A preliminary discussion of semantic web technologies and 3D feature recognition to support the complex parts manufacturing quotation: an aerospace industry case

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Abstract. The complexity of airplane parts is constantly increasing. For example, the airplane fuselage comprises more than 700.000 parts with different dimensions, geometries, tolerances complexity, and multiple materials. This complexity scenario requires an advanced manufacturing park with conventional and non-conventional machining, rapid manufacturing machining, 3D measuring machines, and others. In parallel, reducing these parts' cost and production time challenges the aerospace industry suppliers, ensuring high manufacturing quality. Therefore, this paper explores a preliminary discussion of the Semantic Web Technologies and 3D feature recognition application to assist the complex parts manufacturing pricing and manufacturing planning since this process is made manually by a manufacturing engineer. During all quotation processes (3D part analysis, manufacturing planning, and manufacturing price definition), the engineer spends more than one week to quote a part depending on its complexity. This paper contributes to a Computer Integrated Manufacturing (CIM) domain since it discusses the application of Semantic web technologies and 3D feature recognition technologies to automate extracting the information from the part modelled in 3D and plan the manufacturing process to help to identify the price to manufacture it. Finally, the main research result concerns the identification of the contributions and limitations of the related works in this domain and the research opportunity to cover this research gap.

Keywords: Complex Parts Manufacturing, Quotation, Manufacturing Planning, Aerospace Industry, Semantic Web Technologies, 3D Feature Recognition.

1 Introduction

The complexity of airplane parts has increased significantly in recent years, requiring advanced manufacturing parks and innovative approaches to address the challenges of reducing costs and production time while ensuring high quality. In addition, the creation and production of an aircraft require the collaboration of engineers from various countries and backgrounds who must exchange information and expertise regarding multiple components throughout the different stages of product development or production planning [1].

As airplane technology advances, so does the complexity of its parts. For example, the fuselage of a modern airplane can consist of over 700,000 different parts, each with its unique dimensions, geometries, tolerances, and materials [1]. This level of complexity presents a significant challenge for aerospace suppliers, who must ensure that these parts are manufactured with high quality, at a reduced cost, and within a shorter production time.

Semantic Web and 3D feature recognition have been successfully applied in the quotation of complex parts manufacturing, especially in the aerospace industry [2]. The semantic web allows for the representation of information in a structured and standardized format, which facilitates the automation of processes and data-based decision-making [3].

To address these challenges, advanced manufacturing technologies and ontologies are required. These technologies include conventional and non-conventional machining, rapid manufacturing, 3D measuring machines, and others.

Industrial ontologies can be used to define and share common concepts between different systems and organizations in the manufacturing industry. Increased interoperability can lead to better collaboration and coordination, improve production agility, and make the industry more resilient to changes and disruptions. The research team also presents a methodology for developing industrial ontologies and discusses examples of their application in the manufacturing industry [4].

The manufacturing process of different airplane parts involves multiple domains and knowledge (see Fig.1). However, it takes a long time to budget new aeronautical parts and demands extremely qualified labor for such a task. Additionally, with the amount of information involved, the probability of an error occurring in this quotation process is very high.

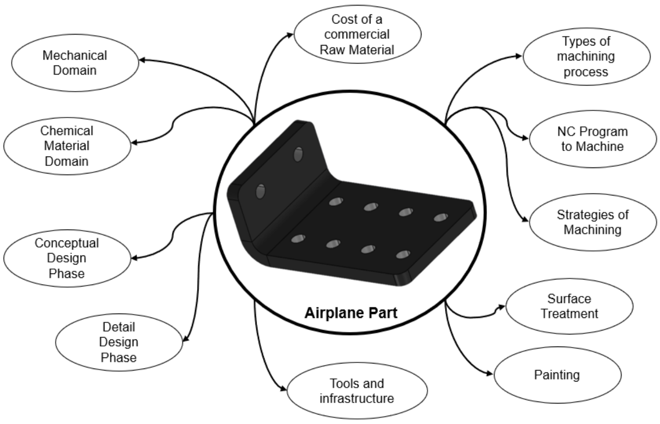

Fig. 1. Multiples domains and concepts in a single airplane part.

Due to the technological rise in the world, Industry 4.0 demands that companies suit the existence of a new market that is increasingly competitive and demands increasingly customized and high-performance products. The growing demand for these products and low cost directly conflicts with the degree of rigidity presented by most manufacturing companies [5]. Thus, companies are required to shape the paradigm of Industry 4.0, in which intelligent systems can quickly adapt to the constant and necessary changes in the smart, integrated, and customized manufacturing process.

According to [6], intelligent processes in Industry 4.0 will reduce equipment maintenance costs by 10% and 40%, reduce energy costs by 10% to 20%, and increase work efficiency by 10% and 25% until 2025. Given this scenario, business organizations that adopt intelligent systems may gain a more significant advantage over companies that mass produce standardized products [7]. Furthermore, those who choose the strategy of differentiating their products through customization tend to become more competitive and have a higher expectation of making a profit, increasing the chance of growth [8].

In addition, it is verified that conventional quotation processes have higher expenses and consume engineering time. In this context, *is it possible to automate the process of quoting aerospace parts based on knowledge representation using ontologies and semantic web-based data provided by the 3D model?*

The main objective of this research concerns the identification of the contributions and limitations of the related works in this domain and the research opportunity to cover this research gap.

Section 2 of this article presents the technological backgrounds, followed by the conceptual approach of the research in Section 3, and Section 4 presents the conclusions and ideas for future work.

2 Technological Background

2.1 Semantic Web Technologies

Semantic web technologies present information and insights in an organized manner, creating a comprehensive understanding within one or numerous fields. Furthermore, semantic reasoning systems and software agents facilitate the seamless exchange, utilization, and processing of data. To impart meaning to the data, technologies such as the Resource Description Framework (RDF) [9] and the Web Ontology Language (OWL) [10] are employed. Furthermore, these technologies are used to formally depict metadata, following the idea of ontology.

Ontologies serve as a means of enabling various functions for both humans and machines, such as information systems and cyber-physical systems. They capture knowledge within a particular domain, promote interoperability and inter-agent communication, and facilitate more adaptive automation while reducing risks [11]. This has led to the growing significance of the ontology concept in fields such as Intelligent Information Integration, Internet Information Retrieval, Knowledge Management, and the Semantic Web [12]. The growing popularity of ontologies is attributed to the potential for providing a shared and common understanding across different domains [13]. They have been designed to impart machine-readable semantics to information sources that can be shared among systems or human entities [13]. Additionally, they are utilized by intelligent systems to promote interoperation between different systems.

A Semantic Reasoner or Rules Engine, aligned with ontologies, is a piece of software that can deduce logical consequences from a set of facts or axioms. This software enables the detection of inconsistencies in information across the product or production process. In recent studies [14, 15-16], ontology mapping and semantic reasoning have been recognized as crucial technologies for addressing the problem of semantic interoperability. Mapping is critical in traditional applications such as information integration, query answering, and data transformation [17]. The mapping process solves the heterogeneity problem between ontologies, as it aims to find relationships between semantically connected entities from different ontologies. The process involves inputting two ontologies, each composed of various components (classes, instances, properties, rules, axioms, etc.), and outputs a similarity match [17].

Semantic web technologies make data on the web machine-readable and accessible to automated processes, improving data representation and data-driven decision-making. For example, in the aerospace industry, semantic web technologies can represent the complex relationships between airplane parts, materials, and manufacturing processes, helping to support decision-making and improve the accuracy and efficiency of cost estimation.

In the aerospace industry, using semantic web technologies can provide real-time information about manufacturing operations and quality control, helping to reduce costs and production time while ensuring high quality. Therefore, the potential of this approach in the aerospace industry should be explored further, as it can significantly enhance the aerospace manufacturing process.

Semantic web technologies and 3D feature recognition offer promising solutions, and this paper provides a preliminary discussion of how they can be used in the aerospace industry.

2.2 3D Feature Recognition

The aerospace industry has progressed and developed specialized tools, such as specialized modeling tools for aerospace sheet metal, to assist at various stages of the product's lifespan. However, despite structural sheet metal parts playing a significant role in airplanes, no automated feature recognition (AFR) method is specifically designed for them.

A feature has three main attributes: geometry, relationships with other features, and parameters. For example, the geometry of a hole is defined by its faces, while its relationship to the parent feature is represented by connecting edges. Parameters of a hole include its location (determined by an axis) and diameter (derived from its geometry). Geometry links feature to their B-rep, while feature relationships reveal the structure of geometric models. This study demonstrates that feature relationships are based on topological adjacency. Feature parameters capture design intent or engineering semantics and can be numerical or non-numerical information extracted from the geometry model. Certain features can have different types, such as curved or planar flanges, and these types are considered additional parameters. AFR is an essential tool for various tasks in product lifecycle management, such as computer-aided process planning, data retrieval, and model difference identification. Although AFR methods exist for sheet metal parts, none are specifically tailored for the aerospace industry [18].

This method elevates the level of abstraction of information from 3D STEP models. The approach involves preprocessing the 3D STEP model to categorize the topological elements of the boundary model (B-rep model) and creating new sets of faces, face boundaries, and edges. Rule-based steps are then used to identify aerospace sheet metal features, which are described by their geometry, relationship with other elements, and pertinent parameters. Upon reading B-rep elements from STEP files, they are stored in memory as C++ objects possessing the same member attributes as the original B-rep elements. These C++ objects find their place within lists, which are implemented using C++ Vectors sourced from the Standard Template Library (STL). Vectors, serving as sequence containers, prove invaluable for managing dynamic data, as they possess the ability to expand their size based on the number of elements they encapsulate. This characteristic sets them apart from fixed-size arrays. Moreover, C++ vectors exhibit automatic storage management capabilities and demonstrate efficiency when confronted with frequent data addition and deletion operations [18].

According to [19] an AFR method for detecting shear features using geometric and topological considerations. Shear features are characteristics of sheet metal components produced through shearing procedures such as blanking, notching, piercing, and cutting. The method explicitly targets the recognition of shear features, but it also recognizes features formed through shearing and deformation processes, such as bridges. Based on [20] an AFR technique for shear features uses profile offsetting to specify the layout for punching tool paths. However, the offsetting approach exposes the areas of the parts that cannot be punched out, which requires specialized tools to manufacture. In addition, variations in the punch diameter may result in changes to the identified features, leading to inconsistent results. Recently proposed by [21] a comprehensive solution for recognizing generic deformation features. Their study treats cylindrical, conical, spherical, and toroidal faces as transitional entities to define deformation. This approach is more geometrically encompassing than any other previously published works.

Figure 2 shows the feature recognition of a 3D part. With this, it is possible to put information in the ontology model.

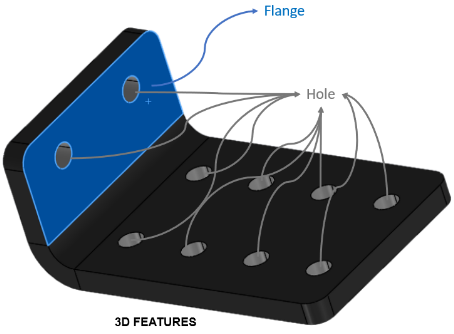

Fig. 2. Feature Recognition of 3D airplane part

The suggested automated feature recognition approach involves two primary steps: categorizing and grouping elements in a 3D B-rep model and identifying aerospace sheet metal features.

3 Conceptual Approach

Manufacturing an aerospace sheet metal component consists of two primary stages: cutting the blank from a metal sheet and shaping the blank as required. In this paper, the generic features of ASM parts are classified into web features, trim features, and deformation features. Figure 3 depicts the proposed categorization of ASM model features. The web is a unique feature among ASM parts, shaped by cutting the blank and shaping operations that produce other features.

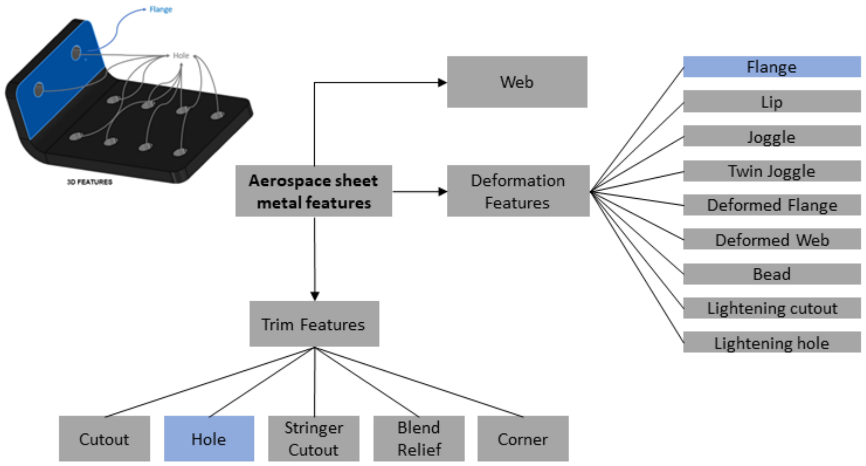

Fig. 3. Types of ASM features

The trim features include a cutout, hole, stringer cutout, bend relief, and corner. Cutouts are created by removing a section of the parent feature as long as the boundary of the parent feature remains unchanged. Holes are a specific type of cutout that has a circular shape. Stringer cutouts, on the other hand, are formed by altering the boundary of the parent feature, such as the web, and dividing the flanges or the twin joggle-induced deformed flanges.

Stringer cutouts are carved out to accommodate the placement of a stringer. Bend reliefs are cutouts that prevent sharp proximity between flanges, which can result in cracking. Since bend reliefs are designed following design guidelines, the length of the relief cuts can be determined. Corners are created by rounding off sharp, convex edges, usually near holes, and are concentric with the corresponding hole. Although both corner reliefs and corners could be considered part of the parent feature's boundary, they convey design intentions, making it essential to distinguish them as separate features.

The deformation features encompass a lightning cutout, lightning hole, flange, lip, joggle, twin joggle, deformed flange, deformed web, and bead. The deformation features are generated by deforming a section of the parent feature. This study assumes that all the bends are formed using a consistent bend radius. The lightening cutouts and holes are fashioned by removing a portion of the parent feature and constructing stiffening lips at the boundary of the removed section.

The flange is formed on the outer edge of its parent feature and is always derived from a web or another flange. It can be categorized as flat or curved, as an assembly or for stiffening, direct or bent, single or multiple, and perpendicular, open-ended, or closed.

Joggles and twin joggles are deformations that create indented areas on the web or flanges. The indented sections of the parent feature are recognized as separate features, known as either a deformed web or a deformed flange, depending on the joggled parent feature.

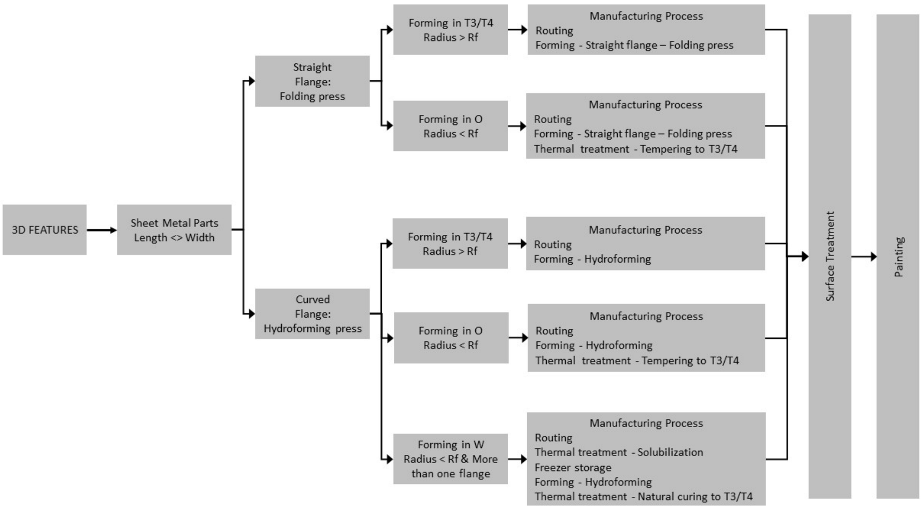

Fig. 4. Flowchart of the ASM manufacturing process

After extracting the information from the 3D model, the data goes through the rules described in the flowchart of Figure 4. In the case of ASM, if it has a straight flange, the manufacturing process should be the folding press. The manufacturing process should be the hydroforming press if it's a curved flange.

Table 1 and Table 2 show, according to the aeronautical standard, the minimum bending operations radius and limitations for each material status and sheet metal thickness.

If the process follows the folding press and the state is between T3 and T4 with a radius greater than Rf, the manufacturing process to be followed is routing, forming, straight flange, and folding press, and then sent to the operation of surface treatment and painting. If the process follows the folding press and the state is in O with a radius smaller than Rf, the manufacturing process to be followed is routing, forming, straight

Table 1. The aeronautical standard is the minimum bending operations radius.

Material	State	Bending Radius (mm)											
	Thickness (mm)	**0.3**	**0.4**	**0.5**	**0.63**	**0.8**	**1.0**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.8**
Sheet Metal	0	0.6	0.6	0.6	0.6	1.0	1.2	1.6	1.8	2.0	2.0	2.0	3.0
	AQ	0.6	0.6	0.8	1.0	1.6	2.0	2.5	2.8	3.0	3.0	3.0	4.0
	T3 e T4	1.0	1.0	1.6	2.0	2.5	3.0	4.0	4.5	5.0	5.0	5.0	6.0
	T6 e T81	2.4	2.4	3.2	4	4.8	6.4	-	8	-	-	10.4	11.2

Table 2. The aeronautical standard is the minimum bending operations radius.

Material	State	Bending Radius (mm)											
	Thickness (mm)	**2**	**2.3**	**2.5**	**3.0**	**3.2**	**3.5**	**4**	**4.8**	**5**	**6**	**6.4**	**9.5**
Sheet Metal	0	3.0	4	4	5	5	5.6	7.2	9.5	10	12	16	35
	AQ	4	4.5	5	6	6	6.4	9.5	12.7	15	15	18	37
	T3 e T4	8	9	10	12	12	12.7	17	21.4	25	30	32	48
	T6 e T81	12.7	14.3	16.7	-	21.4	-	27	34.9	-	-	50.8	-

flange, folding press, thermal treatment, and tempering to T3/T4, and then sent to the process of surface treatment and painting. If the process follows the hydroforming press and the T3 and T4 state with a radius greater than Rf, the manufacturing process to be followed is routing, forming, and hydroforming, and then sent to the operation of surface treatment and painting. If the process follows the hydroforming press and the state with a radius smaller than Rf, the manufacturing process to be followed is routing, forming, hydroforming, thermal treatment, and tempering to T3/T4, and then sent to the operation of surface treatment and painting. If the process follows the hydroforming press and the W state with a radius less than Rf and more than one flange, the manufacturing process to be followed is routing, thermal treatment, solubilization, freezer storage, forming, hydroforming, thermal treatment, and natural curing to T3/T4, and then sent to the process of surface treatment and painting.

The ontology enables the representation of diverse knowledge in the parts pricing process. For instance, it allows determining the appropriate tool for bending based on the radius and thickness of the component or identifying the most suitable machine for manufacturing based on the data obtained from 3D feature recognition.

With this information extracted from the 3D model and identified by ontology and semantic web, the flow of processes to be followed, it is possible to measure the cost of each process involved and then autonomously price an aeronautical component to be manufactured.

4 Discussion and Conclusion

Many challenges have been faced with the arrival of the fourth industrial revolution, both in the academic field and industry. His arrival provided a great technological leap opportunity but suiting and mastering it is not a quick task. Due to the technological rise in the world, Industry 4.0 demands that companies suit the existence of a new market that is increasingly competitive and demands increasingly customized and high-performance products.

From the problematization, it is possible to conclude that conventional cost estimation methods, based on rule-based algorithms and manual data input, are inadequate for the complex and dynamic nature of the aerospace manufacturing industry. Instead, semantic web technologies allow information to be represented in a structured and standardized format, facilitating automation and data-driven decision-making.

The application of ontologies and semantic web technologies has the potential to enhance the aerospace manufacturing process significantly. By improving data representation, data-driven decision-making, knowledge sharing, and combining with 3D feature recognition, these technologies can help address the challenges of increasing complexity and reducing costs and pricing time in the aerospace industry. Therefore, future research should focus on exploring the full potential of this approach in the aerospace manufacturing industry and other domains.

This work allows analyzing the problem of conventional cost estimation methods, generating higher costs for the company. Therefore, propose a solution by developing a system capable of collecting data 3D model and using data crossing to a semantic web and ontology to get knowledge of the system.

The next step in the research is to validate the proposed method by applying the ontology method to improve turning machining parameters. Then, it is believed that it will be possible to implement and validate this system in an industry case, bringing benefits to the entire chain involved, mainly reducing quoting time and making the process more sustainable, both in saving environmental and financial resources.

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