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THE USE OF PRINCIPLES FROM AXIOMATIC DESIGN IN THE MANAGEMENT OF PROJECT DEVELOPMENT

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Abstract: *Project management for the development of a new product involves the completion of specific stages of the market launch activities of the respective product. The systemic analysis method was used to identify the input factors and the output parameters of the management of the product development. On the other hand, axiomatic design was promoted for a systematic and logical approach to various design problems of material systems or manufacturing technologies. The paper presents the results of attempts to use some principles from axiomatic design in the planning of various activities corresponding to the development of a new product. In this way, it was possible to identify functional requirements and usable design parameters in the context of establishing the product development stages of a new product.*
Key words: *management, project development, project stages, systemic analysis, axiomatic design, design matrix.*

1. INTRODUCTION

According to some brief definitions, the concept of management refers to the activity and art of leading or to the set of leading, organizing and managing activities of a certain structure. It is considered that the English concept "management" comes from the French noun "menage" [1], which originally referred to the organization and management of the activities of a human home.

The importance of management can be highlighted by the objectives pursued in carrying out activities such as planning, organizing, coordinating people, leading and controlling; such objectives are those of efficient materialization of activities, of fitting in the planned time and in the allocated budget.

Some categories of management are mentioned in the specialized literature, such as scientific management, operational management, human resources management, maintenance activities management, risk management, quality management, time management, communication management, financial management, acquisition management, etc.

A category of management frequently used in the last decades is that of *project management*, which means the use of specific knowledge, capabilities, tools and techniques available within the project's fundable activities.

In a document prepared for Romania's accession to the European Union, it was considered that project management aimed at planning, ordering and managing tasks and resources to achieve a certain objective, given the existence of constraints related to time, resources and costs [2].

A similar definition was also proposed by the Romanian standard SR ISO 10006: 2005, according to which the management of a project refers to the activities of planning, organizing, monitoring, controlling, reporting and developing corrective actions for all project processes and which is needed continuously to achieve project objectives [3].

The 2017 version of the ISO 10006 standard addresses the guidelines for the application of quality management in projects [4].

A way of approaching the different stages specific to the development of a product was exposed by the American company Switzer [5].

On the other hand, the last decades have consecrated the use of the concept of *axiomatic design*, this being considered an effective tool for planning activities in various fields or designing various categories of equipment. The concept of axiomatic design was originally promoted by South Korean American professor Nam Pyo Suh, being used to better solve the problems raised by the design of manufacturing processes [6-9] .

As its name suggests, axiomatic design is based on the use of two axioms, namely the axiom of the independence of functional requirements and the axiom that the selection of a certain alternative must correspond to the alternative that requires the least information.

From the first considerations regarding axiomatic design in 1978, it has now reached the use of axiomatic design principles in very diverse fields, such as industrial processes, sports, medical activities, etc.

It was therefore normal to approach project management development activities by using various design methods.

Thus, Ekmekci and Koksal considered the use of the TRIZ (Theory of Innovative Problem Solving) method to identify optimal solutions when the problem of developing an innovative product is addressed [10]. They also carried out an evaluation of the effectiveness of using the TRIZ method in relation to other methods that emphasize the stimulation of technical creativity.

In 2016, Gomez Lara published the results of his research activity in the form of a doctoral thesis in which he addressed the issue of developing an integrated design process and which involved the use of Building Information Modeling [11]. His considerations were formulated after developing an analysis in which he used the methodology of axiomatic design.

Weber et al. have appreciated that it is effective to use the first axiom from axiomatic design to improve the management of the development of a project [12]. They concluded that by combining different methods it becomes possible to identify a better design solution, but also agile coordination of the design team's work. It is worth noting that the authors concluded that their approach is a component of a holistic process of designing and developing products for so-called changeable production units.

Puik and Ceglarek found that there are some contradictions between the principles of axiomatic design and those of agile development methods usable for the promotion of a new product [13].

They appreciated that by relaxing the rules of agile design and those specific to axiomatic design in the first stage of design it is possible to effectively use a combination of the two methods.

Dolga considered that the evolution of a technology can be characterized with the help of a relationship of the form [14]:

$$y = \frac{p}{1 + a \cdot e^{-bt}}, \qquad (1)$$

where y is the performance of the technology, t – time, and a and b – coefficient and exponent that define the slope of the curve corresponding to the graphical representation of the mathematical relationship (1). He considered that in the development of a product, the involvement of society, of the population and nature must be taken into account.

In an organizational chart corresponding to the development of a product [Switzer], it is considered that the initiation of such a process implies an optimization of the design of the product, so that it meets the requirements of the customer, but also those of efficient manufacturing.

The importance of a continuous monitoring of the development process of a product was highlighted, to reach convenient results from the point of view of costs and product quality.

In this paper, it started from the premise of the possibility of identifying some connections between the various activities involved in the development of a project and, respectively, the solutions that can be thus used. The work will contain, as such, a presentation of some essential aspects specific to the theory of axiomatic design, following which, in a separate chapter, the problem of developing a project by using some principles from axiomatic design will be addressed.

2. SYSTEMATIC ANALYSIS OF THE PROJECT MANAGEMENT PROCESS

By *system*, in the sense assigned in this chapter, it means a set of independent material or theoretical entities and together making up an organized whole, which introduces order and establishes correlations in a field of theoretical thinking, which regulates the classification of entities or determines the performance of practical activities what contribute to the achievement of a certain objective [15-17].

Systemic analysis is a way of examining a process or an object/equipment through which the said process/object/equipment is given the characteristics of a system, i.e., of an entity that allows the existence of some input factors and some output parameters from that system.

It is useful for the approach to a problem that needs to be solved to be initiated by applying the systemic analysis method. This allows the formation of a global image focused on the structuring of some aspects of the problem that must be solved.

Therefore, the attributes of a system will also be given to the project development management process. As such, the following input factors were identified:

1. **The objectives considered to be achieved by materializing the project;**

3. The material, financial and personnel resources, among those existing and those that may still need to be obtained;

4. The duration in which it is necessary to carry out the planning of the project and, respectively, its materialization;

5. Risks that may occur during the planning and materialization of the project;

6. The existence from the beginning or the subsequent identification of different categories of constraints.

As output parameters from the project development management activity, the following could be considered:

1. Compliance with the proposed final deadlines for project planning and development;

2. Minimal risks of project failure;

3. A good feasibility of the project;

4. Rational and efficient succession of the stages of planning, execution and completion of the project;

5. Reliability and robustness of the project;

6. Resources (material, financial, personnel) efficiently used;

7. Successful completion of the project.

Of course, there is also the possibility that some factors may cause deviations from the intended results. It will be possible to take into account the actions of some disruptive factors, such as:

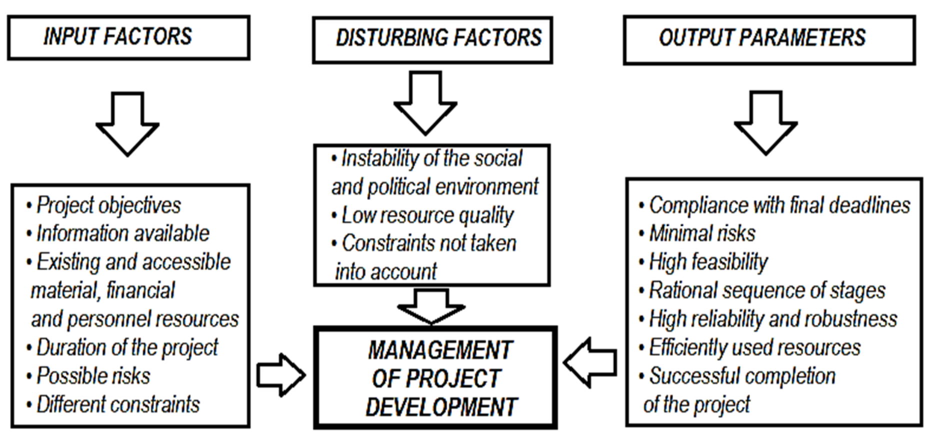

Fig. 1. Graphic representation of the results of the systemic analysis of the project development management process.

2. **Available information, additional information likely to be needed;**

1. The instability of the social and political environment;

2. Less adequate quality of resources;

3. Other constraints not taken into account initially, but whose effects would generate difficulties in the development of the project.

A graphical representation summarizing the previous considerations and resulting from the use of systemic analysis can be seen in Figure 1.

3. AXIOMATIC DESIGN

There are multiple possibilities for classifying design methods, whether they refer to the design of products or processes [14].

Such a classification may take into account the level of novelty embedded in the output of the design activity. There are thus:

- *Routine design*, when it is necessary to obtain a product or process in a very short time, without the possibility of carrying out extensive documentation. The designer is obliged to use only the knowledge at his disposal, allocating only a short time or no time at all for documentation, for identifying several solutions, for selecting one of the identified solutions, etc.

For example, routine design is prioritized when the damage of a part has led to the out of service of a critical part of equipment necessary for carrying out a process of great interest; in such a situation, one can simply resort to drawing up a technical drawing of the damaged part, so that the damaged part can be manufactured as soon as possible and the process interrupted due to the damaged part can be resumed.

It is obvious that the designer will not have enough time to identify an optimal usable solution for replacing the damaged part.

There is, however, even in the case of routine design, the possibility of identifying a superior solution to the one corresponding to the damaged part, by facilitating the participation of intuition in the design process, by using the creative capacity of the designer's thinking, etc.;

- *Creative design*, when the solution of the design problem is allocated a larger period of time, when the designer can carry out a documentation in the field of the design theme, when he can consider several alternatives for solving the design problem, when, through applying appropriate criteria, manages to detach the alternative that best corresponds to the objectives pursued, when it can even use methods capable of stimulating the designer's creativity, etc.

As already mentioned, creative design can take more time than routine design.

If we consider the principle way of working specific to a design activity and especially that specific to creative design, it can be found that it is dealing with:

- *methods based on the results of an analysis carried out from the upper to the lower level*, i.e., from the main objective of the design activity to the detailed aspects that correspond to the solutions used to fulfill each objective of the design. System analysis method, Ishikawa diagram method, design tree method, idea diagram method, morphological analysis method, finite element method, value analysis method, SWOT analysis, etc. can be mentioned here;

- *methods that take into account synthesis*, i.e., bringing together known elements, for the gradual identification of the solution that corresponds to the design theme. Methods or techniques could be included here such as the imposed decision technique [18], the reverse engineering method, the induction method, etc.;

- *hybrid methods*, which first resort to an analysis of the requirements that must be met by the project to be carried out, then solutions will be found to meet each requirement, and later, by bringing together the components capable of meeting each requirement, an appropriate final solution is reached the objective pursued.

Within all three groups of design methods, it is useful to first identify several alternatives for solving the design theme, so that, subsequently, the use of an optimal selection method allows the choose of the most suitable alternative.

Axiomatic design is part of the group of hybrid methods.

In principle, it starts from what the customer wants, and the so-called *customer needs* are defined in this way.

Next, by taking into account customer needs, an analysis of the design theme takes place, by formulating the various *functional requirements* that the final project will have to fulfill.

According to the first axiom of axiomatic design, functional requirements must be independent, that is, they must be designed in such a way that, as far as possible, they require distinct ways of fulfilling them.

It can define in this way the so-called *design parameters*, intended to provide information concerning the solution identified to meet each functional requirement.

For the zero-order functional requirement, the zero-order design parameter will have to be identified, i.e., effectively that solution capable of adequately meeting the customer's requirements.

There may possibly be multiple zero-order requirements, which will be affected by multiple zero-order design parameters.

If in a first step the zero-order functional requirement has been established, next, a process of separating the first-order functional requirements takes place and the first-order design parameters will have to be identified.

If to fulfill a functional requirement it is found that it is possible to use more than one design parameter, the question will be formulated to use a method that allows the selection and continuation of the design activity using only one design parameter.

The second axiom of axiomatic design becomes useful here, that is, the solution that requires the least information should be used. In fact, the solution that has the highest probability of success when that selected solution is used will be used here.

The importance of identifying several alternatives for solving a problem can be highlighted by mentioning the management principle according to which, when for a problem of strategic interest there seems to be only one solution, there is a high probability that that solution is not the better [19]. It is therefore necessary, at least for a problem of strategic interest, to first identify several alternatives to solve it and only later, by using an optimal selection method, to identify the most convenient solution.

It can be seen that the process of decomposition/detailing of the functional requirements makes necessary successive approaches between the functional requirements, on the one hand, and the design parameters, on the other hand. This successive shift between functional requirements and design parameters has been called *zigzagging*.

If the functional requirements will constitute a column matrix {FR} and the design parameters a column matrix {DP}, the correlation between the two matrices will be carried out by means of a so-called *design matrix* [A], according to a relationship of the form;

$$\{FR\}=[A]\ \{DP\}. \qquad (2)$$

The general form of the design matrix [A] can be as follows [7, 9]:

$$[A] = \begin{bmatrix} A_{11} & A_{12} & \dots & A_{1n} \\ A_{21} & A_{22} & \dots & A_{2n} \\ \dots & \dots & \dots & \dots \\ A_{n1} & A_{n2} & \dots & A_{nn} \end{bmatrix}, \qquad (3)$$

where n is the number of lines and columns in the case of a square matrix. There is, of course, the possibility that the matrix [A] is not a matrix with an equal number of lines and columns, and such a situation requires further detailed analysis.

It is considered that the number of components of a line corresponds to the number of design parameters identified for the final solution, while the number of horizontal lines of the matrix is equal to the number of functional requirements of a certain order.

It was agreed that along each horizontal line in the design matrix, the number zero should be written when there is no correlation between the functional requirement and a certain design parameter, and respectively the symbol (letter) X when there is such a correlation.

A design matrix in which the X symbols are located exclusively along the descending diagonal of the matrix (the case of the so-called *diagonal matrix*) is considered *an uncoupled matrix* and is judged to correspond to an optimal solution of the design problem.

If the design matrix includes X symbols located along the descending diagonal and above or below the ascending diagonal, respectively, a *triangular* or *decoupled matrix* is considered to exist and an acceptable design solution is present. This solution could however be improved when it can be transformed into an uncoupled (diagonal) matrix.

There are of course also design matrices where the *X* symbols are placed both along the descending diagonal and above and below this diagonal.

The matrix in question is *considered a coupled matrix* and it could make it necessary to carry out some interventions to be brought to one of the two previously mentioned matrix categories (uncoupled matrix and decoupled matrix, respectively).

The main possible stages of using axiomatic design are as follows:

a) Establishing the design theme;

b) Defining the client's *CN* needs;

c) Identification of *FR* functional requirements and, by zigzagging, *DP* design parameters;

d) Identification of process variables;

e) Outline a solution that corresponds, as far as possible, to the two axioms of axiomatic design;

f) Detailed approach to the actual design aspects, with the use of dimensioning or verification calculations, etc.

4. USING SOME PRINCIPLES FROM AXIOMATIC DESIGN IN PROJECT DEVELOPMENT MANAGEMENT

Pursuing the use of axiomatic design principles in the case of product development management, it will be necessary to identify the various activities/stages that must be completed in this regard.

It is thus considered that the customer is the person who wants to make a certain product, which is characterized by certain novelty elements and which can be transferred to the commercial area.

According to the principles of axiomatic design, the customer's need could be formulated in the following way:

CN: To develop a project development management plan for the realization of a certain innovative product.

Such a customer need could lead to the formulation of the *zero-order functional requirement*:

*FR*0: Ensure conditions to generate the development management plan for the designated product development project.

The zero-order design parameter *DP*0 could be expressed in this case in the following way:

DP0: Developed project development management plan.

The main stages that should materialize for the development of a project are the following [20]:

- Project initiation;
- Project planning;
- Project execution;
- Completion of the project.

Each of the stages of project development can be put in the form of a first-order *FR* functional requirement:

*FR*1: Ensure project initiation;

*FR*2: Plan project development;

*FR*3: Execute the project;

*FR*4: Complete the project.

The aforementioned functional requirements may be associated with first-order design parameters *DPs*, which could take the form:

*DP*1: Project initiation documentation developed;

*DP*2: Development plan of the established project;

*DP*3: Project executed;

*DP*4: Documentation confirming the completion of the project.

Considering the established functional requirements and the proposed design parameters, it is possible to draw up the design matrix in the form of a table (Table 1).

Only the functional requirements and the respective first-order and zero-order design parameters have been entered in this table, but a more complete table could also include the functional requirements and the respective design parameters of higher order than the first order.

The correlations between the functional requirements and the first-order design parameters were highlighted by writing the symbol "*X*" in the corresponding places in the table.

The analysis of the distribution of these "*X*" symbols highlights the fact that they are located along the descending diagonal and respectively below this diagonal.

Such a distribution corresponds to a decoupled matrix, which would allow the characterization of the identified solution as an acceptable solution from the point of view of the first axiom of the axiomatic design.

It is possible that, when it is necessary to select a certain design parameter from among several alternatives for solving the same functional requirement, resort to the use of appropriate selection criteria.

It is necessary to mention that there are still other methods of optimal selection of an alternative when several such alternatives are available to solve the technical problem addressed [9].

Thus, in the case of the so-called *decisions with preferential individual applicability*, a classification of the optimal selection methods can be carried out by taking into account the level of the certainty conditions. There are thus:

- *Methods that will be adopted under conditions of certainty*, such as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), ELECTRE (in French, ELimination Et Choix Traduisent la REalité), WSM (weighted product model), AHP (analytic hierarchy process), ANP (analytic network process), GRA (grey relational analysis), VA (value analysis), PAPRIKA (potentially all pairwise rankings of all alternatives), etc.;
- *Methods applied in risk conditions* (expected value method, decision tree method, etc.);
- *Methods usable under conditions of uncertainty* (the optimistic method, the pessimistic method, the tempered optimism method, the equal probability method, the regret minimization method, etc.).

As stated previously, in axiomatic design, it may be necessary, at a given moment, to choose a design parameter among several such design parameters available and which could contribute to the fulfillment of the same functional requirement.

The problem of optimal selection of an alternative could also come into play when, for

Table 1

Matrix comprising functional requirements FR and design parameters DP
from the case of a device for polishing by using rotating brushes with abrasive paddles.

Line no. 1	Design parameters		Design parameters *DP*			
2			Zero-order design parameter *DP0*			
3			Development management plan of the elaborated project			
4			First-order *DP* design parameters			
5	Functional requirements		*DP*1: Drafted project initiation documentation	*DP*2: Project development plan established	*DP*3.: Project completed	*DP4:* Documentation confirming the completion of the project
6 Column no. 1	2	3	5	6	7	8
7	The zero-order functional requirement	1st order functional requirements FR	Highlighting the *DP* design parameters corresponding to each functional requirement *FR*			
8	*FR*0: Develop the development management plan for the assigned product development project	*FR*1: Ensure project initiation	X			
9		*FR*2: Plan project development		X		
10		*F*R3: Run the project	X	X	X	
11		*FR*4: Complete the project			X	X

.

example, two sufficiently different types of equipment have effectively arrived at that would satisfy the zero-order functional requirement.

In such situations, it is recommended to consider using the second axiom from the axiomatic design, namely *the information axiom.*

According to this axiom, among several solution alternatives, it is necessary *to prefer the one that requires the least information*. In practice, applying the second axiom is aimed at selecting the alternative for which there is the highest probability that its application will fulfill the customer's requirements.

For example, in the development management of a project, there may be a first-order functional requirement that needs documentation in the area of the topic addressed. To this functional requirement could be associated, as design parameters (ways to solve the documentation problem):

a) consulting scientific books and journals in a certain library;

b) consultation of documents available on the web;

c) a hybrid method, based both on the consultation of written documents in libraries and on the consultation of documents accessible on the web.

When an operative consultation is required, documentation by accessing the information available on the web will be preferred. In this way, for the organization of the documentation activity, documentation is characterized by the use of a smaller volume of information which will better correspond to the requirement expressed by the second axiom of the axiomatic design.

Each stage of project management development can be further divided into sub-stages. For example, the initiation step could include the following substages:

- Clarification of the design theme;
- Collection of information;
- Needs analysis;
- Stakeholder analysis;
- Consultation of interested factors;
- Carrying out some preparatory activities;
- Drafting the project proposal.

As divisions (sub-stages) of the project planning stage, the functional requirements *DPs* corresponding to the respective stages could be considered:

*FR*3.1: Clarify objectives pursued by the project;

FR3.2: Identify available resources (material, financial, personnel resources);

*FR*3.3: Identify the strengths and weaknesses of the project using a SWOT analysis;

FR3.4: Identify project stages and sub-stages;

*FR*3.5: Identify the durations of the different stages and sub-stages of the project;

FR3.6: Develop a Gantt chart and make corrections based on Gantt chart analysis;

FR3.7: Identify different risks and measures to mitigate them.

Appropriate design parameters should be established for each of the aforementioned functional requirements. Such design parameters could be the following:

*DP*3.1: Established objectives;

DP3.2: Identified resources;

*DP*3.3: Strengths and weaknesses identified;

DP3.4: Stages and sub-stages of the project established;

*DP*3.5: Set durations of project stages and sub-stages;

*DP*3.6: Developed and corrected Gantt chart;

DP3.7: Risks and mitigation measures identified.

$$\begin{Bmatrix} FR3.1 \\ FR3.2 \\ FR3.3 \\ FR3.4 \\ FR3.5 \\ FR3.6 \\ FR3.7 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 & 0 & 0 \\ X & 0 & 0 & X & 0 & 0 & 0 \\ X & 0 & 0 & X & X & 0 & 0 \\ 0 & 0 & 0 & X & X & X & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & X \end{bmatrix} \cdot \begin{Bmatrix} DP3.1 \\ DP3.2 \\ DP3.3 \\ DP3.4 \\ DP3.5 \\ DP3.6 \\ DP3.7 \end{Bmatrix} \quad (3)$$

To highlight the correlations between the functional requirements and the second-order design parameters, an equation similar to equation (1) can reach the matrix equation (3). Examining this matrix equation allows one to observe that there is a decoupled design in this case, which means an acceptable solution for the analyzed situation.

It is necessary to highlight the fact that apart from the functional requirements that define a so-called *functional domain*, it is also necessary to take into account the various constraints related to the time interval in which the project is estimated to be developed, to the necessary personnel, to the existing financial resources and possibly those that will have to be attracted, to the spaces and equipment necessary for the good development of the project, etc.

5. CONCLUSIONS

The project management concept refers to activities aimed at planning, organizing, monitoring, controlling, reporting and developing corrective actions for all project processes and whose application is necessary to achieve the project's objectives.

The problem addressed in this paper was that of detailing certain aspects of project development management by means of modern analysis and design tools, such as the systemic analysis method and the axiomatic design theory.

A revelation of the various aspects related to project management in general was possible by using the systemic analysis method. On the other hand, the principles of axiomatic design revealed the possibilities of their use to approach the management of project development through the axiomatic theory.

The possible needs of the client were thus identified, in relation to which the functional requirements were formulated and subsequently the design parameters were identified, starting from the way of applying the axiomatic design in a certain practical situation. It is expected to apply in the future the methods addressed only at the level of principle in this paper for the management of the development of a project with direct practical applicability.

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UTILIZAREA PRINCIPIILOR DIN PROIECTAREA AXIOMATICĂ ÎN MANAGEMENTUL DEZVOLTĂRII PROIECTELOR

Rezumat: Managementul de proiect pentru dezvoltarea unui produs nou presupune parcurgerea unor etape specifice ale activitatilor de lansare pe piata al produsului respectiv. Metoda analizei sistemice a fost utilizata pentru identificarea factorilor de intrare si a parametrilor de iesire specifici managementului dezvoltarii unui produs. Pe de altă parte, proiectarea axiomatică a fost concepută pentru o abordare sistematică și logică a diferitelor probleme de proiectare a sistemelor de materiale sau a tehnologiilor de fabricație. În lucrare sunt prezentate rezultatele încercărilor de utilizare a unor principii din proiectarea axiomatică în planificarea diferitelor activități corespunzătoare dezvoltării unui nou produs. În acest fel, a fost posibilă identificarea cerințelor funcționale și a parametrilor de proiectare utilizabili în contextul stabilirii etapelor de proiectare a unui nou produs.

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