THE IMPORTANCE OF MANUFACTURING DRAWINGS IN THE DESIGN PROCESS: A DIDACTIC CONTRIBUTION TO ENGINEERING EDUCATION

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Abstract

During the direct design or reverse engineering process of products and machinery, various geometric and manufacturing information is generated according to the phases or stages of development applied during a project in different subjects. Much of this information is not used or lost and students face various problems when generating manufacturing drawings. This article discusses the importance of manufacturing drawings during the direct design process and its implications for engineering education. To generate the design information, the concept of manufacturing primitive and a classification of the manufacturing drawings that follow the stages of direct design are applied. It is using a case study to show the process of generating and documenting the information. The importance of transmitting knowledge to the student is necessary for their academic and professional training. Using tools that are actually used in industrial practice within their processes. Improving the results of students in their subjects and in

[+] This paper has been presented at the ICAT'20 (9th International Conference on Advanced Technologies) held in Istanbul (Turkey), August 10-12, 2020.

academic or professional stays. Currently, this acquired knowledge has also been important in academic exchanges because the same way of working is being implemented worldwide.

Keyword: Engineering Education, Manufacturing Drawings, Manufacturing.

1. Introduction

Today's world is changing at a speed never before seen in science and technology. Before, changes took longer to be applied by society; innovations now socialize faster. In less than two decades, there has been an exponential growth in scientific and technological contributions in different fields of knowledge, such as in the development of nanoparticles, biotechnology, electromagnetics, robotics, virtual reality, etc. [1].

Technological trends in manufacturing marked by the Internet of Things, artificial intelligence, robotization, and big data analytics are transforming industrial processes. These changes set the tone for what are known as the fourth industrial revolution, industry 4.0, or smart manufacturing. As a consequence of these transformations, the industrialized countries have implemented public and private decisions in the design of programs and projects to redirect strategic and appropriate productive sectors from the opportunities of this industrial phase [2].

One of the basic inputs in the Manufacturing 4.0 process is information. The quantity and quality of information, as well as the ease of being digitized are characteristics that present a serious challenge for designers today. In the case of the design of products and industrial processes, the information must be generated from the first request of the client until the product is delivered, even until the end of its life cycle.

Direct engineering [3], described as that process that generally starts from a need and ends in a product, and reverse engineering [4] that generally starts from a product already produced and delivers a duplicate, are two methods that specifically for product design, and are the generators of geometric and non-geometric information of parts and components.

The study of the geometric and non-geometric information generating methods of parts and components, such as reverse engineering [5] and design methods in general [6], are fundamental in engineering education, since today the information Engineering is valuable and necessary. It is important that students can learn methods and tools that facilitate them to generate, represent, and systematize information from designs and duplicates.

In the direct or reverse engineering process, manufacturing drawings represent the design of a product, machine, or system in terms of manufacturing [7]. The manufacturing drawings represent the geometric and manufacturing information of the designs, parts and components, and therefore they are fundamental for the generation, systematization of information and digitization of useful and valuable information.

However, there are various problems in engineering education related to the generation and systematization of design information. For example, students do not seriously document their proposals or projects or are only concerned with developing manufacturing plans for the final prototype or parts studied. The problems are further exacerbated when observing that the students do not make the manufacturing plans with the appropriate regulations and, above all, they are highly dependent on the software.

It is necessary to propose strategies and methods that improve the teaching and learning of engineering students, mainly in design [8], metrology [9] and manufacturing, which allow generating useful and valuable geometric and non-geometric information on design , parts and components, applying design or reverse engineering methods with the aim of documenting, systematizing and digitizing the information generated.

This article discusses the importance of manufacturing drawings in the design process, as well as the methods by which geometric and non-geometric information of parts and components is generated.

2. Direct engineering and reverse engineering.

The generation of geometric and non-geometric information of designs, parts and components must be supported by the application of methods or techniques in order to obtain useful and accurate data. The direct design method and the reverse engineering method, aided by a large number of software and tools, have been widely used for product design or for making useful duplicates. The direct design method is practically the traditional design method, since it starts from a need or idea and ends in a product.

Conceiving a product consists in the transformation of an idea, in the definition of the characteristics of an object that satisfy that image and in the determination of its manufacturing modalities [10]. The product will go through a series of stages that will go from its conceptual conception to its recycling once its useful life has ended. Design, meanwhile, is a creative and iterative activity; It is a transformation process that causes the change of status of a product. Design begins with a process of converting information related to ideas and requirements for a product and ends with more accurate knowledge of the product.

Design is the evolution of the formulation of a problem, assisted by decision-making in the preliminary stage, which starts from technological and social information, where abstract representations evolve towards a physical product [11].

For the purposes of this paper, the definition of design is reformulated as follows:

The direct design method is the systematic application of an analytical-synthetic process that seeks to determine a physical or virtual model, a product or a machine or system based on certain needs or problems where the reference information is generally limited or does not exist., using a series of iterative phases that can be sequential or concurrent that include manufacturing processes or models.

The design can be studied from different methodologies, which generally answer two main questions [12, 13]:

a) The descriptive methodologies that try to reveal the methods used in the design through the observation of the performance of the designers.

b) Prescriptive methodologies, which propose a more algorithmic approach and a systematic procedure [13].

Descriptive models prioritize the importance of generating a primary solution concept in it. The initial solution undergoes a series of stages that include analysis, evaluation, refinement and, finally, its development. The process is heuristic, that is to say, it uses previous experience, general guidelines and not very refined rules that express the designer's wishes to find the correct solution, but not with an absolute guarantee that it is the right one [14].

Prescriptive models try to persuade or guide designers in how to carry out the design process. These methods usually offer an algorithmic and systematic procedure to follow and are often considered a particular case of design methodologies. The purpose of prescriptive models is to distinguish and locate favorable properties, existing or new, from particular types of design practices [15].

Some authors propose various phases of the design process. For example, in [11] the following are proposed: 1) Definition and specifications, 2) Conceptual design and 3) Product development. In [13] the following stages are proposed: 1) Clarification of requirements, 2) Conceptual design, 3) Basic design and 4) Detailed design. In [3] nine phases are proposed: 1) Analysis of customer requirements, 2) Conceptual design, 3) Design body, 4) Detailed design, 5) Manufacturing and Assembly, 6) Testing and validation, 7) Industrial transfer , 8) Product operational life cycle, and 9) Industrial innovation.

On the other hand, reverse engineering is also a design process, only that unlike direct design, it usually starts from a product, machine or system and its objective is to obtain a model or duplicate. Formally speaking, reverse engineering is defined as follows [11]:

Reverse Engineering is the systematic application of a guided analytical - synthetic process with which seeks to determine the characteristics, properties and / or functions of a system, a machine or a product or a part of a component or a subsystem. Its main purpose is to determine at least one model or characteristic of an object or product or reference system whose information is limited, incomplete or does not exist.

This method also consists of phases [4]: 1) Present the reference object, 2) Define the references, 3) Define the objectives, 4) Formalize the problem, 5) Design programs and research procedures, 6) Apply the programs to the reference object, 7) Obtain a representative model of the reference object, 8) Perform the tests to generate a reproduced object representative of the reference object, 9) The conclusions of the process are described, 10) The obtained model or duplicate is re-evaluated and 11) Possible applications of the reproduced model are studied.

The definitions of direct design and reverse engineering, have a common term, that is, both are generators of information on products, machines or duplicates.

3. Geometric and non-geometric information of parts and components

There are usually two kinds of information that are generated during the direct design or reverse engineering of a product: 1) Geometric information and 2) Non-geometric information. The first class groups' information about dimensions, shapes and topology of the objects studied, while the second class usually represents manufacturing information, such as manufacturing processes, raw materials, costs, etc.

The generation and representation of information in the design of machines, parts and components are two tasks of fundamental importance. During the process of direct design and reverse engineering, information is gradually generated, starting with few and confusing data, up to more advanced product models generated with high-quality information. The generation of information requires experimental, computational and mathematical tools, and above all, the guidance of the direct design method or reverse engineering, as the case may be. For example, for the generation of geometric and dimensional information in [9], five procedures that assist Metrology were generated within the programs of reverse engineering of parts and components. These methods require the use of statistics and regulations to generate the dimensional information of the products.

The representation of information is a crucial task for the design of the product and its possible improvements and applications. Formally, manufacturing drawings (see Figure 1) are standard representations of design in terms of manufacturing [7] and are widely used. However, in computational and information management terms, manufacturing primitives [16] have been an option that revolutionized CAD / CAM integration. In fact, most CAD software is based on the theory of primitives. Table 1 shows some manufacturing primitives [17].

Another important aspect that must be met by the information generated from the design process and reverse engineering is the capacity with which it can be transmitted and digitized. There are various communication formats and protocols to be able to standardize information [18]. STEP and IGES are some of the most used in the industry.

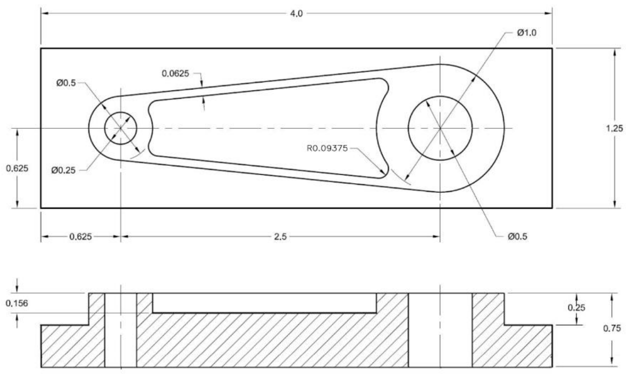

Figure 1. Portion of a manufacturing drawing.

Table 1. Information generated during the direct design process.

Forging	Extrusion	Stamping
Planes	Webs	Slots
Ribs	Ribs	Fingers
Bosses	Tongues	Corners
Fillets	Walls	Holes
Webs	2D Intersections	Cut-Outs
3D Corners	Hollowness	Notches
Bends/Twists	Corner Breaks	Windows
Casting	**Tool & Die**	**Structural**
Planes	Circles	Plates
Cylindricality	Webs	Shells
Projections	Walls	Beams
Depressions	Corner Breaks	Frames
Hulls	Slots	Trusses
Solids	Hollowness	Columns
Holes	Tongues	Arches

4. The importance of manufacturing plans in direct design

Manufacturing drawings are without a doubt the most important and best protected documents within the design or reverse engineering process. The manufacturing drawings in fact represent the design in function or in terms of manufacturing, so it is possible to affirm that there is no design without manufacturing. In other words, design and manufacturing are terms that are strongly linked functionally and operationally.

On some sides the manufacturing drawings are known as technical drawings that comply with regulations. Formally speaking, a manufacturing plan is defined as follows [7]:

A manufacturing plan is a physical or digital schematic representation of the design of a part or a set of parts that can be interrelated, in terms of manufacturing. Said representation contains geometric and non-geometric information of the parts and components, in addition, it must comply with the following considerations:

1. Geometric and non-geometric information (manufacturing, costs, etc.) must be clear and as explicit as possible.

2. The information must be objective (essentiality, degree of importance of the information, etc.).

3. The information must be complete, finite, and well-defined. 4. The information must be regulated.

5. The information must be free of vagueness and ambiguity.

The previous definition imposes a severe restriction on technical drawings or diagrams, since they must comply with formal aspects such as regulations. Manufacturing drawings are usually the ultimate documents of the entire design process. However, these do not represent the full documentation of the design process or reverse engineering, since much of the information that is generated in a development is not considered or disregarded, or simply is not contemplated because it is thought that It's not necessary.

The detailed design phase is where the manufacturing plans are generally developed, since information is already available from the design body, which is the main provider of technical and specialized information, such as stress calculations, deformations, materials analysis and simulation, among others. However, geometric and manufacturing information is generated from the first contact with customers and little by little it grows and specializes until it becomes valuable and useful information, which much of that information is concentrated in the manufacturing plans and in generation of prototypes or machines.

The generation and documentation of geometric and manufacturing information must be treated following a logical order or the design process as presented in [11, 13], since each stage or step is of utmost importance in product development. . In [7] nine phases of direct design are presented and whose importance in relation to information is summarized below:

1) **Analysis of customer requirements:** at this stage, highly relevant design information is generated as it is the first contact between the designer and the customer, and between quick ideas and proposals, since the result must be a quote and an employment contract. In this stage, diagrams, diagrams, extended ideas, sketches, reviews, basic computer representations and searches for basic information, costs, materials, among other information necessary to make a proposal to the client in terms of design, costs and delivery times are generated.
2) **Conceptual design:** The information generated at this stage is essential for the design process, since on the one hand, it must validate or discard the proposal for a quote and, on the other hand, the activities carried out require in-depth study and time to mature ideas. In this phase mature ideas, schematics, drawings, computational models, usually solid models of the machine or components (representative models), simple calculations and simulations, scaled prototypes, materials, more elaborate research, and analysis of other ideas are generated. Similar to the proposal in the quote. This phase generally provides a final product proposal that must be developed and validated.

3) **Body of the design:** In this phase, all the studies, analyzes and calculations necessary to validate the final proposal of the conceptual design are generated based on engineering knowledge. Therefore, the geometric and non-geometric information that is generated is specialized and of great importance in the design process. In this phase, material studies are carried out, the necessary calculations are made to select geometric shapes, solid modeling, forces, stresses, deformations, flow calculations, simulations, velocities, accelerations, and everything necessary to engineer the conceptual design proposal. . This phase considers important aspects related to the manufacture and manufacture of prototypes, machines, parts and components.
4) **Design in detail:** This design phase is of utmost importance since studies are carried out on those details that were not considered in the body of the design, such as adjustments, tolerances, selection of materials and non-critical connections. The main geometric and non-geometric information is concentrated in this phase and the manufacturing drawings of the prototype or the components are developed.
5) **Manufacture and assembly:** The objective of this phase is to manufacture and assemble the parts of the prototype, taking into account mainly the manufacturing plans. The information generated allows correcting faults or seeing details that were not considered in the previous phases. Therefore, the manufacturing drawings are corrected or improved based on the information that is generated.
6) **Testing and validation:** Once the prototype has been manufactured and assembled, it is required to comply with a series of specifications and regulations. In this phase, valuable information is generated and applied to improve designs and manufacturing drawings and to verify product functionality.
7) **Industrial Transfer:** In this phase the product is prepared to be transferred to the customer. The information generated is important because maintenance manuals, operation manuals and everything necessary for the machine or parts to function correctly must be developed and delivered to the customer. The corresponding calibrations and adjustments are made and the machine is tested in the field. In addition, all the documentation is delivered to the client, such as technical information, settlement of contracts, guarantees, among other information.

8) **Product operational life cycle:** In this penultimate phase, constant monitoring is maintained on the operation of the equipment delivered to the customer to detect faults and other details. The information generated serves to correct details and reorient maintenance if possible.
9) **Industrial Innovation:** This phase retrieves all the possible information to improve the products or to make changes in the designs. The information generated is useful for decision-making in companies that design machinery.

The direct design process is an information generator in all its phases. The manufacturing drawings, although they represent a concentration of the geometric and non-geometric information of the products, do not have all the design information. It is necessary to generate, document and digitize all the information that is produced during the design process, since as a whole (and not only the manufacturing drawings) it is the basis for design corrections, future improvements, and profound innovations.

On the other hand, the manufacturing drawings are the heart of the design process and these must be carried out with objectivity and clarity so that they can be interpreted without any problem. They must carry enough information (no more, no less) so that they can be read and understood, and they must be clear and free of ambiguities and vagueness.

The manufacturing drawings that are generated in the detailed design and those that are transferred to the client (in case of having contracted the engineering), must be compulsorily regulated. To classify the manufacturing plans, it is necessary to consider three moments during the development of the direct design process: 1. Time 1: Creation of the product idea 2. Time 2: Formalization of the product idea 3. Time 3: Radical changes of the product. Table 2 shows a concentrate of the information generated during the entire design phase [7].

Table 2. Information generated during the direct design process.

Time	Phases of the methodology	Type of manufacturing plane	Description	Product or semi-product
Time 1	Analysis of customer requirements	Primary representations of the idea	Ideas, extended ideas, search for proposals, freehand drawing, computational representations of the idea, and basic representations of the product	Sketches, written ideas, and non-formal representations
Time 2	Conceptual design	Representations of the idea of the first formalization	Mature ideas, modeling of solids, scaled prototypes, first calculations, limited sketches and materials	Semi-dimensional sketches and semi-formal representations
Time 2	Body of design	Representations of the second formalization	Calculation of materials, kinematic variables, dynamics, sizing, simulations, models in solids	Spreadsheets and semi-planes
Time 2	Design detail	Representations of the second formalization	Detail of piece, basic connections, formalization of sketches, and introduction of drawing and manufacturing norms, formalized plans	Formal manufacturing plans
Time 2	Fabrication and assembly	Representations of the prototype	Manufacture of parts and components according to the plans and assemblies according to the plans, development of the first formal prototype	Reconfigured plans
Time 2	Validation and tests	Representations of the prototype	Prototype tests, calibrations and definition of operational parameters	Final plans
Time 2	Technology transfer	Representations of the transferred machine	Installation plans, maintenance plans, and final plans	Final plans, maintenance plans, and/or assembly plans
Time 2	Life cycle analysis	Representations of technology update	Continuous improvement of the machine and small innovations	Improved plans
Time 3	Technologic innovation	Representations of the innovation	Major changes in the design of the machine, considerable improvements, or radical change of product	Plans with major changes

5. General aspects of manufacturing primitives on a manufacturing plan

Although the generation and interpretation of manufacturing drawings are one of the most crucial tasks in the direct design process and in reverse engineering, the digitization of information plays a role of great importance in the context of manufacturing 4.0. For decades manufacturing primitives have been one of the most widely used feature models for CAD / CAM relationships. However, these models must be fed with geometric and non-geometric information. Subsequently, the primitives must be formatted in one of the protocols that exist for the transfer of information between the packages that mainly assist in design and manufacturing.

A primitive is a computational representation that combines geometric and non-geometric information of a part or a set of parts. Such information can be used for some specific purpose [19].

If the non-geometric information is manufacturing, then the primitive is manufacturing. In a natural way it is possible to affirm that the manufacturing drawings are primitive generators. Formally speaking:

A manufacturing drawing is a representation that combines geometric and non-geometric (manufacturing) information for a component or set of components.

This proposal or hypothesis is important since it is possible to transform the information from the manufacturing drawings into manufacturing primitives and, therefore, the information can be digitized. A manufacturing drawing has the following families of manufacturing primitives:

1) P_{MP} : primitive raw material
2) P_{PP} : primitive of prepared products
3) P_{MAE} : primitive of operations
4) P_{SUB} : primitive of by-products
5) P_{PT} : primitive of the finished product

Suppose that a raw material needs to be systematized by means of primitives, for which the manufacturing operation is considered to be a machining that must start from a 7030 brass cylindrical bar. This primitive is as equation (1):

$$P_{MP} = \{\{\text{"cylindrical bar"}\}, \{l,\phi\}, \{7030 \text{ brass}\}\} \quad (1)$$

Here, l and ϕ are the length and diameter of the raw material. A representation of a manufacturing primitive related to manufacturing operations is as equation (2):

$$P_{MAE} = \{\{ P_{MP}^{M} \}, \{G_{MAE}\}, \{p \in \partial_{MP}, \underline{e_i} \in \Re^3, \varnothing_1, L_1, a_i\}, \{H\}, \{\tau\}, \{w\}\} \quad (2)$$

Where, P_{MP} is the raw material manufacturing primitive, G_{MAE} is the geometry of the extracted part, $p \in \partial_{MP}$ is a reference point located on the raw material boundary, and $\underline{e_i} \in \Re^3$ is a unit vector, $\varnothing_1$ is the roughing diameter, L_1 is the length of the roughing, H is a cutting tool, τ is a path, and W is a movement of the tool or part (raw material) and a_i is an extra parameter that may well take information or is an indicator.

6. Manufacturing plans and engineering education

Design and manufacturing education requires a modification to the conceptual processes related to the design of prototypes, parts and components. The use of design methods, such as reverse engineering and direct design, must be promoted in each project developed and students must know the importance of the generation, representation and digitization of information.

The manufacturing drawings must be developed with all the appropriate technical drawing standards since they are not simple drawings, but rather represent the heart of the design. They contain the most valuable technical design and manufacturing information from the design process. However, students must be able to systematize all the information from the direct design or reverse engineering phases, that is, from customer requirements to the last phase of technological innovation if it is direct design.

Since manufacturing drawings can be considered as generators of manufacturing primitives, it is necessary for students to develop the best possible drawings and with the appropriate technical information, since manufacturing primitives represent an enormous opportunity for the digitization and transfer of geometric and non-geometric information between different computational packages.

7. Conclusions

This article has presented some considerations on the importance of manufacturing drawings and their relevance in engineering education. The main conclusions are summarized in the following points:

- During the application of the design or reverse engineering process in the analysis of some machine, it is necessary and important that the students generate, represent and digitize the information that is produced. All the information is important and it is required to document as far as possible the direct design process or the reverse engineering process.
- Although manufacturing drawings are the most important documents of the design process, there is much more information that must be collected and structured so that it can be useful for possible improvements or to innovate the product.
- The digitization of information can be improved if the manufacturing plans can be considered as generators of manufacturing primitives.

- Engineering students must be capable of generating useful and quality information in all phases of direct design or reverse engineering, and above all, they must have the necessary skills to develop manufacturing plans objectively and with adequate regulations.
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Acknowledgment

The authors of this work thank the Technological University of the South of Sonora, the La Salle Noroeste University, the Superior Technological Institute of Cajeme, the Sonora State University and the Municipality of Cajeme for the support given to this research.

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