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Parametric Cad in the teaching of drawing for Mechanical Engineer

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Abstract

For more than two decades, Computer Aided Design (CAD) has been increasingly taking part in the teaching of drawing for mechanical engineers and similar areas. The number of papers and communications presented by teachers of this area has increased in the last three decades, in different specialized and general events such as engineering, and the teaching of engineering congresses. 1 From the teaching point of view, the innovation has been centered in the increasingly use of the most spread CAD software in the world. 2 The use of it has tended to replace in a complete or parcial way the precision drawings, that were traditionaly made on boards by hand. In recent times a new inflection appears on the stage when the programs with an analytical parametric design philosophy and characteristics were introduced. The emergence of this kind of software impacts again on the traditional teaching of engineering drawing, putting in the hands of students and from the early stages of their studies a tool that necessarily leads them to get involved in aspects of design, even in the case when the expected goal is just to get a drawing. At the same time, the representations under international drawing standards became so simple as we could never have imagined before. This paper tells how the decisions were made to move towards a new paradigm of computer aided representation and how it was integrated to the concepts already present in the syllabus of the subject by means of tasks that imply the analysis of a mechanical system, its representation, the proposal of modifications on it, and the development of a technical report.

Introduction

Unlike what happens in Architecture and Industrial Design teaching, where the subjects of representation systems are learnt along the initiation the project and design, in engineering teaching, design matters have always been included in advanced stages, currently called in Argentina " professional cycle", the drawing has remained in the so called cycle of "basic sciences", at the present. Leaving aside discussion about the relevance of this content organization, it is clear that the knowledge and skills of its own do not found a common thread to their effective implementation in project design, up to the times when students are in advanced stages of their formation. [1]. Having realized this shortcoming, we have been implementing for many years complementary practices in order to approximate the simple representation of technical objects to aspects of functionality, manufacturing and product improvements and especially ensuring that the objects of representation were meaningful to the student, through the analysis of the aspects recently described. [2] Our proposal was already exposed during the Second Argentine Congress of Engineering Education (CAEDI), many years ago.

2. Impact of CAD in education and production

2.1 In the academic field

In Argentina, during the second half of the eighties early versions of CAD programs began to timidly appear in the classrooms of technological careers. But only one decade after, the infrastructure conditions allowed its teaching. Universities in general remained at the rear and when they began to get hardware equipment available for the students, it was scarce and became quickly obsolete. Before this, the teaching of CAD was only limited to single demonstrations of the CAD programs capabilities, and perhaps poorly understood by the students. Our experience about the incorporation of CAD in the teaching of technical drawing, in mechanical, aeronautics, chemical and industrial engineering careers, at the School of Engineering, La Plata University, has been reported in previous works. [3] [4] [5]. The program has always been expensive for the public universities in Argentina, even "educational" releases. Dealers of the most popular software seem not to take into account that thousand of students are trained every year spreading the knowledge and handling of the mark, not cooperating with facilities in the use of licences. It is estimated that only in the institution from which this work belong to, about 300 students per year are trained to a basic but solid level. Those students, as future engineers, are likely to be elected for qualified jobs, because of their knowledge of the most popular CAD software, among other reasons. And in the future when they get management positions,

[1] Successive meetings of EGRAFIA [2] AutoCAD from Autodesk ®

they will probably select this same software to be purchased. At the present, in Argentina, all universities, with different variants teach AutoCAD. From our place we have always argued that what we must teach is drawing for engineers "with" CAD, but not a particular trademark software. In other universities the *course AutoCAD* has its own identity. We don't share this position. For us, CAD and the use of and specific software is considered just a methodological and instrumental content; it's not a content itself and much less a separate course of drawing. Among different schools of engineering, the variants also exist in the extension and depth. From our point of view, CAD must take just the place traditionally occupied by board and precision instruments in the drawing of technical plans. These are tools that have been fully replaced in our classrooms. Thus, a typical practice can start from a sketch or figure of a real object represented in perspective which the students have been solving under the ISO system, and then managing the model space and paper space. The CAD has been, since its formal breakthrough role in our classrooms, merely reproductive: from the real shape to the standardize representation. But one day, the parametric CAD bursts on stage and impacts both in the design processes, the manufacturing industry and in the formative cloisters. Teachers felt forced to rethink the practices of CAD when teaching drawing for engineering.

2.2 In the productive areas

Meanwhile, in technical offices, CAD systems despite its enormous advantages over hand drawing were used as "virtual board" where a mechanical designer applied the same concepts and methods of work so far embodied by pencil, paper, board and instruments. The conceptual leap was relatively simple and old designers learned to use CAD more o less easily, and moved their skill very quickly from graphics boards to monitor. But they still went on building plans through the combination of lines, arcs, and abstract views in two dimensions, and so on. They were drawing "in the old way" but with "new tools". First, imagining what they wanted to drqw, then sketching it in some lines that were finally scrubbed. This type of work is still used today, especially among those who didn't want or have not been unable to take the next step. Another frequent application of CAD in early times used to be the "digitalization of planes", which meant to move from paper to CAD drawings. This was a poor use of CAD capabilities but allowed modifications not fixed on the paper. Many years later began to be available tools to design directly in 3D, but nobody seemed to be encouraged to do it. Very few people seriously designed in three dimensions. It was just a "curiosity" that required much work, a deeper understanding of programs and, ultimately, did not provide more than nicer visualization of an object.

3 Parametric an conventional 3D modelling

The possibility of constructing three-dimensional models is available from quite old releases of CAD programs. But building such models from a rough and enough flexible sketch, in order to get in later stages final shape and dimensions without go back the followed road, appears with the parametrical philosophy. When the generation of parametric programs appeared produced a new inflection in the teaching of drawing for engineers. A "sketch", as usually named, is, in terms of a parametric program, an approximate drawing traced on a grid trying to approximate some of the characteristic forms of the object with a flat figure. Later operations (the most common extrusion or revolution) will convert the sketch into a basic solid but pretty close to the definitive model. Once finished this model will be the base to obtain standardized planes using a capability of the software than means just to "touch a button". Thus, getting 2D drawings becomes the last step. One reason of that is that in some situations the plan on paper is not essential. This flexibility in the model generation stage opens a door closed for the students until this moment: the possibility of design while drawing. An additional capability is to establish "association" with calculation software to evaluate the model under work conditions. The parametric software of 3D solid design allows a flexibility never seen before. The most recent releases that incorporate intuitive operations (features or characteristics) may be associated with mechanical manufacturing, operations. The designer can imagine that starts from a solid block which will be "virtual machined" to obtain the final forms. This makes it much more intuitive, and allows the designer to visualize rapidly from any point of view his idea, enhanced. All these advantages can be summarized as follows:

3.1 Advantages of parametric CAD

• The dimensions may be associated parametrically, allowing the generation of families of products or parts without having to model them again. For example, in the case of screws, the proportions of the hexagonal head and the diameter are approximately the same when moving from one series to another, allowing the generation of different size screws only varying length and diameter parameters from a first screw already drawn. It is also advantageous when working under theory of "series of machines" [6] or when geometric similarity for pumps, in hydraulic machines, is applied.

• The work structure or flow of operations is recorded in a "tree work" into which the designer can go to and come from, changing an operation or dimension according to the needs of design.

• Operations of design that may be associated with manufacturing operations such as drilling, bending, etc. allow a less abstract planning of the operations that will be made, following a logical and real order in a workshop.

• The enormous interaction that has been achieved between other CAE or CAM programs, allows a design to be performed in any software, and then automatically parsed into another, simulating the manufacture before launching the design into production. This way, problems arising from the manufacture or the simulation under service conditions can be easily modified on the original model.

• Evolutions on previous products can be analyzed on existing equipment; missing parts can be designed taking care that there is no interference, that the parts work smoothly without friction and fulfilling its function, all before their definitive production.

• Libraries are availability within the program or online, avoiding the creation of specific blocks (i.e. screws, seals, bearings, etc).and allowing the designer to concentrate on the project.

4 How a parametric CAD is

Conventional CAD systems are based on vector combination of geometric entities (points, lines, curves, polygons for 2D mode, with the addition of surfaces and solids for 3D mode). All these entities must be sized and once the dimension is assigned, it must not be changed in order to keep the consistency of the project. Its roll is predominantly metric and reproductive, although it must be admitted that this classification made sense with the emergence of parametric systems. In parametric modelling pieces are directly designed. A set of them belonging to a mechanism can then be assembled in a project. The pieces are assembled by adding constraints between the surfaces, edges, planes, points and axes. Each of them can be corrected as many times as necessary without having to discard what has already been developed, both on the part itself and on the others linked in the assembly. In a similar way, a part can be the start point to variants of the same, not needing to start from scratch. This capability allows the production of series of products on a single basic design or the improvement of products and manufacturing. Whenever necessary to alter dimensions, they will be automatically adapted as much as necessary to the geometry already defined, even in other related parts. The material can be selected from the beginning of the project. The parts are modelled defining their *characteristics*. These in turn are based in sketches such as those in fig.1 and fig.2.

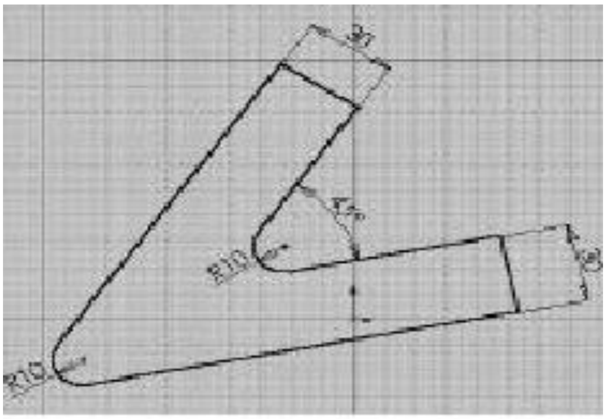

Fig. 1 Example of sketch

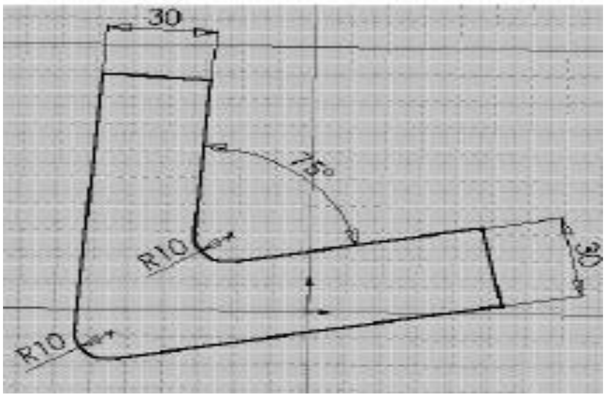

Figure 2 Sketch modified

All the sketches and features can be corrected at any stage of development, without having to rebuild the entire partition. This way of working is much more intuitive than those developed in metrics systems, except that, in them, a modification involves restarting at least from the point where the correction is performed, or directly start again. Unlike metric CAD, vector drawing is based on the resolution of simple geometries, referred to a spatial coordinate system, which are then modified in order to get drawings, both 2D and 3D. Unlike that, the analytical design parametric constitutes a new paradigm for modelling solids. Under this paradigm, the geometry of a model is determined by a set of values of the parameters or relationships defined in their design. Therefore, the dimensions are subordinated to different parameters, so the designer can control the geometry by varying those values.

4.1 Adaptive Design

The adaptive design is that design that "fits" to environmental changes based on which it was related. In general, is not based on one part but on an assembly where one, two or more parts are taken as a reference and a new piece that interacts with them is created. After creating a new piece, any change in the assembly which modifies the geometry, will be updated or "adapted" automatically. For this goal it is necessary to have the adaptively relationship function activated. If it is off, the assembly tells us what parts can not be moved because of interferences and/or Inconsistencies in the restrictions of the mounting. For example let us suppose an arm that links two parts, anchored to a bolt on a wheel. If the design is adaptive and the diameter of the wheel or the diameter of the bolt are changed, the arm will be stretched or shortened or the diameter of accommodation changed in order to keep the functionality of the whole. In contrast, if the design is not adaptive, if the wheel is modified, the assembly will find conflicts because the arm is no longer useful for the application it was created.

4.2 Dimensions and Parameterized

In general, the parametric paradigm implies association of variables or expressions with the values of model dimensions. Thus, the modelling of a solid is expressed in terms of some variables that represent the dimensions of the model and are involved in the exact calculation of the geometry of the design. So, changing one dimension "parameterized", the software immediately set the part taking into account the variables preconfigured. In parametric design, parameters, relationships or restrictions may be:

• geometric: as perpendicular, colinearity, matching, symmetry, tangent, etc.

• dimensional: for example a dimension d2 is defined such that half of a dimension d1 (d2 = d1 / 2), so that modifying d1, the system automatically updates d2.

The parametric CAD is also analytic for its impact in the design process allowing visualizing model details, checking contact between parts, doing questions about distances, assigning materials to the parts calculating weights, inertia, etc. In addition, provides tools for create surfaces with the ability to analyze and verify them. Correct surfaces are those where mutual links are continuous referred to tangentially and curvature, and not contain areas where continuity had not been lost. On the other hand, it is noteworthy that parametric paradigm has been nourished by the design by features: standard threads, screws, washers, bearings, gears, reinforcements, ribs, keyways, faceted, and so on., which can be easily incorporated into the design through a extensive library of features. Another important particularity of a parametric program is to offer two distinct environments of work:

- the *sketch environment*, where the initial profile, contour or 2D section id drawn, provides the basis for 3D modelling.
- operating environment where a range of solid modelling operations, allow creating the 3D volume from the 2D sections defined in the sketch environment or modify the 3D volume.

Moreover, different applications developed under this paradigm offer several modules of work:
1. Module *Part* or *piece*, used in the modelling of a component. It has two working environments: sketch and operation.
2. Module *Assembly*, for the assembly of components developed in the module *part*, where the mounting restrictions are established in order to indicate how the parts are linked in the device.
3. Module *Drawing or Layout* where technical documentation can be generated from the 3D solid model through presentations or layout, using commands that automatically generate orthogonal views, auxiliary views, details, sections and isometrics and the incorporation of dimensions, symbols and references. That is, the mere fact that the student passes these stages even to model a highly simple part, has introduced him into a methodology of design. This does not imply to be neither the best nor the only way. In the future the student will have a more canonical training in terms of mechanical design. But, undoubtedly, after making small 3D models will be passed through a procedure that will leave a mark in their future practices of design. In summary, Parametric Design allows to: Establish geometric and dimensional constraints in the parts. This will ensure its forms, dimensions and proportions; avoiding unintended distortions during design or when a modification is introduced In the latter case, the program recalculate the dimensions in order to keep the restrictions.

- Provide operations and predefined elements that can be incorporated to design: holes, fillets, chamfers, threads.
- Access to libraries of mechanical components that can be incorporated in the design: screws, nuts, washers, bearings, gears, nuts, shafts, springs, etc, without having to draw them.
- Make determinations from the design: turning radii, axes and principal moments of inertia, etc.
- Generate technical documentation of the project: drawings, materials lists, etc, identifying each part in the drawing with the reference.
- Automatically solve orthogonal views, isometrics, sections, auxiliary views and details. In addition, they are automatically updated every time any modification is done.

Access to a library of graphics and symbols for the technical plane: notes, tolerances, finishing of surface, etc...

The ability to detect interference between parts that must be assembled not only solves detailed and complicated analysis, unavoidable in a conventional process design, leading the student to a methodology of analysis of the progress of his project. The program warns about the inconsistencies of its proposal and student realizes that it should be revised although the program takes his place, in a similar way that word processors check a text.

4.3 Obtaining the Standard Plan

Obtaining a standardized plan in views was an immediate objective in the traditional way of working. But in parametric CAD they may be obtained from the model 3D through a specific module along with the assembly in exploited perspective. Desired views are selected and defined sections are automatically added to the plane. A perspective embedded in the same plane can be obtained additionally. Animation can be given to the assembly either for use as a handbook of procedure for assembly or as a demonstration of its operation.

5 Differences between metric and parametric CAD in classroom

We have introduced three years ago the parametric CAD in the course of *Gráfica para Ingeniería* taken by students of the degree of Mechanical, Electromechanical, Aeronautics and Materials engineering. The change has been bold in the sense that not only seeks that students to reproduce real objects as solid models, but this is done in the context of analysis of a machine on which they are asked to carry out the redesign or upgrade of parts. This practice is called *Integrator Work* because integrates the practices of sketching, solid modelling, analysis of the operation, assembly and manufacturing methods, and finally the production of a technical report [7] [8] [9]. When the student works with metric CAD models creates a technical plane without having an overview of the Project. That's because his attention is focused in a mere formal resolution of the model, representing a two-dimensional views, according to Monge rules, and taking advantage of the standardized resources like sections, dimensions, etc. This allows the students to get skills of resolution of geometrical figures. In contrast, when modelling with parametric software, the field of possibilities is greater: the student may explore the shapes just changing some parameters and getting different results; at the same time can introduce himself in many concepts of technology because, if he wants to generate a hole in the project he needs, as in the real case, trace a centre mark; concepts of design must be taken into account, and translate them as parameters. This means a qualitative jump in the conception of the morphology of the objects. Since this jump, students don't draw plans; they make the model directly in 3D, and then obtain the technical plan through very simple tools, creating main and auxiliary views. On the other hand, the link between variables (parameters) or the automatic update of the geometry, when changes are made, and their impact on the plane, is one of the advantages highlighted by students. Flexibility allows modifications with just no effort during the development, lead to other versions of the product from identical morphology, design new parts that fit in the existing assembly. This is the case of the real parts of the fig. 3, whose model is presented in Fig 4.

Figure 3 Real part

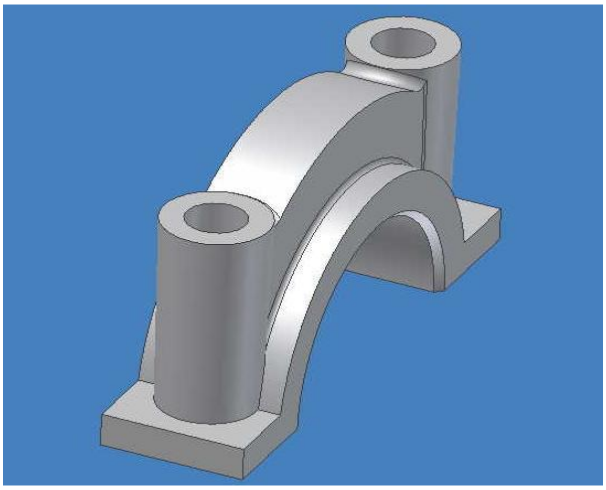

Figure 4 Model of Real part

From it and taking advantage of their similarity the part shown on Fig. 5 has been modelled. The new models are shown in Fig. 6.

Fig. 5 Real model similar to shown in fig. 3

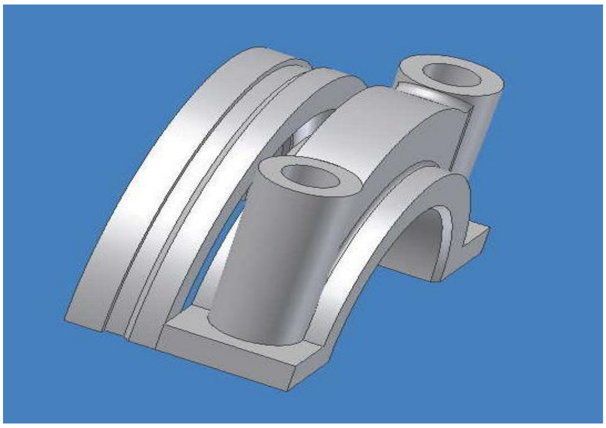

Fig. 6 Model derived from an existent one

This is not possible when a traditional CAD is used, because the geometry must be redrawn according to the modification. Once the implicit procedure of modelling is known by students, they are able to seek the result even if not the best way is used. This makes the process a comprehensive learning. It is implicit that the use of parametric CAD programs necessarily puts students in the practice of drawing elements directly in 3D, choice slightly used (but possible) with the metric programs. This was the only intention when parametric CAD. But very quickly we realized that this new way of work allowed us to test a methodological proposal of introduction to design with the same dedication and effort. Moreover, the method that uses software to generate solids results a teaching aid to conceptualize basic and simple shapes as previous of more complex shapes involved in the final model. These basic shapes are classic geometric shapes called "primitive." In turn, following Félez [9] the management of primitives is an aid to the dimensioning as they "invite" to dimension guided by the fundamental dimensions of the “primitive” solids. Although it is worth to note that in parametric design there are two different actions that can be confused: the first is the sizing that is, the allocation of dimensions to each shape in the modelling stage, linked together through parameters. The other action is the establishment of the dimensions on the technical plane, which are usually constructive dimensions.

Conclusion

For all the reasons mentioned before, we believe that a parametric CAD program used within the context of a degree course of graphics for engineering becomes a tool that allow the students to have a first experience in mechanical design, even when developed in the context of the basic sciences, when the students have not been yet introduced into the engineering calculation. Since the beginning of its implementation the students have shown that they are able to interpret complex shapes, translate them into 3D and test changes on them that necessarily involve design tasks. The quality of the graphic product generates a satisfaction in the students never seen before when working in the old way. Taking into account the current structure of the syllabus, the Parametric Design CAD used as a way of teaching drawing for future engineers, became a "ground wire" for the anxieties of students that are just starting their studies.

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