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STUDY OF COMMUNICATION ISSUES IN THE DESIGN PROCESS OF AN INDUSTRIAL PRODUCT

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Abstract. This paper describes an experiment conducted to observe iterations within a design process. The main purpose of this research is to investigate iterations during the design process through a laboratory experiment, aiming to comprehend their occurrence and underlying reasons. Various manifestations of iterations observed in practice are identified. This study intends to aid in categorizing iterations to differentiate between beneficial and undesirable ones. The findings from this study could potentially enhance practices within the field of engineering design.

Keywords: Design process, Communication issues, Design iterations

INTRODUCTION

In this paper, a laboratory experiment was undertaken to observe the iterative nature of the design process. Iteration is an omnipresent element of the design process. The scale, novelty, and interconnectedness of a project directly influence the importance of iteration [1, 2]. Iteration can be characterized as the repetition of design tasks triggered by the emergence or identification of new information or errors [3].

For industries, engineering design serves as a source of competitive advantage. One critical factor for corporate success is the reduction of product development lead time. For product developers, understanding iterations is essential for effectively managing the design process.

However, the design process is complex and dynamic. To grasp its intricacies, experts have employed a variety of methods and models. While these models complement each other, their approaches vary depending on context, expert perspectives, and scope. Unfortunately, many models are developed based on intuition and practical experience.

The experiment presented in the present paper aims to observe and comprehend the production of iterations, their effects, and the methods used to anticipate them. The paper is structured as follows: a literature review of design process models incorporating the iteration aspect of engineering design; the research methodology employed in this study and the experimental setup; the experimental data, observations, and their analysis; a summary of our findings and suggestions for future research.

LITERATURE REVIEW

Modelling is a key approach to understanding and influencing the design process. It allows for a deeper comprehension of both the functional and behavioural aspects of design, facilitating the definition, testing, and improvement of strategies for design execution. The literature offers a diverse

typology of models, categorized into prescriptive and descriptive families, with prescriptive models being particularly relevant to the study of iterations.
Smith and Eppinger [3], [4] propose a model for sequential processes with iterative components, aimed at minimizing design process duration by establishing an initial activity sequence. However, this model relies on certain assumptions about activity durations and probabilities.
Krishnan's [5] model addresses the management of concurrent design activities, focusing on optimizing overlap to prevent premature design decisions and subsequent iterations. Despite its effectiveness, this model is limited to handling only two overlapping activities and lacks consideration of feedback from downstream to upstream activities.
Yassine [6] presents a mathematical model for managing design activities, accommodating various configurations including sequential, parallel, or partially overlapping tasks. This model incorporates random variables to calculate iteration durations and quantities.
Numerous research papers have examined iterations in the design process, with Osborne highlighting their significant impact on development timelines, particularly in semiconductor design. Pahl and Beitz [7] describe the design process as iterative, resembling mathematical methods for solving equations, where iterations refine design solutions within and between phases, particularly in interdependent design activities where parameters influence one another, necessitating an iterative approach for effective computation.

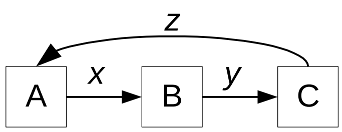

Figure 1. A design iteration

DSM (Design Structure Matrix) is a method for modelling and managing activities in the design process. It is used to describe the input/output relationships between design process activities, showing the structure of information flow in a project composed of multiple activities.
The DSM method relies on a matrix representation to describe the sequence of activities in a project and the relationships between them. The use of matrix representation for system modelling is not new. In fact, the DSM method was introduced around 1981 by Steward [8] as a method for managing the design of complex systems. Initially, this method was used only to represent the precedence relationships between activities. Subsequently, it was adopted by many authors who enriched it by adding measures of the degree of dependence between activities as well as measures of the durations and costs of these activities.
In summary, literature highlights the importance of an iteration, indicating that it is crucial for solving complex problems, adapting to changing contexts, potentially minimized through emphasis on central information nodes, and significantly impacted by slight variations in task time when it is carried out.

	A	B	C
A			1
B	1		
C		1	

Figure 2. A DSM representation of the design iteration from figure 1

DESIGN EXPERIMENT

The process of design is inherently social. Using experiments to observe designer interactions and the progression of processes is invaluable in comprehending the multifaceted aspects of design. Observations play a crucial role in depicting the complex human behaviours inherent in engineering design.
Design activities can occur in various contexts: undertaken by an individual designer, a design team, or multiple teams. Design team members may work synchronously or asynchronously and may be geographically dispersed [9].
The primary aim of observations is to delve into cognition, creativity, and innovation within the design process. Examining the work of design teams provides insights into the design process within an organizational framework.

Our study focuses on observing iterations within a design activity carried out by a multidisciplinary team. Observational techniques were employed to document the design process, with these records serving as the basis for various analyses of participant activities.
The experiment outlined in this paper took place in the Product Design and Development Laboratory within the National University of Science and Technology POLITEHNICA Bucharest, Pitesti University Center. The objective of the experiment was to redesign a robotic arm that will be used on an assembly line in industry. This redesigned product required adaptability to diverse conditions and the ability to operate in environments with numerous human operators and equipment.
The participants in the analysed experiment worked in a multidisciplinary team coordinated by a leader. They were selected as follows: two industrial engineering specialists, two robot programmers, two rapid prototyping specialists, one logistician, one ergonomics specialist, and one economist. Occasionally, foreign students on Erasmus mobility were also included in the team to provide an external contribution, allowing problems to be viewed from both technical and cultural perspectives.

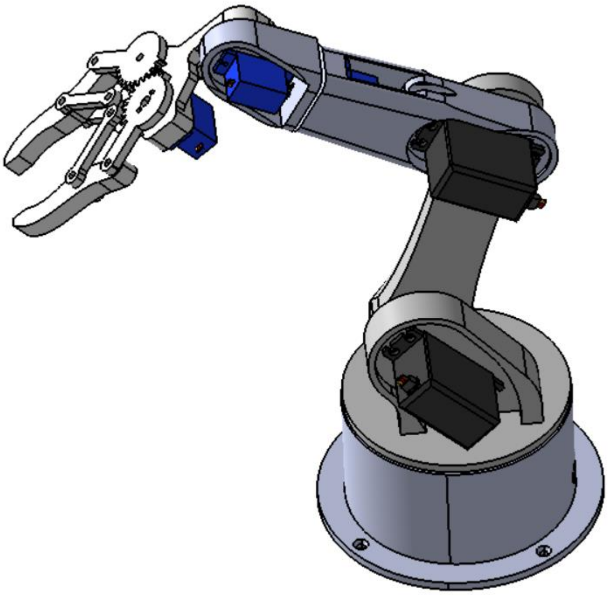

Figure. 3. The product - a robotic arm

OBSERVATIONS AND RESULTS

The design tasks conducted by the designers were initially determined, and subsequently, all iterations were identified based on the connections between these tasks, using the DSM method, as depicted in Figure 4.
Information exchange between tasks (figure 5) is denoted in the off-diagonal elements of the matrix. Two primary types of information flow are recognized: feed forward (found in the lower diagonal elements) and iterations (present in the upper diagonal elements). This representation facilitates the capture of cyclic information flows and enables the identification of iteration requirements.
After analysing the DSM matrix, three primary sources of iterations were identified:
The change of objectives: Throughout the design process, initial data or proposed solutions may undergo changes for various reasons, necessitating the repetition of certain design tasks.
Task interdependence: Certain tasks within the design process are interdependent, requiring multiple iterations to reach a satisfactory solution. The overall duration of the design process often hinges on the initial scheduling of these interrelated tasks.
Design errors or misunderstandings: Errors in design become increasingly significant as the complexity of the process and the number of individuals involved rise, particularly in contexts such as simultaneous engineering, where multiple disciplines converge.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A				x							x				
B	x			x										x	
C		x		x			x		x						
D															x
E			x				x						x		
F								x		x					
G			x		x									x	
H												x			
I			x	x			x	x							
J															
K				x		x							x		x
L									x						
M			x		x		x				x				
N		x						x				x	x		x
O														x	

Legend: *Presentation of the problem; Analysis of solutions for the robotic arm; Choice of type of grippers; Study of the mechanism of the arm; Electrical connection arm - the command module; Detailing solutions for the arm elements; Analysis of the command for the arm; Solution development of the command platform; Developing the software for the platform; The risk analysis; The choice of materials; Evaluating the product in terms of functionality and safety; Detailing solution for the robotic arm; Rapid prototyping of the elements of the robotic arm; Testing the solution for the robotic arm.*

Figure. 4. The DSM representation of design process

Main causes of misunderstandings in the design process

1. *Poor documentation of project specifications* can result in confusion regarding project requirements and objectives. Team members risk wasting a lot of time and energy trying to figure out what their role within the project is. This can result in errors, loss of productivity, decreased motivation and low morale.

2. *Multidisciplinary teams* are meant to bring together various skills and perspectives to solve a problem. They are highly valuable since they are able to find solutions to complex problems more quickly and efficiently. Yet, there are some drawbacks associated with the use of multidisciplinary teams.

Not all people are willing to share ideas and experiences, or to receive critical feedback from other people. While it is essential to include people with different levels of education and various backgrounds in a team, a lot of misunderstandings may occur among them. First of all, communication and collaboration may be hindered when team members are specialists in different fields and find it hard to get their ideas across to their co-workers. The use of jargon supports efficient communication between same-field colleagues, but discourages non-experts from engaging. If it is used inappropriately, it may cause confusion and misunderstandings, excluding those who are not familiar with the terminology. Hence, it is essential to take account of the context and the audience when using specialized language to ensure effective communication across diverse groups.

Not even specialists in the same field are exempt from experiencing misunderstandings while designing a product. They may interpret data and research findings differently. They may have different approaches based on different individual experiences and preferences.

Second, the diversity and complexity of technical language leave open the possibility of misunderstandings. For a Romanian economist, the English word „leverage” has a completely different meaning from the ones known by a mechanical engineer (*1. raport dintre creanțe și capital; 2. mecanism cu pârghii; transmisie prin pârghie*).

3. *Misunderstandings and breakdowns in communication* appear within a team when there are cultural conflicts among team members. The direct consequence, besides tension and loss of productivity, is a cumbersome design process. People belonging to different cultures usually have different styles of communication. Some of them are more straightforward, others are more reserved when it comes to sharing information. Encouraging a culture of collaboration stimulates knowledge sharing and

cross-cultural learning. Instead of letting cultural diversity hinder productivity, team members should take advantage of it since it stimulates creativity and allows them to see things from different perspectives.

4. The transfer of information where it is needed may be hindered if team members have *low proficiency* in the team's working language. Misunderstandings may occur even among good speakers if they are used to speaking/hearing different varieties of English. It is well-known that most words have the same meaning in British and American English. However, there are a lot of examples of the same thing being referred to by different words in British and American English (gearstick/gear shift, stick shift; glove compartment/glove box; gearbox/transmission; windscreen/windshield). There are also differences in spelling (metre/meter; analyse/analyze; tyre/tire; aluminium/aluminum) and in pronunciation that some employees may find confusing.

4. Although actual *differences between generations* are not as significant as stereotypes may suggest, they may have different ways of interacting and managing things. They have different values and codes of conduct. Misunderstandings caused by vocabulary and generational preferences for different means of communication (face-to-face communication, email, telephone, messaging, social media, etc) can have a huge impact on the overall success of the new project.

People belonging to different generations have different ways of working, communicating and responding to feedback. Employees in their twenties and early thirties prioritize connectivity in the workplace. Those in their late thirties to sixties prefer more autonomy when carrying out a task.

5. *Designers' perspective on and philosophy of design* may vary a lot depending on their work experience. Some of them prioritize aesthetics whereas others lay emphasis on functionality and usability. Those who work for low budget companies usually look for cheap solutions. On the contrary, those working for powerful companies are hardly limited by budget constraints. They are free to use high-quality materials, the latest technologies and top talents to achieve the best results. When designers belonging to these two different categories are working within a team, clashes may arise unless efforts are made to reach a balance between cost-effectiveness and quality.

Design Error Indicator

This indicator shows the rate of time spent on iterations stemming from design errors.

$$I_{er} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{e} T\_er_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{k} T\_iter_{i,j}} \cdot 100\% \qquad (1)$$

Where:

i, j: are variables;

n: is the total number of design tasks;

k: is the total number of iterations for task "i".

e: is the total number of iterations produced due to design errors, for task "i";

$T\_er_{i,j}$: is the time spent to complete iteration "j" produced due to design errors, for task "i";

$T\_iter_{i,j}$: is the time spent to complete iteration "j" for task "i".

For the analysed experiment, we have: I_{er}=24%.

The impact of each type of conflict

The interactions among product design participants often result in conflicts due to differing viewpoints on the product. Based on the frequency of intervention generating iterations to resolve conflicts, as well as the time spent on these iterations, we have proposed a matrix of interaction impact on the duration of the design process.

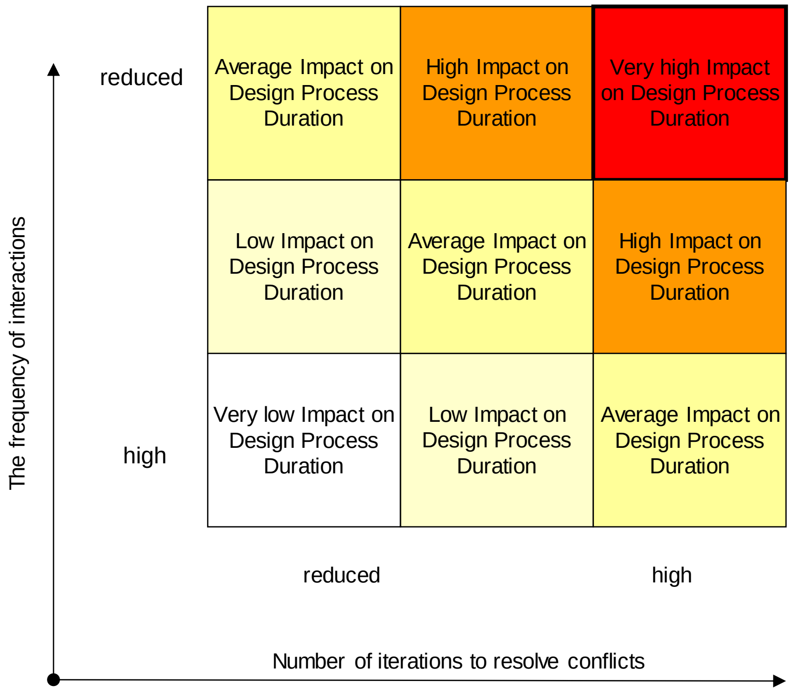

Figure. 4. The Impact Matrix of Interactions on Design Process Duration

In this case, the proposed indicator has the following expression:

$$I_{\text{int}} = \{Ii_1, \ldots, Ii_n\}, \qquad (2)$$

$$Ii_i = \begin{pmatrix} i_{11} & i_{12} & i_{13} \\ i_{21} & i_{22} & i_{23} \\ i_{31} & i_{32} & i_{33} \end{pmatrix}, \qquad (3)$$

Where:
I_{ii}: is the impact indicator of interaction type "i" on the process time;
I_{int}: is the general indicator in the form of an impact vector;

Based on the number of elements Iii and their values, the project manager can gain insight into how to negotiate conflicts between participants and can also identify which interactions are most sensitive in order to try to improve them in the next phase.
It is preferable to have a reduced number of elements in the I_{int} vector, and furthermore, to have elements in the impact matrices located below the main diagonal.

For the experiment studied, for a short interval of time, the design participants carried out only one iteration to resolve conflicts. For this iteration, only one intervention of type "f" was performed. In this case, the value of the impact indicator for each type of conflict-generating interaction on time is:

$$I_{\text{int}} = \{Ii_i\} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$$

CONCLUSIONS

Experiments return invaluable insights into the design process. In this study, we conducted an analysis of iterations within a design experiment, with particular focus on design errors.
When objectives change, voluntary iterations become more frequent as they are crucial for exploring the solution space to accommodate new design requirements. Consequently, a multitude of short

iterations, characterized by their rapid iterative nature, are undertaken to refine the chosen solution swiftly.

Design errors play a significant role in the iterative process, often leading to prolonged iterations and impacting the overall duration of the design process. Unfortunately, these sources of iterations are unpredictable and occur randomly.

Such an analysis of a design experiment is instrumental for project managers in structuring and allocating design teams effectively, particularly in optimizing product design within the evolving landscape of globalization.

REFERENCES

[1] ANGHEL, D-C. (2007). Contribution à l'analyse des itérations dans le processus de conception: proposition d'indicateurs d'évaluation de performances, Thèse de l'Université de Technologie de Belfort-Montbéliard et de l'Université de Besançon. Université Henri Poincaré.

[2] ANGHEL, Daniel-Constantin, BELU, N., Ionescu, L.-M., & RACHIERU, N. (2017). Study of iterations in the design process of a product for automotive industry. MATEC Web of Conferences, 112(1). https://doi.org/10.1051/matecconf/201711209011

[3] Smith, R. P., & Eppinger, S. D. (1997). A predictive model of sequential iteration in engineering design. Management Science, 43(8), 1104–1120. https://doi.org/10.1287/mnsc.43.8.1104

[4] ANGHEL, Daniel-Constantin, & ISTRATE, M. M. (2020). Analysis of interactions between participants involved in the design of an equipment of monitoring the microclimate conditions in the automotive industry. University of Pitesti. Scientific Bulletin - Automotive Series, 30(1), 1–6. https://doi.org/10.26825/bup.ar.2020.001.

[5] Krishnan, V., Eppinger, S. D., & Whitney, D. E. (1995). Accelerating product development by the exchange of preliminary product design information. Journal of Mechanical Design, Transactions of the ASME, 117(4), 491–498. https://doi.org/10.1115/1.2826709.

[6] Yassine, A. A., Chelst, K. R., & Falkenburg, D. R. (1999). A decision analytic framework for evaluating concurrent engineering. IEEE Transactions on engineering management, 46(2), 144-157.

[7] PAHL, G., & BEITZ, W. (1996). Engineering Design: A Systematic Approach. Publisher: Springer London ISBN: 978-3-540-19917-5,978-1-4471-3581-4.

[8] Steward, D. V. (1981). The design structure system: A method for managing the design of complex systems. IEEE transactions on Engineering Management, (3), 71-74.

[9] BOUDOUH T., ANGHEL D-C., GARRO O., Design iterations in a geographically distributed design process, Advances in Design, Edited by H. ElMaraghy and W. ElMaraghy, Springer Verlag, pp. 377-386, jan. 2006. ISBN : 1-84628-004-4., 2006 (Cod CNCSIS 53), 522 pag. 2013.