A SYSTEMATIZATION PROPOSAL FOR THE PRELIMINARY AND DETAILED DESIGN PHASES OF THE PRODUCT DEVELOPMENT PROCESS

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Abstract: *During the product development process, the design process encompasses a number of activities which, if well organized, help designers and development teams in their tasks. Along these lines, the main design process phases include activities such as a survey of clients' needs, the generation of product conceptions, the layout configuration or preliminary arrangements, and manufacturing detailing. The objective of systematized development is to obtain products of maximized quality, whilst minimizing costs, and time. This work aims at focalizing on the design process final phases, with the purpose of suggesting a systematization scheme for the preliminary and detailed design phases, involving methods and auxiliary tools. The proposed systematization consists of a breakdown of the phases into activities and tasks, which guide the designer or the design team in the execution of their work within an environment of integrated development (Simultaneous Engineering). These phases include the use of DFX methods (Design for X), tools and graphic software for dimensioning, modeling, simulations and management, and CAD/CAM/CAE systems in general. Some results of the application of this systematization are also shown in the development of a product.*

Keywords: *design methodology, systematic design, preliminary design, detailed design, product development.*

1. Introduction

The use of different methodologies in product development is being studied by a number of authors, and used by some companies in their development processes. What are usually different in these methodologies are the nomenclatures that are used. However, the information surrounding the process has the same content, and the results obtained bring about benefits which stimulate their use and research. This work focuses on the final phases of the design process, that is to say, the preliminary and detailed design phases, as shown in figure 1.

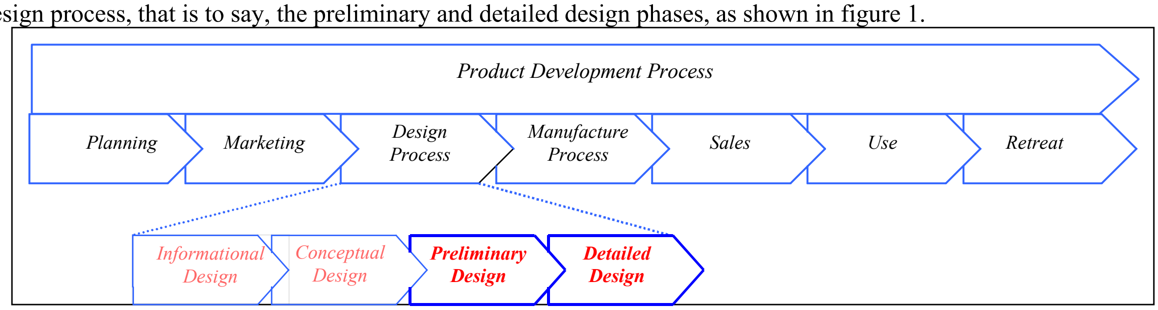

Figure 1 – The preliminary and detailed design phases, and the product development process.

This work follows the line of product research and integrated development with an emphasis on design methodologies, design support software, and other software that involve the agricultural context. The agricultural machinery sector, according to Romano *et al* (2001), utilizes an informal design process usually guided by the experience and practical knowledge of the engineers responsible for the design development, generating products that according to research done by Brazil (1984) *apud* Romano *et al* (2001), were either traditional models, or copies of products developed by third parties, incorporating some improvements in functional terms but without paying much attention to aesthetic, safety, manufacturing and assembly aspects, among others.

The intention of this work is to help product development, more specifically, the final phases of the design process. In the methodologies presented by different authors studied, such as Back (1983), Hubka V. (1987), Blanchard B. S., Fabrycky W. J. (1990), Ullman (1992), Pahl and Beitz (1996), Baxter (1998), and Maribondo (2000), the final phases of the design process in general are defined as: preliminary design, and detailed design. These phases are divided into prescribed steps, where each one has its own specific function within the design activity. According to these authors, the utilization of these methodologies is applicable to different industrial activities, and the design team would determine the emphasis on the application of the proposed steps.

A gap in the final phases of the design process was identified, principally with regard to their methodic ordering and sequencing, taking into account the techniques, methods, and tools available. This work will therefore present a systematization of the preliminary design and detailed design phases, as well as their application in the development of an agricultural implement.

1.1. The preliminary design

The preliminary design is divided into different activities, which in accordance with the nomenclature used, can include steps, tasks, stages and phases. However, the main objectives and activities involved are basically the same used in the different methodological approaches found in the literature. The preliminary design begins with information coming from previous phases, such as: the utilization of the structure of functions and the principle(s) of the solution(s) originating from the conceptual design phase, in other words, the conception of the product is necessary; management and control information; design requirements and specifications; and other pertinent documents. Summing up, one can say that the entry into this phase, is the concept of the product. According to Pahl & Beitz (1996) this phase is extremely important, as the design team group takes simultaneous decisions, and these have repercussions in other areas.

As previously shown, the authors studied first established divisions for the product parts. Thus, in accordance with the type of functionality and technology involved (mechanical, hydraulic, electric, etc.), the functions which must be performed by the product are divided into systems, subsystems or mechanisms of main or auxiliary use, components and parts. From then on, the product parts are developed in a differentiated way within the technologies involved in each division (systems, subsystems, etc.). This development can be done using computer tools for design such as software that include (CAD, CAM, CAE, CALS and CAPP)[1] according to Blanchard B. S., Fabrycky W. J. (1990), where models and simulations can be generated for different purposes. Additional activities can also be carried out, such as the selection of materials, dimensioning, and manufacturing processes control, among others.

As to model development, models can be iconic, analogic, mathematical, and symbolic, with the objective, according to Back (1983), of getting near to the real problem and obtaining a practical solution in a reasonable space of time. By using models one can obtain product performance data which helps in the decision making process.

Within the design process, one can further find different methods which help by supplying information and orientation regarding specific design questions. Hence, methods like design for X (DFX) are indicated for those purposes, and the authors studied sometimes mention the possible use of such methods in specific phases, apply or indicate which methods should be utilized with certain characteristics (manufacturing, environment, etc.) within their methodology.

1.2. The detailed design

The objective of the detailed design is to develop and finalize the design, so that drawings, documentation and dimensioning can be completed and then sent to be manufactured. Some authors at this stage already include the preparation and development of manufacturing procedures, but, since this is part of the design process, these activities can be carried out in parallel and by the sector responsible for the product's manufacture. Thus, in any way, the design team does its job to design the product having in mind the characteristics which involve its manufacture, as well as those which are pertinent and originate from other areas.

The detailed design is when the product obtains its validity as regards manufacturing procedures. Apart from the final dimensioning and optimization of components and parts, supply contracts, outsourcing arrangements and the respective quality certificates for services rendered are also drawn up, together with updates and records relating to development information and technical information from clients, as well as the record of lessons learned, the formalization of the operations manual, and product training, among others. To complete this phase, the resulting documentation is released for manufacture.

2. Development directives for systematization.

The objective of this item is to present some initial definitions for the development of systematization, taking into consideration work already done at NeDIP, such as Ferreira (1997), Fonseca (2000), Maribondo (2000), Mazetto (2000), and Bitencourt (2001), among others. Standardization can be seen with respect to the nomenclatures and activities involving the initial phases of the design process (informational design, and conceptual design). It is therefore proposed that the same approach be developed, utilizing their output information, and the form of representation already used in similar work.

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[1] Systems like: CAD (Computer-aided design), CAM (Computer-aided manufacturing), CAE (Computer-aided engineering), CALS (Computer- aided logistics), CAPP (Computer-aided process planning) Blanchard B. S., Fabrycky W. J. (1990).

The preliminary and detailed design phases are phases which deal with the development of product conception[2], taking into consideration information obtained from the conceptual design phase, complying with the specifications generated in the informational design phase. It should be stressed that these activities apart from having the support of the methodologies studied in the literature, also counted on the analysis and discussion of various specialists and researchers, who are involved in product development.

Hence, directives were established with a view to guiding the formulation of activities and tasks of these phases, on the condition that these would not restrict the possibilities for the creation and development on the part of the engineers and designers during the use of the systematization. The directives established to guide the development of the systematization involved: the presentation form of the final phases of the design process; the breakdown of final phases of the design process; methods, tools and support documents for the design process; mechanisms for the evaluation of the design process; and the form of presentation of the results of the design process.

3. Systematization proposal for the preliminary design phase

The breakdown of the Preliminary Design phase is made by means of activities and tasks, considering the methods, tools and auxiliary documents for development, as represented in figure 2. The preliminary configuration activity will be detailed in item 3.1, more specifically the task 3.5, which presents an application of the method Design for Assembly - DFA when this systematization is used in the development of a product.

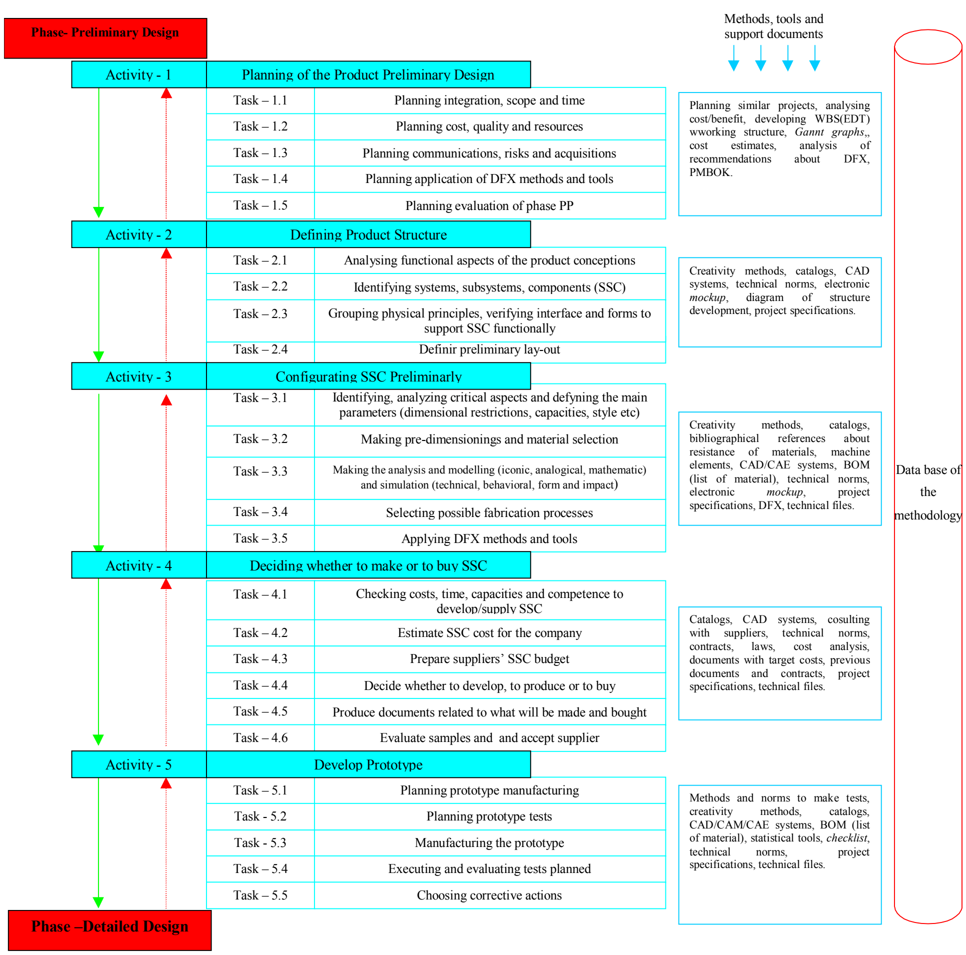

Figure 2 – A representation of the systematization proposed for the Preliminary Design.

Firstly we have the **planning activity,** which has as its object the performance of some basic procedures for the management and control of the preliminary design phase. Here, the purpose, tasks, and phase control are planned, and a

[2] Conception: "it is the idealized representation of a system or subsystem structure where the charateristics of the elements and the relations essential for its functioning are determined in a qualitative manner." Roozemburg, N.F.M, Eekels, J. (1995).

risk analysis of the development is made. Communication strategies between the team and others are defined, as well as the resources that the development of the preliminary design requires. Detailed information on these points can be found in PMBOK (2000).

This activity also considers the planning of the DFX application, which involves basically the research and usage definition of this tool, in accordance with the available resources, and its development and requirements as to its application. For BRALLA (1996), DFX are similar to a knowledge basis about research, with the objective of designing products that maximize all their characteristics, such as: high quality, dependability, services, safety, users, environment and market time – and at the same time minimizing the costs of the product life cycle and manufacture.

There is also a task responsible for the planning of the phase evaluation, in which the forms and metrics of control and evaluation of the design process development should be verified.

Another activity which is defined as, **to define the structure of the product**[3], has as its main objective to divide the product into parts based on the principle of solution adopted in its conception, and in accordance with the functions previously assigned in the conceptual design. In order that these functions can be complied with, a breakdown is made of the conception in systems, subsystems and components (SSC) of the product, attributing names to them, as the functions which involve the conception must be attended by certain, duly identified parts. Thus, it is possible to index physical principles for what was not defined in the conceptual design, having in mind responding to questions of product interface and forms, establishing the arrangement of these and a preliminary layout with main dimensions.

When the product presents modular characteristics, it is possible to define the product's structure within the modularization criteria for the breakdown into SSC, doing the latter activities in the same way.

In the activity denominated **to configure SSC preliminarily**, critical aspects of the product are identified and analyzed by means of a check list, in the form of items which should be observed during a product's lifetime, such as performance, manufacturing, assembly, use, discard, and others. A check list also analyzes and defines the main parameters of: style (colors, appearance, finish), forms, dimensions, capacities, and also analyzes and verifies the compliance with product specification for each SSC.

These parameters can assume quantitative values, and must not be confused with design requirements. They involve questions like: a certain necessary flow is compatible with the engine power available; what height adjustment options are necessary; the height adjustment influences the driving effort, etc. It should be stressed that in this activity the tasks should be done simultaneously, since some information serves as input for other tasks, such as the selection of materials, the pre-dimensioning, and the realization of modeling and SSC analysis using different representation languages, like: semantical (explicative verbal or textual representation); graphical (geometric elements to describe or represent objects); analytical (equations, rules or performance or behavior procedures; physical (representation by solid models, scale models, prototypes, etc.). Another important question in this activity is the identification of possible manufacturing processes of the SSC, predicting the need for teamwork and real interaction between members. This activity also includes the possibility of the application of DFX methods and tools, on the condition that certain issues such as which method will be applied, in which way it is available, what training is necessary etc. are previously planned for this design level.

An activity is also dedicated to decide on the **viability of developing, producing, or buying SSC for the product.** At this point, costs, time, capacities, and competence for the development or supply of SSC are surveyed. Development and production costs for the company must be estimated in the same way, bearing in mind potential negotiations which should guarantee an effective result for the next task, that of decision making. Hence, a decision should be made, based on the information at hand, about which situation is the most advantageous to develop and produce or buy SSC from third parties. The finalization of this activity occurs when the samples from the parts bought confirm that the quality specifications for the product have been met, approving the supplier and his responsibilities in order to guarantee the effective functioning of the product.

The **prototype development activity** can be initiated simultaneously with activities prior to the development of the design, depending on the purpose and possibility, with the management of this activity to be conducted at the discretion of the team or design manager. Here, the prototype is firstly planned and then manufactured, with the purpose of guaranteeing the necessary support with regard to the information and specifications of the parts for manufacturing purposes. In the same way, in the next task, the prototype tests are planned, defining type, duration, resources, implications with regard to the simplification of the manufacturing and the working processes (all parts are necessary to enable the performance test), the follow up and registers, aiming at conducting effective tests considering all the anticipated factors and parameters for the control and certification of performance.

After the planning, the prototype is built in accordance with the considerations made, with adequate follow up and support. When the initial planned tests are carried out, it is of utmost importance to register the results so that they can be evaluated and corrective measures be defined. During the tests there must be interaction with the original design, that is, modifications must be registered and checked as to the possibility of implications to the design. In the task denominated definition of corrective actions, a document or report containing these results is issued, as well as the necessary updates which will be used for the detailed design phase.

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[3] Product structure: Starting from the conception of the product, it is the organization of the functional elements of it in blocks, up to the understanding level of its principles and possible concrete presentation.

This completes the preliminary design phase, which is then followed by the next phase, that of the detailed design. This design will utilize the information and documents generated, such as drawings, with a certain degree of detail, an electronic mock-up, a developed prototype, and a list of corrective actions originating from the test results.

3.1. Application of DFX methods and tools

This application was carried out during the case study involving the systematization for the preliminary and detailed design phases. The product was a modular agricultural implement, containing information from previous work done for the informational and conceptual design phases, according to Mazetto (2000). In this application, DFA (Design for Assembly) software was used from *Boothroyd Dewhurst, Inc (BDI)* 8.0. version in activity 3 and task 3.5, following previous planning in activity 1 of the model in figure 2. The main objective was to simplify the agricultural implement design, in order to assemble its SSC.

The main dimensions are shown on the implement as illustrated in figure 3, where letter “a” indicates the part named supporting plate, which will be the object of the analysis.

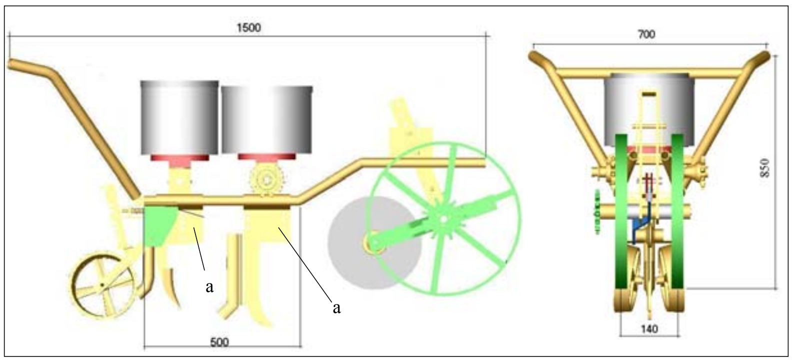

Figure 3 – Developed modular agricultural implement (sowing-fertilizing-machine, scarifier and plow).

In order to use the DFA software, the structure of the product was first added, and then the user was asked to examine each part by means of a series of questions about four areas: functionality, geometric form, manipulation difficulties, and insertion difficulties. During the addition of the implement’s parts, welding operations were also added, since some parts should be welded during assembly.

The representation of the results can be seen in figure 4, where a comparative graph has been generated showing the old design and the redesign. The main generated result refers to the assembly operations in general (*Assembly labor*), such as alignments, positioning, the welding itself, and other factors which generate the major part of the assembling costs, representing 122 MU[4] of a total of 147 MU. With regard to the reduction of costs of the actual design as against the old design, it should be mentioned that the previous cost of 147 MU was reduced to 133,81 MU thus saving 13,19 MU of the cost of the whole assembly system.

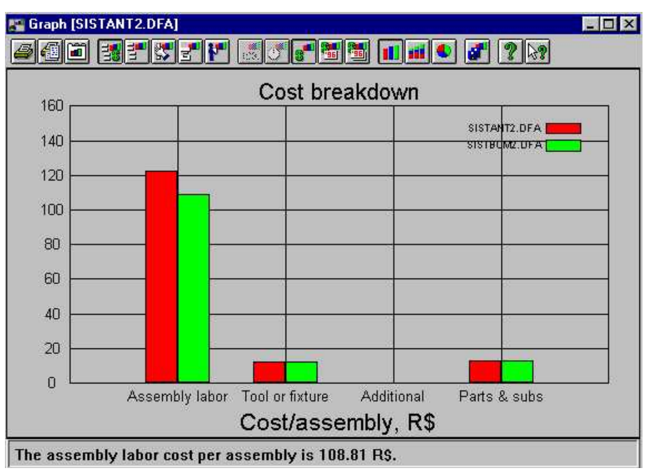

Figure 4 – Figure comparing the old design (red) with the redesign (green).

[4] MU: is the representation in monetary unit numbers.

We may conclude that there was a significant improvement on the design after using the DFA software, because we could observe some pertinent aspects in the assembly of each single piece. We could also see that some characteristics such as the use of response charts in the assembly, placement and welding made the design reach high time indices, which then reflected on its costs. This can be observed in Figure 5, in which these additional operations correspond to 69.92% of the assembly time.

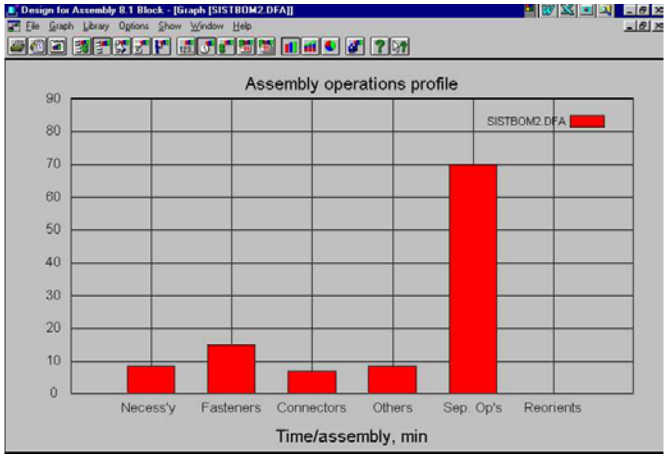

Figure 5 – Assembly time result for additional operations.

The main considerations pinpointed by the DFA software were related to additional operations that include the welding operations performed during the assembly process. Thus, team was stimulated to make significant improvements in some subsystems of the implement in order to reduce such operations. Figure 6 illustrates the process in which the supporting plate "c" started to be produced in one single piece that gained folds and eliminated piece "b", resulting in the piece format "e". Thus the manufacturing and assembly were simplified, facilitating the fastening of piece "e" to the chassis of the implement. This piece is used six times in the subsystems of the agricultural implement, therefore six pieces – in addition to the welding that used to be made to link pieces "b" and "c" on both sides – were eliminated with this simplification.

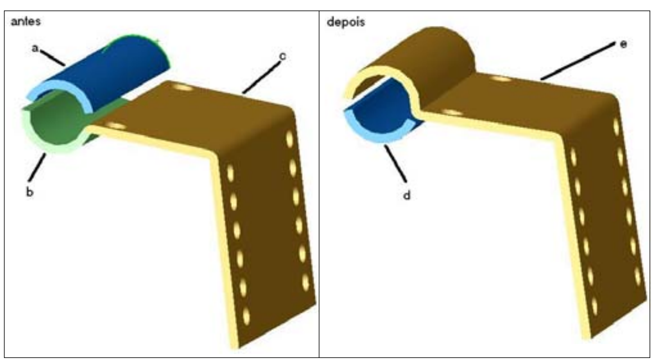

Figure 6 – Representative figure of the redesign, being: a: Counter plate; b: Tube interface plate; c: Old supporting plate; d: Counter plate; e: Redesigned supporting plate.

Apart from the simplification of the product structure, other significant improvements were obtained during the analysis, such as the reduction of nuts and bolts, etc., as shown in the comparison in table 1.

Table 1 – Main results of DFA application.

	Old design	New design	Reduction
Number of pieces	291	277	4.81%
Number of weldings	333	259	22%
Total assembly time (min)	122.43	108.81	11.13%

The systematization has helped with the application of this method, providing some input parameters such as: the product structure, assembly cost/hour, pieces that form the subsystems and their specifications, dimensional interfaces and lay-outs, among others, facilitating analysis. It can be observed that the systematization activities have outlined the main characteristics necessary for these phases of development, demonstrating that they are well-located, thus facilitating the application of this type of tool as well as the application of other tools and methods pertinent to these phases.

4. Systematization of the detailed design phase

The breakdown of the detailed design phase is also done in activities and tasks, using methods, tools and pertinent documents according to those shown in Figure 7.

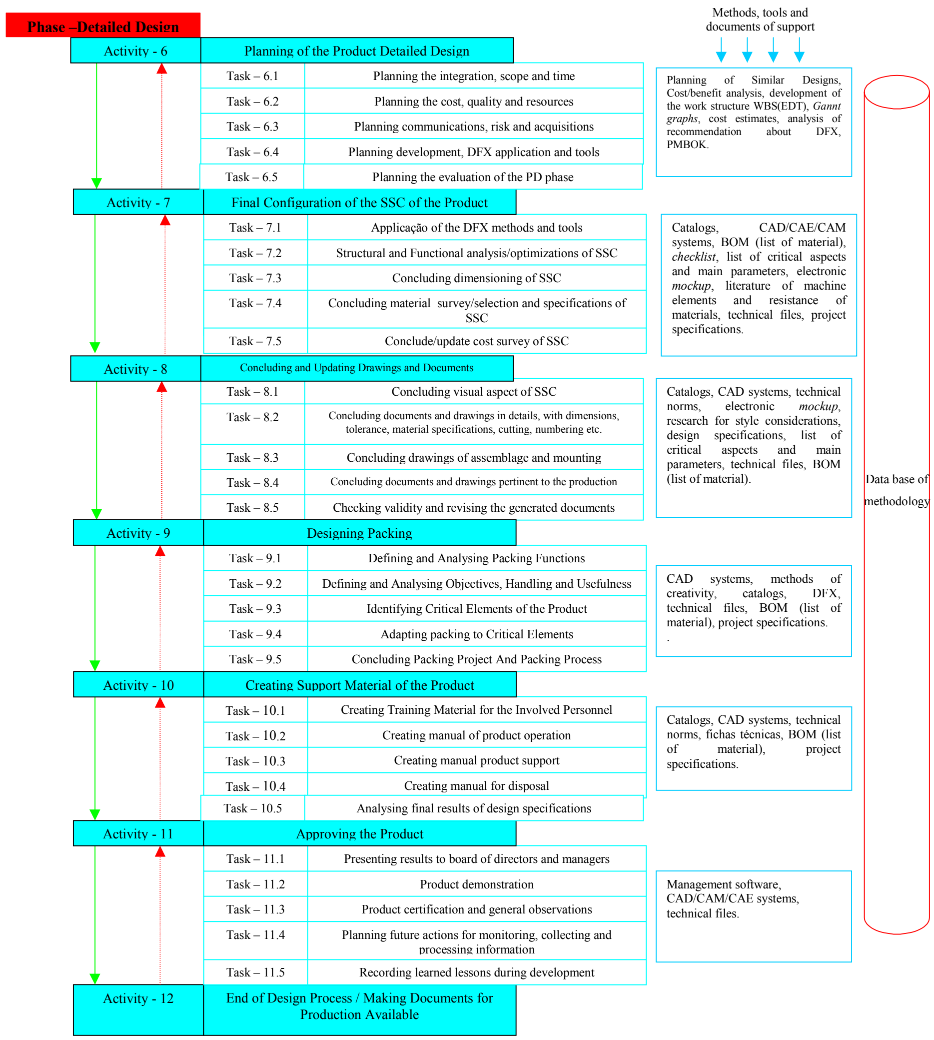

Figure 7 – Representation of the systematization proposed by the Detailed Design.

The beginning of this phase uses information coming from the preliminary design phase such as the documentation of dimensions, a survey and final specifications of materials and costs, a list of critical aspects and main parameters, modeling results and simulations, a list of design specifications, planning documents, technical product files, and other eventual documents which are pertinent to the development.

An introductory activity defined as **the detailed design planning** aims to perform some basic procedures for the management of this phase, which is similar to the planning of the detailed design phase. The majority of the information included in this planning can be established in advance, and such information can be updated and revised during this activity. The scope and the tasks that are necessary for the management of the phase are planned during this activity. An analysis of development risk is made, and communication strategies between the team and others are defined together with the resources that the development of the detailed design requires. Detailed information about these questions can be found in PMBOK (2000). The research and use of the DFX are also considered during this phase, taking into account the available resources and the needs for their application, development and knowledge.

Finally, there is a task which is responsible for the planning of the evaluation of the phase. In this task, the means of control and evaluation of the design process must be analyzed.

The activity defined as the **final configuration of the product** first involves the analysis of the possibility of applying DFX methods and tools, according to earlier planning in the previous activity. The task of analysis and/or structural and functional optimization of SSC aims at concluding configurations from the information obtained in the results of tests conducted with the prototype or SSC. Also some effort is applied to complete the dimensioning stage, the final survey or the material selection and specification of SSC, always using the technical files as information repository.

The **activity of completion of drawings and documents** aims mainly at completing documents and drawings which had been created up to that moment. In order to achieve this, the first task is to complete the visual aspects of the product, which involves the finishing of exposed parts, colors, cowlings, and other considerations and needs which are related to the product's appearance. Then, the documents and drawings are completed in detail, with specification of dimensions, tolerance, materials, numbering for system layout, materials and their characteristics, including the completion of drawings of SSC sets, as well as drawings involving assembly characteristics. Even though there are CAD systems which generate these design details, and list the materials etc, not taking these factors into account is not justifiable.

One task also aims to complete documents and drawings pertinent to manufacturing, which will subsequently be sent to this area. This task may seem redundant in this activity, but not every document generated in the design is sent for manufacture. Finally, because of the completion aspect of this activity, a task involving the verification and revision of documents and drawings must be conducted, given that these documents and drawings have details and specifications that need to provide complete information for future activities.

The following activity was established aiming **to design the product package**. Sometimes, this issue is not properly discussed in some methodologies or even in company designs. However, it assumes relevant importance when the fact that any product is transported, packed and negotiated in specific packages is taken into account. Therefore, according to Romano (1996), the analysis and definition of the objective of the package, regarding its functions, aim, handling, usefulness, critical elements, aspects of package classification, among other characteristics are considered in this activity. All of these tasks have the same characteristic of continuous development, as well as the creation of drawings, etc. while the activity is in progress. After this, we have access to the data necessary for completion of the package design and the packing process.

The **activity** called **creation of material for product support** is related to the creation of material for personnel training in the working place, transport, technical assistance and other potential activities that involve the learning process about the product. This phase involves the creation of a specific manual to operate the product. Such a manual should contain settings, adjustments, working limit capacity, special care to be taken, guiding information for product maintenance and, finally, an instruction manual for product disposal. This activity included a task for the final analysis of compliance with the design specifications. Such specifications followed all the development phase and, in this moment, quantitative compliance with each specification is investigated, because it is in this phase that all the activities regarding product development are completed.

The **product ratification** is an activity that basically consists of the presentation and final certification of the design process results for the people involved in the process. The first task is related to presentation of results based on costs, time, and other final specifications for managers and managing committee. After this, the product is presented, showing details and general characteristics in a physical model, and general observations are certified and documented. Finally, the planning of future actions involving the monitoring and the collection and processing of market information related to the product are taken into account, and a record is then made of the lessons learned during the development and which had not been stored until then.

One last activity is dedicated to the **completion of the design process,** which represents a landmark in **sending and making available documents created for the manufacturing area**. This activity is defined by Clark and Fujimoto (1991) as the confirmation of design completion, in which the manufacturing process will be certain that the prototype will be manufactured, will have produced the tools for manufacturing, will start the pilot run and then conduct the production startup.

5. Results and Discussion

Results of the application of the systematization in the development of agricultural implements were positive and contributed towards improving some aspects of the systematization. The aim of the application was to analyze in practice how the behavior and interaction between the activities of the systematization and the development needs would be, because the product (the agricultural implement) was in fact developed within stipulated time limits, manufacturing process needs, and mainly, following design specifications that represent the quantified market needs. In Table 2, a comparison is made between the methodologies studied and the systematization proposed, involving aspects that were considered important. The division established was: "yes", when in line with the characteristic; "unclear", when the characteristic is not clear regarding its understanding and content; "no", when the characteristic was not satisfactory.

Table 2 – Comparison of results between the methodologies of the preliminary design and detailed design phases.

Characteristics Evaluated	Pahl & Beitz	Back	Maribondo	Ullman	Baxter	Hubka	Blanchard Fabrycky	Systematic Proposed
Formal construction and language	yes	yes	yes	unclear	unclear	yes	unclear	yes
Managing information	unclear	unclear	unclear	unclear	unclear	unclear	unclear	yes
Levels of breakdown	yes	yes	yes	unclear	unclear	yes	unclear	yes
Flexibility for methods and tools	unclear	unclear	unclear	No	no	unclear	unclear	yes
Level of detail	yes	unclear	unclear	unclear	unclear	unclear	unclear	yes
Evaluation mechanisms	unclear	unclear	unclear	No	no	unclear	unclear	yes
Information of other processes	unclear	unclear	unclear	unclear	unclear	unclear	unclear	yes
Interaction and relationships	unclear	unclear	unclear	unclear	no	unclear	unclear	yes

The main objective of this comparison was to identify these characteristics in order to make it possible to improve the systematization that is proposed. Following this procedure, it is possible to highlight unique planning activities, focusing on activity management, the consideration and DFX localization of the phases, activity regarding the development of the prototype, activity regarding product packing, simple language and the possibility of developing simultaneous activities.

Therefore, main attention was addressed to maintaining interactivity and simultaneity of information coming from the other phases, as well as the interaction and coherence between the design process and the other processes involved with the product.

6. Concluding Remarks

During the proposal of this systematization, we came to the conclusion as to how important such a task is, in as much that it generates a lot of discussions exactly because of the fact that it formalizes and makes explicit the knowledge about the design activity. The modification of the content during the application of this systematization to different designs is understandable, and could even be due to the advent of new software which could help in some tasks. However, this modification needs to be handled in full awareness and be well based, in order not to bring about incorrect conclusions and also not to overlook the methodological process that has been studied and used in the planning and performance of the designs.

During the application of this systematization in the development of the agricultural implement, important results in the product itself were achieved. Such results showed that this systematization is perfectly applicable during the development of the preliminary and the detailed design phases. The agricultural implement developed is extremely competitive in the market, because of the improvements which were made to it, and also because of the customers' needs which were met, following the use of this systematization.

The final conclusion is that the objective was achieved with the use of this systematization, which made it possible to organize and make available information to enable the realization of the final phases of the design process. It also optimized the characteristics considered as being important in product development, using the methodologies studied as an example.

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