Ontological Model of Knowledge Management for Research and Innovation

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Abstract. Organizations should focus on effective knowledge management in order to improve their competitiveness in the current Knowledge Age. Given this need, ontologies have emerged as a new approach for the development and implementation of knowledge management systems. Ontologies allow applying modeling methods in order to design the structure of the organizational knowledge.In this work we present an ontology-based model for the knowledge management in research and innovation. The knowledge-based model proposed allows describing aspects such as the business model processes, the organizational intellectual capital, and the dynamic behavior of the processes of a research and innovation organization.

Keywords: Business model · Business process · Ontology · Knowledge management · Research and innovation

1 Introduction

Research and innovation are a mixture of different skills and activities. Throughout history, research and innovation as a way of knowledge generation have taken routes through which disciplinary knowledge has transited. These routes became less clear taking into account the current world, where the amount of information available in the Web and internal organizations have been steadily increased. Therefore, there is a need for new mechanisms that allow performing knowledge management activities in an efficient way. Knowledge management within university research institutions must be identified with the organizational culture, the dynamism of knowledge generation, and a multidisciplinary approach. This fact requires to consider the intellectual capital through its three areas, human capital, structural capital and relational capital, as well as the organizational learning. The present work is based on the business model processes and is focused on the research and innovation processes. Applying our approach to the aforementioned process will allow measuring and assessing the generation and dissemination of knowledge, as well as providing the users with this knowledge, avoiding withholding knowledge at the organization.

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An ontology is a formal and explicit specification of a shared conceptualization [1]. It provides a formal representation of knowledge structures in a reusable and sharable way. Ontologies provide common vocabulary with different levels of formality for a domain. Also, they define the semantics of the terms and the relationships between them. Knowledge management processes require determining the structure of the knowledge in order to promote problem solving. As was previously mentioned, the ontology allows the representation and sharing of the knowledge. Therefore, we used an ontology-based approach in order to represent the knowledge generated from research and innovation processes.

In this work, we propose an ontological model for the knowledge management at a Research and Innovation center. This model describes the research and innovation processes and the technologies that support such activities. This work is structured as follows. Section 2 presents the state of the art concerning knowledge management. Section 3 discusses the justification of our model. Section 4 presents the theoretical basis of this model. The methodology followed as well as the model itself are presented in Sect. 5 and 6 respectively. Finally, conclusions and future work are presented.

2 State of the Art

Nowadays, there are research efforts that adopt an ontology-based approach for knowledge management. In [2] the authors present an integrated enterprise-knowledge management architecture, focusing on how to support multiple ontologies and manage ontology evolution. Another research effort is the presented in [3], where the authors present a generic ontology-based user modeling architecture, known as OntobUM, which is applied in the context of a knowledge management system. The proposed user modeling system relies on a user ontology, using Semantic Web technologies, based on the IMS LIP specifications, and it is integrated in an ontology-based KMS called Ontologging. In [4] the authors present IkeWiki, a semantic wiki focused on collaborative knowledge engineering. This wiki provides support for different levels of formalization ranging from internal texts, to formal ontologies, and its sophisticated, interactive user interface.

Bueno [5] defines the intellectual capital as knowledge accumulation that generates value or cognitive richness in an organization. It consists of a set of intangible assets (intellectual) or knowledge-based resources and capabilities, which when put into action by a determined strategy in combination with tangible capital, is able to create value and core competencies in the market. The author recognizes the intellectual capital as an entrepreneurship and innovation generation system. Also, he emphasizes the role of the components or capital that integrate the model: human capital (Capital related to the people's knowledge), structural capital (Organizational and technological capital which refers to the knowledge related to the intangible assets created by the organization and its technological development), relational capital (Business and social capital linked to the intangible assets developed by the organization and the individuals who belong to it. Also, the development of this capital is based on the relationships established with the market agents and the society in general). On the other hand, the Intellectus Model [6] seeks the evolution

capacity of the intellectual capital from a new component or entrepreneurship and innovation capital as a set of accelerators identified in the elements and variables of the aforementioned components, which act with a multiplier effect of intangible assets in the organization. Osterwalder [7] defines the business model as an abstract representation of the business logic of an organization through an ontology model. This model consists of three large blocks. The first block represents the resources, activities and third-parties that help to produce and maintain the offered value. The second group reflect the value of incomes and costs of the first block. Finally, the third block represents the customer-related activities.

The works cited in this section represent significant research contributions to the knowledge management area. However, they are not focused on the research and innovation domain, which is the focus of this work. Furthermore, this model is based on the Intellectus Model, the business model proposed by Osterwalder, and the process model for knowledge management proposed by Nonaka and Takeuchi [8]. Our approach aims to provide a model, supported by a technological architecture, for knowledge management at university research and innovation centers.

3 Justification

In 1998, higher education systems received a call from UNESCO to increase their ability to live in the middle of uncertainty, in order to meet social needs, change and bring about change under precepts of solidarity and equality, to preserve and implement rigor and originality, making scientific research a requirement to achieve and maintain an essential quality education level [9].Over the following decade, UNESCO ratified this call emphasizing the need for universities to become a dynamic factor of social development by means of its processes and resources. Among the recommendations made by this organization are [9]:

- Quality assurance requires qualified, talented, and committed teachers and researchers.
- Universities must pay special attention on the establishment of interinstitutional relations, aiming to encourage the generation and strengthening of the capacities of the countries, thus ensuring diverse sources of good academic staff in the fields of research and knowledge generation, at a regional and global scale.
- Research systems at higher educational institutions must have flexible organization in order to promote science and interdisciplinary at the service of society, establish an appropriate balance between basic and applied research, as well as to maintain effective links between global knowledge and local problems.

The impact of knowledge management on Research and Innovation at higher education is given by the changes produced in this new vision of the universities, which establishes that there must be interdependence between scientific disciplines. Therefore, from a point of view of Research and Innovation, knowledge management is imperative. Knowledge management supports research processes and its production activities, as well as the register of good practices.

The ontological model presented in this work provides the Research and Innovation center of the Agrarian University of Ecuador with a guide to managing the experiences and results of research activities, as well as a scheme for the creation of memory, experience, and knowledge of research and innovation. The proposed model focuses on four fundamental axes that support continuous knowledge interchange: (1) the register of researchers' experiences through their products, (2) the dissemination of such knowledge among research centers, universities, sponsors, and society, (3) the preservation of that knowledge, and (4) the availability and accessibility of that knowledge as needed. With this understanding, this model will allow continuous learning improvement and the generation, access, and application of that knowledge, thus providing competitive advantages such as talent, effective leadership, learning, and collaborative work.

4 Theoretical Bases

Ontologies have been applied to different domains such as biomedical [10], neuroscience [11], information management [12], finance [13], management [14] and cloud computing [15]. Osterwalder [7] adopts the ontology-based approach to represent the business logic of an organization. This ontological model describes the business model through nine blocks focused on the value of a business proposal oriented to the customers.

On the one hand, the basic components of knowledge management are the creation, preservation and transfer of knowledge [16–18]. Knowledge creation depends on the internal and external learning [19]. Preservation and transfer of knowledge enable the organization to have an organizational memory, thus making it possible the access to knowledge as needed [20]. On the other hand, the knowledge creation model proposed by Nonaka [8] distinguishes between tacit and explicit knowledge. This model is based on the relationship between tacit and explicit knowledge through socialization, externalization and combination processes.

Nowadays, the ontology-based approach represents the basis of current knowledge technologies. This approach requires an information and communication infrastructure that allows sharing knowledge. This infrastructure must include elements such as knowledge repository, directory of knowledge sources, directory of learning sources and groupware tools, among others [21].

In this paper, we propose an ontology-based model for knowledge management in Research and Innovation which is based on three main works, the CANVAS model [7], the Intellectus model [5], and the Nonaka and Takeuchi model [8]. The next section describes the methodology followed for the design of the aforementioned model.

5 Methodology

The methodology used to develop the model proposed in this work was adapted from the one presented in [22]. Figure 1 shows the structure of this model which is composed of three layers: business model and processes, knowledge management, and knowledge management technologies. These layers are represented by means of ontological models,

this fact allows to represent all knowledge generated from research and innovation processes. In addition, the researcher can visualize the knowledge from the same perspective.

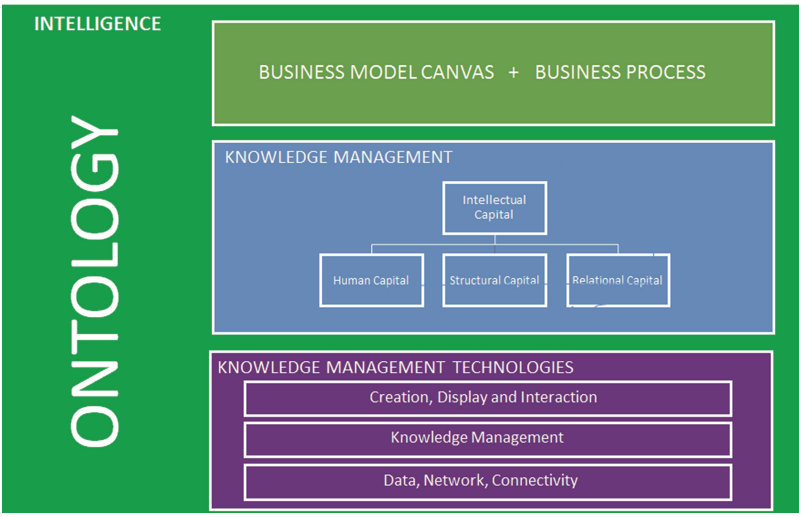

Fig. 1. Methodological structure for the development of Ontological Model for knowledge management in research and innovation.

The business model layer describes the logic of a research and innovation center, from the business model to its organization. The knowledge management layer describes the intellectual capital through the knowledge generated by business processes. The above-mentioned layers are supported by a technological architecture that allows the establishment of a collaborative environment.

The first phase of the design process consists of the identification of the business model and the business processes. Then, the intellectual capital is established based on the business processes and taking into account the knowledge management processes. These phases are supported by knowledge management technologies. Finally, all collected knowledge is represented by ontological models. The ontology development phase was performed by using the Ontological Engineering, specifically Methontology [23] and the Protégé OWL. The next section describes the ontological model proposed in this work.

6 Ontological Model for Knowledge Management in a Research and Innovation Center

As was previously mentioned, the first phase of the model design process was the development of the CANVAS model which describes the logic processes of a research and innovation center. This model is composed of nine blocks: key partners, hey activities,

value proposition, customer relationship, customer segment, key resource, distribution channel, cost structure and revenue stream. Each block is decomposed into constituent parts defined at different levels of granularity that meet the specific needs. Figure 2 shows the CANVAS model developed.

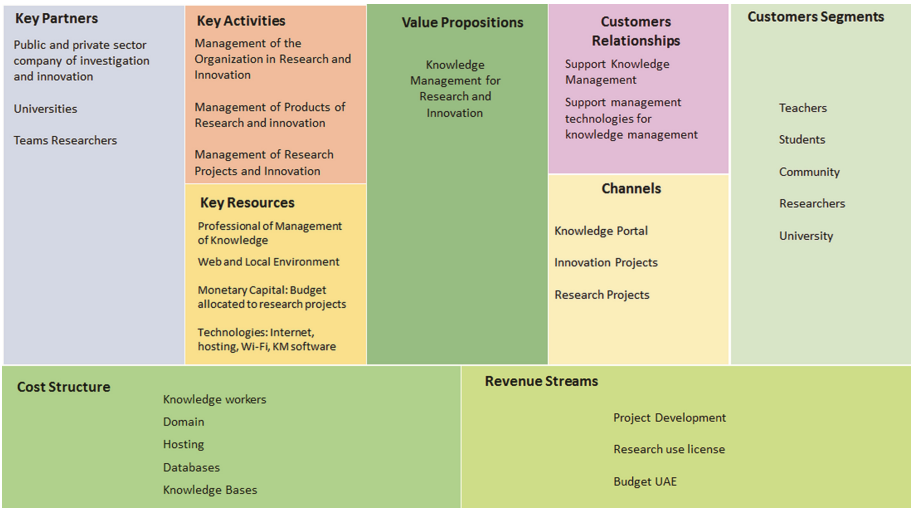

Fig. 2. Ontology business model CANVAS for research and innovation

This model is focused on researchers, teachers, students and universities. The value proposition of the business model is the effective performance of knowledge management in research and innovation centers. Figure 2 shows the key business activities which make up the CANVAS model, they are: organizational management, product management and the management of innovation projects sponsored by public institutions and other universities and researchers, and the resources such as laboratories and technological infrastructure. These activities are supported by the revenue sources managed from an established budget.

The activities described above are immersed in the intellectual capital parameters as follows: Human capital describes who does what in the organization and describes the roles, thus providing support to the organizational management. Product and project management are modeled by means of the structural and relational capital. These kinds of capital are presented in Fig. 3.

The organizational capital allows managing the following activities:

- The management of users and research groups. This activity takes into account the environmental conditions, which refer to the elements that guide the activities of the organization, including organizational culture, scientific and technological surveillance and external relations.
- The organizational culture is the set of values, principles, habits, rules and regulations governing the activities between researchers and research groups. These activities are composed of economic and university policies and internal and external

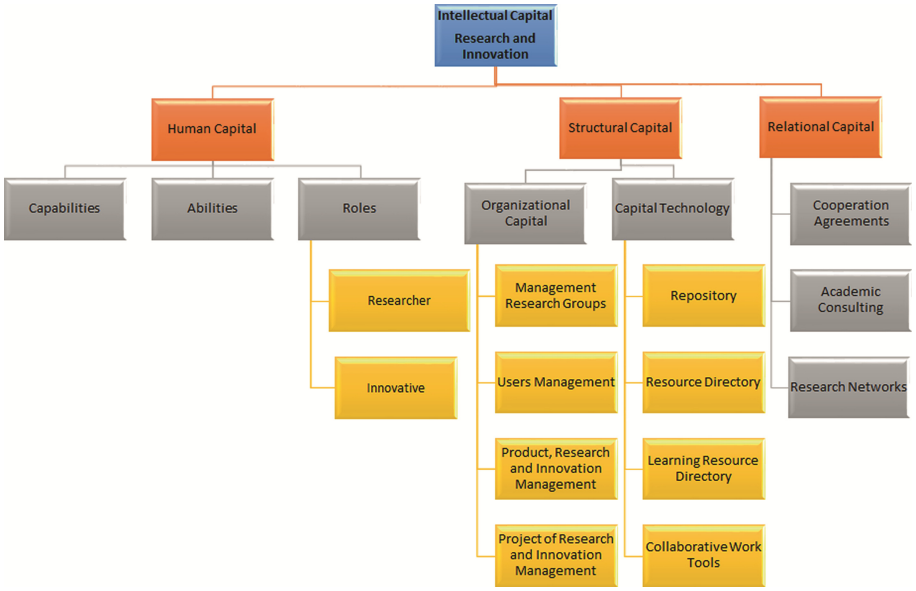

Fig. 3. Intellectual capital for research and innovation.

regulations that serve as a reference for the organization, structuring, and implementation of the research and innovation center.

- Product management. It consists of activities such as scientific and technological surveillance which aim to monitor the guidelines, progress and scientific and technological advances, by means of external variables that affect the domain to be monitored, thus allowing the generation of research and innovation products.
- Project management. It refers to activities focused on the planning, development and monitoring of research and innovation projects.

The technological capital contains the management processes related to the human, structural and relational capital. Relational capital manages both internal and external relations and research centers. These relations are generated through requirements, agreements, consulting and research networks. The processes of human, structural and relational capital and its sub-processes are complemented by the organizational activities such as those shown in Fig. 3. For example, the research group management is performed by the researchers who must have certain skills and abilities. These activities are supported by technologies. Furthermore, they have relationships with other researchers through cooperation agreement.

Figure 4 shows the knowledge management processes which are related to the development of the environmental conditions and the intellectual capital of research. These processes describe how the human capital must interact by using technological products and knowledge products that make up the intellectual capital of the model. These processes are represented using the model of Nonaka and Takeuchi [8] which allows representing the dynamisms of the model.

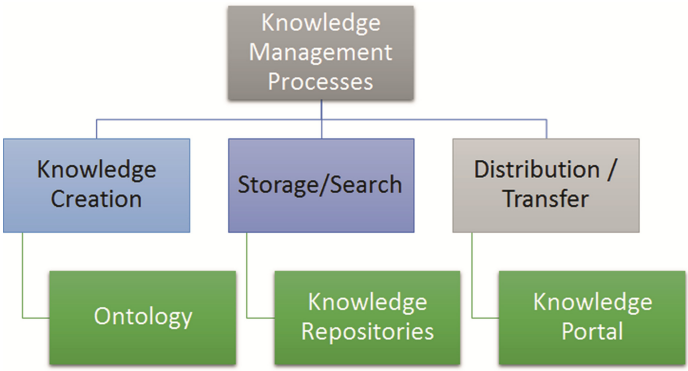

Fig. 4. Knowledge management processes for research and innovation.

Table 1. Ontology axioms of research and innovation

Natural language sentence	First order logic predicate
The Business Model of Knowledge Management of Research and Innovations have Customer Segments, have Customer Relationships, have Key Resources, have Revenue Streams, have Channels, have Cost Structure, have Key Activities, have Key Partners and have Value Propositions	V x BusinessModelR&I(x) => have (x, CustomerSegments) Λ have (x, CustomerRelationships) Λ have (x, RevenueStreams) Λ have (x, Key Resources) Λ have (x, Channels) Λ have (x, CostStructure) Λ have (x, KeyActivities) Λ have (x, KeyPartners) Λ have (x, ValuePropositions)
The Research and Innovation Knowledge Management have Intellectual Capital	V x R&IKM (x) => have (x, IntellectualCapital)
The Intellectual Capital have Human Capital, have Structural Capital and Relational Capital	V x IntellectualCapital (x) => have (x, HumanCapital) Λ have (x, StructuralCapital) Λ have (x, RelationalCapital)
The Human Capital have Role, have Abilities, and have Capabilities	V x HumanCapital (x) => have (x, Roles) Λ have (x, Abilities) Λ have (x, Capabilities)
The Role is a Novel Research, or is a Senior Research, or is a Novel Innovative, or is a Senior Innovative, or is a Group Coordinator	V x Role (x) => isA (x, NovelResearcher) V isA (x, SeniorResearcher) V isA (x, NovelInnovative) V isA (x, SeniorInnovative) V isA (x, GroupCoordinator)
The Structural Capital have Organizational Capital and have Technological Capital	V x StructuralCapital (x) => have (x, OrganizationalCapital) Λ have (x, TechnologicalCapital)
The Relational Capital have Cooperations Agreements, have Academic Consulting and have Research Networks	V x RelationalCapital (x) => have (x, CooperationsAgreements) Λ have (x, AcademicConsulting) Λ have (x, ResearchNetworks)
The Knowledge Process have Knowledge Creation, have Knowledge Storage, have Knowledge Search, Knowledge Distribution, Knowledge Transfer	V x KnowledgeProcess (x) => have (x, KnowledgeCreation) Λ have (x, KnowledgeCreation) Λ have (x, KnowledgeDistribution) Λ have (x, KnowledgeTransfer)

The knowledge creation process refers to the conversion of tacit knowledge possessed by researchers, students, and innovators, and also to explicit knowledge, for example by creating research and innovation products. The Storage/Search process is the set of actions that allow saving and searching the collected knowledge, e.g., the type of knowledge searching that occurs in technological and scientific monitoring. The Distribution/Transfer process refers to the information exchange that enables knowledge dissemination among internal and external individuals. This task is supported by knowledge management technologies such as ontologies. This ontology is obtained from the business model, the intellectual capital and the knowledge management processes for research and innovation centers. Table 1 shows the first-order axioms that describe and define the knowledge model.

The knowledge model is expressed through the first-order logic predicates shown in Table 1. These statements are translated through concepts, properties and axioms. Figure 5 shows the ontological model for research and innovation. It should be mentioned that this ontological model is based on the model proposed in [24]. The first version of this ontology is composed by more than sixty classes and three inferred classes. On the one hand, the orange ellipses represent the inferred classes, which are obtained through axioms. On the other hand, the yellow ellipses represent the asserted classes.

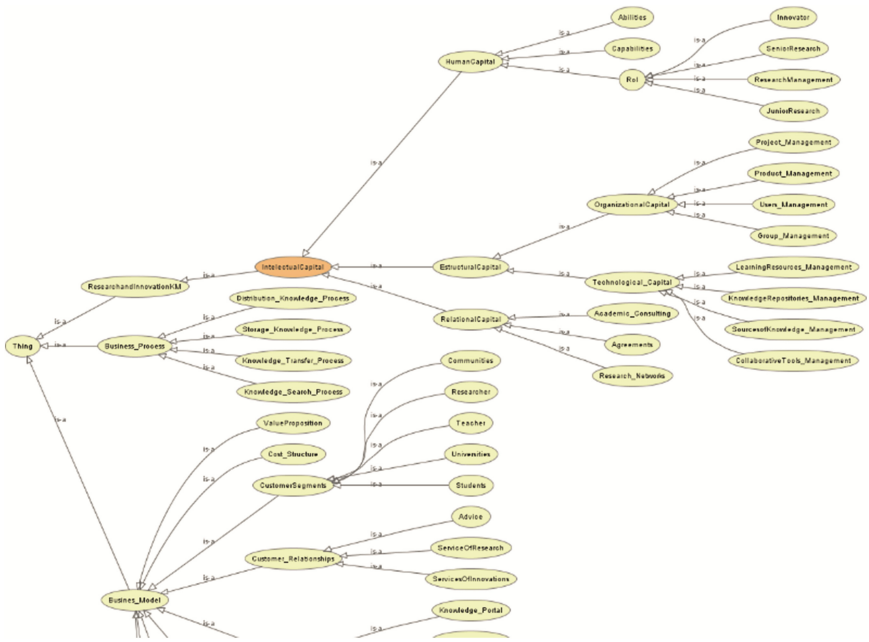

Fig. 5. An excerpt of the ontology of knowledge management for research and innovation. (Color figure online)

The technological architecture that will provide support to the model here proposed is based on the architecture presented in [25]. Figure 6 shows the architecture proposed in this work, which is focused on the research and innovation process.

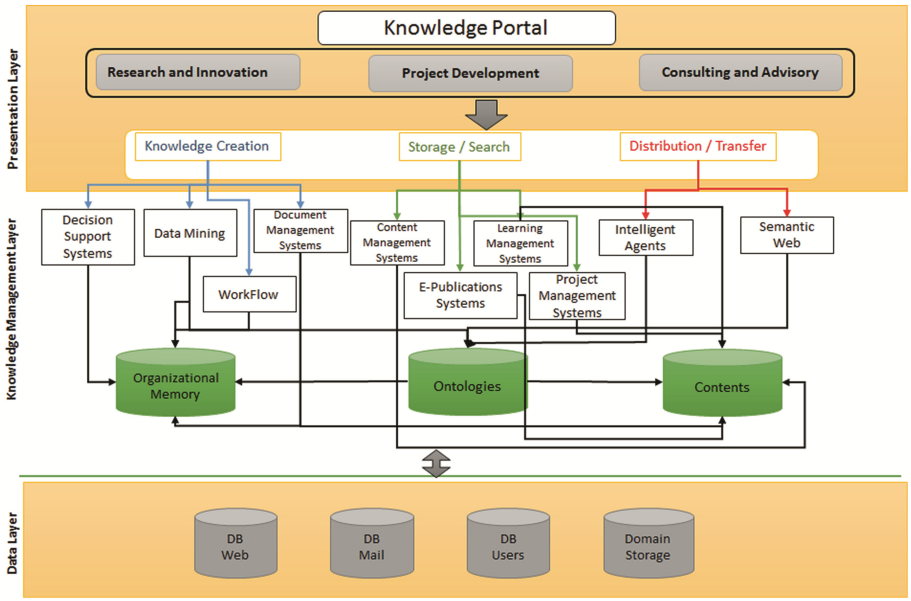

Fig. 6. Technological architecture of ontological model for knowledge management in research and innovation

The knowledge management layer is composed of technologies that support directory of knowledge sources, the directory of learning sources and groupware tools. Concerning knowledge creation, this layer considers data mining, workflow, ontologies and document management systems. With regards to the storage/search process, this layer provides a tool for content, system learning, and project management. Finally, this layer provides collaborative tools, intelligent agents, and Semantic Web tools focused on the process of distribution/transfer of knowledge.

7 Conclusions

The present work presented our effort to offer an ontology-based model for the knowledge management in research and innovation centers. This model aims to address the need for mechanisms that allows universities to improve their competitiveness in the current Knowledge Age. Furthermore, this work is based on successful applied works such as the Intellectus Model, the business model proposed by Oster-walder, and the process model for knowledge management proposed by Nonaka and Takeuchi.

In addition to the model proposed in this work, we also suggest a technological architecture that aims to provide support to the ontological model for research and

innovation. This architecture will allow users to generate, integrate, and share the knowledge generated from research and innovation processes. The interaction among the layers that compose the architecture will be guided by the ontological model. It should be mentioned that, as future work, we plan to assess the ontology from a point of view of a particular criterion of application [26], in order to determine the effectiveness of its application in a research and innovation domain.

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