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Analysis of industrial expectations for the integration of human factors from the early design phase

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Design process;
Human factors and ergonomics;
Industrial system;
Information of use
survey.

Abstract

To understand how industrial designers take into account the information and conditions of use especially the Human Factors and Ergonomics (HFE) from the early design phase, we surveyed more than 50 companies. We analyzed their design work and evaluated if they need a new structured method to provide a real image to understand what is going on in the companies, what they do, use, and how they answer this problem. Also, we proposed to them the method developed by [1,2], that aims to integrate the HFE from the early design phase, and represented in the survey. The objective is, first, to verify the availability of designers to use a new method to help them integrate HFE into their design process and, second, to improve the presented method based on the integration of Lean principles into the design process. The survey has been answered by more than 50 experts in engineering design, which represented companies in France, Germany, and internationally in different sectors of activity such as machinery and equipment, industrial materials, automotive equipment, and products, in which we found quite a few cases of interactions between humans and machines.

1. Introduction

Following the fourth industrial revolution, human-machine interaction is affected and many innovative solutions are now available to meet user requirements in terms of user-friendliness and safety.

However, there are some limitations of work that address the design work in terms of providing to the designers some systematic methodology for considering the information and conditions of use (Production systems, machines, products).

The goal of this paper is to provide an update of the activities carried out by the designer to integrate the use of information into the design phase and to analyze the applicability of the method proposed by [1,2] on the integration of the information and conditions of use from the early design phase.

This work does not involve to present in details the method proposed by Sun et al. [1], but to analyze the results of the survey of the companies questioned. However, to show the added value of the Sun Method and to give the readers a good understanding of the survey presented in this project, we have chosen to show the Sun method presented for the companies during the survey and a review of the literature on the methods of taking into account the conditions of use. The end goal is to create a dynamic between our laboratory and some companies to popularize the capitalization and use of information related to Human Factors and Ergonomics (HFE). Our project consists of four steps:

(a) Preparation: To prepare all that is necessary (List of companies to contact, attached document, questionnaire)..., to successfully select and contact companies;

(b) Survey: The questions are answered and collected;

(c) Analysis phase: To analyze the obtained answers;

(d) Collaboration: To adapt, use, and validate the method proposed in [1] and [2].

For that, this paper contains 6 sections: The first part of Section 2 is to give a literature review of the design methods of integrating the HF/E from the early design phase, then in the second part, we focus to present the method of the integration of the use of information from the early design phase presented by Sun et al. [1]. In Section 3, we present

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the step followed to prepare the questionnaires.

In Section 4, we analyze and discuss our survey and the appropriate results. In Section 5, we present a global discussion of the survey. Finally, we present the conclusion of this study and future research directions in Section 6. We focus in our work on the systemic integration of information related to the use of a product or system from the early stages of design.

2. Literature review

2.1. HFE integration from the design phases

The HFE has evolved as a single, independent discipline that focuses on human-machine systems, seen from the unified perspective of science, engineering, design, technology and management of human compatible systems, including a variety of natural and artificial work processes and environments [3]. Many studies and surveys mentioned in the literature attempt to study, understand and harvest the integration of information related to the safety of use from the early design phase of the system (simple product or machine). Gero and Kannengiesser [4] proposed a fundamental framework that link function, behavior and structure together, in order to the knowledge of the design is grounded in its experience and its interactions with the environment. Lux and Quillerou-Grivot [5] have analyzed the activity of assembly line operators to help designers to improve their design practices. which delivered to the designers a real view of the work of the operators, thus helping them to design on future means of production in favor of better health and safety at work. Marsot [6] has developed a survey taken on machine designers to understand these practices on the integration of risk prevention requirements from machine design to open prospects for the future to improve the integration of this information. Tihay [7] has also developed a survey of users of collaborative robots to verify how designers use these technologies to meet the safety requirements of the user and to highlight the limits of these new technologies. Through interviews Norwegian design company with a focus on safety-critical systems, proposed model that can provide opportunities to understand how design methods can be adapted and evolved to support professional design practice [8]. Dantan et al. [9] analyzed the behavioral interactions between the end user and the manufacturing machine driven from the structure of the system. Human and ergonomic factors relevant to these interactions are modeled and simulated to assess system design using specific indicators of productivity and working conditions. Sun also in [2] made a very detailed stat of the art about HFE integration in design process.

These surveys show clearly that various studies seek to consider the HFE into the design phase. That shows that the topic of the safety of use begins more and more fundamental in engineering design.

Returning to the topic of considering of HFE into the design phase, the two current existing studies are Technology-Centred Design (TCD), and the other is User-Centred Design (UCD).

TCD integrates HF/E from the detailed design phase but not from the early design phase. This late integration requires changes that could have negative to system performance and human behavior. The UCD suggests that end-user information consider the use of information in each phase of the design process [10]. However, this approach is avoidable due to some barriers such as related to time-saving, high cost, and loss of information during the transmission process.

Almost of design processes involve iterations. Preliminary design drawings are refined over and over as the design progresses until the mutually dependent variables become in agreement [11].

Integrating HFE information into a late design phase can lead to design changes and iterations. These undesirable changes can be avoided if the use of information can be involved in early design phases [12]. Also, additional procedures and devices introduced for the purpose of ensuring the usability and safety of the user can also degrade the performance of the product [13].

These changes are noted by Wan et al. since 2003 [14] as easy and less expensive to implement in the early phase.

One of the main reasons for these changes is the insufficient consideration of HFE information in the first phase of the design. Considering HFE information in the design phase can improve the user experience and reduce iterations [15,16].

According to the following criteria: cost, performance of the system and human behavior, Slim et al. [17] show that user experiences are heavily integrated into the production system design process to ensure that technologies of Industry 4.0 satisfy the needs of users in term of safety when applying Lean manufacturing.

Sun et al. [1] have proposed a new approach that not only defines the behavior of the product / system to fulfill the technical functions, but also takes into account the behavior of the user of this product / system to perform the manual functions.

In the next section we present the method that we propose to designer to evaluate their feedback about it.

All these works did not study how industrial designers perceive these methods and we did not find any evaluation concerning the usability of these methods by the designer.

2.2. Proposed method of the integration of HFE from the early design phase

In order to reduce modifications in the later design phases required to meet ergonomic standards, when integrating HFE in the design process, Sun et al. [18] proposed a systematic method that takes into account information related to use. Sun et al. [1] enhances the first proposition by integrating the three-level function-task-behavior framework, Figure.1 and based on the simultaneous design of the product/system and its user manual. This framework is applicable to the design of a complex machine, equipment, production system, and simple product. It contributes to a time-saving, less expensive, and standard methodology for designers to decrease the iterations caused by the integration of HFE in the early design phase and improves product and user performance.

In general, a product manual is considered as a representation of the technical information of the product Renaud et al. [19]. It is supplied with the product to the customer.

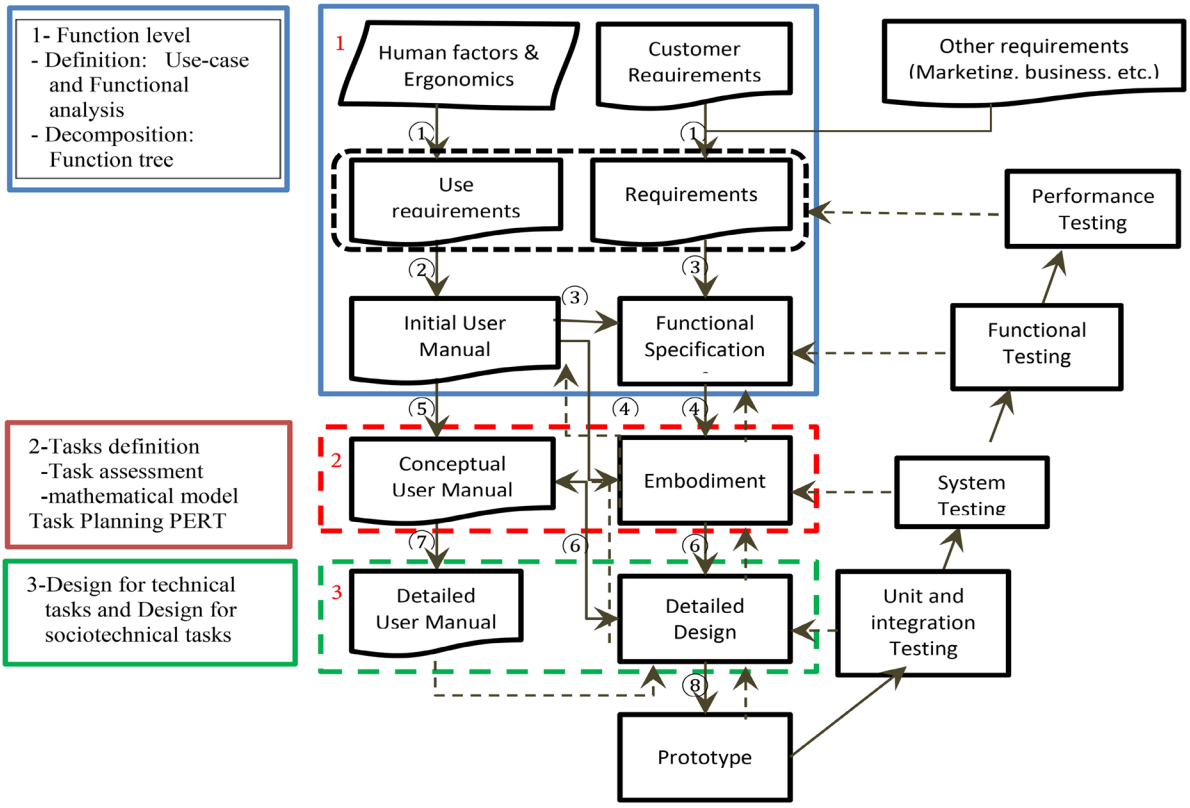

Figure 1. The steps of the proposed methodology.

However, the product receives more attention than its product manual. The instruction manual is usually created by an expert at the end of the design process. In fact, a good user manual not only can help the user to use the product in a correct and efficient way but also, can help companies in saving a lot of the cost of training staff and customer service. However, user manuals seem to be less valuable than they should and many users do not rely on them. In order to design a successful product, Renaud et al. [19] stated that the best way is that the product manual should be written first and then the design work. In Sun et al. [1], 3 levels are proposed: in the specification level, the designer defines the initial product manual that directs the functional specification and the embodiment of the manual functions according to the requirements of the use (Figure 1).

At the first level, the designer defines the tasks to perform the functions provided in the specifications. In this case, the designer defines the tasks performed by the product as technical tasks, and the tasks performed by the user as sociotechnical tasks.

In the second level, the initial product manual will be detailed to provide a conceptual product manual that is the guideline for detailed design. At this level, the designer will propose the structure that fulfills the technical functions compatible with the sociotechnical (manual) tasks to be performed by the user.

Finally, in the third level, the designer refines the tasks performed by the user and those to be performed by the structure after performing the detailed design of the structure. Then, it analyzes the interaction between the user's behavior and the behavior of the product in order to check the overall performance of the product/system and its user. It was noted that the guideline of the method is to avoid bad interactions between the product/system and users. Overall, any interactions that cause an ergonomic problem, or that affect the safety and/or health of the user must be eliminated. The application of this method requires time and modifications in the classical design process. It needs some additional tools, so, by this works, we wanted to evaluate the applicability of such a method by the company's designer, for that we did our study to determine and note what happens in industrial companies designing products and/or machines that need to define use conditions.

3. The project of the survey proposal

3.1. Proposed method of the integration of HFE from the early design phase

The big challenge in this project is to evaluate the acceptability of the proposed method of Sun by the experts in the industrial world of design (design offices, designers, design engineers...) and measure if they are interested to collaborate with us. It is therefore necessary to find the right way to contact companies and convince them of our method (Companies, attached document, questionnaire...).

To achieve these objectives, we have to identify their needs and difficulties: know how they work? how they take Human Factors in their design process? etc.

The SWOT matrix in Figure 2 presents a strategic planning technique that identifies strengths, weaknesses, opportunities, and threats related to our project.

3.2. Development of the survey

To develop a questionnaire, we followed the methodology mentioned in Figure 3.

3.2.1. Purpose

The purpose of this survey is to take stock of the situation in industrial enterprises to see how they do to integrate the HFE

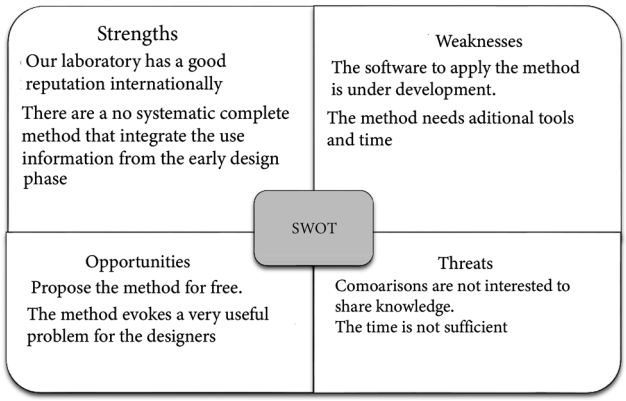

Figure 2. SWOT matrix.

industrial enterprises to see how they do to integrate the HFE into the design processes of their products.
To achieve this goal, our questionnaire was developed through the Google Forms service which is a tool to create online surveys and send them to target recipients.

3.2.2. Structure

The questionnaire consists of two parts:

i. Questions about how HFE aspects are taken into account by industrial companies;
ii. An attached document explaining the method.

3.2.3. Modalities

The companies mainly targeted are in France and Germany. But some of them are international, which is particularly important for the representativeness of the survey.
The final version of the survey has written in English.
The address of the survey is:
https://goo.gl/forms/0OdG5RCRmeURy4Jm2

3.2.4. Write the questions

The 17 questions in this survey are single choice or multiple. They are grouped as follows:

- 12 questions about the design methods used by companies regarding the place of human factors and use-related information in their design processes as well as the problems encountered in integrating this information and the consequences of this integration:
  1. In your design work, are there any modifications (iterations)?
  2. In which stage (s), do design changes often occur?
  3. Choose the reason (s) for your design modifications.
  4. Are you currently integrating Human Factors (HF) and use information into the design phase?
  5. In which phase (s) do you integrate the HF and use information?
  6. Currently, how do you integrate HF and use information?
  7. What solution(s) do you choose when design modifications are needed?
  8. What are the consequences of introducing safety systems and additional procedures?
  9. Do you think that are you a "good" user of your product?
  10. Normally, when the product manual should be written?
  11. Usually, who should write the product manual?
  12. Are you interested in a method that allows you to eliminate or reduce the needs of safety systems?

- Four questions showing the benefit of our systematic method:
  1. Would you like to introduce this method to carry out design work?
  2. Do you want to systematically collect use requirements and information?
  3. Would you like to complete functional analysis with a task analysis?
  4. Would you be ready to define the input, output, control, duration, and support resources for each task required to perform a function?

- The last question asks companies to work with us to test the proposed method and make a feedback.

3.2.5. The survey pre-test

The questionnaire was tested on a small sample of our laboratory. It is timed in order that designers do not exceed 5 minutes to respond. Finally, it is corrected several times by the team depending on the problems encountered.

3.2.6. Capture the answers

Answers are automatically collected on a spreadsheet, along with the responder's name, position, department, and company for which they are working.

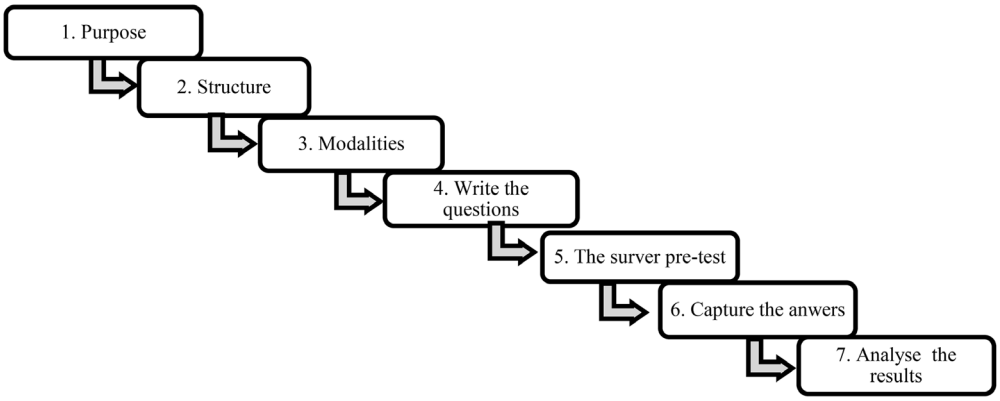

Figure 3. The steps to develop a questionnaire.

Table 1. List of surveyed companies.

Location	Total of companies	Sectors of activity			No. of companies responded
		Automotive equipment	Industrial materials	Machinery and equipment	
France	220	110	60	50	23
Germany	160	70	60	30	19
International	120	50	50	20	11

3.2.7. Analyze the results

Statistical analysis and analytical is done in order to note of the integration of human factors in the companies and highlight the utility of the method.

3.3. Contact companies

The method has been sent to 500 recipients who work in 500 companies in France, Germany and internationally, in different sectors of activity such as machinery and equipment, industrial materials, automotive equipment and products, Table 1. Selection of the companies was based on information that they work on ergonomics into the design phase of their products (system or machine).

The survey is made available via E-mail lists and LinkedIn service and taking advantage of the large network of the CSIP laboratory and INSA of Strasbourg. It was an asset to share the questionnaire more with the design experts. The names of the companies are not mentioned due to privacy rules.

4. Results and discussions

In this section, we analyzed in detail the answers of companies and we discussed them question by question. Our aim of this detail is to be the more precise and to able to identify on what we must focus to improve the work of designer to integrate HFE in design process without or with a minimal overcharge.

We present below a detailed statistical analysis of the obtained results.

Question 1: In your design work, are there any modifications (iterations), Figure 4?

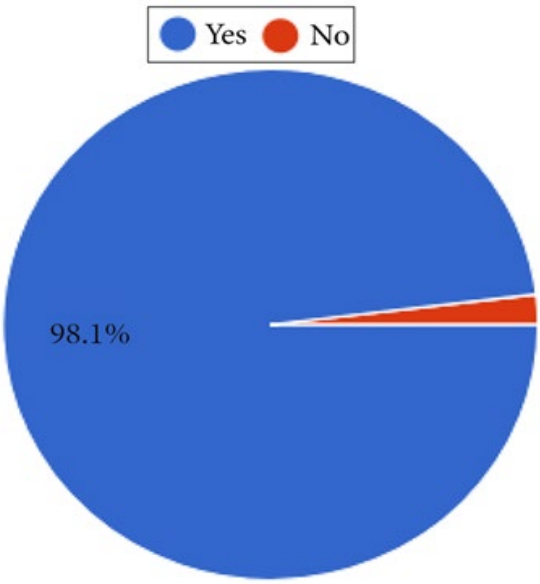

Figure 4. Answers of Question 1.

For this question, we had 50 answers. We can see that iterations come in all the design processes of responding companies. Hence the need for a method that reduces modifications.

Question 2: In which stage(s), do design changes often occur? (Multiple choice), Figure 5.

We also had 53 answers. The answers show that iterations can happen in all phases of design.

Question 3: Choose the reason(s) for your design modifications, Figure 6?

We also had 53 answers. This shows that despite the presence of a different reasons for iterations, the most of these modifications are caused either to respect standards and ergonomic laws, or to integrate the requirements of customers. These answers show the importance of our project.

Question 4: Are you currently integrating Human Factors (HF) and use information into the design phase, Figure 7?

We had 52 answers. Most users incorporate HF into design phases information about user and use.

Question 5: In which phase(s) do you integrate the HF and use of information? (Multiple choice), Figure 8.

We had 49 answers. According to the answers obtained, integration is done in the different phases, which confirms our hypothesis that there is no formal method of integrating usage information.

Question 6: Currently, how do you integrate HF and use information, Figure 9?

We had 48 answers. The most favorable method is FMECA analysis. Some interesting answers are related to our method such as "interviewing and contacting customers and user", "based on experiences", etc.

Question 7: What solution(s) do you choose when design modifications are needed, Figure 10?

We had 46 answers. There are different choices of solutions, but the most adopted is either by introducing safety systems, which decreases the overall reliability; Either by redesigning the product which costs very expensive, and wastes time.

Question 8: What are the consequences of introducing safety systems and additional procedures, Figure 11?

We had 41 answers. Answers confirm that integrating these safety systems reduce system reliability, accessibility, and visibility, and therefore reduces productivity. When one of these systems is in failure, all systems must be stopped to repair the failure.

Question 9: Do you think that are you a "good" user of your product, Figure 12?

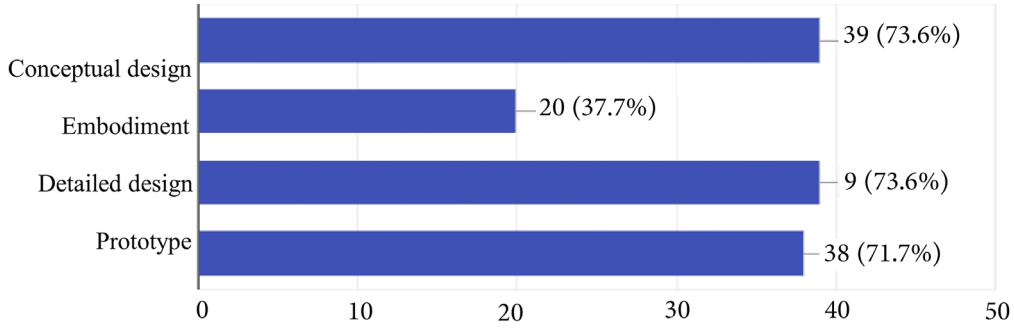

Figure 5. Answers of Question 2.

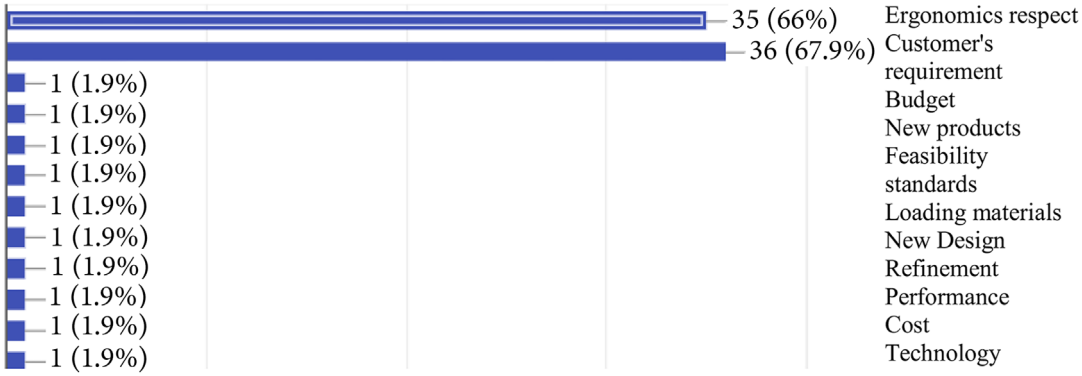

Figure 6. Answers of Question 3.

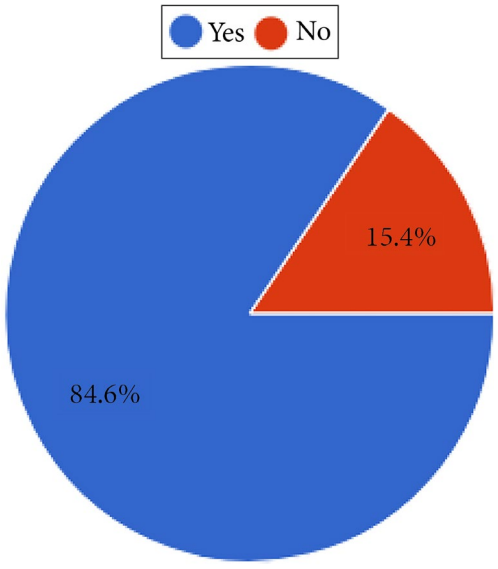

Figure 7. Answers of Question 4.

We had 46 answers. Almost half of the designers are aware that they are not good users of their products. However, more than 58% think they are good users of their products. However, Renaud et al. [19] noted that in the design process, the way of product use is taken into account in an intuitive manner. That means that the way to use the product is considered differently by each designer because of the lack of well-developed and structured methods and tools [20].

Question 10: Normally, when the product manual should be written, Figure 13?

We had 49 answers. Most of the answers show that the product manual is developed too late in the design process. We said too late because the decisions to design the product are already taken and product use will be constraint by the product itself. This causes modifications and complicated procedures for use. This is contrary to our method which is used to take into account the use and to write the product manual in parallel with product design.

Question 11: Usually, who should write the product manual, Figure 14?

We had 49 answers. Most of these answers show that the manual is written by designers and not by users.

Question 12: Are you interested in a method that allows you to eliminate or reduce the needs of safety systems, Figure 15?

We had 50 answers. Half of this answer shows that designers want help to eliminate or reduce the need for safety systems. And the other half show that designers believe that they have done their job well or that there is no way to do better.

These 12 questions prove that there are problems with iterations. These problems have solutions that are expensive and can reduce performance. There are no systematic methods that integrate the use of information from the early design phases.

This is why such a method is so important.

In the following, we present the answers to the 4 questions concerning the proposed method.

Question 13: The attached method is developed to allow designers to create a product manual for integrating use requirements and HF into the design phase. Would you like to introduce this method to carry out design work, Figure 16?

We had 32 answers. 75% of the answers show an interest in such a method that creates a product manual and incorporates the conditions of use and HF in the design process.

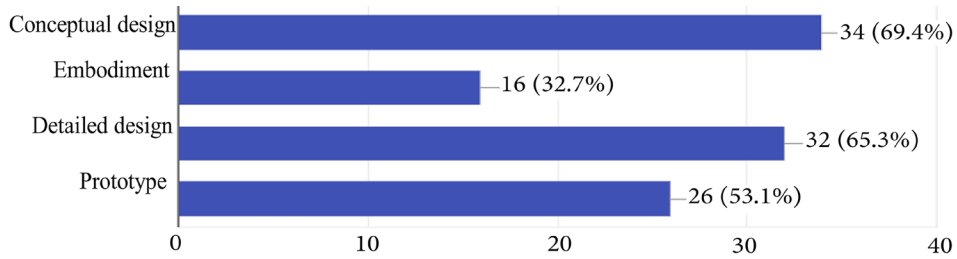

Figure 8. Answers of Question 5.

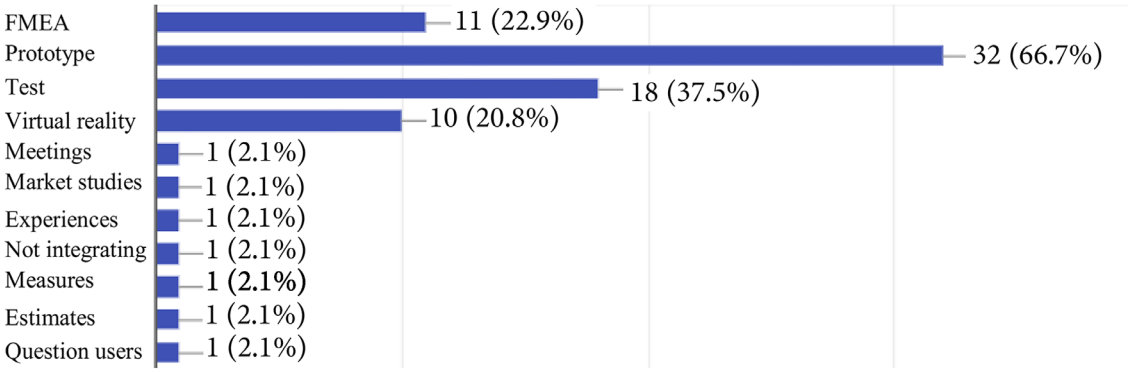

Figure 9. Answers of Question 6.

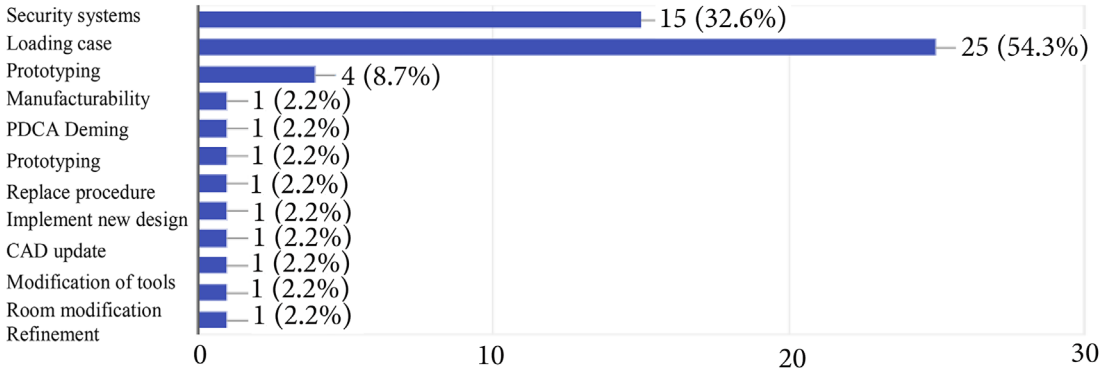

Figure 10. Answers of Question 7.

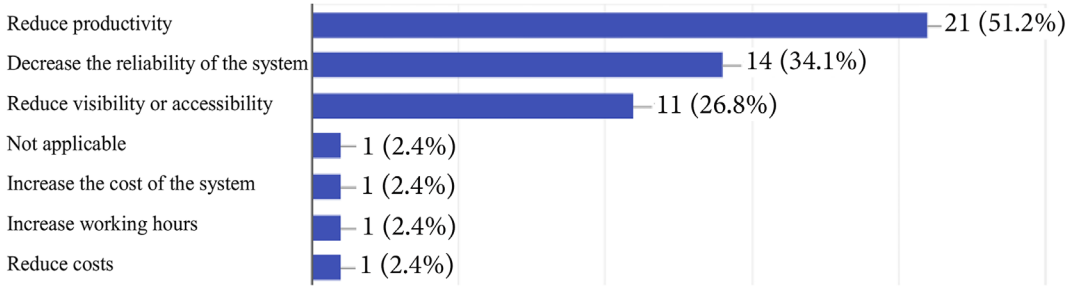

Figure 11. Answers of Question 8.

Question 14: Do you want to systematically collect use requirements and information, Figure 17?
We had 17 answers.
Most answers are interested in such a systematic method that collect use requirements and information.

Question 15: To take into account interaction between product and user, would you like to complete functional analysis with a task analysis, Figure 18?
We had 32 answers. Most of the answers are interested in such a method that takes into account the interactions between the product and the user by completing functional analyzes of the product by a user's task analysis in using this product. This means that the designers know that additional analyses are needed to optimize the design of their products.

Question 16: In order to better define use requirements and information, would you be ready to define the input, output, control, duration, and support resources for each task required to perform a function, Figure 19?
We had 29 answers. Most of the answers are interested in such a method that allows us to define all the elements to carry out the tasks necessary to fulfill the functions. These results confirm that the proposed method is easy to understand.

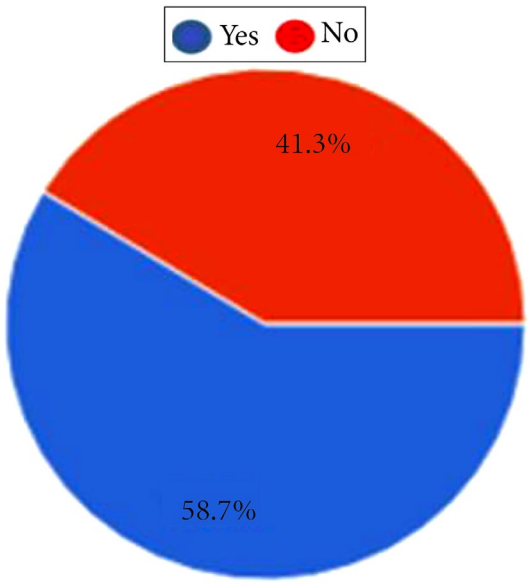

Figure 12. Answers of Question 9.

Question 17: If yes, an introduction to our method will be presented with the survey. Please contact us if you are interested, Figure 20.

We had 29 answers where 22 of them say yes (percentage of 75%) they want to collaborate to learn about the proposed method. These 22 of 53 are interested, present 41.5% of participant companies.

5. Global discussion

Currently, about 53 companies answered the questionnaire, a percentage of 10.6% of the companies contacted. Based on the statistical analysis of the responses, we conclude that modifications often occur at all stages of the design process, for a variety of reasons. Among the reasons, respecting ergonomic standards and laws and meeting customer requirements are the most common.

Late integration of the information of use and late development of the user manual can also cause these modifications. To solve this problem, designers introduce safety systems, which decreases the overall reliability of the system. And sometimes they choose to redesign the product, which is very expensive.

These answers prove that:

1. There are no systematic methods that integrate the information of use in the early design phase. This is why such a method is so important;
2. Designers believe that they know how the product will be used. But in reality, they imagine how user will use the product/system based in their experiences or on the feedback of customers that often is not the end-user;
3. Designers believe that they apply good and systemic methods and tools because there are no keys performance indicators to evaluate their work on this point;
4. Designers believe that the product meets standards with the lowest cost possible. Also, here we noted that there is no measure tools or methods evaluate the performance of the designers;
5. Designer used many different methods in their work to integrate HFE in the design process.

The answers also show clearly that the topic of the safety of use is more and more fundamental in engineering design. After analyzing the answers, we have shown that most experts in the field of design in different manufacturing areas are interested to:

- Integrate the information of use into the design phase;
- Optimize the human-machine interaction;
- Reduce the need to apply Lean and other methods of improving performance in the use phase;
- Integrate Lean principles from the early design phase to enhance industrial performance;
- Respect the environment;
- Understand the needs of the end-user (Behaviours, tasks, etc.) in his workplace to help him perform his tasks optimally in an Industry 4.0 context;

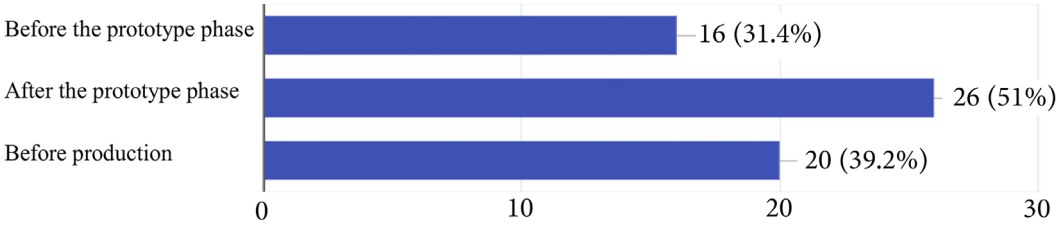

Figure 13. Answers of Question 10.

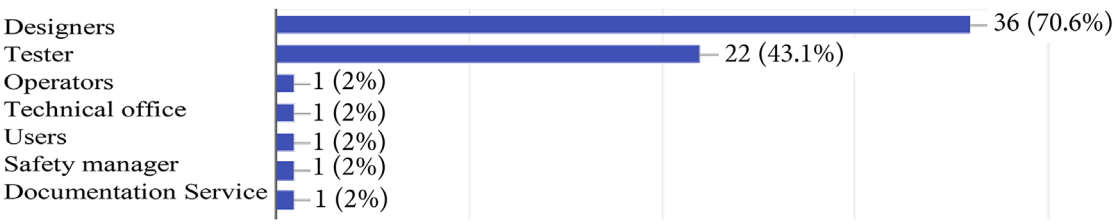

Figure 14. Answers of Question 11.

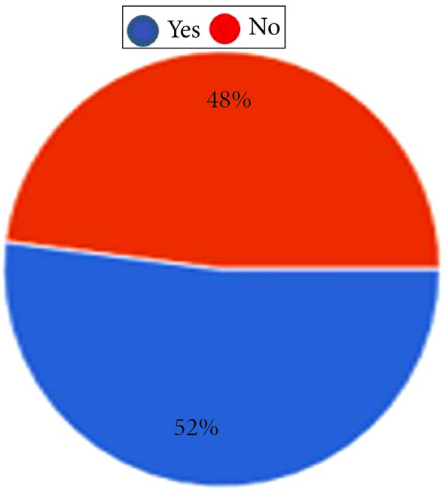

Figure 15. Answers of Question 12.

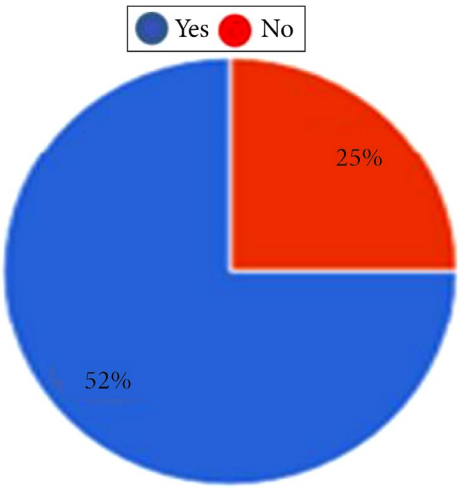

Figure 16. Answers of Question 13.

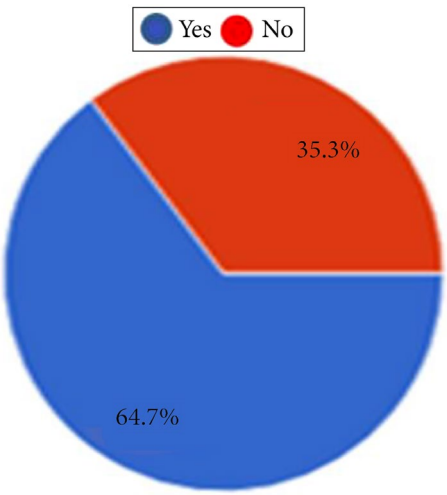

Figure 17. Answers of Question 14.

- Show concretely that the designer needs a useful tool to carry out optimally his design work.

So, 22 companies of these 53 (41.5%) answered the questionnaire, want to work with us. These companies aim to delate the cap between their vision of the problem and the solution they propose and what happened to the user when using their proposed artifact.

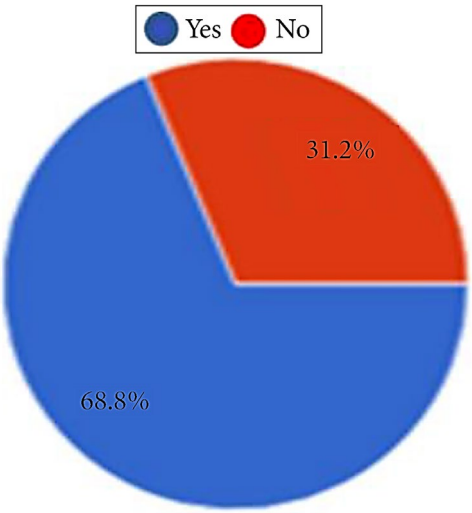

Figure 18. Answers of Question 15.

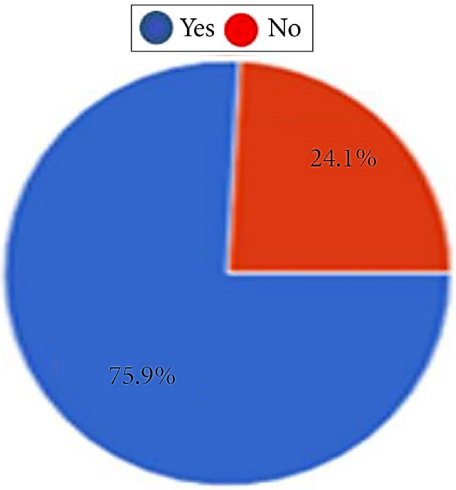

Figure 19. Answers of Question 16.

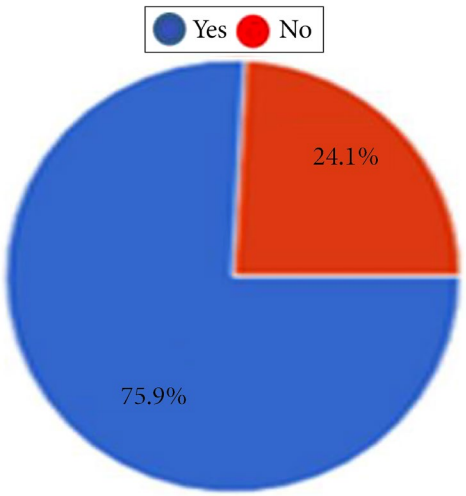

Figure 20. Answers of Question 17.

The experts integrate the information concerning the conditions of use are interested in such a method which, from the early design phase that:

- Considers the interactions between the product (system, machine, final product) and the end-user;
- Defines all the elements to carry out the tasks necessary to fulfill the functions, from the point of view of designer and user;

- Meets ergonomic standards and laws in a systematic way;
- Reduces changes and modifications in the design process.
- Avoids proposing complicated use procedures, when the reduction of end-user risks is not possible;
- Allows writing the product manual in parallel with the design process.

6. Conclusion

In this paper, we prepared a survey to understand what has happened in industrial companies regarding the integration of HFE in the design process.

We analyzed the answers of the designers in different companies that present different sectors in France and Germany.

We present the method of Sun in [1,2], which provides a systematic way to define, analyze, and evaluate all the necessary information related to the use and user into the design phase. This method is very helpful for the designer to consider the information of use during the design process. We linked the proposed method concerning the integration of HFE in the design process, and the expectations of industrial designers.

We conclude that there are no systematic methods to integrate the HFE into the design phase. Hence is the value of such a method.

Until now, 22 companies want to work with us. One company has already collaborated with us.

Our future work consists to improve the proposed method by identifying the more important criteria for designers to integrate methodologically and systematically HFE in the design process. We seek also to propose a new framework not only to integrate methodologically and systematically HFE in the design process but to be able to cover more criteria to make the system performant, agile, sustainable, etc. Integrating Lean from the design phase can be useful to consider more criteria to improve the overall performance of the production system in an Industry 4.0 context. This leads us in the following to analyze the convergence and divergence between these two concepts Lean and Industry 4.0 to integrate them from the design phases. It should be noted that, in this study, we did not evaluate the importance of cultural factors, so the way of integration of the conditions of use between French and German designers has not been compared. But it could be an interesting subject to study and analyze, especially with the new technologies of industry 4.0 that limit human work and increase automation.

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