Geometric Knowledge Analysis based in Part Functional Descriptions

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Abstract: Parts have associate elementary functions descriptions to each constructive detail. A first try to understand this relationship is to look for, if exists a clear-cut syntactic standard to create the functions description. After, it is necessary to establish some measure's method to evaluate how the functions are repeated in several mechanical parts with some existent standards and how to associate it to one or more elementary solid geometries, such as groove, hole, groove, round, chamfer, and others. This correlation may lead, initially, to the likely feature operator in CAD system, which is used to create solid geometries that accomplish the desired functions to the product. So, CAD 3D geometric modeling can be accomplished from the functions description executed for the parts that integrate the products technical systems. When a functions group with design meaning can be, in some way, associated to the solid geometry, it may realize a new paradigm in the mechanical design: the product design from the function-form transformation. This elementary functions description is closely to the geometric structure that gives the part's shapes. This article shows the process to identify functions description and its phrasal structure applied to the mechanical parts of an off-road Baja vehicle design.

1 INTRODUCTION

This article presents the current advances in the research on the "shape function" mapping. At first, it re-organizes the computational implementations previously performed in Linhares (2005), and explores a new approach, now, based in a technical terminology which operates the relations between the geometric details of parts and its functional description areas. Also, it tries to look for patterns of language that directs the choice basic geometry solid in parts modeling.

Implementations carried out in Linhares (2005) describe various correlations between functions structures, functional areas, and solid features. The implementation becomes possible to filter and identify some languages patterns in terms of phrasal components in functional descriptions and associate them with design meaning and its functional areas, and also, those that have link to the solid features associated to the geometry model created in CAD systems.

However, each time a certain type of solid geometry or solid feature is required by the functional description, based on design intent, it is very likely, that it has the same verbs, nouns or other phrasal components to describe the part functional areas. To count the repetition of phrasal components may be implemented computationally, and it can be the first indicators that there is a way to associate them to the part geometry description. Also, part functional description in terms of functions has a semantics composition, which if precisely identified may lead to geometries alternative to design intent

It also was noted that these repetition patterns can be help to find preliminary solution principles during the design when all description are linked to terminological similarities verification. In several design processes designers use phrases to describe and communicate intentions and solutions contain verbs nouns and qualifiers (VNQ). Those descriptions, here considered as a phrasal structure, belong to the part preliminary solution principles chain.

Designers must study advance the “behavior in use” of parts in the mechanical system or sub system in order to get knowledge about their functions and theirs preliminary solutions principles (Pp’s). This procedure of learning becomes easy to the designer to find geometric solutions, to identify physical region or detail in a part.

When the designer looks at several products’

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projects, he always is able to identify repeated patterns among several parts, systems or sub-systems that compose them, although it depends of the type of product or application domain. If he looks to the part details, the final geometries are largely associated to specific design requirements and pre-defined for the part in the assembly in carrying out their functions. It can be seen, in some study case, where the functions described by the designers will lead to the same repeating patterns as will be showed latter in the text. In this paper will be emphasized functions descriptions made for an off-road Baja vehicle.

2 RESEARCH BACKGROUND

Most of researches have showed that 2D and 3D parts geometric modeling begins in the product conceptual definition where primary definitions, based on principle of solutions are going to give initial shape to a part and after to the product as whole. So, most of users and design requirements have to take in account to produce the objects embodiment in accord of solution principles chosen from functions they are able to identify to the product.

This paper was written to readers that know about design methodology researches. The transition function-form is a design activity in the interface between conceptual and preliminary design phases, when using the Pahl/Beitz design methodology process. In this interface, questions about product/assembly/part shapes and functionalities have been strong importance in the design process.

Roth (1985) *apud* Hundal (1990) shows that in functional/conceptual design and preliminary design, the product model description (PMD) can be represented in the computer for product data definition (PDD).

Hubka and Eder (1988) use the term "action mode" and emphasize that the technical systems components must be developed simultaneously and indicate that before describing functions is necessary to understand the design principles associated with carrying out those functions.

Hundal (1990) has written about the systematic design method proposed by Rodenacker (1984) and Pahl and Beitz (1988). They appointed scientific procedures to aid the new products and processes development, based on principles (physical, chemical, biological) rather than pre-conceived solutions and existing products

Deng et al. (2000), warn the importance of the functional deployment and constraints definition between the product physical components elementary functions. The authors use the design model "Function-Environment-Behavior-Structure – FEBS", to represent the product functional inputs and outputs. Case and Hounsell (2000) present a methodology used to validate a representation based on *features* that capture the designer intentions related to the part geometry functional, relational and volumetric aspects.

Roy et al., (2001) proposed a method to design synthesis by part functional requirements mapping which is done in a restrictions multi-stage optimization during the design process stages. This function-form mapping can replenish the product design specification, modifying, and optimizing the organizational structure from product level to part level.

Pahl et al., (2005) propose preliminary design guidelines. These guidelines can be considered as parts preliminary design principles. They are: thermal expansion, creep and relaxation, corrosion, wear, form, manufacturing, maintainability, recycling, safety factors and technical standards.

These requirements can compose a checklist for the designer serving as a guide in parts functions defining. Linhares and Dias (2001a, 2001b, 2003a, 2003b) have written several papers presenting an approach to the development of a computational framework for modeling part functions to achieving a correlation model between the functional and geometric domain in the product preliminary design stage, following the Pahl and Beitz (1996) methodology.

In the product development process, a reference model (PDPMR) was proposed in Back et al. (2008) and implemented by NeDIP research group, in which, like Pahl and Beitz, the process may be is broken down into several tasks with inputs and outputs, and so, providing mechanisms to accomplish each task in design of a product.

Users and designers have to transform design requirements in function description and those in the solid geometry modeling, building the details of each parts, to the group of parts and finally to each details of the product. One of these tasks is to establish the functional defining basis in the product level.

Bouzeghoub (1997), points to the importance of promoting the use of natural language as language specification and query databases. Points out important projects dedicated to language dictionaries definition from the end of 80 years in many research laboratories, but the result spread was limited to specialized communities.

Formal languages, which are sets of words built on an alphabet, are specific languages used in the context grammars preparation. They have specifics semantics and syntax fixed or standardized, there are no ambiguities. However, attempts to translate formal expressions into knowledge concepts or cognitive, often result in failure.

3 MECHANICAL PART DESIGN AND THE FUNCTIONAL SPACE

The hierarchical model is widely used in several fields and is much appropriated to classify elements of the physical objects representation. Products component and its corresponding meanings in terms of functions have been used extensively in the mechanical design. In Table (1) is showed how to classify design functions applied to the product design process.

This compilation is resulted from several researches where various types of functions classifications was been proposed by authors in the literature Pahl and Beitz (1988), Back et al., (2008). In the Table (1) an hierarchical product description includes the product global function (*GF*), the partial functions (*PF*) and the elementary functions (*EF*), extended to assemblies, and to the parts in particular.

Table 1: Overview with various design functions classifications collected the theoretical review.

Classification	PRODUCT	ASSEMBLY	PART
Hierarchical	Global Function (*GF*)	assembly Global Function (a*GF*)	part Global Function (p*GF*)
	Partial Function (*PF*)	assembly Partial Function (a*PF*)	part Partial Function (p*PF*)
	Elementary Function (*EF*)	assembly Elementary Function (a*EF*)	part Elementary Function (p*EF*)

The prefix (a) and (p) indicates the role of the component in the product hierarchy. The Figure 1 shows the corresponding UML representation of the product physical and functional levels hierarchy. The small diamond between representations frames of each functional and physical level mean the associated representation table aggregation. This means that a PRODUCT is made up of ASSEMBLY aggregations and consequently each ASSEMBLY aggregations by PARTS aggregations. The frame on the top right of Fig. (1) Represents the Global Function level (*GF*).

The recursion symbol in the representative framework of ASSEMBLY means that one new ASSEMBLY can be formed by aggregations of the several other assemblies (sub-assemblies), and finally, the last level of representation is one ASSEMBLY (sub-assembly) composed of the PARTS aggregations. The physical representation levels have their respective functional representation levels.

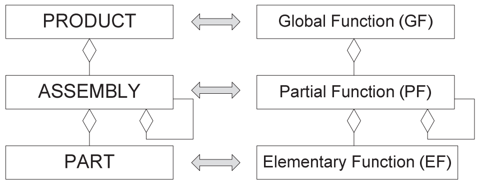

Figure 1: Product physical and functional levels – a *UML* representation.

The representation used for product can now be extended to the physical areas and part functions representation, as shown in Fig. (2). The Figure (2) shows the UML representation of the part physically as well as the functional levels. This representation uses the same composition logic used for the corresponding product physical levels representation. The Global Function (*pGF*) adds Partial Functions (*pPF*), which in turn adds Elementary Functions (*pEF*), all related to the part as a whole.

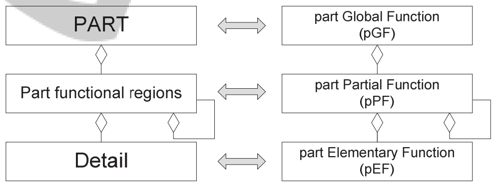

Figure 2: Part physical and functional levels - a *UML* representation.

In the Table (2) is showed a set of design functions in the design process of a product, assembly, and parts. The term function can be extended to specify different concept applied to the parts, including "geometry form", part applications, "manufacturing process", action mode, etc. In same classification type it can have the same name in different level of product hierarchy while to other it can be more specialized for a specific level.

The classification types are important to understand and to describe better the mapping and representation process between design and manufacturing, particularly in the CAD/CAM systems.

Many authors has written and agreed to the fact that the function based design is important in geometry form to define product and parts layouts, as discussed earlier. Also, they believe about the

Table 2: Extended design functions classifications in design process review.

Classification	PRODUCT	ASSEMBLY	PART
Geometric form	rotational Function (*rtF*); prismatic Function (*prF*); laminar Function (*laF*); mixed Function (*ixF*)		
Part application	mechanical Function (*mcF*); hydraulic Function (*hdF*); pneumatic Function (*pnF*); electroelectronic Function (*eeF*); computational or programming function (*ifF*)		
Manufacturing process	stamping Function (*stF*); sintering Function (*siF*); machining Function (*mcF*); casting Function (*ctF*)		
Complex level	Product Functions (F_I): mechanical systems composed of assemblies and parts	Assembly Funtions (F_{II}): simple mechanical systems that can also carry a larger functions group.	Part Function (F_{III}): elementary systems, manufactured without assembly operations.
Qualification	Primary Function (*PrF*); Secondary Function (*ScF*); Acessory Function (*AcF*); Derived Function (*DeF*):		
Action mode	fastener Function (*Fx*); support Function (*sF*); transmission Function (*tF*); transport Function (*pF*):		
Descriptive representation	Function described by verb (*Fv*); Function described by verb and noun (*Fs*); Function described by verb, noun and qualifier (*Fq*).		

necessity to represent the product functions, either through a graphical model, or computationally or yet in a database resource. These techniques facilitate understanding and verification of inter-functional relationships, and providing a better use behaviors visualization and anticipation. Part contains geometric features essential to the performance in its life cycle. It means, the part functional specificities, in terms of the design process, have it geometric shape closely related with the material, resistance, dynamic requests, definitions, among other specific requirements.

3.1 Functional Descriptions Model – (VNQ)

The phrasal descriptive structure provides a grammatical components logically sequenced that may include design intentions when is written on a standard grammatical pattern.

Many authors suggest using only verbs to define product functions in order to describe appropriated solutions as design principle. However, to the part function description is better to extend such simplified description, including a phrasal sequence composed by "verb + noun + qualifier", shortly (VNQ), whose basic structure is showed in the Figure (3).

The verb expresses the action that a part or some part geometry is created for. The verb expresses is related with the hierarchical level corresponding to the physical model adopted. The noun is the object upon which the verb action concerns and the qualifier means a specialization of the designer intention, because it embeds and specialize part design requirements more precisely.

Thus, the format or grammatical sequence can lead the designer to describe the functional needs, and as it is inside a grammatical pattern help to organize ways to find standard of functional structure in part design.

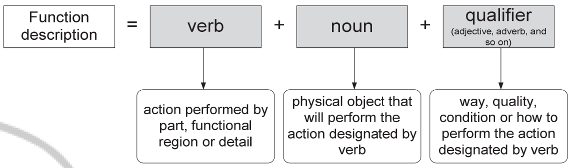

Figure 3: Representation of the basic structure to part function description.

Such pattern of functional structure may be extended to describe physical areas, and CAD/CAM features sequences used to compose geometrically a part. In both cases, the functional structure are simplified by using only the noun and the qualifier in their descriptions, as showed in the Figures (4) and (5), respectively.

In the physical region/area description is more used colloquial patterns in design engineering domain. Otherwise, the solid features description begins with the grammar used in the CAD/CAM system, according each user interface vendor. So, the first description is characterized by expressing the design intent, while the second structure is described in the tree of features of the CAD/CAM system, showing how the designer realizes the geometric embodiment of the physical description. Both are built on different linguistic corpora, but that converge towards the same goals: the systematic mechanical design.

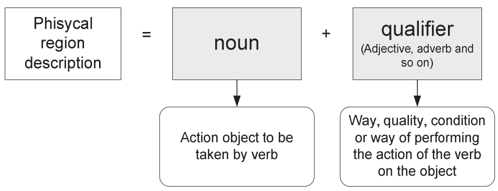

Figure 4: Basic structure representation for part physical region description composition.

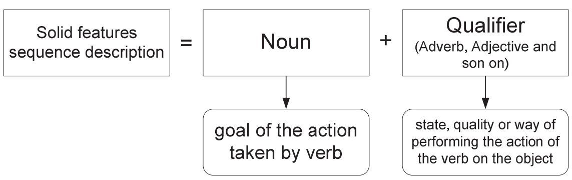

Figure 5: Basic structure representation for the solid features description.

Verbs design used in parts functional descriptions, physical regions, and solid features can be defined in the part design dictionary. In it, the verbs contained in the technical language of a given design scope, and can be, either added or removed or even replaced for the design intended descriptions composition, in terms of functions. The database implementation contains the full of the verbs listed in linguistic corpus implemented and can be dealt by means of computer interfaces to aid the mechanical designer to choose them to describe parts functions. The Table (3) shows some examples of design verbs used described actions necessary to parts functionality.

Table 3: Design verb list.

absorb	speed	set	housing	balance
trigger	add	feed	cushion	pump
engage	admit	align	enlarge	capture
join	compress	connect	control	convert
cut	lead	derive	untie	download

Also, the Table (4) shows some design nouns used in the physical regions descriptions and solid features necessary theirs descriptions. Also, the same database should have to contain the full set of the nouns in the linguistic corpus implemented to aid the mechanical designer to write the functional description at each level.

Table 4: Design noun list.

lamp	foundation	ring	arrangement	base
finish	food	bulkhead	washer	stop
coupling	relief	support	sprinkling	rod
removal	socket	area	actuator	block
agitation	damping	rim tires	balancing	pump

The qualifiers database includes words like horizontally, alternative, angular, angularity, previous, horizontal, inclined, lower, assembled, etc. Examples of grammatical elements or words classes that are related to the mechanical design domain are shown in Tab. (5).

Together with verbs, nouns and qualifiers there are a set of terms, commonly called of technical terms, which are largely used by designer to describe the role of part belonging to an application domain in product design. An additional database element including technical terms may help technologists and designers to project product and details based in the functions description, as described in the Table (6). It may lead to a standard set of word, and also allow them to control and manage projects if they have better familiarity with the technical terms used within the design scope.

Table 5: Word class and qualifiers values used in mechanical design.

Nº	word class	possible value
01	adjective	perpendicular, axial, smooth, straight, knurled, grooved,
02	adverb	perpendicular, axially, above, before, in, out, horizontally
03	article	the...
04	conjunction	and, or, what, as, since, though, as, which, as…
05	numeral	one, two, thirteen, twelve hundred, first, sixty, third, ,
06	preposition	since, between, until, against, without, under, about, on, in,
07	pronoun	my, this, he, all, some, several, both, any, much…
08	noun	coupling, gear, screw, rod, torque, rotation, shaft, pulley,
09	verb	adjust, filter, position, retain, transmit, pull, merge...

4 THE PRODUCT ANALYSIS

This research was applied to motor vehicle designed for off-road competitions, organized annually by SAE Brazil, called of the competition SAE Baja. It geometric and functional requirements are considered by designer as very singular.

The information registered on the design of the vehicle was produced by student team. The team are studying in the mechanical engineering program of *the Instituto Superior Tupy (IST) of the Educational Society of Santa Catarina (Sociesc)*. The vehicle is a *minibaja* TR-02 and the part nomenclature used was done, from design study project. In the Table (6) is appointed the CAD/CAM features names used to details geometrically components and parts of a *minibaja* TR-02 studied. Also, the column *Prof* indicates if the feature needs to be built by using a 2D profile or not, to produce the geometry. The Table (7) shows the total of features in each subsystem, as well as the part total number (in units).

The part classification was done in terms of global shapes, like rotational, prismatic or mixed form. The phrasal structures description was created by engineering academics team that acts in the vehicle Baja design and manufacturing. The team searched to identify which were the best phrasal structures, types coordinate the system that was more appropriated to use in CAD geometries definitions, the “solid features”, to model each vehicle part. So, the terminologies verification used in the physical structures identification, the names that are assigned for parts, the identification of its

Table 6: Technical terms list used to identify the solid features details in CAD systems.

nº	technical terms	prof. (*)	nº	technical terms	prof. (*)
01	cylindrical trough hole		10	internal prismatic round	
02	cylindrical blind hole		11	external prismatic round	
03	not cylindrical hole	X	12	radial rotational chuckhole	X
04	internal rotational chamfer		13	axial rotational chuckhole	X
05	external rotational chamfer		14	prismatic chuckhole	X
06	internal prismatic chamfer		15	conical chuckhole	
07	external prismatic chamfer		16	radial rotational rebound	X
08	internal rotational round		17	axial rotational rebound	X
09	external rotational round		18	prismatic rebound	X

(*)(prof. = profile)

Table 7: Mechanical Elements of the TR-02 Baja vehicle.

MS code	Mechanical System (MS)	Units number
01	chassis	101
02	direction	25
03	transmission	11
04	front suspension	86
05	back suspension	12
	Total	**235**

functional regions and details contribute for the students to understand the design meanings study involved in the mechanical design intentions and helps them to systematize the part functional design in the preliminary design phase. The units' subdivision (quantity) and part types were very important to understand the whole design process. Later, in a second phase of this research, where the statistics of the repetition standards occurrences was measured, they learned more precisely the descriptive structures phrasal meaning, how to combine its composition elements in relation to the best terms used in each case and how it was related technical terms used in the solid features available in system CADCAM**.**

5 CONCLUSIONS

This paper presents a model of functional description that allows helping computational implementations to discover patterns repetition in functional structures, physical regions, terminologies and solid geometries of mechanical parts.

The emphasis was to describe phrasal structures to the functions, physical regions, technical terminologies and solid features. To build the database was used a Baja competition off-road vehicle design, modeled in system CAD/CAM and built physically by a student team of the Superior Institute Tupy of the Educational Society of Santa Catarina, hosted in the city of Joinville - SC.

The results lead to the conclusion that looks for standards word repetition are important to give background to the students in design and manufacturing process. They understand better how to map functional and geometric spaces of part design. They learned, also, that the part final geometry creation depends on the mechanical design intentions.

These, in turn, depend on the knowledge about involved variable in the product design as a whole, but specifically, of the each part requirements and preliminary design principles. Thus, the part final geometries definition passes for a previous organization of the tacit knowledge and goes for a taking of decisions constant process concerning the information correct guiding on the part adequate behavior in the assembly.

Probably, the behavior used in the design analysis is one of the most important factors to describe the part functions because it has to take in account several design information, like the part in use, the work regimen, and how each geometry will be playing its functions.

Therefore, in the future, this research have to rework some aspects of the descriptive structures computational implementation in the measure of the database of verbs, nouns and qualifiers are going to increase. Later, will be necessary to include in the database more products and parts and how those measures will behavior statistically.

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