A Parametric Approach for IT Use and Flexible Design in Small and Medium Size Enterprises

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Abstract: The purpose of this paper is to illustrate the advantages of applying a parametric design approach on the devise and manufacture of new products in small and medium size enterprises (SME). Market drivers for innovation have posed a significant challenge in most SME: while product life cycle times are shortening, the need for more customised products is increasing. Technology has become a major tool to address this challenge. However, SME (particularly in developing countries) can not always afford the required budget for technology adoption not to mention the lack of skilled human resources. As such, this paper contains a developed framework and software applications that were developed and put into practice in a Mexican SME, manufacturer of office furniture. As a result, product quotations, specifications and technical drawings are generated in a fraction of time, as compared to traditional design processes. This framework can easily be extended to other SMEs.

Keywords: Flexible design, computer aided engineering, product customization, productivity, small and medium enterprises.

1. INTRODUCTION

Operations strategy has long been considered either as a competitive weapon or as a corporate milestone. It is seldom neutral. Developing sources of competitive advantages through operations has been in the mind of many industrial engineers since the industrial revolution. At that time, the masification in the manufacturing of products gave rise to lower production costs due to scale economics; this continued to be the main source of competitive advantage until the decade of 1960 [1-3]. Later, the tendency was to develop specialized factories that manufacture products in a single location. In the following decade it changed to flexible factories offering a wide variety of products. During the 1980´s, the search for quality in products and processes was the driver of industry. Since the early 1990´s, reducing time in all the stages of the supply chain is the strategy that companies follow to get a competitive advantage. Nowadays, all these sources have become customary requirements for all industries to remain competitive; consequently they have to find new strategies to increase their efficiency in order to have an advantage over their competitors [4].

In general, most multinational enterprises have implemented the previous sources in different manners on their multiple locations all over the world. Nevertheless, numerous small and medium enterprises (SME´s) in developing countries have not done so due to (i) the lack of technological resources or (ii) capital to afford skilled human resources. Moreover, the main economical activity of SME´s is as suppliers (tier 3 or lower) for larger enterprises, so proper networking and outsourcing mechanisms are highly needed [5-7]. For these reasons, international and successfully implemented tools and method are not necessarily a guarantee of success in SME. It is necessary to develop new strategies adapted to the cultural, economic and technological conditions of these countries in order to increase its competitiveness. Product design and process redesign capabilities represent a significant area of opportunity for this task. Computers, information technology and engineering design are a platform for flexible designs, lower cost and rapid design process, as illustrated in this paper.

2. CASE STUDY

2.1. Problem Definition

The case study illustrated in this article involves a typical small size company in Mexico, specialized on the manufacturing of office furniture for government and private offices such as lockers, cabinets, desks, etc. This company and most of its employees have been in the market for more than twenty years. However, its existence is in danger due to the arrival of new competitors and new customers demands.

An analysis of product specifications required by clients led to the main problem. It was found that most of the contracts are subdued to internal specifications from the costumers in an open contest. This implies that specifications are subject to changes from contract to contract. As a result of only having a standard model, the company was not able to meet the requirements of different open contests and thus, an important number of potential contracts were lost. It was detected that the problem could be ascribed to the lack of a family of products: a collection of parts similar in both size and geometry or on the manufacturing processes required. This opportunity area has been documented in previous publications [8-10], where utility to product distinctiveness and cost are the leading factors to initiate the design of modular products. Consequently, the company requires high flexibil-

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ity in the design process of their products while remaining within their financial capacity and fulfilling their needs. As such, the need for flexible designs became a major task for the company in order to stop the increasing number of open contest in default (and the lack of sales). A family of lockers was selected to start up the devising of a framework and software tools used for this purpose.

2.2. The Need for Flexible Designs

Lockers considered in the family of products can be fabricated with one to four divisions (doors) and were manufactured according to internal standards with dimensions of 380 x 400 x 1,800 mm (Fig. **1**) An objective of this project was to move away from these standard dimensions and provide the company with the ability to produce customized lockers for each contract while keeping the existing manufacturing processes and assembly lines. This approach consisted on developing standard modules based on functionality, architecture and refining [11,12]. The approach to follow was to use CAD systems together with parametric design in order to increase the flexibility of the design process.

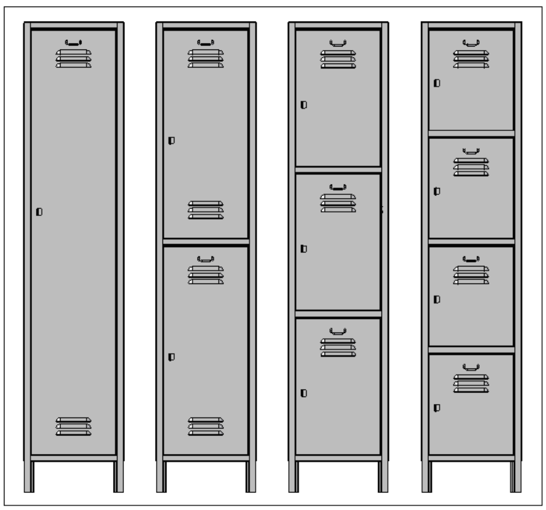

Fig. (1). Family of products (lockers).

The lockers are composed of different pieces; each one made of cold rolled steel. The raw material comes in steel sheets. The dimension of the sheets can change depending on the supplier; they can be 3 or 4 feet wide and 6, 8 or 10 feet long. The sheets are shaped by some manufacturing process depending on the piece of interest. The common manufacturing activities include: cut, die, bend and weld, for the final assembly (Fig. **2**).

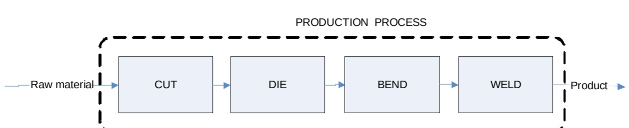

Fig. (2). Manufacturing activities.

New designs took into account the effects of bending. When the material is bend the longitudinal dimensions change. To determine the final dimension it is necessary to know the length of the neutral axis (the original length a sheet needs to have for a specific blending operation). An approximation of the neutral axis can be made with the next formula [13]:

$$L = \alpha\,(R + kT) \tag{1}$$

Where: L is the length of the neutral axis, α is the bend angle measured in radians, R is the bend radius, T is the material thickness and k is the neutral factor (location of the neutral axis along the sheet thickness), as illustrated in Fig. (**3**). For instance the back leg of the lockers is an "L" shape of 30 mm per side and 280 mm in length made of gauge number 14 metal sheet.

By applying equation (1) it is possible to compute the required dimensions of the "unbended" metal sheet in the following manner. The bend angle is 90 degrees ($\pi/2$ radians), a gauge 14 means a sheet thickness of 1.9 mm, the neutral factor is 1/3 and the bend radius is half the thickness. These characteristics led to a neutral axis length of 2.5 mm, which together with the unbended length of the metal profile, resulted in a flat piece of metal sheet of 56.8 mm width and 280 mm in length.

In a similar manner, equation 1 was used throughout the program to compute the unbended length for the different parts that compose the locker.

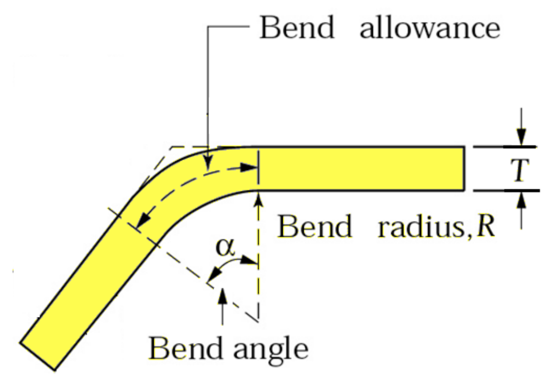

Fig. (3). Neutral axis in bending operations.

After bending, the material recovers partially its original shape. This process is called elastic restitution (elastic springback) and it can be calculated [14].

A worst case scenario was analysed for elastic restitution after bending (the slimmest thickness used). Results indicate that that the elastic restitution is 0.996. Thus, this phenomenon was neglected throughout the project.

3. PARAMETRIC DESIGN

3.1. Locker Parts

To achieve the objective of making a flexible family of lockers, it is necessary to identify which pieces change as global measures (width, W; depth, D; and tallness, T) are modified. Parametric designs can be performed by relating the dimensions of each piece to the global measurements of the final product.

The material thickness (h) has to be considered because it affects the dimension of the pieces and the raw material costs of the locker. Hence, any dimension (d_i) of any component of the product can be expressed as:

$$d_i = f(W, D, T, h_i) \qquad (2)$$

Lockers' architecture is conformed of 15 different pieces. These pieces are presented in Fig. (**4**). Next to each part name are the first letter of the global dimensions that affect the measurement of the part.

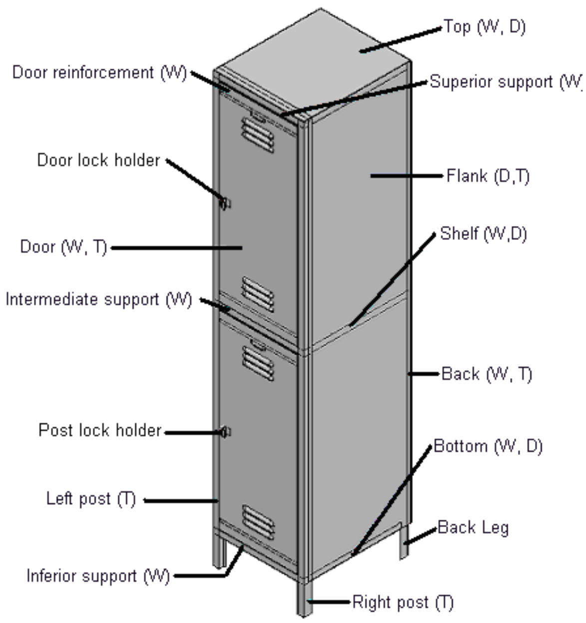

Fig. (4). Locker parts.

Once the pieces are identified, all the measurements of the pieces have to be related to the global dimension with equivalence functions (equation 2). In these functions, material thickness is included and can be controlled by the company to reduce material cost while maintaining the rigidity and resistance of the product (see example in Table **1**).

Table 1. Example of Functions

Functions	
	BACK Back and width ext = Width Back_width_int = Back_width_ext - 2(Back_thickness) Back_length = Tallness - 120 FLANK Flank_width = Depth-22 Flank_length = Back_length

Parametric design techniques are also performed for the metal sheet required in the making of each piece. The representation methods followed in this work for modular systems and parametric designs are based on product, problem and process aspects documented in the literature [15-17]. As a result, the required length of each dimension previous to the bending operation is estimated.

Technical drawings are required to communicate locker design to the manufacturing plant. A suitable CAD program is required to achieve this task. As such, a software program that delivers instructions from the parametric design to the CAD system was developed as part of this work. This software is an interphase that takes and manipulate design data, changes design elements and instruct technical drawings. This software program is case specific so an appropriate CAD system needs to be identified.

3.2. The Use of CAD Systems

The selection and implementation of a specific CAD system is also a relevant issue to incorporate in this project. These systems are used to improve the performance of a design teams and to deal with the problem of defining standard modules and finding a unique modular architecture [8,18]. Specifically, the implementation of CAD systems led to more efficient designs, a faster project and a reduction on final product costs.

Selecting the most adequate CAD system for every company represents a key factor for a successful implementation. Due to the different level of design necessities in different companies, there are different levels of computer aided design software [19,20]. They are usually divided into two categories: two dimensions and three dimensions. Also they can be classified depending on their power or robustness into low (2D), medium (3D), and high (3D) level systems. The difference between medium and high level software is that the first are just CAD and the other are CAD/CAM/CAE [21].

In order to select an appropriate CAD system it was necessary to know its characteristics. In general, in this project it was found that a good solid modeler has the following characteristics:

- *Flexibility*: it must support solids of all shapes.
- *Robust*: the modeler has to produce constant and suitable solids, in other words it can not allow the construction of non-feasible objects.
- *Simplicity*: it has to be easy to use and friendly with the users.
- *Economic*: the modeler has to justify the investment required for its acquisition.

For small size companies in developing countries it is affordable to implement a medium level CAD software. This means they will own a tool to help them be more efficient and improve their design team performance while remaining within their limited budget.

4. IMPLEMENTATION STRATEGY

4.1. Design Framework

The implementation process was developed by aims of product design and development techniques, starting with a functional decomposition approach. This implementation process was analysed as a black box, as depicted in Fig. (**5**).

The black box was decomposed in order to produce a first concept. A product concept is an approximate description of the technology, operation, and shape of a product: this concept represents how the product will meet the needs of the customer. In order to develop a concept, it is necessary

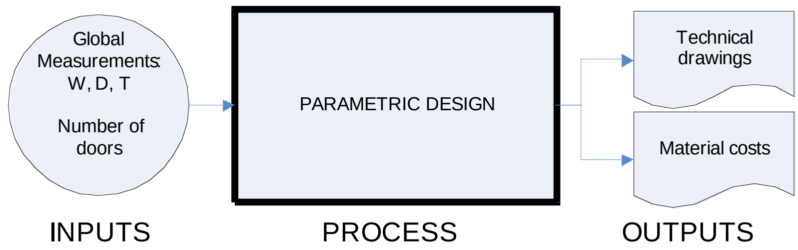

Fig. (5). Implementation process for parametric designs.

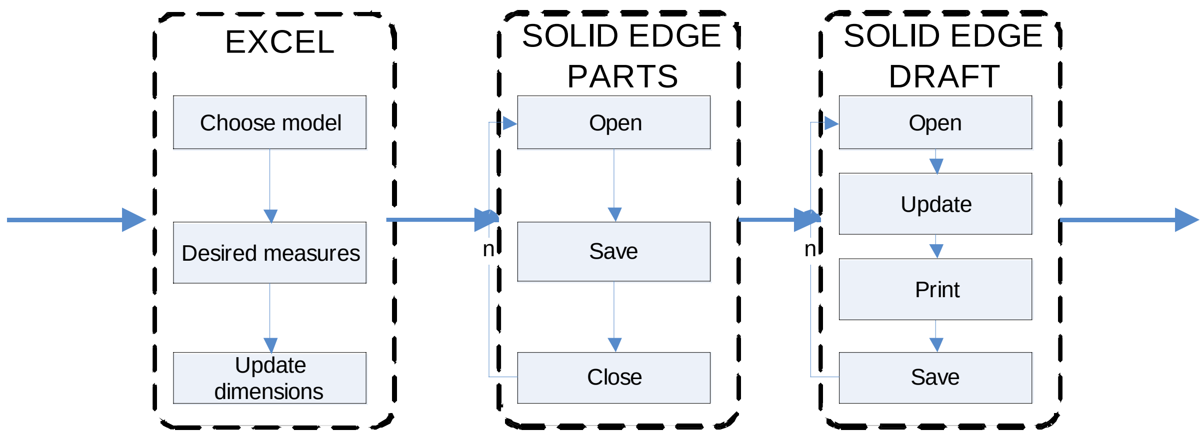

Fig. (6). General implementation architecture for flexible design of lockers.

to vision the product as a series of connected functions (or sub products) that work together. The process of defining these functions is known as functional decomposition and helps identify the critical functions that the product has to perform to translate them later on into features of the product. For the present research the required functions were identified as:

- (i) Interaction with the user
- (ii) Parametrization of locker design
- (iii) Customization of product
- (iv) Generation of technical drawings
- (v) Estimation of material cost

An effective solution (i.e. concept generation) should involve a series of interlinked components that will perform all the functions in a closed loop. Each of the critical functions previously identified should be translated into a component (or components) that will be further developed and refined, thus defining the product architecture (Fig. **6**).

(i) The implementation process should enable the user to input the desired requirements for the locker; hence a Graphic User Interphase (GUI) was developed. The GUI was programmed using Microsoft Excel with Visual Basic for Applications (VBA). It is important to mention that this program was already working in the company and their employees have been trained to manipulate it.

(ii) The parametrization of the locker is performed by means of a custom-made program that controls the measurements of all parts. The main output of these parametrization consists on a series of organized data that is used as inputs for generic models, as explained in a further section. As such, developing a generic solid model highlights as a critical requirement for the implementation a flexible design. This function provides the dimensions of all the locker parts described in section 3.

(iii) Customization of the product. Several authors have demonstrated the advantages of customization as a means for satisfying customer preferences [22]. Specifically, the flexible design illustrated in this application delivers significant benefits such as gained surplus from offering each potential customer her ideal product and reduced cost on raw materials inventory due to risk pooling under stochastic demand.

(iv) The information thus generated should be uploaded into the generic solid model of all parts, assembly and drawings. A medium level CAD software was selected because of its capability to be manipulated by the custom-made interphase program used in this project.

(v) Material cost estimation is directly calculated from the size and weight of materials, associated to unitary costs. The interphase program computes the volume of each single part and relates it to the bill of materials. The program also estimates scrap turnover.

4.2. Final Implementation

The graphic user interphase displays (see Fig. **7**), on a first set of windows, asks for the selection of the type of locker model to be designed (one to four doors) and then for

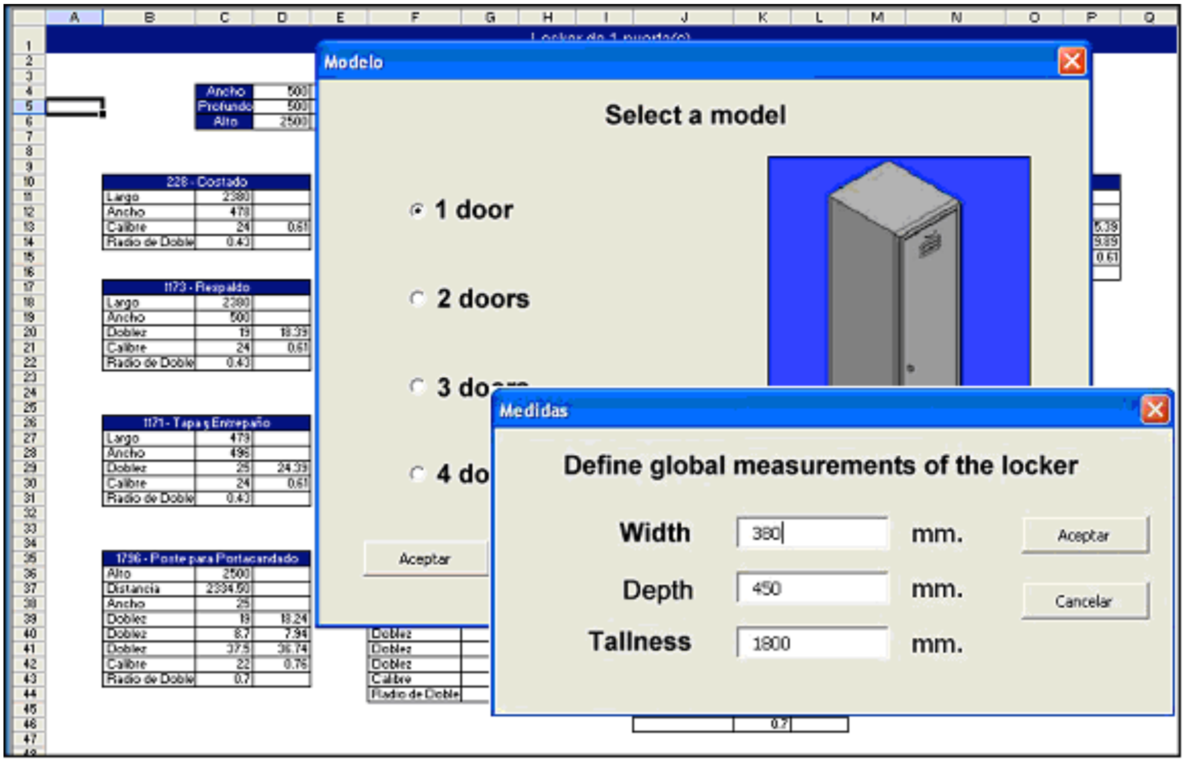

Fig. (7). Model menu and design specifications.

the global measurements of the lockers (i.e. the customer requirements). From this point, all parts dimensions are set, automatically, in different fields. As explained above, these fields are related to the design elements in the CAD software. Every time a dimension is changed in Excel, it will automatically be updated in the CAD software. Additionally, the program includes a function to change material thickness for each of the pieces of the locker (desirable to reduce material costs).

Moreover, the program performs a consistency test to ensure that global dimensions are between the lower and upper limits (see Table **2**). This range is determined by the locker configuration and process constraints (i.e. the global width is limited by the post width and by the vents, both dimensions are fixed)

Table 2. Upper and Lower Dimensions for Lockers

	Lower Limit	Upper Limit
	mm	mm
Width	200	1200
Depth	150	1200
Tallness	1350	2900

Once the global dimensions of the desired locker are changed in the spreadsheet, the CAD parts are recalled and all the dimensions change to the new customer requirements.

Finally, the user should call the draft module of the CAD program and open each piece. Updates of the draft are obtained by clicking one button and all the production drawings for the new locker are ready to be printed and start the manufacturing process using standard operations. Fig. (**8**) depicts the technical drawing change of a standard part to a custom modified one.

An advantage of working with an external spreadsheet is that the company only needs one generic piece for all the different versions.

The program also calculates the cost of the steel used in the locker. This is obtained by requiring the user to specify the price of one kilogram of steel and also the rescue value of it (price conditions change constantly with time, which explains why this function requires user interaction).

For each piece, it is determined which raw material sheet will be used and how many pieces can be made out of it. This decision is made in order to minimize scrap. The mass of the raw material sheet is divided by the number of pieces that can be obtained. The result is the amount of material, without scrap, that will be used for that piece. Then the mass of the piece is calculated. The price of the steel for each piece is obtained by multiplying the mass of the piece by the price per weight and to this value it is necessary to subtract the difference between the amount of raw material (without scrap) and the mass of the piece multiplied for the difference between the material price and the material rescue price. Finally all the pieces costs are added and the raw material cost is determined, as shown in Fig. (**9**).

CONCLUSIONS

This paper reports on the use of engineering design, computers and information technology in manufacturing. A

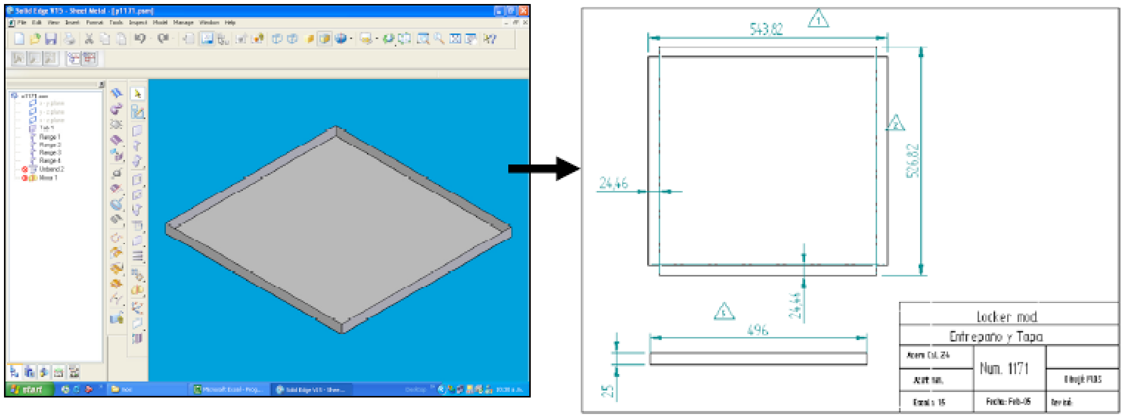

Fig. (8). Automatic generation of technical drawings.

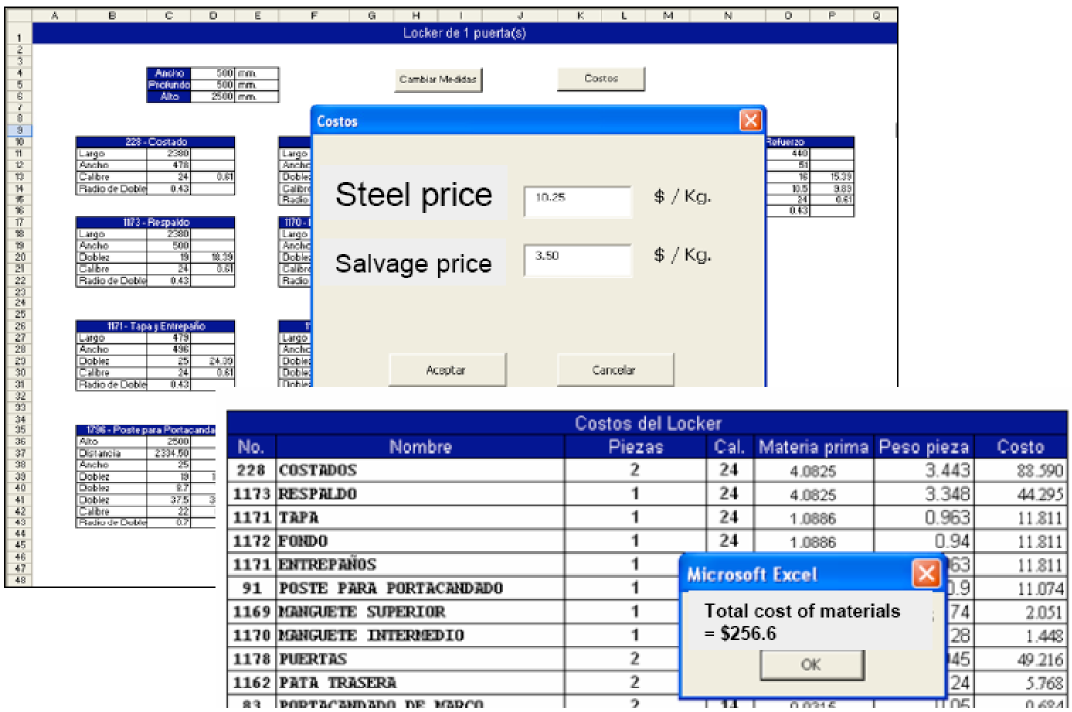

Fig. (9). Material cost computation and BOM.

case study was presented to illustrate the development and implementation of a design framework that is based on: parametric designs, in-house software, CAD/CAE and a database. Small and medium size enterprises can benefit from this framework even under budget restrictions. As a result of the implementation of this project, the company analysed in the cases study has a flexible family of lockers (see Fig. **1**). Once the parts are design in CAD, all changes in the measurements of the product can be modified through the spreadsheet without being an expert in computer aided design software.

Specific benefits in time were also achieved. Before the implementation of flexible design, the company used to take one or two days to calculate and re-engineer all the pieces drafts if the global dimensions are changed. With the methodology presented in this research it takes the company about 10 minutes to perform a re-design of a new set of lockers. The implementation represents a fraction of the time previously spent for the same activity, allowing a better response to the customer, effective cost planning and manufacturing activities.

The usage of existing resources has been extended by utilizing excel for the implementation. The selection of a middle level CAD software allowed for an increase on productivity for a relatively small investment of capital. The acquired promptness to answer to open contest requirements has been translated into more contracts to the company.

This development can be extended to other design projects. The presented methodology and implementation can be easily adapted to other product families (cabinets, desks, etc.), hence increasing the overall competitiveness of the company. This methodology can be applied to other SMEs requiring to include the advantages of flexible design into their product range. Engineering design and the use of computers represent the platform for this implementation.

Finally, the design standardization process presented in this paper restricts the amount of different designs that could be implemented but no necessarily leaves creativity out of the equation. The possibility to include different designs can be included in the process by adding modules to include different families of lockers with different attributes.

ACKNOWLEDGMENTS

Support provided by Asociación Mexicana de Cultura A.C. and Consejo Nacional de Ciencia y Tecnología (CONACyT) is highly appreciated.

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Received: October 14, 2008 Revised: April 16, 2009 Accepted: April 21, 2009