Proceedings of the IMProVe 2011
International conference on Innovative Methods in Product Design
June 15th – 17th, 2011, Venice, Italy

Adaptation and implementation of a process of innovation and design within a SME

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Article Information

Keywords:
Innovation
Design
SME
Functional bases

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Abstract

A design process is a sequence of design phases, starting with the design requirement and leading to a definition of one or several system architectures. For every design phase, various support tools and resolution methods are proposed in the literature. These tools are however very difficult to implement in an SME, which may often lack resources.
In this article we propose a complete design process for new manufacturing techniques, based on creativity and knowledge re-use in searching for technical solutions. Conscious of the difficulties of appropriation in SME, for every phase of our design process we propose resolution tools which are adapted to the context of a small firm. Design knowledge has been capitalized in a knowledge base. The knowledge structuring we propose is based on functional logic and the design process too is based on the functional decomposition of the system, and integrates the simplification of the system architecture, from the early phases of the process. For this purpose, aggregation phases and embodiment are proposed and guided by heuristics.

1 Introduction

A design process is a sequence of design activities which begins with the design requirement then leads on to define one or several system architectures [1]. For each design phase, the literature proposes various support tools and resolution methods [2]. After analysing these methods, we realised that, in the majority of cases, it was difficult for a small company, which is not specialised in designing manufacturing processes, to apply and exploit all these different support tools.

This work was carried out in an SME manufacturing footwear. The aim was to propose a process that could guide the company in designing new production processes. In this article we propose a sequential and iterative design process, based on creativity and the re-use of existing knowledge to search for solutions. Iteration and reuse are taken into account to meet the need to reduce deadlines and design and development costs. In general, this design process concerns mounting or assembly procedures.

Bearing in mind the difficulties of appropriation in an SME, for each phase of our process, we propose resolution tools that are specifically adapted to the context of a small company. The main phases in our design process are presented in the next paragraph. After this, we describe in more detail the second and sixth phases.

2 Design process

Figure 1 (Fig.1) shows a global view of the proposed design process. This is a detailed view of the block diagram presented in the article [3]. Our design process starts with an external functional analysis phase. Once the client's requirements are analysed, functional specifications can be drawn up and details of any specific requirements are provided with which we can define the Technical specifications for requirements.

The overall function of the production process is then decomposed into tasks then into sub-tasks or elementary functions. The aim is to have a sequential vision of the process to be designed. Different tools are available to the designer to assist in this phase. In fact, we first developed a graphic tool with which we were able to visualise the decomposition process, and reuse the functional decompositions of existing processes in our partner company [3]. We also propose a generic sequencing of mounting and assembly procedures, presented in paragraph 3.

To reduce the number of elementary functions and simplify the system architecture, we proposed a function aggregation phase, in which we were guided by two aggregation heuristics [3]. We used bases of verbs and complements to structure this phase and define the heuristics [4]. In fact, the choice of functions that can be aggregated depends on the verbs used to express the functions.

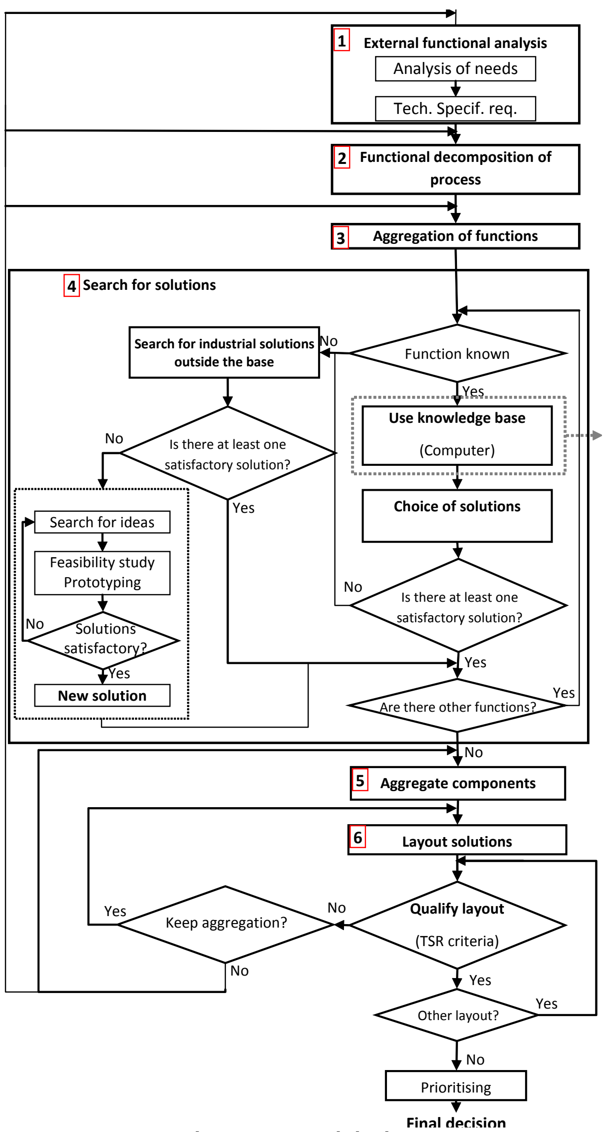

Fig. 1 Proposed design process

When all the functions are defined, the fourth phase of the design process is the search for technical solutions. First, we begin by consulting our knowledge base where all solutions that have previously been validated and approved in the partner company are stored [4]. If the knowledge base does not contain an appropriate solution (e.g. in the case of new functions), or if the solutions it offers do not conform to the specifications, then we carry out an external search for other industrial solutions. If the industrial solutions also prove unsatisfactory, the search for solutions is then based on a creative process guided by the MAL'IN (Méthode d'Aide à L'Innovation – *Method to assist innovation*) software [5]. These creativity sessions will be followed by a technical feasibility study phase and a prototyping phase for the concepts that are selected.

The fifth stage of the process is component aggregation. The purpose of this phase is to study links between components to reduce their numbers and thus facilitate the solution layout phase. Six component aggregation heuristics are defined for this phase [3].

Phase six of our process is the solution layout phase, which is also simplified using the layout heuristics described in paragraph 4.

The designed process is finally described as qualified if it meets the requirements set out in the specifications. If not, the designer then has two possible choices:

- Either keep the phase five aggregation and modify the layout.
- Or modify the aggregations made in the component aggregation phase, then look for a new layout. If none of the layouts prove to be qualified, the designer must then move back up the block diagram towards the function aggregation phase, the functional decomposition phase and if need be to the external functional analysis to make modifications.

Table 1 (Tab. 1) summarises the input/output in each phase of the design process, and the recommended methods.

Phases 3 to 5 have already been described in some detail [3]; here we will only look in detail at the phases that assist with functional decomposition and solution layout.

	Phase	Input	Output	Recommended methods
Design processes	External functional analysis	Client's requirements	Technical Specifications for Requirements (TSR)	APTE method
	Functional decomposition of process	Technical Specifications for Requirements (TSR)	Functions+ sequencing + transitions	1. Graphic tool, 2.Reuse decompositions of existing processes, 3. Generic sequencing of processes
	Aggregation of functions	Functions+ sequencing+ Transitions	Elementary functions and/or Aggregated functions	Aggregation heuristics 1 & 2
	Search for solutions	Elementary functions and/or Aggregated functions	Technical solutions	Knowledge base + external industrial solutions + creativity tools (MAL'IN)
	Aggregation of components	Technical solutions	Technical solutions and/or Aggregated solutions	Aggregation heuristics 3-7
	Solution layout	Technical solutions and/or aggregated Solutions	Architecture(s) of process	Layout heuristics 8-21
	Layout qualification	Architecture(s) of process	Layout(s) qualified	TSR criteria
	Prioritising/ Decision-making	Layout(s) qualified	Layout(s) prioritised/ Process selected	Project prioritisation file

Tab. 1 Deliverables associated with the recommended methods in the design process.

3 Phase 2: functional decomposition of production processes

We represent a production process as a succession of tasks. One task or sub-task represents a function carried out in the process. An elementary function is an elementary action that cannot be broken down further. It is expressed using a standard language in the form "verb - complement", where the verb and the complement are chosen from verbs and complement databases [4]. Each base is broken down into four classes, where each class corresponds to a semantic level that becomes more and more precise.

Functional decomposition is an important stage in the design of new processes [6-7] and has an impact on the subsequent definition of their architecture. It consists of breaking down the global function of the system, defined in the first phase, into major tasks then into elementary functions. This involves defining a logical sequence between these various tasks or functions, in order to present the process to be designed in its entirety.

To assist the designer in defining this functional decomposition and the sequence of functions, we propose three methods: visualisation using a graphic tool to represent the decomposition [3], reusing functional decompositions from existing processes and generic sequencing of mounting and assembly processes.

3.1 Logic of generic sequences

Our analysis of the processes involved in the production of slippers by our partner company produced the following observations:

- a slipper is made from pre-cut elements,
- these elements have to be assembled, hence they have to be removed from a stack or collected from a storage system,
- next, the elements have to be put in place and correctly positioned,
- then they undergo a specific action (gluing, folding),
- finally, the assembled elements are removed.

All these actions involve using verbs from the family "to shift", either when the different elements are taken to the assembly point, or to the final storage point or to undergo specific actions.

We also noted that when we carried out a functional decomposition of processes that already existed in the company, the verbs from the family "to shift" were used the most. In fact the rate at which these verbs were used in existing processes was 70% (percentage calculated from capitalised processes).

On the basis of these observations, we set up generic sequences of the mounting and assembly processes.

We started from a parent generic sequence constructed using the "to shift" family of verbs as a base. Next we suggested various child generic sequences, i.e. with a more precise description from the lower levels in the graphic representation of the tasks.

3.2 Parent generic sequences based on the verb family "to shift"

A specific action is one that is represented by a verb that is not a member of the "to shift" family. A mounting and assembly process is characterised by a specific action framed by "shift" type actions, as follows:

- Retrieve the element
- Place the element in position
- Specific action
- Remove the element

This sequence was deduced using the functional decomposition of existing processes in our partner company. This observation is corroborated by the fact that 70% of verbs used to analyse existing processes belong to the "shift" family. We can therefore define a parent generic sequence based on verbs from the "shift" family:

[Take or retrieve or unstack or ….] then [move or move forward or ….] then [position or centre or ….] then [specific action] then [take or move or remove or ….]

The choice of verb depends on the case in question. The verb base will help here as there are a great many verbs in the "shift" family, which in fact makes up 30% of the base.

3.3 Child generic sequences for placing in position

The choice of verb determines the sequential break down. On the other hand, we can propose generic sequences, especially for putting a part into position.

Placing something in position is a task that occurs frequently, in that an element moves from an initial position to a final position. Moreover, retrieval and removal also imply initial and final states.

Let us take an example where a part is placed on a plane surface. Figure 2 (Fig.2) poses this problem.

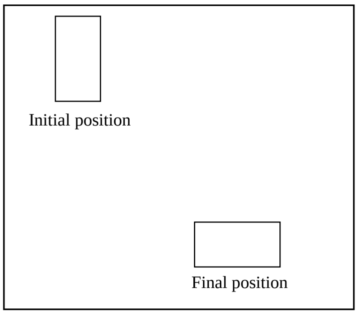

Fig. 2 Positioning a part on a plane surface

To move a part from one position to another (Fig.2), different plane trajectories are possible. For each trajectory there is a corresponding decomposition into elementary functions using verbs from the "shift" family. In other words, an example of a successive sequential vision (Fig.3):

[Shift] then [reverse] then [pivot]

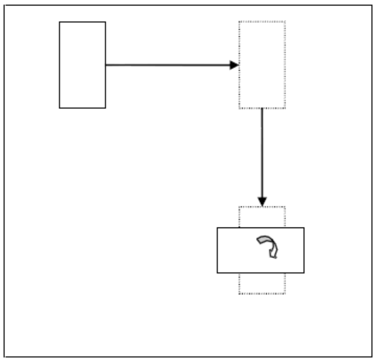

Fig. 3 Example of a possible plane surface trajectory

The advantage of these sequences lies in the fact that the associated solutions involve simple, standardised components such as jacks, conveyors and rotary jacks.

Successive tasks can also be carried out simultaneously, thus saving time, although this will sometimes impose choice of component. The generic sequence then becomes:

[[Shift] then [reverse]] and [pivot]

The alternatives to these plane (2D) displacement sequences are 3D trajectory sequences, in other words, the element will leave the plane in which the initial and final positions lie. These sequences will give volume infrastructures, conveyor systems and manipulating robots.

3.4 Child generic sequences for specific actions

Specific actions are those which are defined by verbs other than those from the "shift" family, in our case. Note that at the lower levels we will have structures equivalent to the parent generic sequence but relating to the tool or the system carrying out the action.

A specific action is carried out by a specific sub-action characterised by a verb of a different family from the "shift" family, it is framed by actions of the shift type, as follows:

- Retrieve the tool or the system
- Place the tool or the system in position
- Specific sub-action
- Remove the tool or the system

The generic sequence for the tool or the system is then written:

[Take or retrieve or unstack or ….] then [shift or move forward or ….] then [position or centre or ….] then [specific sub-action] then [take or shift or remove or ….]

If the tool is fixed in position, there is no need for a generic sequence, as the parent sequence already describes the process since it is the element (e.g. the sole) that moves.

3.5 Alternative child generic sequences

The preceding sequence (§ 3.4) shows that to carry out the specific action, there must be a relative positioning of the element and the tool. One then has to carry out, simultaneously, a relative displacement as well as carrying out the action. The alternative generic sequences will then be:

Case 1: the tool or the system is fixed
[Shift element] and [operate tool or system]

Case 2: the element is fixed
[Shift tool (or system)] and [operate tool or system]

Case 3: neither is fixed
[Shift element and tool (or system)] and [operate tool or system]

An example that often occurs in the processes used in our partner company, an illustration of the alternative child generic sequences, is that of putting adhesive on the soles. As Fig. 4 shows, the function "Spread adhesive" can be carried out either by moving the sole and keeping the adhesive nozzle in a fixed position (case 1), or by moving the adhesive nozzle while keeping the sole fixed (case 2).

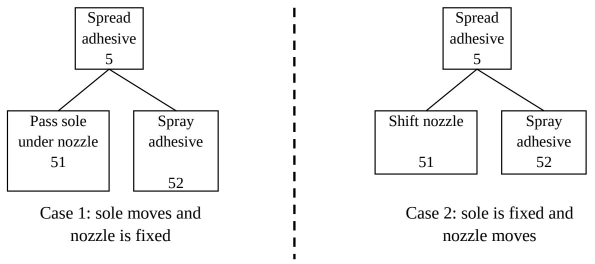

Fig. 4 Alternative child generic sequences for the "Spread adhesive" function

3.6 Use of generic sequences

Using the parent generic sequence it is possible to decompose the global function of the process and hence discern all the specific actions. These will be either known (they form part of the knowledge base) unknown, or to be reconsidered in the new process. This analysis is therefore carried out at a high systemic level. Unknown actions will be the subject of innovative design using the MAL'IN method.

Using the child sequences it is possible to go down the systemic levels towards elementary tasks or functions. This decomposition enables us to define the process correctly.

It must be remembered that the designer has the knowledge base at his disposal and that he can decide to use functional blocks, and multifunction components that are known and validated. These components can then replace an entire chain of tasks.

The choice of task or changes in choices will be made on the basis of criteria from the Technical Specifications for Requirements. Choices may be based on a requirement for:

- Reduced operating cycle time,
- Increased productivity,
- Ease of maintenance,
- Ease of control,
- Different costs involved in investment, ownership,…
- Time needed for a return on investment
- …..

4 Phase 6: Layout of technical solutions

The layout problem involves setting out a series of components while optimising the interactions between them. Layout problems have been studied many times in the literature. The complexity of these problems is due to the many variables that generate models and different resolution methods. In the case of the design of complex systems, we mainly find problems of three-dimensional layout. Many examples of three-dimensional layout have been dealt with in the literature, using specific methods [8-9-10]. There are therefore no standard methods that are valid for all layout problems. Moreover, the methods proposed are complex and are based on algorithms and calculation tools that are too unwieldy in the context of an SME.

For these reasons, we believe that for the SME partner it would be judicious to use layout heuristics in order to find one or several possible process architectures. To this end, we define a layout problem as being both a problem of positioning and linking. We are looking for relative positioning of technical solutions in relation to a reference and linking between them. We also take into account problems associated with the environment and man-machine interaction, as we are trying to identify the objectives or the constraints that will enable us to produce layout heuristics.

Figure 5 shows a model for a technical solution layout problem: the system is composed of n inter-linked components and a reference. The arrangement of the components one in relation to the other and in relation to the reference creates a positioning problem for which we propose placement heuristics which will help the designer solve it.

Some interaction heuristics are also proposed and are linked with interactions between the different components. Interactions also concern the external environment.

Man, i.e. the user in a particular external environment, and his interaction with the process, will require control over operational safety and the safety of the man/machine interface. The process environment will be affected by (or will affect) the way the process functions and this will impose sustainable development constraints. When man and the environment are taken into account during the layout phase, this will produce operational safety and sustainable development heuristics.

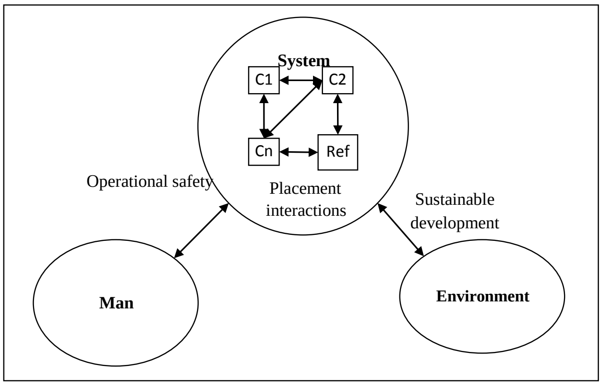

Fig. 5 Modelling a layout problem

4.1 Placement heuristics

A reference is a physical element in relation to which all components must be positioned. The components and the reference are functionally and geometrically linked together. Generally, constraints of non-overlapping, interactions between components and affiliation are imposed which define the placement constraints of the layout problem. We propose two heuristics linked with this type of problem.

Heuristic 1: The components must be positioned and linked to a reference directly or indirectly.

This heuristic is the point of departure of the layout phase. First, the reference machine is defined (stand, frame,…) which is the point of reference for the components. The components must all be linked either directly or indirectly to this reference. If the reference is a stand or a frame, the process that is carried out will have coherence and independence.

Heuristic 2: Encumbrance of the machine must be reduced by adopting architectures that evolve as follows: 1D→2D→3D→4D.

As the design of a machine evolves, it will move through all stages from 1D to 4D.

A sequential vision and traditional handling and shifting systems naturally follow an evolution in a single direction with successive positions moving in a single direction (1D).

Reducing the trajectory will impose rotational shifts and hence the positioning will be in a (2D) plane.

Controlling encumbrance is linked with shifts in space. The machine will integrate components enabling it to evolve in space, thus it becomes 3D.

Finally, the layout of the machine can evolve over time in accordance with significant moments or types of product to be manufactured, thus the architecture becomes 4D as it changes over time.

By applying heuristic 2, problems of compactness and adaptation can be solved.

4.2 Interaction heuristics

Interactions between components concern the passage of functional fluxes related to energy, matter and signals or information. The link with the reference is a specific interaction.

When interaction problems are analysed, then specific heuristics are required.

Heuristic 3: Energy loss must be reduced by grouping together components that use the same type of energy.

Controlling energy loss is linked with reducing energy paths. These will be reduced if components using the same energy are grouped together.

Heuristic 4: Interaction components must be standardised, reduced, or even eliminated completely.

Links can be made between the different components via interactions. These may be made directly (ideally) or via an interaction component. Interaction components transport energy between active components. For example, these may be cables in the case of a flux of electrical energy, pipes in the case of hydraulic energy flux, shafts in the case of a flux of mechanical energy.

The more standard the interaction components, the more easily available they will be (market, spare parts, stocks) and the more quickly and easily they can be replaced. In addition, these components represent a source of energy loss and this is why we try to reduce them and eliminate them as far as possible.

Heuristic 5: Choosing interaction components between components and between component/reference, based on an analysis of isostaticity or hyperstaticity of the whole.

All components must be linked to the chosen reference by interaction components or direct interactions. The designer must choose the interaction components while considering their degrees of freedom. The whole will be isostatic or hyperstatic.

Isostasy will ensure ease of assembly. A hyperstatic unit on the other hand will be more rigid.

Interactions will generate induced effects. For example, a hyperstatic assembly produces stresses and strains. It is therefore important to list the induced effects associated with the interactions and to analyse their impact on the whole and how the process is conducted. Table 2 (Tab.2) summarises the produced and induced effects in a sliding rail or sliding pivot, depending on which reference is used [11].

Produced effects	Induced effects
Strain	Play/Restraint/Stresses/Vibrations
Friction	Wear/Heat transfer/ Dilation/Retraction /Play /Restraint/Stresses /Warp

Tab. 2 Produced/induced effects associated with a sliding rail or pivot.

4.3 Operational safety heuristics

To ensure that the production process continues to operate correctly, the designer must take the safety of the operation into account throughout its life cycle.

We therefore propose heuristics linked with the system's operational safety. The system must be designed to ensure reliability (ensure continuity of operation), maintainability (must be repairable), availability (be ready for use) and safety (no catastrophic events).

Increasing the autonomy and flexibility of the system are also objectives to consider during the component layout phase.

Heuristic 6: Any encounters between man and danger must be avoided by keeping them separate, either physically or virtually.

Heuristics 6 concern security measures vis-à-vis the operator. Any dangerous phenomena must be eliminated or avoided as much as possible by adding physical or virtual separations and choosing suitable design characteristics. Exposing people to dangerous inevitable phenomena or to phenomena that cannot be sufficiently reduced must also be minimised. This can be achieved by reducing or eliminating the need for the operator to intervene in dangerous areas.

Heuristic 7: Actuators must be synchronised or indexed to increase the machine's reliability.

Synchronising actuators will reduce waiting times and the number of shutdowns between the different operations in the cycle and thus increase the machine's reliability.

Heuristic 8: Access to maintainable or interchangeable components should be easy.

To reduce machine maintenance time, it is essential to have easy access to maintainable or interchangeable components.

4.4 Sustainable development heuristics

The issues surrounding environmental challenge have recently provided yet another reason for scientific interest to focus on the problems of layout. The design of production processes must now take sustainable development into account by respecting norms and regulations.

The "Design for better eco-efficiency" guidelines, developed by the World Business Council for Sustainable Development (WBCSD) provide general directives for designers wanting to develop an environmental design procedure [12]. These guidelines set out seven eco-efficiency axes.

The heuristic that we propose is based on these eco-efficiency axes and applied to process design.

Heuristic 9: Analyse the procedure according to the eco-efficiency axes:

- Reduce material influence
- Increase energy efficiency
- Reduce risks of toxicity
- Increase recyclability and reuse
- Optimise resource use
- Increase life span
- Increase flexibility and functions

5 Conclusion

To meet the needs of an SME wanting to bring some innovation to their production processes, we have put forward a complete design and innovation process based on creativity and the reuse of existing resources when searching for technical solutions.

This process deals with mounting or assembly procedures, and we hope that it will become a useful design tool for the footwear production SME. For each phase of our process, we have set out resolution tools specifically adapted to the context and the resources of an SME.

The design process proposed here was used to design entirely new production processes in the partner company. These studies show the relevance of a global design process, and of the heuristics that we put forward. Knowledge reuse and tried and tested technical solutions have enabled us to reduce the time taken to search for solutions and have resulted in the validation of a new and innovative procedure.

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