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0-3D Design method: a new design management technique to support Design for Manufacturing

A.J. Baptista[a], L. Reis[b], M. Leite[c]*

[a]INEGI – Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, Porto, Portugal
[b]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal
[c]UNIDEMI,Departamento de Engenharia Mecânica e Industrial, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

* Corresponding author. Tel.: +351-212-948-567; fax: +351 212 948 531. *E-mail address:* ma.leite@fct.unl.pt

Abstract

Design complexity and its relation to Design for Manufacturing continues to be a challenging topic, namely when the objective is to address these aspects in a straightforward manner to young or less experienced design teams. The availability of practical methodologies that induce rules to support novel design creation, in the environment of manufacturing processes, continues to be scarce. This work presents a novel approach named - *0-3D Design Method* - that aims to define, in a systematic and geometrical manner, practical rules that allows mechanical designers to relate, in a codified manner, the design geometry of a given mechanical component to the typical manufacturing processes that permit its physical embodiment. The method proposes the definition of types and sub-types of parts, based on the number of spatial dimensions that need to be modified for a given design construction, and its relation to the manufacturing phase of the product life-cycle. A practical mechanical design example is presented to demonstrate the methodology, mapping the parts necessary for the design of a cutting head of a machine-tool.

Keywords: Design for Manufacturing; Lean Product Development; Product Architecture

1. Introduction

Design complexity is a theme with several aspects of relevance. There are several approaches to clarify what is a complex product, and how to decompose complexity to enable a good design. Complex products, which may include hundreds of parts, such as a car or a plane need special decomposition schemes. For example, Fixson describes a tool where product, process and supply chain are interconnected and Ulrich presents the case of modularity as a source of division of a product into independent parts for easier development [1, 2].

Gershenson et al. present a review of different research concerning measuring modularity and methods on how to obtain it in product design [3]. In their search they found out that there are several ways of measuring and methods for modularity, some qualitative and others are quantitative, and highlight some inconsistencies on the proposed methodologies.

Nomenclature

- 3D Part – parts that for its physical materialization the bulk material must be modified in all three orthogonal geometry dimensions.
- 2D Part – parts that undergo shape modification essentially in two directions, or when a 3-dimensional conformation is performed the thickness maintains constant.
- 1D Part – parts where the raw material is typically modified in one direction, or in case of conformation, there are two directions that maintain equal dimensions before and after conforming.
- 0D Part – parts that are usually standards in the sense that they are acquired directly from suppliers in a processed way and ready to assemble.

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Another review is presented by Bonvoison et al. about modular product design [4]. In their review the authors describe 15 different modularization principles and corresponding modularization metrics, such as material, assembly processes similarity, commonality, service frequency, among others.

There is also a trend concerning product families and platforms for enabling product variety and mass customization. Siddique et al. design a product platform using the concepts of modularity, standardization and mutability, among others to achieve such customization [5]. But there is at least one aspect of this special topic that need attention from the research community, a practical methodology to induce rules to support novel design creation considering manufacturing constraints in a logical and more intuitive way, namely to junior or less experienced design engineers.

In design there are always several options within a product, to produce complex parts in complicated manufacturing operations, or to use several simpler parts and assembly them all together to get the desired function. In the studies and standardization approach by Spies in 1959, [6], the forged parts are proposed to be classified in three main classes: compact shape, spherical and cubical (Class1); Disc shape (Class 2); Oblong shape (Class 3), please see Figure 1. This kind of approach has its virtues since it provides standardized (discrete) orientations towards forged parts design complexity management, and intrinsically coded guides regarding design for manufacturing in forging.

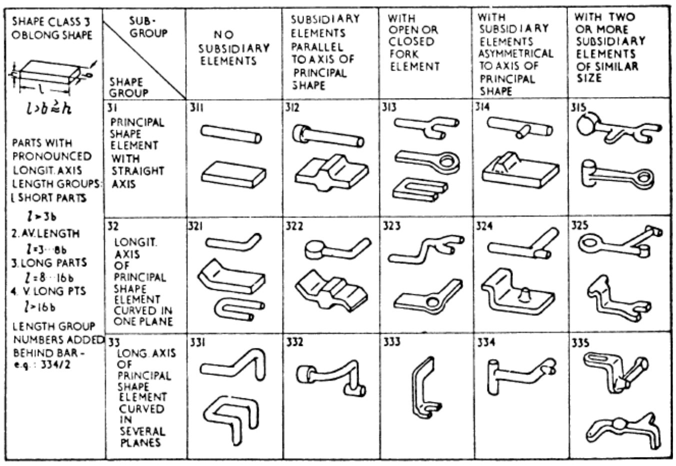

Figure 1. Example of classification of forging shapes (from [6]).

In this paper it is presented a new design approach – *0-3D Design Method* – that aims to facilitate the Design-for-Manufacturing aspects and product parts complexity management. It relies on the decomposition of products based on the manufacturing features of each component. In this methodology, a designer will be able to understand the manufacturing and assembly emergencies of their design decisions, based on a standardized classification of parts geometry, regarding the most common manufacturing processes applicable.

The design options for a given engineering product can be visualized and comprehended regarding the manufacturing and assembly tasks needed to build the product. This visualization can also be used for the development of new versions based on the history of the product. This way the proliferation of parts and its typology concerning manufacturing can be accrued in a straightforward manner.

A future link to cost can be added to the methodology, to ensure that cost estimations are taken in account, so that the tool becomes more complete and more robust to complex design management and design teams can standardize with a rationale of knowledge regarding Design-for-Manufacturing.

The *0-3D Design Method*, when translated into a practical design tool is intended to be served at different levels of the hierarchy in a product development team. For example, the general manager might want to see the aggregated values of each component (number of parts of each class, according to its complexity and onerous cost) and the novice engineer will focus on the classification scheme on the intended manufacturing process, learning the differences and manufacturing implications of his design options for a given component geometry. The aggregated values will help develop design for X policies regarding assembly and manufacturing whether the number of complex vs standard parts are used. The novice engineer will take benefit from having to decide at each part level what are the implications of his selection on the overall component. The tool also makes the design decisions more transparent, since the standardized classification of parts according its based geometry, will provide a common design language in terms of the product development management.

2. Methodology

The *0-3D Design Method* was firstly idealized to support the novice product designer towards more intuitive Design-for-Manufacturing conscience, by the definition of a standardized component classification method that could relate the component geometry, and complexity, with the most commonly applicable manufacturing process. The fundamental premise is that a given component (part) complexity is related to the bulk material modification, by a given manufacturing process, in some of the three orthogonal directions (X, Y, Z axis). The design of a new product could be then evaluated on this perspective, in order to assess the component complexity and the most commonly applicable manufacturing process.

Initially four types of categories of parts are proposed: 3D; 2D; 1D; and 0D. The description of the parts classification is presented below, starting from the most complex type: 3D, to the simplest type: 0D. The 3D type is related to a given part design, that for its physical materialization, the bulk material must be modified in all three orthogonal geometry dimensions (X, Y, Z axis) as shown in Figure 2. Regarding the manufacturing processes that commonly allow the materialization of 3D type parts, one can have for example: forging, milling, electron discharging beam and 3D printing.

2D parts are parts that undergo shape modification essentially in two directions, or when a 3-dimensional conformation is performed, the thickness remains constant. Typical processes include laser or water sheet cutting, stamping, sheet metal bending, punching and similar. An example is presented in Figure 3.

In 1D part, the raw material is typically modified in one direction, or in case of conformation, there are two directions that maintain equal dimensions before and after conforming. Typical processes associated are tube bending, bar bending, structural members cutting, standard shape profiles forming ("I-shape", "U-shape", "T-shape", etc.), and similar. An example of this case is provided in Figure 4.

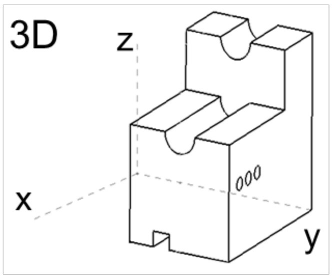

Figure 2. 3D Type part in the *0-3D Design Method*.

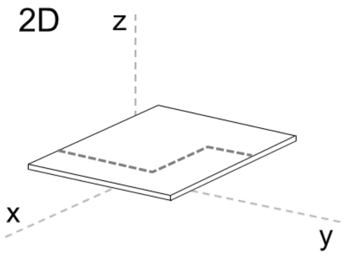

Figure 3. 2D Type part in the 0-3D Design Method.

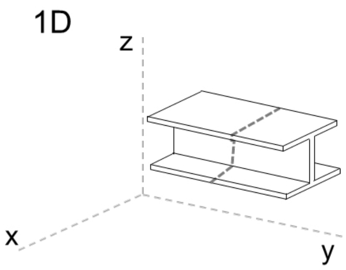

Figure 4. 1D Type component in the *0-3D Design Method*.

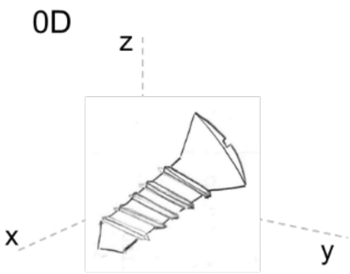

Figure 5. 0D Type part in the 0-3D Design Method.

0D parts are usually standards in the sense that they are acquired directly from suppliers in a processed way and ready to assemble. In this case we are usually considering fasteners, bolts, rivets, shaft keyways, bearings, shaft couplings, hydraulic and pneumatic elements, actuators, washers and similar, please see Figure 5.

Typically, 3D parts tend to be the mostly costly concerning manufacturing. Usually, parts associated with 2D have costs inferiors to elements classified as 3D and 1D parts have costs lower than 2D and 0D parts lower than 1D parts, respectively.

This decomposition is a first step to obtain an overview of the technological processes that are needed to build each part of a product. Each category can be further decomposed in different levels. For 0D parts we propose a decomposition in 3 levels: 0.1D for fixation elements such as fasteners, bolts and rivets; 0.2D for pneumatic and hydraulic elements; 0.3D for motors and actuators. For 1D and 2D parts one can assume the complexity of the operation and decompose relating with the number of operations required: 1.1D and 2.1D for 1 to 2 operations, 1.2D and 2.2D for 3 to 5 operations and 1.3D and 2.3D for more than 6 operations. In the case of 3D parts one can assume also a decomposition: 3.1D for parts that are built with 1 setup or using less than 3 tools; 3.2D for parts that need 2 setups and 4 to 6 tools; 3.3D for parts that need 3 setups or more than 6 tools. Therefore, for this paper, the authors propose a decomposition of a design in 4 categories each with 3 levels depending on the complexity of the technological process.

3. Case study and results discussion

To test the effectiveness and advantages of use of the *0-3D Design* methodology, a case study was prepared based on a real design project of a milling head for a machine tool. For confidentiality reasons, the data were masked in relation to the parts names and to the total number of parts, but the analysis demonstration and methodological conclusions here presented are not affected.

Based on the methodology application along the design team, i.e., one technical manager of the company and several design engineers with different experience levels, it was possible to create several visualizations of the mechanical part frequency of use in the case study for 3 design alternatives in the milling head system. One of the visualizations possible is to use a radar chart visualization of 3 design alternatives with results normalized to the maximum parts in each level (please see Figure 1). Table 1 shows the total parts in each category and the total number of parts. Alternative 1 have 119 parts, alternative 2 have 253 parts and alternative 3 have 172 parts. It is clear from Table 1 and from Fig. 1 that some alternatives have no parts characterized as 1.1D, 1.2D 1.3D, 2.1D and 2.3D. This is due to the nature of the component utilized and might be expected in other cases for other levels.

It becomes clear from Figure 1 that alternative 3 has much more parts than the other two alternatives, also much more 0.1D, 3.2D and 3.3D parts. Alternatives 1 and 2 have more 0.2D, 0.3D and 3.1D. Alternative 3 has zero 2.2D and 3.1D parts while Alternative 1 and 2 have several parts within this category.

These results allowed the company and particularly the engineering department to assess the design options impact and consequences of different design alternatives for a critical system of a machine-tool design. One base result was to establish a new design language within the engineering department, assessing with good definition the part complexity for manufacturing (design-for-manufacturing orientation) and to better support the lack of experience of young engineers and CAD designers of the department. The application of the *0-3D Design method* must be taken beyond the engineering department frontiers. It is fundamental to link the parameterization of the tool with the manufacturing department/division, so that the assessment of the different part design, and its classification, is correctly aligned. Regarding the design management, it was possible to the company to realize, in a quantitative way, the type of parts, their related manufacturing needs and complexity, and to compare the different design alternatives for a given system of its product.

4. Conclusions

This manuscript presents a novel approach for multi-profile design (junior designer, engineer design, product manager, technical manager, etc.) decision support method in mechanical design projects. The *0-3D Design Method* presents a set of rules for product decomposition. The method presents practical rule for mechanical engineers and is intuitive, yet systematic and structured. The method allows mechanical designers to relate, in a codified manner, the design geometry of a given mechanical component to the typical manufacturing processes that permit its physical embodiment. The decomposition of a complex product is based on the number of special dimensions that need to be modified for a given design construction, and its relation to the manufacturing phase of the product life-cycle. A practical mechanical design example is presented, based in a real design case for a machine-tool company, where the methodology was deployed, demonstrated, and become a company standard design tool to support either young, senior design engineers to better support the design-for-manufacturing aspects and impacts trade-offs right from the beginning of design phase.

An important extension of the methodology is underway related to its affinity and advanced design management support to design-for-cost, relating in the right correlation the design types and sub-types of components with their intrinsic cost and impact in the product cost break-down.

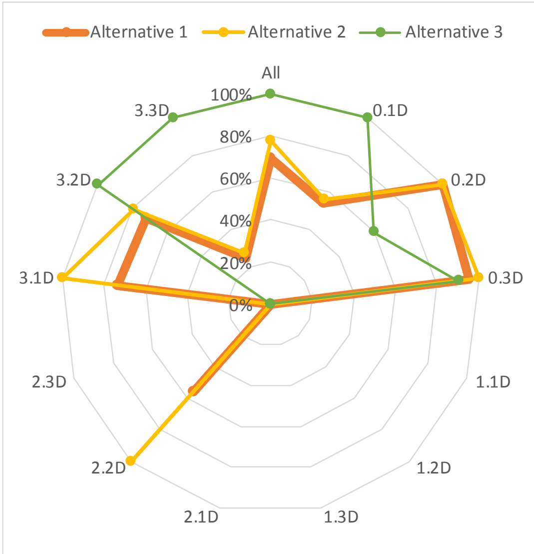

Figure 1. Radar chart for 3 alternative solutions.

Table 1. Number of parts for each category and level.

Alternatives	0.1D	0.2D	0.3D	1.1D	1.2D	1.3D	2.1D	2.2D	2.3D	3.1D	3.2D	3.3D	Total
Alternative 1	32	5	20	0	0	0	0	5	0	14	31	12	119
Alternative 2	33	5	21	0	0	0	0	9	0	19	34	13	134
Alternative 3	59	3	19	0	0	0	0	0	0	0	43	48	172

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