or to the technical cycles of such technosphere has become.

One of the strategies for implementing the IM is partially through the bags of by-products, which have as their object reduce the ingress of virgin raw material per unit produced. This strategy allows companies from various sectors diffuse, request and exchange by-products that can be used as a raw material in their production processes. The confidentiality of the process of exchange is the main base of the bag, which requires the intervention of the corporations of traders as trust centers, who channeled the supply response to the demand for another industrial. Currently, depending on the type of intervention of the management unit in the exchange of by-products, four different types of bags [9]: Exchange active or passive information, mediation in the transfer and direct transfer of materials.

These strategies form cycles at the end of the life-cycle of products or systems through identification of needs of different agents of the productive system, which may be satisfied by the materials recovered in the inverse manufacturing is a strategy of sustainability reactive. Compared to the same it is the proactive, looking back at the design phase of the adoption of solutions on the basis of materials and resources that may be biological or technical nutrients that the be cycled on the naturesphere or such technosphere has become at the end of its useful life, contribute to an urban industrial metabolism and integrated with the natural environment.

2.2. DESIGN OF THE PRODUCT FOR THE INDUSTRIAL METABOLISM

The design of products targeted to provide high efficiency and to produce a less impact on natural systems during their life cycle is not sufficient to meet the current demands of sustainability. This perspective may involve an approach more closely linked to a technical efficiency of the design, by limiting a utilization of the benefits of the natural system. It is for this reason that there are other approaches to the design of the product that cover in greater or lesser extent the concept of IM with proactive approach, the most notable are [10-13]: *Green Design, restorative design, design of Reconciliation, Regenerative Design, C2C and the Genomic Model of Eco-design and Eco-innovation* (MGE2) [14].

The MGE2 model [12-14], Fig. (1), is being developed with the purpose to support the design and development process of products whose life cycle is sustainable and inspired by the natural reference points, linked to the standards of the series ISO-14000 and LEED certification and integrating the paradigm C2C [15] and all those aspects in the *life-cycle analysis (LCA)* of products and systems. Pursues the incorporation in products and systems of a number of features in the design phase that dictate its sustainability, during its manufacture, its use and in response to the end of its useful life, where they must return again and again as technical nutrients and biological to the technosphere and naturesphere. For this, they have to be equipped with a character auto-author evokes and auto-reclaimable, achieving a flow of adequate nutrients, i.e. simulating food chains that are still living beings in their ecosystems. The MGE2 model is structured in several levels of action arising from the requirements of the products and their interactions with the industrial and urban systems. Each of the levels introduces techniques and tools:

- Toxicity: Substance flow analysis and substances model C2C.
- Cyclicity: Material flow analysis and analysis of food chains.
- Energy Efficiency: Exergy analysis and clean energies C2C.
- Water Efficiency: Water footprint and water balance.

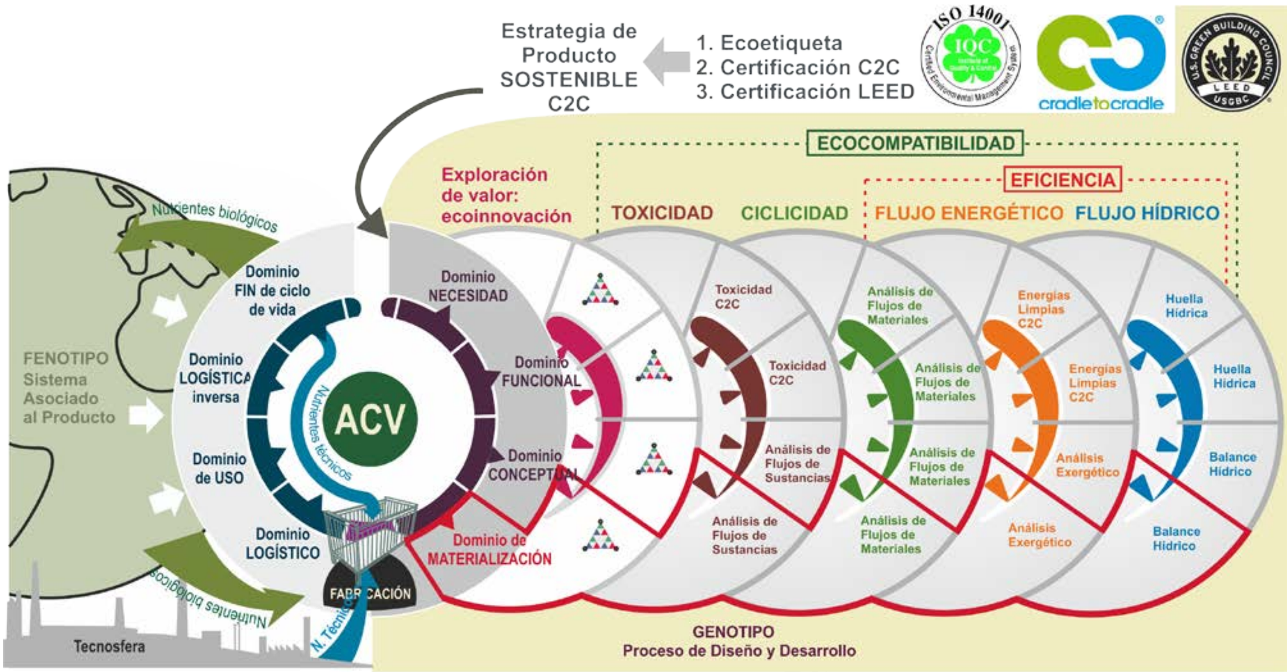

Fig. 1. Genomic Model of Eco-design and Eco-innovation [12].

A case of applying detailed model of the MGE2 to the design of a product type is located at [12].

2.3. SMART INDUSTRIAL METABOLISM BASED ON MAS

According to the definition of Wooldridge and Jennings [16], an agent is a computer system that interacts with its environment and that can have autonomy, sociability, reactivity and proactivity. Agents can be classified [17] in categories (reagents, cognitive, deliberative) based on similar characteristics, despite the fact that agents set up a heterogeneous population. These characteristics are reflected through the properties, objectives and rules of behavior for the agents, establishing various architectures of agents that allow them to adopt the behavior desired collective in the MAS [18], formed by various agents in interaction.

The evolution of the systems of manufacture, production and services which constitute IM, presents a growing trend in the use of information technology-based distributed in MAS [19], which enable you to reduce transmission of information and to guarantee the anonymity if established. In what refers to the methodologies for the development of MAS the majority have been proposed on the basis of extensions or improvements in line with other already existing methodologies [18]. As well, it is possible to perform a three-fold classification of these methodologies: the object-oriented methodologies, the methodologies of the legacy of knowledge engineering (for example, as further (conceptual modeling of Multi-Agent Systems) and MAS-COMMONKADS METHODOLOGY (Multi-Agent System Common Knowledge Acquisition and Design System), and the methodologies based on the paradigm of agents (which include Cassiopeia, HLIM (High-Level and Intermediate Models), Prometheus, SODA (Societies in Open and Distributed Agent spaces), Tropos and Gaia). With regard to the technology that allows you to map the knowledge of the manufacturing systems and productive service IM, are various execution platforms for the development of communities of intelligent agents, among which are: JADE (Java Agent Development Framework), FIPA-OS (Foundation for Intelligent Physical Agents Open Source), Jackal, OAA (Open Agent Architecture), etc. recent work troop proposed models and architectures based on intelligent agents that serve to support the various aspects of the industrial ecology [6,20-21]. In these jobs are set features such as the properties that you must possess the agent, typology of actors and their capabilities, as well as criteria for decision-making under the framework of sustainability, integrating under the concept of intelligent environment [22]. In this work, the model developed is conceived, from the perspective informational (smart), to the aspect of sustainability associated with his metabolism.

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2.4. ONTOLOGY OF SUSTAINABILITY

Although it is possible to find different definitions of ontology, all researchers seem to agree on the importance of ontology in the representation, distribution and reuse of knowledge of a particular domain. A definition of ontology is that offered by Weigand [23], where an ontology is a database that describes the most important concepts of the world or some domain, some of their properties, and how the concepts relate to one another. However, the definition of ontology is the most frequent offered by Gruber [24], which provides that an ontology is a body of knowledge represented formally based in a conceptualization. Still the conceptualization and a simplified abstract view of the world that you want to represent with some purpose. Gruber [24] establishes a set of entities with which they will be able to model a knowledge domain, typically: classes, attributes, or properties), and relationships. Still the ontologies designed to allow the exchange of knowledge and reuse between entities within a domain.

One of the aspects that presents today a special interest in the modeling of the sustainable management of industrial processes and urban, is the development and establishment of ontologies of the information [25-26] to enable the modeling and formalization of knowledge in the domain of industrial ecology, including the classification and characterization of the technologies, materials, substances and waste, as well as the profiles of users, the parameters economic, environmental and social, and other aspects associated with a cyclic metabolism, efficient, safe and eco-compatible, and the ontology thus defined can be used to proactively manage metabolic cycles of the materials, in order to integrate the natural metabolism And industrial level of eco-industrial park, see Fig. (2).

It is possible to conceive an ontology of sustainability that abstracts domain of knowledge in several concepts or classes. Some of which may be taken directly by the agents [27], being formalized their interactions in the ontology. Hence, it is possible to develop ontologies for MAS with knowledge of sustainability from shared ontologies and standardized where specifying the structure of data.

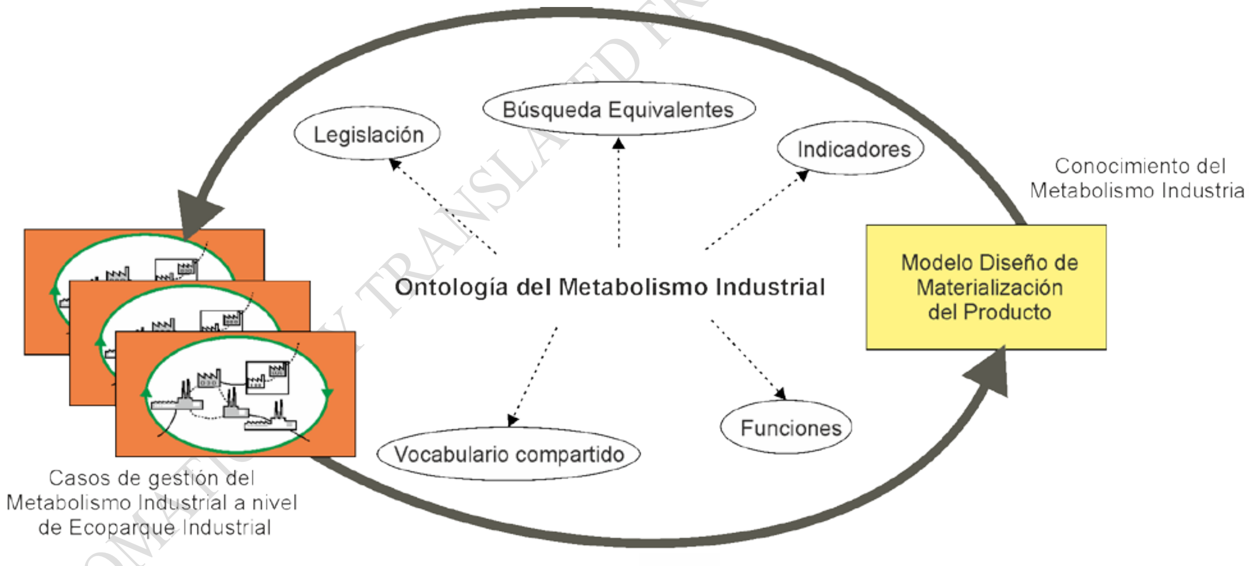

Fig. 2. Ontology of applied sustainability.

3. ONTOLOGICAL MODEL OF INDUSTRIAL METABOLISM

Proposing the development of an ontological model of sustainability that provides support to the management of IM a level of eco-industrial park (with companies exclusively on production and design and production of products) from the perspective of the closing cycle of materials and substances. In these environments of industrial construction it is possible to conceptualize the knowledge associated with the three domains that make up the sustainability [28]: environmental, economic and social, as seen in Fig (3). In each of the domains is necessary to define the components of the ontology based on a semantic and set itself [25, 29], specifying for each one of them their description and properties. Well, the ontological model exposed establishes relationships between environmental indicators (efficiency, cyclicity, toxicity, acidification, etc.), social indicators (security, satisfaction, health, development, etc.) and economic indicators (cost of recycling, re-use, etc.), in addition to contemplate the conventional indicators [30] process-oriented (such as delivery time, cost of production or quality level). By monitoring the information of sustainability at the level of product, process (machine), plant and eco-industrial park as a whole.

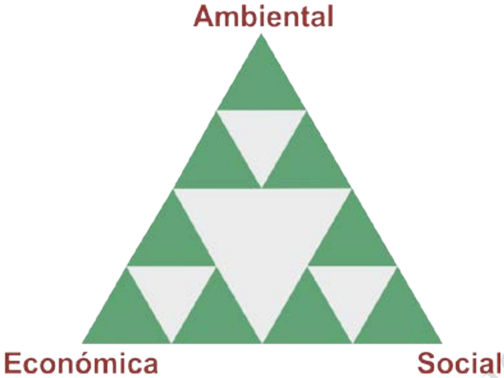

Fig. 3. Triple perspective of sustainability.

The proposed model is designed to enable a collaborative work between the different entities that compose it. Allowing communication, understanding and cooperation between the actors, as well as the exchange of information, the search for solutions and local and global decision-making. In order to support this system defines an ontology that promotes understanding among the various agents and that at the same time support the development of each of the skills they have. The ontology that is proposed to integrate into the model has been structured in two parts [31], see Fig (4). The first part is constituted by a domain ontology database called cross ontology, which enables the cooperative work between the agents. While the second part provides an individual or specific ontology that enables each one of the agents to use knowledge and particular functions within the system.

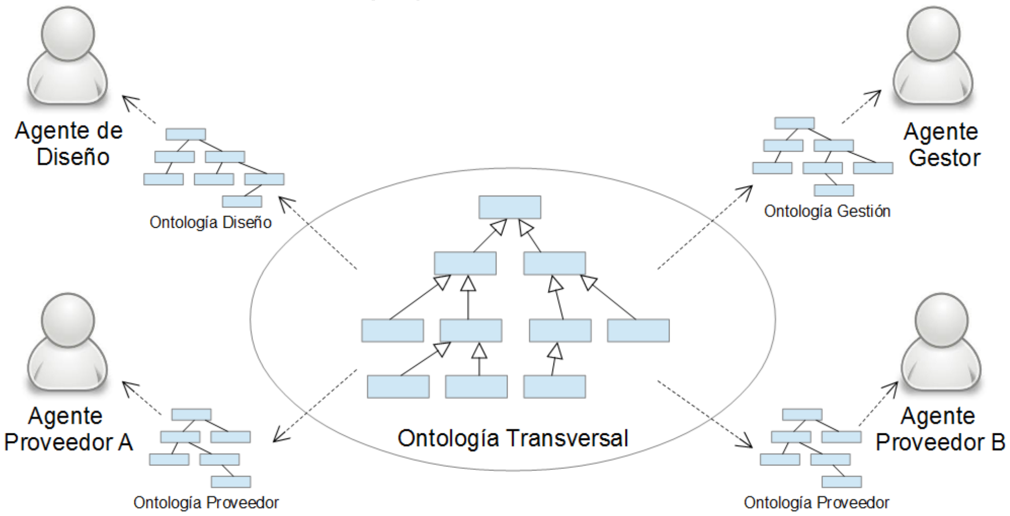

Fig. 4. Cross ontology and specific ontologies.

The ontological model proposed for the design processes of realization of products under the framework of IM is presented in Fig (5). The following describes each of the ontologies, showing the classes, attributes and relations of the own domain [24], which have been modeled using UML class diagrams (Unified Modeling Language*)*. While an ontology can be represented in UML, RDF (Resource Description Framework), DAML+OIL (DARPA Agent Markup

Language Ontology From Layer), OWL (Web Ontology Language) or any other representation that you can define objects, properties and relationships.

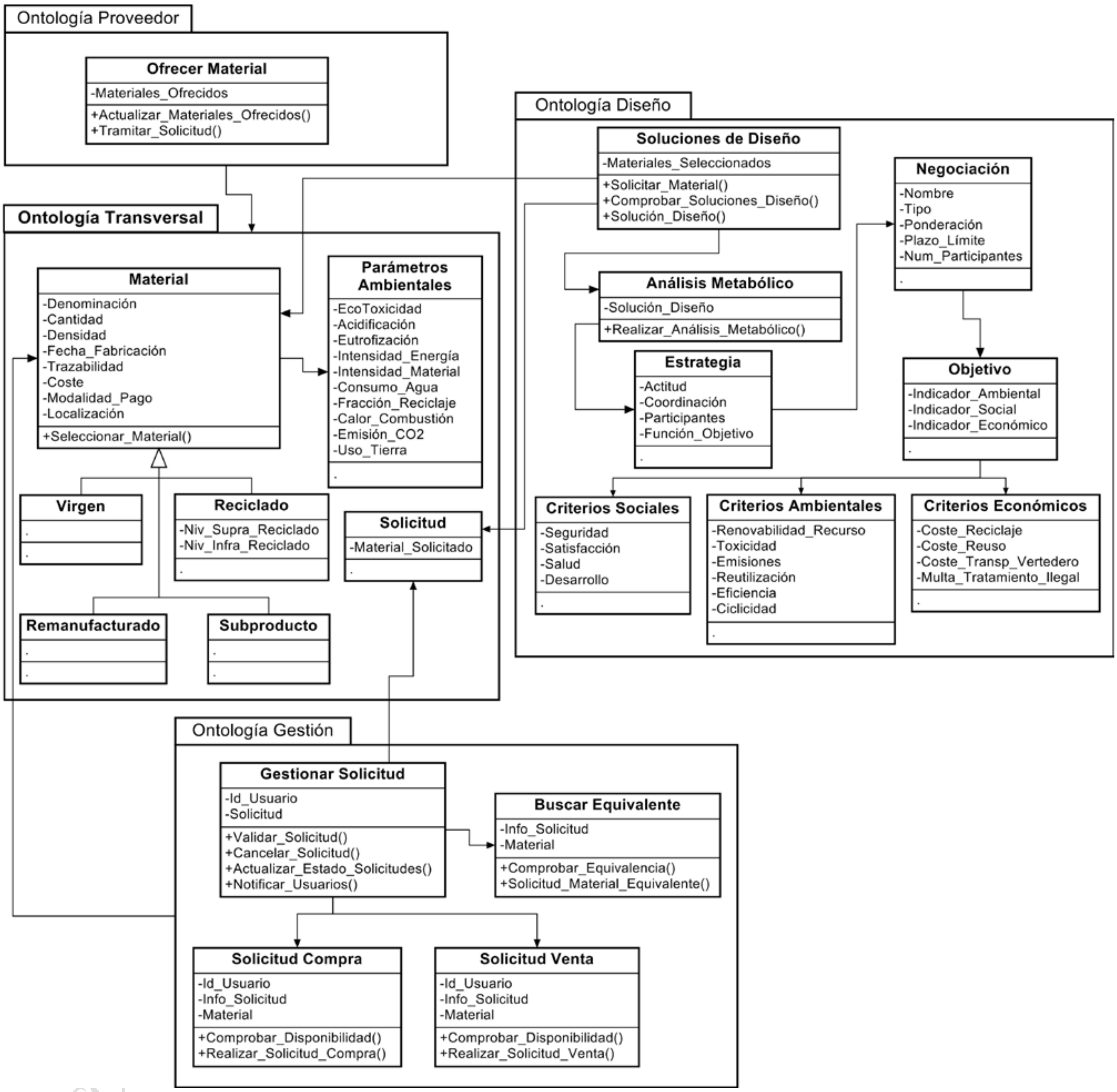

Fig. 5. UML class diagram of the ontology of the sustainability of the Industrial Metabolism.

Cross Ontology is structured according to the knowledge about sustainability to be shared by all the actors involved in the system so that the understanding may be possible. To be one of the objectives of the metabolism the closing of cycles, the knowledge associated with the subject matter must be transverse. Each agent has shared knowledge of the attributes that have the materials (understood as material for the raw material, products, recycled material, re-manufactured products and by-products) that are the subject of exchange between companies or production processes, and the environmental parameters associated to allow the decision-making. At the same time, is included in the ontology sectional to the knowledge of the applications, since it will be the way in which agents can communicate to reach agreements on the exchange of materials.

Ontology Design contains the specific knowledge to manage the design solutions of realization on the basis of the selected materials, being able to carry out metabolic analysis in accordance with the transversal knowledge of the attributes of the materials. The metabolic analysis in turn is associated with the strategic knowledge for the negotiations between agents. The concept of strategy includes the attitude of the participant, the existence or not of coordination with other actors in a common strategy, the number of participants and the target function that pursues the strategy. The strategy has associated a negotiation which establishes, among other a goal to achieve in accordance with the three indicators of sustainability.

Provider Ontology includes specific knowledge for which the providers of media are able to offer them to the rest of agents that are members of the system.

Management Ontology contains the knowledge management of requests for materials, including both the requests of offer as acquisition. Further develops the specific knowledge necessary for the search of by-products equivalent to the requested materials.

4. CASE STUDY

The main objective of the proposed case is the closure of cycle of material within the IM and natural way of enhancing the cyclicity, efficiency and toxicity in the urban ecosystem and industrial. The case study is referred to the process of materialization in the design, within the MGE2, of a trash of urban furniture, depending on the material characterized in Fig. (6), and among the possible options for selection of materials is illustrated for the case of selection of virgin materials and recycled, post that simplifies their analysis without modifying its objective. On the basis of the entities involved in the case, is the conceptual design of intelligent agents that constitute the MAS and employing the ontology proposal in the resolution of the use case. The MAS raised is configured on the basis of a brokering architecture.

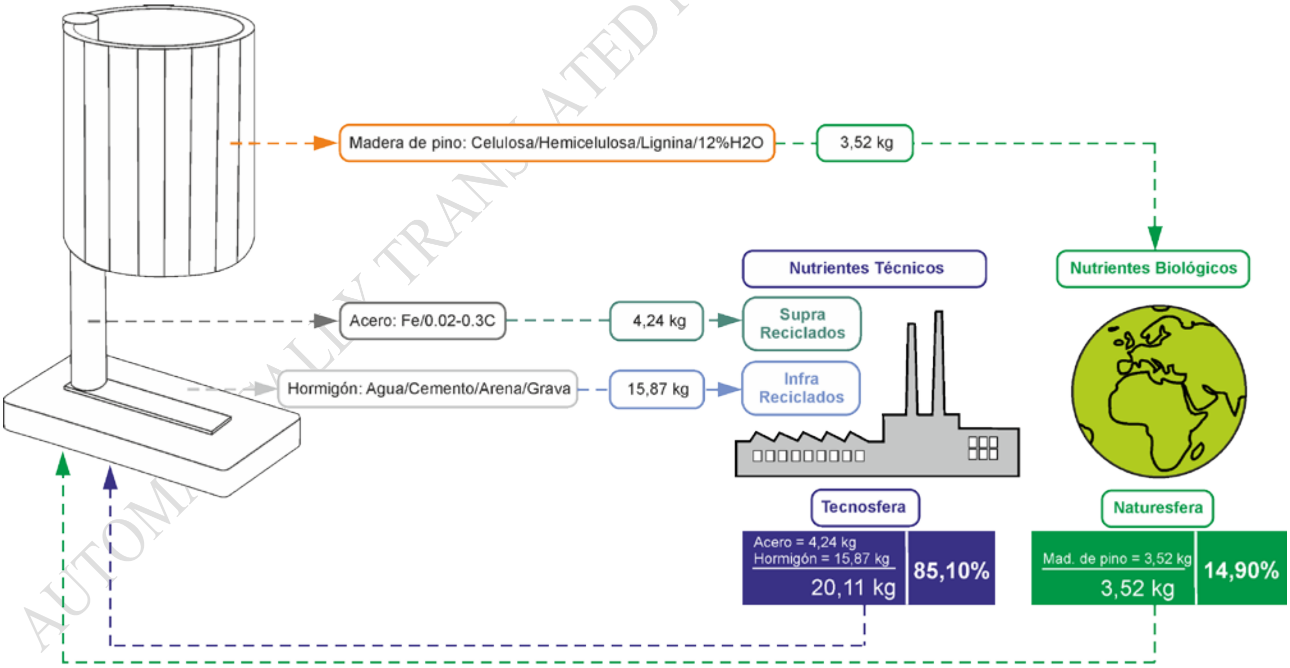

Fig. 6. Metabolic flows and cycles of product on technosphere and naturesphere.

The agents of the MAS responders, as shown in Fig. (7), are identified as Design Agent, Provider Agent and Manager Agent. These intelligent agents support the various human agents that may be involved in the design process and materials management. The actions are carried out every one of the agents are described below:

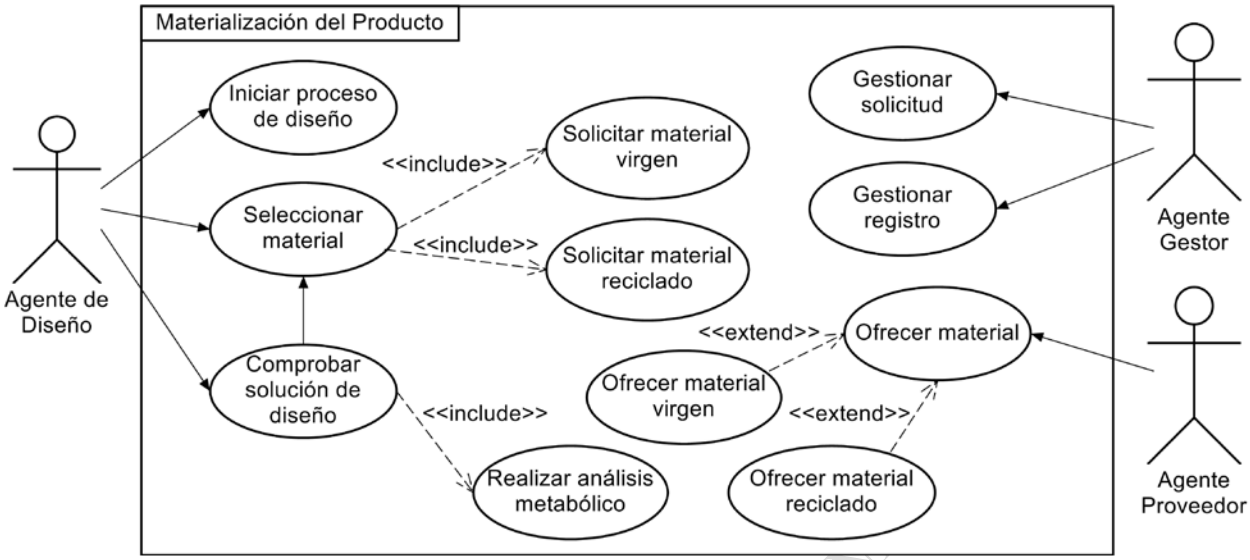

Fig. 7. UML use case of the process of materialization in the design of the product.

Agent Design: starts the process of product design in the domain of materialization, select materials and conducts the requests of materials to the managing agent. The information returned by the Agent Manager allows you to perform the metabolic analysis of the materials and start a process of negotiation on the basis of the business strategy, oriented toward ecological criteria, to the obtaining of the ISO certification, C2C, etc.

Manager Agent: centralizes the management of materials in the corresponding level. Acting as a broker agent that handles the registration of materials and applications, so that makes possible the establishment of communication for negotiation between the agent applicants and sellers of materials.

Agent Provider: the Agent Manager communicates the desire to sell their material generated, indicating its attributes and environmental parameters, and the conditions it sets for the transaction, which must be considered in the negotiation process.

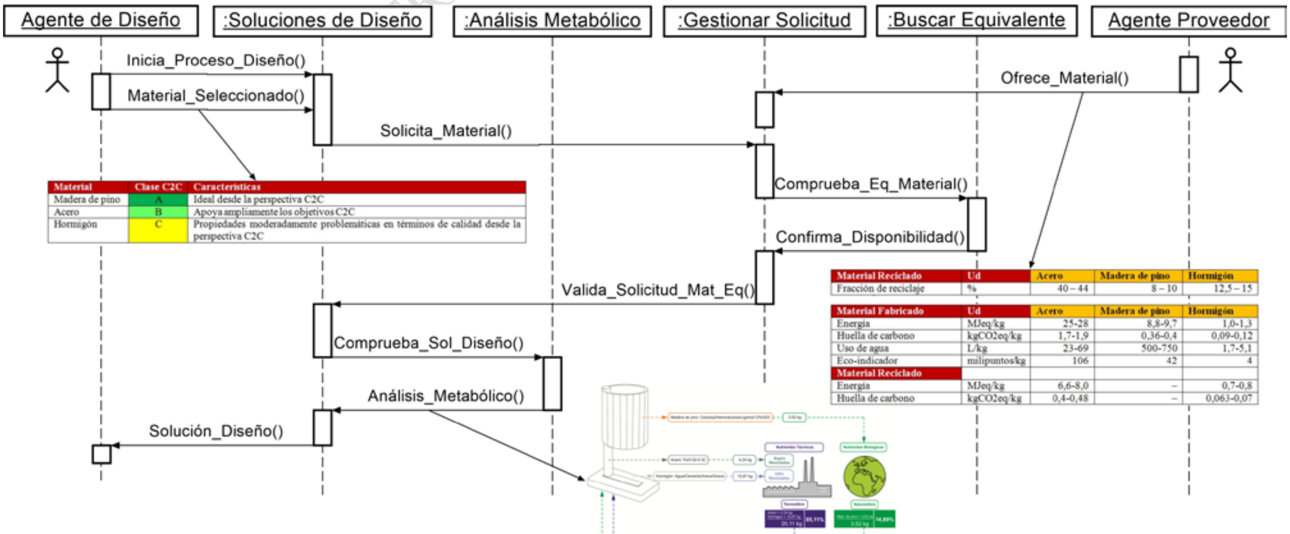

Fig. 8. UML sequence diagram of the process of materialization in the design of the product.

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Fig. (8) shows the UML sequence diagram of the process described in order to identify the dynamics that originates in the design process of materialization of the product, through the instantiation of the classes defined in the ontology proposal, see Fig. (5). The Design Agent initiates the process of design and makes the choice of materials for the trash: pine wood, steel and concrete, by sending a request for material to the managing agent, making use of the *Material and Request* classes defined in the Cross Ontology. Manager Agent looking for materials equivalent to the requested, using the *Check_Equivalence()* function defined in the class *Find Equivalent* of the Ontology Management, thus allowing avoid exclusive use of virgin raw materials and pursuing his replacement by recycled products, remanufactured or byproducts equivalent. Confirmed (or not) the existence of such materials equivalent, through the function *Validate_Application()* belonging to the class *Manage Application*, the Manager Agent informs the design agent for the characteristics of each material, using the attributes of the class *Material* and the attributes of the class *Environmental Parameters*. The Design Agent with the information received appropriate to assess the validity of the use of the materials proposed by *Check_Design_Solutions()* function of the class *Design Solutions*. These checks are focused on the perspective of IM, using the *Make_Metabolic_Analysis()* function of the class *Metabolic Analysis*. This metabolic analysis is included in the business strategy of the company and guided by a process of negotiation, where the goal is to satisfy the triple perspective of sustainability, under social, economic, and environmental criteria. In particular the class *Environmental Criteria* includes the attributes *Toxicity*, *Efficiency* and *Cyclicity* defined in the MGE2, Fig (1). The test is completed the solution of design proposal, the Design Agent confirms the design solution through the *Design_Solution()* function of the class *Design Solutions*.

The information generated in the design process of materialization of the product in the three levels of performance for the MGE2 model (toxicity, cyclicity and Efficiency) is detailed below.

4.1. TOXICITY

The study of toxicity assumes prior knowledge of the composition of the materials, from which the product is manufactured, with the goal of adequately managing toxic control. In the case study the composition of each of the materials is as follows:

- Pine wood: cellulose, hemicellulose and lignin, 12 %H20.
- Steel: Fe, 0.02 -0.3C.
- Concrete: water, cement, sand, gravel.

Characterization of the substances in terms of toxicity, it is concluded that none is included in the list of banned chemicals established according to the standard C2C certification [32]. Verified the list item is to classify materials on the basis of their exposure and risk (ABC system-X), as shown in Table 1.

Material	Class C2C	Features
Pine wood	TO	Ideal from the perspective C2C
Steel	B	Broadly supportive of the objectives (C2C
Concrete	C	Properties moderately problematic in terms of quality from the perspective C2C

Table 1. C2C Classification of materials.

4.2. CYCLICITY

The design solution obtained has associated a classification of the selected materials in order to identify the metabolisms and management strategies associated with the product. Well in Fig. (6) identifies the pine wood as biological nutrient and the steel and the concrete as technical nutrients (indicating the level of recyclability), with the indices of cyclicity that are reflected in the Fig. (6) and Table 2.

Recycled Material	Ud	Steel	Pine wood	Concrete
Fraction of recycling	%	40-44	8-10	12.5 -15

Table 2. Index of cyclicity.

4.3. EFFICIENCY

The built-in power to the product must be characterized and quantified according to the standard C2C certification [32], considering all the stages of the product and establishing a strategy to optimize your development. The use of water resources incorporated in the product can be quantified by the water balance, which sets the total volume of fresh water used to produce goods and services. In this case study data of energy flow and water flow are obtained on the Table 3 on the basis of the use of manufactured or recycled material.

Manufactured Material	**Ud**	**Steel**	**Pine wood**	**Concrete**
Energy	MJeq/kg	25-28	8.8 -9.7	1.0 -1.3
Carbon Footprint	Kgco2eq/kg	1.7 -1.9	0.36 -0.4	0.09 -0.12
Use of water	L/kg	23-69	500-750	1.7 -5.1
Eco-indicator	Millipoints/kg	106	42	4
Recycled Material				
Energy	MJeq/kg	6.6 -8.0	-	0.7 -0.8
Carbon Footprint	Kgco2eq/kg	0.4 -0.48	-	0.063 -0.07

Table 3. Eco-properties of materials depending on the phase of obtaining.

Completed the process of materialization of the product begins the process of negotiation between players. The Design Agent send a request to the Provider Agent, previously identified thanks to the broker process, and will make an offer on the material, based on the business strategy and the environmental objective. The process of negotiation can finalized in success or failure.

5. CONCLUSIONS

This article proposes an ontology of sustainability for the sustainable management of IM Intelligent, bringing significant benefits compared to the current management of these systems that do not have a global vision. The integrated use of a MAS allows you to decrease the times in the management of the flows, ensure the anonymity of the organizations involved in the processes of exchange and at the same time establishes a shared ontology and individual that facilitates the identification, analysis and closing cycle of the materials.

Highlights the importance of an intelligent information system that allows you to manage and integrate the processes of information with the purpose of supporting the decision-making under the principles of industrial ecology. Providing a structurally organized information available and accessible, making it more easy to identify the relationships between the flows of information, and evaluate under the criteria ecological, economic and social.

The proposed model for the design phase is extensible to other stages of the product life cycle. May develop similar models in production, recycling, etc. that seek the improvement of the cyclicity, efficiency and toxicity in the industrial and urban ecosystem.

The integration of the MAS and the ontology of the sustainability proposed in the development phase, so that future work will focus on the validation of the proposed model. In order to enrich the considered strategies and negotiations, as well as expand the ontology to all existing agents in the industrial and urban ecosystem under the triple perspective of sustainability: environmental, economic and social.

APPENDIX A

Acronyms	
LCA	Life Cycle Analysis
CoMoMAS	Conceptual Modeling of Multi-Agent Systems
C2C	Cradle to Cradle
DAML+OIL	DARPA Agent Markup Language Ontology From Layer
FIPA-OS	Foundation for Intelligent Physical Agents Open Source
HLIM	High-Level and Intermediate Models
JADE	Java Agent Development Framework
MAS-CommonKADS	Multi-Agent System Common Knowledge Acquisition and Design System
MGE2	Genomic Model of Eco-design and Eco-innovation
IM	Industrial Metabolism
OAA	Open Agent Architecture
OWL	Ontology Web Language
RDF	Resource Description Framework
MAS	Multi-agent system
SODA	Societies in Open and Distributed Agent spaces
UML	Unified Modeling Language

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