Formalization of a knowledge base applied to dental implant

Vinicius Biscolli Biasi[*], Marcelo Rudek[**], Anderson Luis Szejka[**], Osiris Canciglieri Junior[**]
[*] Pontifical Catholic University of Parana - PUCPR - Control and Automation Eng. Dept., Curitiba, Brazil
[**] Graduate Program in Production Engineering and Systems - PPGEPS, Curitiba, Brazil

***Abstract*— With the expressive amount of terms and concepts generated over the years for all the existing domains, a formalization and possible validation of such domains were given as necessity. In the medical field, for example, more precisely in the field of implantology, terms are used daily in different ways around the world. The standardization of such terms is extremely important for human and machine understanding, thus creating a semantic interoperability between both systems. Thus, the use of ontologies as a method of knowledge formalization has been an approach to benefit the human understanding for any real domain. Applying this method to the area of implantology, ontological basis comes to benefit the professional dental surgeon at the time of decision making in choosing which type of dental implant to be applied to each particular case. This method consists of determining which implant is to be applied before a numerous physiological parameters of the patient compared to structural parameters of existing dental implants. For this method to be a real application, the formalized ontologies must contain and supply all essential data related to this domain. Therefore, this project focuses on the formalization of an ontological basis aimed at the application of a dental implant before physiological human and implant variables by itself. In order to obtain the results, it is essential to keep in mind the real meaning of the semantics and interoperability concepts, which should be applied together to the formalization of an ontology. In addition, it is necessary to analyze the application of these concepts in the dental field so that a case study based on the formalized ontology can be applied later. The formalization of the ontology was made based on Protégé software created by specialists of the university of Stanford in California. The results showed that not only an efficient but also effective solution for such an application was obtained, making the decision of dental professionals simpler with lower failure rates and better acceptance of the patient's body in relation to osseointegration.**

I. Introduction

Over the years, the technology has improved the way people communicate and share information around the world. With these changes, the human being, responsible for generating an increased amount of information every new day, had to adapt themselves to this new environment around them. Gradually, this amount of information turned into a huge pile of lost and unorganized files that people use daily. The Web is a great example of environment that face this problem, where thousands of new data are added every single minute in it by the users, but most of it erroneously, further aggravating the problem of creating a polluted environment. In order to solve this issue in an effective way, methods have been created, tested and/or applied before these situations to benefit users and professionals in every domain to find the right and most relevant information in an easier and faster way. The use of ontologies is an example of this method, which creates a kind of controlled vocabulary for a specific domain. This method, created by philosophers, were used to study the being and its existence [1], which later was introduced into the Computer Science and Artificial Intelligence field to be used as a relation between terms and concepts for every different domain [2]. In the field of dental implants, ontologies come with the proposal of helping the dental surgeon in choosing the best type of implant for each specific patient case, which nowadays is done manually by the professional over TC images and an initial consult.

In this paper we target how the formalization of such ontology was performed in order to achieve the expected results. It will focus on the preoperative planning and decision making step, as shown in Fig. 1, where all the parameters are obtained and the choice of the best dental implant is made. The processes of structuring an ontology will be based on thousands of medical concepts created and used in various areas of healthcare. In addition, it will be demonstrated and discussed results of the application of the ontological basis structured in a case study within the domain of dental implants.

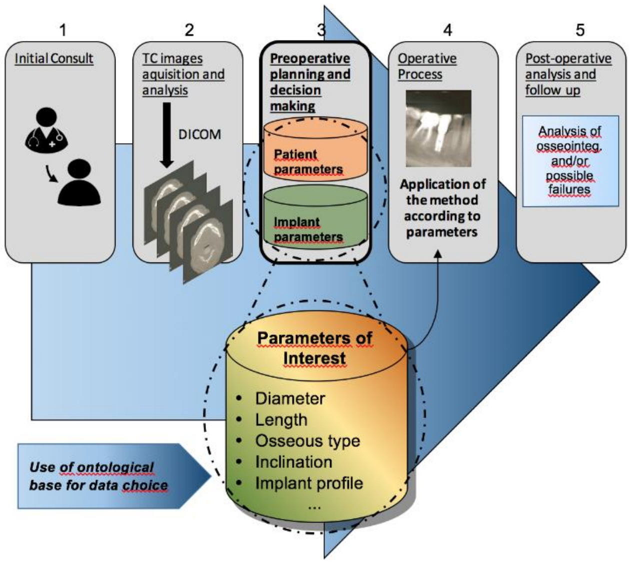

Figure 1: Process model of dental implant application

II. Background

The use of implants to restore the loss of a tooth has become a widely growing alternative in the last decades and its results have been increasingly encouraging. [3]

Implants in general are structures willing to do the work of absence or support of some component of the human body, such as bones. The author states that implants are nothing more than medical devices produced to replace a missing biological structure, to support a damaged biological structure or to repair a structure of the existing one. [4] They are recognized today as a great oral solution for many problems that improve both the functionality and the aesthetics of the patient. [5] One of these problems is known as edentulism that represents the partial or total loss of teeth, respectively, representing 30% of edentulous people above the age of 65 years. [2] Not only aesthetically, edentulism is also responsible for oral dysfunctions that affect people's health and quality of life. [5]

In order to decide and apply the best option in between thousands of implants, the professional needs to obtain some parameters which will assist it in the decision making. Some technologies are available today in the medical field, more precisely, medical imaging technologies have been of great help to physicians when making decisions about which implant and which tools should be used. [2] Before diagnostic imaging technologies, DICOM images are one of the options to assist in this issue. The use of the DICOM ontology is responsible for describing medical image metadata of DICOM files created from a CT scan. With the use of these imaging technologies it is possible to extract images of the DICOM format that allow the communication of medical information regarding to medical diagnosis. [6]

Although these technologies can assist the dental surgeon at the decision making moment, it is not guaranteed that the professional has enough experience to decide which implant is the best option before those parameters obtained. In this case, the use of ontologies for the medical field can benefit both professionals and patients with a more precise decision.

III. Ontology Structuring: Parameters of Interest

In order to start structuring an ontological basis, it is necessary to understand the context in which it will be applied. In general, a study and prior understanding of the subject is necessary in order to formalize the structure.

For the case of medical assistance in the decision making regarding which type of dental implant will be used for a particular patient, it is necessary to understand in advance which are the parameters of interest for each specific case.

The first one is the parameter group of the patient, which include parameters such as site diameter, length, osseous type, inclination and others. These are the parameters that will be used to choose the most appropriate type of dental implant.

These parameters can be obtained in two different moments. The first one is the analysis made over the initial consult with the dental surgeon, as shown in Fig. 1, step number 1. The professional analyzes the issue and verify if is necessary to perform a surgery or not. In sequence, the TC images, Fig. 2, are acquired and used to obtain the parameters of interest of the site.

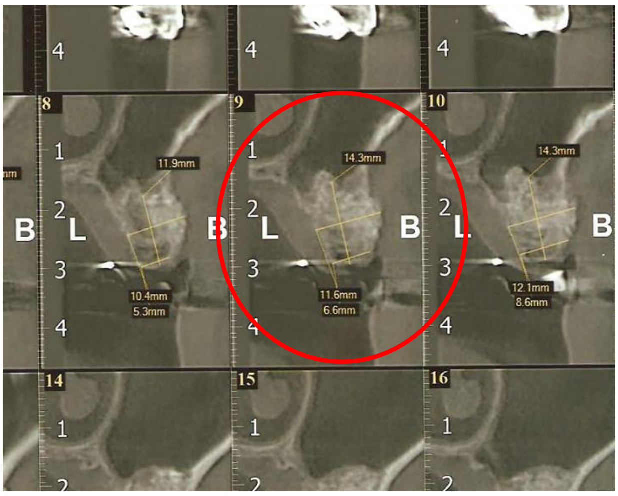

Figure 2: Analysis of the site before TC image

The second group of parameters are the implant parameters by itself. As stated before, every patient has a specific case which demand a specific type of implant. For instance, implant profile such as, length, diameter and material are some parameters that it possible to find in different types of these devices. Also, it is important to know where the implant will be applied, which means, in the mandible or maxilla, at the front or the at the back of it. Consequently, there will be a wide range of choices that must be analyzed in order to find and selected the best option as part of the solution.

Some parameters are often responsible for cumulative overload to implants, and these parameters must be studied and planed preoperatively, such as muscle strength, inclination, location and quality of bone tissue, implant positioning and, consequently the prosthesis with their respective shapes as well as other physiological variables of the patient. [7] Such parameters can influence in the primary stability of the dental implant, being this factor one of the most important in the rate of successful and durable implants. [3]

One of the reasons of choosing the best implant before these parameters, is the fact that it will result in a better osseointegration for the patient. Osseointegration, as the name implies, is the functional connection that the bone has in relation to the titanized dental implant. This phenomenon occurs when the dental implant is inserted into the bone by moving the osseous cells to the surface of the metal implant.

Also, osseointegration can be influenced by factors extra to the type of material, being these, its shape or design and also its surface topography. [8]

IV. Methodology for Ontology Base Structuring

Using the methodology 101, is possible to structure an ontology base which will be applied to a specific domain, in this case for the decision making of dental implant.

This methodology is clearly understandable, as shown in Fig 3.

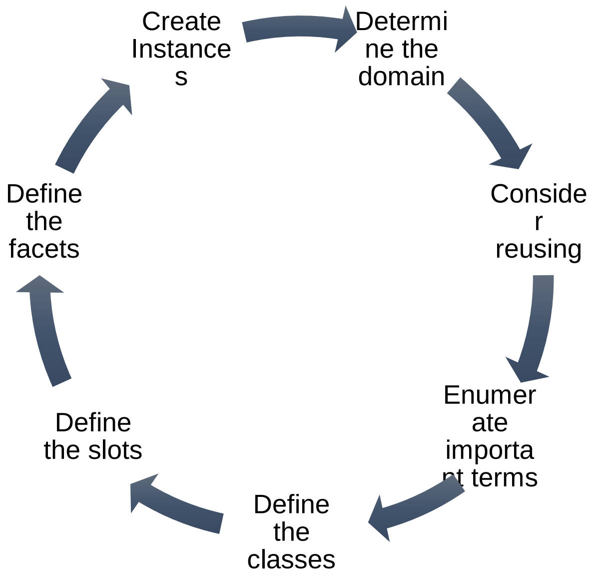

Figure 3: Methodology 101 for ontology structuring

The initial idea is to answer some macro questions regarding this methodology, which will define the general scenario in question [9]. Some of these questions can be seen as:

- What domain will this ontology cover?
- What will be the use of this ontology?
- For what types of questions will the ontology provide answers?
- Who will use and maintain this ontology?

As known, this project aims to formalize an ontology regarding to dental implants decision-making, so some questions can be applied as shown in Table 1 below.

TABLE I.
EXAMPLE OF MACRO ANALYSIS OF THE SYSTEM

1.	What is the best type of implant to be used?
2.	What are the dimensions of the site?
3.	What is local osseous type?
4.	What is the site inclination?
5.	What is the bone quality and quantity?
6.	What is the best implant material?
7.	What is the application site?

Once the macro analysis of the system is performed by the above questions, it is possible to perform a more precise analysis regarding terms of interest for each of these macro issues. These terms will be used as classes or subclasses, properties and even relationships between them.

TABLE II.
EXAMPLE OF MICRO ANALYSIS OF THE SYSTEM

1.	Length Diameter Profile (threaded or solid)
2.	Spacing available Available bone depth (check veins and arteries local) Available bone width
3.	Type 1, 2, 3 or 4
4.	Inclination between 0 and 20 degrees Inclination bigger than 20 degrees
5.	Need for bone grafting or not Amount of bone around the implant (minimum 1mm for better osseointegration)
6.	Titanium / Titanium alloy / Chromium-Cobalt (Cr-Co) / Nickel-Chromium (Ni-Cr) / Zirconia
7.	Maxilla / Mandible

Besides these parameters, it is important to check if this type of ontology was previously created by another author. In this project, an ontology created by Trappey was used as base for the structuring of the new one.

The main idea of the ontology created by the author was to break down the dental implant and divide it into main components such as Implant Fixture, Implant Assembly, the Screw Device and the Implant by itself. If we look at this project, the decision making is taken over 2 main ontologies parameters, the human being and the dental implant device.

For the human being ontology only common parameters such as name, age, gender, and patient-related physiological and anatomical parameters were used, which was enough to reach the expected results.

V. PROPOSED ONTOLOGY

Based on the last few parameters, it was able to structure classes and subclasses as well as slots for the classes. An example of the Dental Implant proposed ontology can be seen in the Fig. 4.

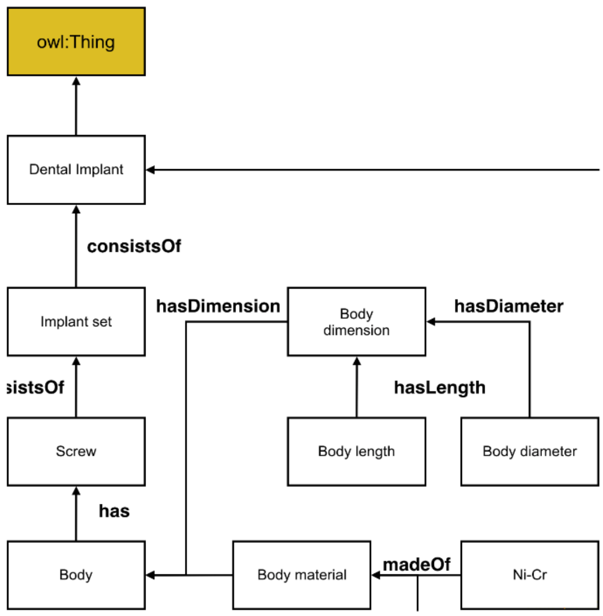

Figure 4: Example of the proposed Dental Implant ontology

Once structured the whole ontology, it is possible to created such structure into a software which will provide the user the ability of mapping, check, modify and test the actual ontology. Connecting all the classes and subclasses in Protégé software, Fig. 5, a mapping graph is shown, which is possible to verify the connection between all the structure classes, slots and also the later instances which will be created according to the necessity of the user.

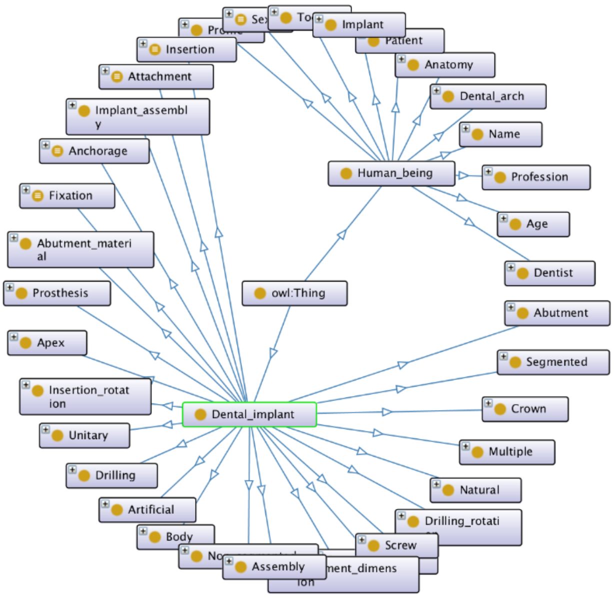

Figure 5: Example of ontology structure in Protégé software

As can be seen in the two ontologies implemented in the Protégé software, there is the connection from other subclasses that does not belong direct to the ontology Human being or Dental implant, it occurs because these are only equivalences between subclasses of the main ontologies that are grouped and presented in this way in the software.

If we think about any class, it is not enough to define itself, thus is possible to create class properties, known as slots. Slots describe relationships between classes and they are nothing but structural attributes to this relationship, for instance, *-hasDepth-*, *-typeOf-*, *-sameAs-*, *etc.* [10]

An example of slot is shown in Fig. 4 as part of the current ontology, for instance, *-consistsOf-*, *-has- and -madeOf-*.

Once defined all the slots is it important to define the new constraint. A constraint, also known as a *facet*, describes a value type assigned to the slot, or property, restricting this attribute to that type of value. These restrictions may have single or multiple cardinality depending on the property to which it applies. For values, the *facets* can be in several forms, being the most used in the form of string, number, Boolean and even in the form of instance, which relates to another individual or class. The Fig. 6 demonstrates an examples of facets used to structure the actual ontology implemented on Protégé.

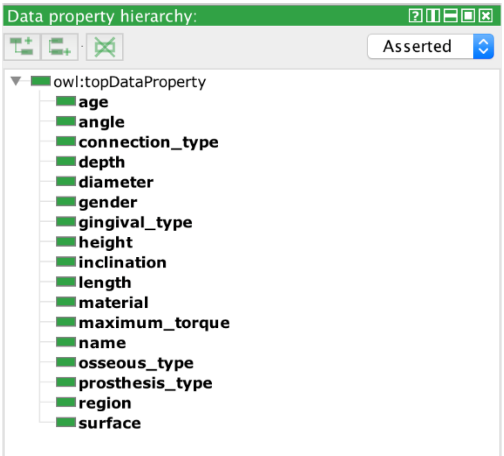

Figure 6: Ontology facets

It is also possible in this step to define the domain and range of properties, and the domain will be a class whose slot or property is attached, while the range will be an instance or object created based on a class, being used in a slot.

An instance represents an object created by an entity or an abstract class [11], for example, Morse Taper is an instance created to receive the parameters regarding to a dental implant class and Patient_1 is an instance of the class Human Being, which will receive values and properties from its class. Given some values of the properties from the objects, a particular human being will result in receiving a specific type dental implant.

The Fig. 7 represents one instance created based on dental implants features, such as, bone type, region of application, maximum torque that can be applied to the implant, type of connection (internal or external), etc.

Every type of implant has their own features which will differ from the others in order to make the ontology logic decides which is the best option for a particular case.

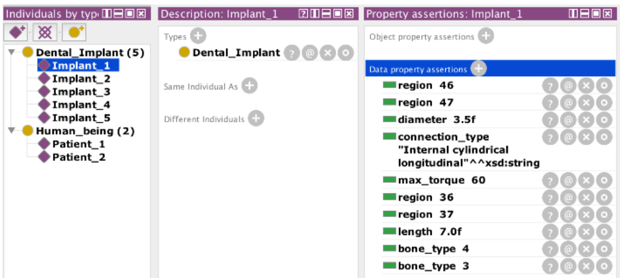

Figure 7: Example of dental implant instance and its features

A final version of the proposed ontology, divided in the two main ontologies Dental implant and Human being, are shown in Fig. 8 and Fig. 9, respectively. As stated in the beginning of this paper, this is a formalization for a new concept of decision making in dental implants area, this is not a validated ontology. The validation of an ontology is a step ahead of this project purpose. Before this, new implementation or modifications can occur with the continuous development of this project.

Figure 8: Dental Implant proposed class ontology

As it can be seen, some of the classes are represented with an *equal sign* inside the yellow circle. It means that these classes are equivalents, in other words, they are synonyms that receive the same value or meaning inside the ontology. It happens when inside one domain it is possible to find a class with different expressions or terms to be used in the structure.

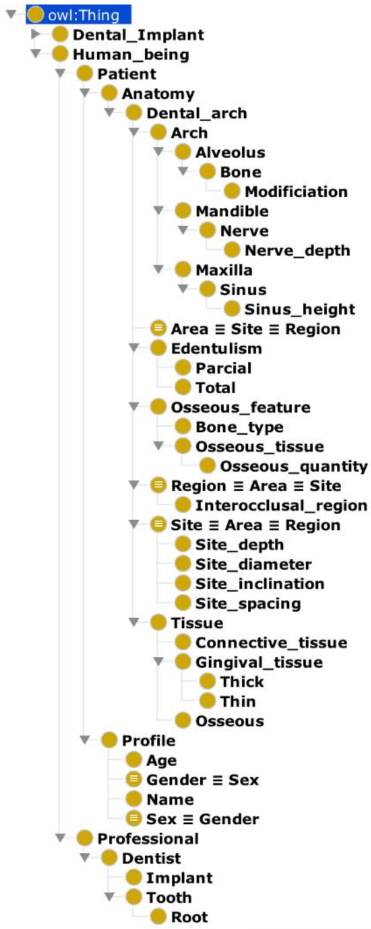

Figure 9: Human being proposed class ontology

VI. Case Study: Example

For the current project, 2 distinct patients and 5 different types of dental implants were created in order to test the actual ontology performance. Each one of the patients received different parameters that will make the ontology assume a different instance for each one of them.

An example of this, can be seen in Fig. 10, where the patient number 1 receives the implant number 1. It happens because the features that the implant 1 provides, supply the need for the patient 1. For example, the spacing (diameter) necessary to apply the implant 1 is minimum 4.1mm, knowing that is always important to have 3mm spacing in between implants or teeth to apply a new dental implant. [12] Likewise, it is possible to apply this dental implant if we check the necessary depth, region of application and bone type. [13]

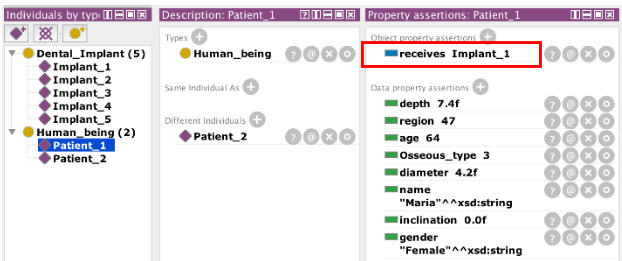

Figure 10: Case study - Patient 1 parameters

If we compare the parameters of patient 1 above with the parameters of the implant 4 below, shown in Fig. 11., it can be clearly seen that both parameters do not match. In specific cases where two or more implants fit the necessity of the patient, it is necessary to look in some others parameters which may not influence the general demand for dental implant applications, such as implant material, bone quantity, etc.

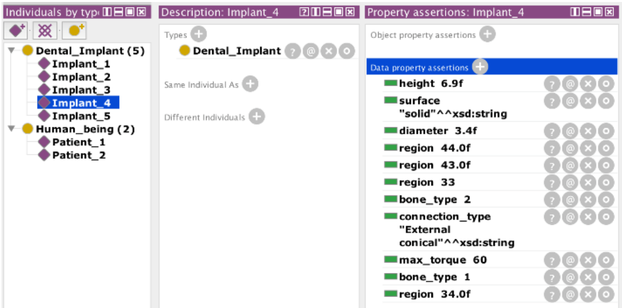

Figure 11: Case Study - Implant 4 parameters

In the example for the case above, the best option was using the abutment 2, which specifies the use for cases where you need no site inclination correction.

Before the choice of the best implant option, it was also necessary to choose the best abutment option, which led to look over parameters such as site inclination, angle of application, etc. This parameters, together with the type of connection for the abutment and the implant body by itself, will determine which is the best option for a particular case.

The Fig. 12 shows the comparison made between all these 3 instances where it is able to clearly understand their connections and the good results for this application.

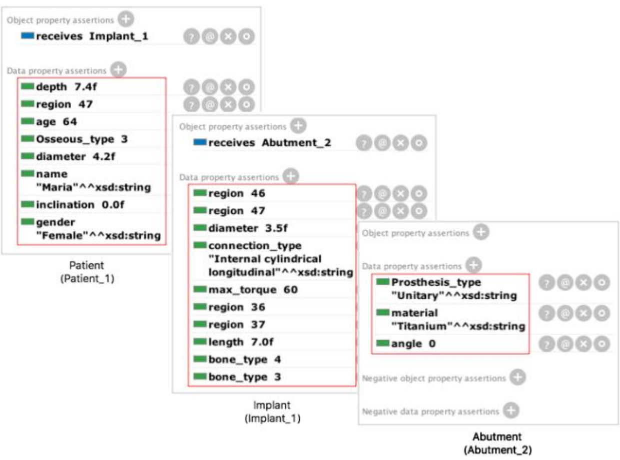

Figure 12: Results of the case study, over ontology use

This comparison can be equally seen in Table 3. The green cells represent parameters that match with the patient (P_1) requirements, in the second column.

*I_(1:4): Implant_(1:4) and *A_(1:2): Abutment_(1:2)

TABLE III.
COMPARISON OF ALL INSTANCES BEFORE PATIENT PARAMETERS

	P_1	***I_1**	*I_2	*I_3	*I_4	*A_1	*A_2
Ø	**4.2**	**3.5**	3.9	4	3.1	-	-
L/D.	**7.4**	**7.0**	6.5	7.5	6	-	-
B_T	**3**	**3/4**	3/4	1/2	1/2	-	-
Incl.	**0**	**-**	-	-	-	10	0
Reg.	**47**	**36/7 46/7**	13/4 23/4	16/7 26/7	36/7 46/7	-	-
P_T	**U**	**-**	-	-	-	M	U

Where, Ø: diameter, L/D.: length/depth, B_T: Bone type, Incl.: Inclination, Reg.: Region, P_T.: Prosthesis type (Unitary or Multiple).

VII. CONCLUSION AND FUTURE WORK

The formalization of the new ontology made possible to obtain new parameters of interest, which have not been proposed in previous works. Thus, it became a more complete and efficient base regarding dental implants.

It also can be noticed that the formalization of the new proposed ontology was achieved successfully through tests applied to a study case, which made necessary to guarantee the correct functionality of the base.

For future projects, the author will be able continue on: i) Update the basis for possible future validation. ii) Interaction with other basis to achieve more precise results. iii) Automate the implant search method to make it more efficient. iv) Creation of rules and inferences to restrict the outcome of the dental implant choice.

REFERENCES

[1] M. E. V. Pickler, “Web Semantica: Ontologias como ferramentas de representação do conhecimento”, 12 ed. Perspect. Ciênc. Inf. 2007.

[2] V. B. Biasi, “Proposta da formalização de uma base de conhecimento aplicado a implante dentário”, Curitiba, PR: Pontifical Catholic University of Parana, 2016.

[3] I. Turkyilmaz and E. A. McGlumphy, “Influence of boné density on implant stability parameters and implant sucess: a retrospective clinical study”. 2008, pp. 1-8

[4] M. Manić, Z. Stamenković, M. Mitković, M. Stojković and D. E. T. Sheperd, “Design of 3D Model of Customized Anatomically Adjusted Implants”. 2015, pp 269-282.

[5] S. B. Gonçalves, J. H. Correia, A. C. Costa. “Evaluation of Dental Implants Using Computed Tomography”. In: 2013 IEEE 3rd Portuguese Meeting in Bioengineering (ENBENG), 2013. pp. 1-4.

[6] A. L. Szejka, M. Rudek, J. M. Perussolo, O. C. Junior, “Conceptual Reasoning Model for Supporting Strategic Planning of Dental Implant Surgical Process”, 2011, pp. 249-256.

[7] P. V. Sanitá, L. A. P. Pinelli, R. H. T. da Silva, J. C. M. Segalla, “Aplicação Clínica dos conceitos oclusais na implantodontia”, 2009, p. 268-275.

[8] N. Sykaras et al, “Implant materials, designs, and surface topographies: Their effect on osseointegration. A literature review”, 2000, pp. 675-690.

[9] N. F. Noy and D. L. McGuinness, “Ontology Development 101: A Guide to Creating your First Ontology”, 2001, pp. 1-25.

[10] C. Rosse and J. L. V. M. Junior, “A reference ontology for biomedical informatics: the Foundational Model of Anatomy”, Seattle, WA: University of Washington, 2003.

[11] E. P. da Silva, “Classificação de Informação Usando Ontologias”, Post Graduation Thesis. – Federal University of Alagoas. Maceió. 2006.

[12] M. R. Wood and S. G. Vermilyea, “A review of selected dental literature on evidence-based treatment planning for dental implants”, Report of the Committee on Research in Fixed Prosthodontics of the Academy of Fixed Prosthodontics. 2004. pp. 447-462.

[13] J. L. Wennstrom, F. Bengazi, U. Lekholm, “The influence of the masticatory mucosa on the peri-implant soft tissue condition.”, 1994, pp. 1-8.