PROPOSAL OF FUNCTIONAL KNOWLEDGE INTEGRATION ON THE PART DESIGN PROCESS APPLIED IN THE TRANSITION FROM CONCEPTUAL TO PRELIMINARY DESIGN

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Abstract. *On the interface of conceptual and preliminary design of the product design process (PDP), it is necessary to find out the specific characteristics of each product part. One technique is to extend the analysis of the product functional decomposition to the part design. This analysis implies in the geometric decomposition of the part in functionalities terms. As in the product, the hierarchic organization of the part functional structure includes a global function that can be decomposed in partial and elementary functions. This fact suggests that each part functionality can be described in our own natural language. Generally, the part geometry modeling depends upon the designer experience over the design process, mainly, when he/she needs to adjust geometric details to the parts setup on the product. However, this modeling mode makes the reusability harder, as well as the functional knowledge management on this stage of the PDP in relation to other designs of the same or even other domains. Tools and methodologies used in the natural language processing (NLP) are reviewed and the main difficulties are mapped. In relation to the part functionalities descriptions, there are two main objectives: the first is to verify how such tools and methodologies avoid the ad hoc modeling and the second is to find correlations between syntactic patterns and geometric shapes.*

Keywords: *Functions description in written natural language; natural language processing (NLP); parsing, integration & reuse of functional knowledge, functional knowledge's.*

1. INTRODUCTION

In relation to the consented structure of the product design process of NeDIP (Integrated Product Development Center at UFSC – Florianopolis, SC), shown in the Figure 1, this work focused in the interface between the conceptual and *preliminary* product design. On this interface, as a process of geometric shapes configuration of the product parts (embodiment process), the part design process also evolves in stages just like the product design process and it is build by the stages of conceptual and *preliminary* part design, also shown in the Figure 1 (McGinnis and Ullman, 1992; Rosa et al., 1995; Mukherjee and Liu, 1997; Linhares, 2000). So, the part design process also starts with the incomplete knowledge over the final product and this process evolves with the development of the conceptual design stage for the part detailing (Schulte and Weber, 1993; Mukherjee and Liu, 1997; Roy et al., 2001; Dias and Linhares, 2003). Moreover about this interface, one of the big challenges to the design methodologies and designers is to propose computational tools that help the designers at the transition function → part geometric shape (Roozenburg and Eekels, 1995).

There are at least two origins of such challenge. The first is the lack of methodology to make formal the tacit functional knowledge of the designers created by the creativity, intuition and previous experiences. One of the biggest problem of the tacit functional knowledge is the functional modeling oriented only by the personal viewpoint (Santos and Dias, 2007), named as *ad hoc functional modeling* by Santos (2006). The second one is the inefficiency of CAD systems to acquire the functional knowledge, since then, even with the spring of feature-based technologies, they can only acquire geometrical information.

In other words, it's necessary to comprehends the functional structure with its requirements and functional restrictions (methodical functions) to understand how the designers convert this *tacit functional knowledge* in concrete geometric shapes (technical functions) (Schulte and Weber, 1993). This way, the research work proposes a tool to acquire, integrate and reuse the functional knowledge, based on functional concepts, by applying a methodology to the functional reasoning in the part design process.

So, the tasks of the proposed tool are: (i) to process the design and tacit knowledge of the designer, functionality textual description in natural languages; (ii) to extract the knowledge units, functional concepts, related to the geometric features of the part physical structure and (iii) to store the functional knowledge formalized by the previous procedures, so that it could be reused, modified and updated to be used in other designs of the same or even other domains.

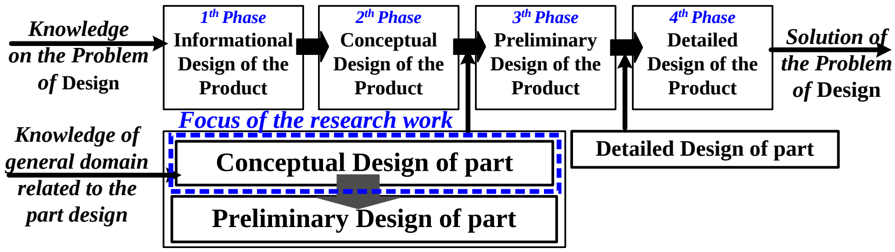

Figure 1 – Main functional knowledge insertions in the reference model of the product design process of NeDIP/UFSC (Adapted from Frank, 1991; Rosa et al., 1995; Mukherjee & Liu, 1997 and Linhares, 2000)

The Figure 1 above depicts the stages of the product/part design process related to the reference model of NeDIP/UFSC. This figure delimits the focus of the research and the main insertions of the knowledge: (i) knowledge about the design problem and (ii) *tacit functional knowledge* of the designer.

2. RELATED WORKS

The technical language of the designers, or, usual language of their work environments, have been processed in some stages of the part/product design process, as some examples are listed in the Figure 2. The aspects of the processed functional descriptions, from the technical language of the designers, are the ones related to segments of texts in CAD systems files or engineering drawing sheets in general.

The Figure 2 shows the stages of the part/product design process where the NLP is normally used and following are some works related to this subject.

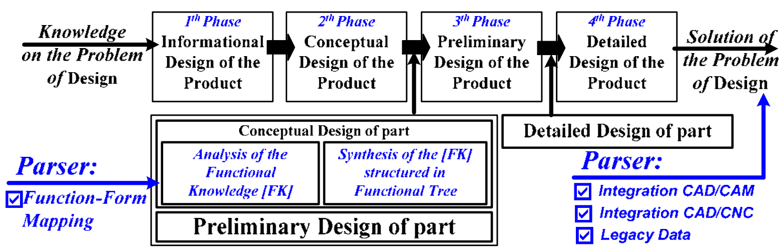

Figure 2 – The use of a parser (in NLP) in the part/product design process related to the reference model of the product design process of NeDIP/UFSC (Santos: 2006)

2.1. Aspect of the functional or purpose (goal) description

Keuneke (1991) analyses the product representation based on the function, behavior and structure to understand the significance of functional knowledge. He concludes that, in high semantic level, the function is a textual description of functional purposes (goals) conceived by the product functional structure. This way, while the function describes the functional behavior of the product by its functional purpose states, the functional knowledge describes the various functional representations through many kinds of viewpoints.

As of the *functional knowledge* emerges the necessity to describe the functional structures of a part/product by using a *linguistic knowledge* compatible with the natural language used by the designers when designing. To the different specifications of functional knowledge it is worth to emphasize the Keuneke advise to classify the verbs in functional terms. For example, functional verbs for: (a) accomplish an specific partial state; (b) accomplish and sustain a desirable state; (c) maintain the system out of a undesirable state (d) regulate state changes through some well known inter-relationship.

So, the functional knowledge representation of the product combines a sequence of functional information, where the: (i) structure specifies the parts and inter-relationships; (ii) function specifies results, functional purposes and activities and (iii) behavior specifies how the function works in relation to stimulus/results, functional purposes and activities. Thus, for Keuneke a functional structure is a mapping of functional behaviors that improves the part/product description, besides the geometric attributes with the ones which the designer is used to think about.

Ullman and McGinnis (1992) analyzed, too, the functional verbs with the verbal registry technique to understand the propagation of functional restrictions and the features selection in the design process of mechanical components. As a result of the transcription analysis of verbal protocols, the authors proved that the designers include new functional restrictions to the design and these facts emerge from the functional knowledge of previous experiences of other designs. The authors classify the introduced functional restrictions in: (i) given, (ii) introduced and (iii) derived. The classification proposed by the authors has the purpose to make an inference mechanism available to explain "how the designers use functional restrictions in the design" and "how functional knowledge helps the selection of some functional restriction instead of others".

Moreover, according to the authors, the restrictions in a functional sentence (textual description of functionality) are included in the functional purposes, such as in *"the size is nineteen (19) inches"* or *"the button diameter is smaller than the height of the external lever"*. The authors perceived that the design evolution happens every time the designer need to decide over the refinement of a special constrain of the design. This way, a decision taking of the design occurs every time a significance/value of a functional purpose description of a design object (feature), or of an inter-relationship between the descriptions of functional purpose, must be changed or initialized.

2.2. Processing aspect of the functional description

Chakrabarti and Bligh (2001) discuss the lack of support to the knowledge systems for three functional reasoning approaches: (i) Freeman & Newell model; (ii) Yoshikawa paradigmatic model and (iii) Pahl and Beitz systematical model. This lack of support, for example, cannot guarantee the generation of conceptual solutions to the three models of functional reasoning on the design process of part/product.

The authors investigated how the functional knowledge, in the physical descriptions of the design objects, could guide the designers in the resolution of a design problem. Thus, to understand how the functional requirements of a design problem are translated into schematic descriptions of conceptual design solutions is an important subject of research. This way, each functional reasoning model is composed by two pieces: (i) A functional representation of the objects under the reasoning and (ii) A reasoning schema. According to the authors, there are two functional representation languages to the functional reasoning: (1) the natural language and (2) the analytic language. However, an ideal approach of functional reasoning should offer at least three different requirements: how to support (i) design of any nature; (ii) conceptual solution synthesis to a specific design problem in a given design level and (iii) elaboration of conceptual solutions through detailing levels.

Chuan-Jun Su, Fuhua Lin and Chao-Hsiang Su (1998) proposes the approach of the syntactical interpretation of concepts in the analysis and data interpretation in engineering drawing sheets of mechanical designs. Some examples of usual concepts are: given drawing values, type of the feature (as the type of the hole), primitive entities (type of geometrical shapes), recognition of dimension text (measures), guides/anchors (dimensional representation), lines, line associations with dimension text and recognition of tolerance of the types of features.

Prabhu, Biswas and Pande (2001) used a parser to process functional descriptions exported from DXF/IGES files. The technical language (functional description) is processed by a feature grammar, whose information is composed by geometric data based in CAD systems. One example of technical language is "8 HOLES, ϕ 125, EQUISPACED, DEPTH 175" or "4 HOLES, ϕ 18, DEPTH 22.25".

Mukherjee and Liu (1997) propose the shape-function mapping in the part design process to abstract the part geometrical sketches. The mapping is the result of the correlation between the functional information derived from the design specification (DS) and features of predefined shapes. The functional descriptions describe critical aspects of functional regions of the parts body – a set of relationships called by functional signature. To this purpose, the authors propose a new concept of function based on verbs (V), noun (N), attributes magnitude (M), attributes direction (D), object (set of nouns) and keywords (set of specialized words). So, the abstractions of the part geometry sketches are generated by the NLP function-shape mapping on the part design process.

3. METHODOLOGY PROPOSAL FOR THE FUNCTIONAL REASONING

The methodology proposal for the functional reasoning on the process of part design objects to improve the ability of the designers and integrate the functional knowledge on the functional decomposition (Pahl and Beitz, 1996) in the part design process. The proposal extends the part functional model proposed by Linhares (2000) on the modules of the: (a) parser and (b) integration & recovering of functional knowledge. The proposed modules are intended to convert the tacit functional knowledge into formalized and storable functional knowledge so that it can be made available to reuse, changes or modifications on the same or even other designs. In this work, the tacit functional knowledge is understood as the knowledge yet to be formalized about an inter-relation between some functional conceptual and some desired effect caused by a constrain of material, geometrical shape, manufacturing process, assembly, among others that the designer known by taking it in account as a result of previous design(s) experiences (adapted from Nonaka and Takeuchi, 1997).

The activities diagram of the methodology proposal for the functional reasoning on the part design process, depicted in the Figure 3, is composed by three modules: (i) part functions editor; (ii) parser and (iii) integration and recovering of functional knowledge.

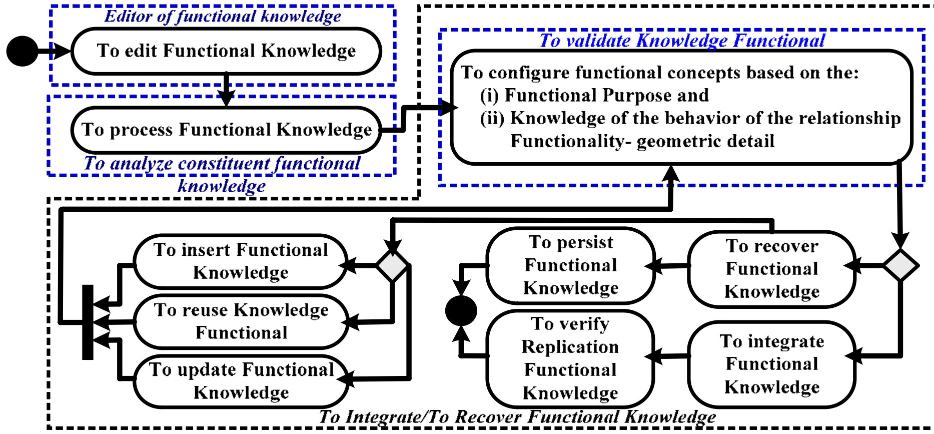

Figure 3 – Activities diagram of the methodology proposal for the functional reasoning on the part design process

The research work supposes as hypothesis that the functional knowledge is composed by functional concepts, where each functional concept is loaded by the semantics that can be correlated to some relationship and/or aspect of the part geometrical structure. This way, it is proposed the investigation of the functional concepts included on the textual descriptions of the part function tree that can build geometrical models to the part physical structure automatically.

The research work proposes to acquire, treat and differentiate the various types of functional concepts used on the subjective activity stage, on the part conceptual design. The proposed methodology has the following objectives: (i) to structure a database with functional knowledge derived from the part design process; (ii) avoid *ad hoc* modeling and (iii) mapping syntactic patterns. The first objective intends to make possible the reuse of functional knowledge. The second one intends to make feasible the utilization of functional concepts structured on the functional knowledge.

Thus, the designers could use a common structure to describe the functionalities of each geometrical detail imagined on the part geometrical design. Besides this, they could make use of their own natural language written on a structured way (transcription of their functional reasoning) and according to the domain of the design context. The third is to discover the possible correlations between the syntactic patterns and possible geometrical shapes of the physical structure of the part.

3.1. Part functions editor

The part functional editor is an extension of the part functional model proposed by Linhares (2000). The extensions enforce the ability and integrate the functional knowledge of the designers on the functional decomposition (Pahl and Beitz, 1988) of the part design process. The editor is based on the linguistic approach to process the natural language of the designers and uses the object oriented approach to portability and system robustness. Some of the editor functionalities are 'New Tree', 'Add part function', (partial or elementary function) 'Remove part function', 'Save functional Tree' and 'Open Functional Tree'. The functional arboreal structure is of top-down kind. Each functionality of the part function tree is linked to one functional description (sentence) related to a functional region or geometrical detail, but according to the design viewpoint.

About the functional knowledge, according to the researches of Kitamura and Mizoguchi (2002), the *ad hoc* modeling occurs when one of the following factors appears: (i) inconsistence, (ii) lack of reusability and (iii) improper categorization. The inconsistence occurs in the functional description based on bad structured functional concepts. The lack of a rich and broad structure of functional concepts and of an operation system well based has been the greatest problem to the reusability of functional knowledge. Moreover, the lack of hierarchic structure of functional knowledge based on well known criteria is pointed out as a cause of improper categorization.

As a result, the *ad hoc* modeling problem is not imbued in the functionality description structure. In other words, the problem isn't limited in trimming the written shape of the functional descriptions of the designers, compelling the designer to comply in functional descriptions of the structure as "verb + noun" or "verb + adjective + noun" or "verb + noun + adverb". In opposite to the qualitative process theory (Forbus, 1984), that is focused in the qualitative aspects of physical process, this work focuses the qualitative aspects related to the geometrical shapes of the parts.

The *ad hoc* modeling problem lies on the hierarchic structure of functional concepts, more precisely on the "functional concept" itself. However, on this research work, a functional concept is understood as relevant functional information (qualitative) about some aspect of the mechanical part physical structure included on the functional description of a geometrical detail, or of a functional region, or even of the part itself.

3.2. Parser

The processing of the designers technical language is accomplished by the parser – processing the functional descriptions of each functional interface or geometrical detail of the part. This methodology is used to capture the: (i) functional reasoning of the designers over the functional viewpoint and (ii) functional concepts included on the functional knowledge. The activities diagram, in the Figure 4, shows the main tasks that the parser needs to accomplish on the proposed methodology.

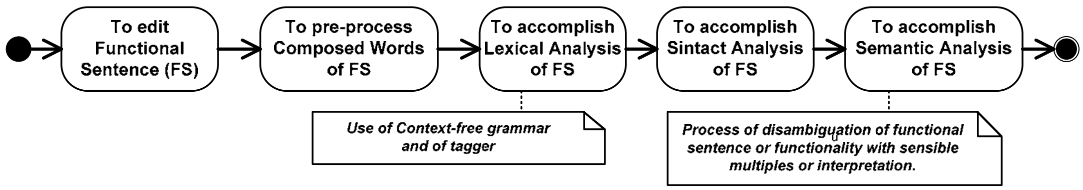

Figure 4 – Activities diagram of the parser to the processing of the mechanical part functional knowledge.

Firstly, the functional sentences are edited by the designer. One of the purposes of the edition is to capture and analyze, for example, the main typos, orthographic errors, languages vices and *regionalisms* – specific written customs of the technical language of the designers. Following this, a preprocessor verifies and sort the composite words on the functional descriptions. This process includes the identification and separation of significant components of the functional sentence to be analyzed, such as words and absolute and relative separators (Santos, 2002).

The process of lexical analysis is grounded by a free context grammar and a labeler. A linguistic *CORPUS* of the application domain of a part design process environment was assumed *a priori* as a reference to the grammar and labeler. On this research work, a linguistic *CORPUS* is a set of linguistic data, systematized according to criteria, sufficiently broad in width and depth, so that they could represent completely the linguistic use or some of its scopes, given in such a configuration so that they can be processed by a computer, intending to return various and utile results to the description and analysis (Berber Sardinha, 2004). Thus, the grammar was constituted by representations of valid syntactic structures and mapped from the linguistic *CORPUS*. From the three kinds of labelers, namely: – (i) manual, (ii) linguists prepared and (iii) automatic – the labeling was primary accomplished manually.

The interpretation and disambiguation process of the functional knowledge on the NLP were accomplished by the syntax and semantic analysis. The extraction, insertion, modification and reuse of the functional concepts of the designer's technical knowledge are fundamental to the interpretation process on the generation of alternative conceptual solutions of part design. All thought, the generation of alternative conceptual solutions will be left to the next stage of the systems evolution. The disambiguation of functional knowledge is accomplished by the structuring of the functional concepts by the designer itself.

3.3. Integration & recovering of functional knowledge

The task of the integration & recovering of functional knowledge system is to add, update, modify and reuse the functional knowledge, with the support of the MySQL database management system. The Java™ programming language, by Sun Microsystems, was chosen as a language to describe the functional reasoning system to the part design process. The choose was made leaded by the portability, platform independence (as, for example, GNU/Linux, MS Windows or Apple MacOS) and the object oriented paradigm (helping the system to evolve to more sophisticated versions).

The basic functional operations of the functional concepts related to a functional knowledge are the addition, update, modification and reuse. These functional operations intend to formalize the tacit functional knowledge. The configuration – validation of functional concepts is related to the process of geometric rational thinking of the designers. Thus, when the designer operates a functional knowledge (in the shape of a functional sentence) he/she will need to justify each one of the new functional concepts operated. And, besides this, the system will verify the existence of inconsistencies of each semantic value introduced by the accomplished operation.

The Figure 5 shows the activities diagram of operationalization proposed on the methodology to the functional reasoning on the part design process. This way, the designer can operationalize his/her functional knowledge satisfying the design purposes.

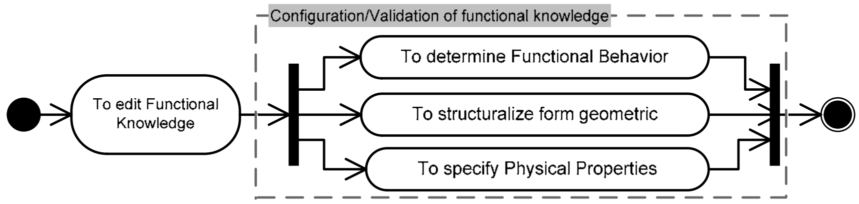

Figure 5 – Activities diagram to the configuration/validation of the functional knowledge of mechanical parts.

4. FINAL CONSIDERATIONS

The article presents a proposal that, besides integrating the functional knowledge on the conceptual design of the part design process, provides its reuse, alteration and update. The systematization process of the functional reasoning to the part design process is composed by three modules: (i) functional editor, (ii) parser and (iii) integration & recovering of functional knowledge. The systematic approach is based on the linguistic approach, object oriented paradigm, MySQL database management system and Java programming language.

The linguistic approach, applied to the part functional descriptions, is used to treat: the problem if high semantic level and of the *ad hoc* modeling itself on the stage of part conceptual design. Thus, it has as subject: to discover syntactic patterns that can help on the function/form mapping and to make possible the categorization of the functional information related to the main levels of abstraction – from the functional interfaces and referenced aspects to the requirements/constrains of manufacturing (fabrication and assembly), material and geometrical shape, for example.

The main advantages of the systematic approach for the functional reasoning to the part conceptual design process are: reuse of functional knowledge, structuring of functional concepts related to the relationship between geometric function/shape and a methodology to understand the conversion from functional knowledge to feasible geometrical shapes by the designers.

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