ARTICULATING ERGONOMICS AND ENGINEERING DESIGN TO DEVELOP HEALTHY AND SAFE WORK ENVIRONMENTS

Moraes, A. S. P.[1], Arezes, P.M.[1], and Vasconcelos, R.[2]

[1]Production and Systems Department - School of Engineering
University of Minho
Campus de Azurém
Guimarães, Portugal 4800-058
Corresponding author's e-mail: sophiapiacenza@gmail.com

[2]Faculty of Psychology and Educational Sciences
University of Porto
Rua do Dr. Manuel Pereira da Silva
Porto, Portugal 4200-392

Abstract: The main purpose of this paper is to emphasize the need for integration between ergonomics and engineering design to develop healthy and safe work environments and to suggest some requirements to promote this integration. In industrial contexts, ergonomics methods are traditionally applied for evaluating the risks of a specific workplace or task. However, to contribute to the conception of work environments, ergonomics should be articulated with the engineering design processes. To promote and facilitate this articulation, ergonomists should be part of the design teams, communicate with specialists and understand the context in which they are working. This articulation should be done as early as possible, and be maintained in all of the development stages of the engineering design process. Ergonomists should provide competitive criteria, apply compatible methods according to the specific goals of the project and evaluate the feasibility of their proposals considering the current constraints.

1. INTRODUCTION

Ergonomics has been growing as an important science interested in relation of human activities with other elements of a given system. Ergonomics methods are traditionally applied in industrial contexts for evaluating risks of a specific workplace or task. However, this approach may be deficient, as the main objective of ergonomics is to optimize human well-being and promote the overall performance of a system. Ergonomics practitioners, also called ergonomists, realized that by keeping their position in a diagnostic approach, they have less leeway left to influence on workplace design and risk prevention.

Ergonomists understood that to be more prominent they need to anticipate their approach. By doing a "post-design" evaluation, ergonomists have little opportunity to make significant and important design changes (Burns and Vicente, 2000). Over time, ergonomists became more interested in being close to those who are mainly involved in design of the work environment, i.e., engineers and designers. More and more often, ergonomics approach became integrated in the engineering design process.

Today, the majority of research related to safety, ergonomics and design shows clearly the existence of a consensus between people in industry and researchers on the fact that good industrial performance cannot be obtained without taking human factors into account in a serious way (Fadier and De la Garza, 2006). Therefore, integration between ergonomics and engineering design has not been always an easy going articulation.

The main purpose of this paper is emphasize the integration between ergonomics and engineering design as an alternative to develop healthy and safe work environments and suggest some requirements to promote this articulation. Some of the comments and statements presented in the current study were collected from case studies regarding integration of ergonomics into design processes, found in a literature review. To ensure this paper´s statement, studies were collected from different contexts, present different methodologies, and had different objectives, even if all are interested in the articulation between ergonomics and engineering design:

- Launis *et al.* (1996) got their results from a three-year research program in Finland to investigate, develop and test workplace design practices, methods and information systems;
- Broberg (2007) made a questionnaire survey with 680 engineers from Danish enterprises;
- Wulff *et al.* (1999a and 1999b) conducted exploratory case studies to investigate the perception of designers regarding ergonomics requirements in two large-scale offshore oil/gas installation projects;

- The study of Hasan *et al*. (2003), in an offset printing line project, propose a tool and a methodology to help designers take safety requirements into account at the design stage;
- Fadier and Ciccotelli (1999) present a case study of the improvement of a wood-dust extraction system of numerically controlled routine machines;
- Haslegrave and Holmes (1994) analyze the training environment of young ergonomists and engineers in the United Kingdom.
- Burns and Vicente (2000) got their results from a project of a control room in a nuclear power plant;
- Cordiner and Graves (1997) show the support of ergonomics related to prevention of human errors during the refurbishment of a gas processing plant;
- Cross and Cross (1995) used Delft Protocol workshops to make observations of teamwork and social processes in design.

Firstly, it is important to understand why traditional design approaches are usually not sufficient to design safe and healthy workplaces. An overview about the causes and some empirical evidences are shown in the first part of this paper. In the second part, based on main characteristics of the engineering design process, some needs are suggested to promote the articulation between ergonomics and engineering design process.

2. THE SEQUENTIAL APPROACH AND PROMOTION OF OCCUPATIONAL SAFETY AND HEALTH

Developing healthy and safe work environments is a challenge for companies nowadays. One of the keys to achieve this goal underlies in proper comprehension of safety and health integration model into industrial contexts.

In traditional engineering approaches, occupational health and safety are commonly considered after the design, construction, implementation and use of workplaces. Not rarely, health and safety at work has been taken into consideration even later, for example, after the occurrence of work accidents or after the acknowledgment of high rates of occupational injuries and diseases related to a specific workplace.

In a post-integrated safety model, design engineers firstly seek to achieve the required functions and technical design, and then go on to 'secure' the production system, to satisfy legislative requirements or normative conditions (Hasan *et al*., 2003), or to ensure a sufficient level of safety (Fadier and De la Garza, 2006). It is usual to find safety procedures and devices aiming to protect workers that actually hinder work process. Actually, these procedures and devices might restrain the accomplishment of the tasks objectives, originating severe constraints in terms of accessibility and visibility (Hasan *et al*.) or put the worker in a 'lawbreaker' position. Johnson (1996) affirms that introducing safety devices does not always reduce the frequency of accidents because operators adjust their response to technological improvements. The protective equipments can lose their efficiency when they are neglected, removed or destroyed by workers. In the end, only personal protective equipments are left in mean of health and safety at work. As stated by Fadier and De la Garza (2006), the sequential consideration of safety and ergonomics in design is one of the reasons why, in spite of introduction of new technologies and the abundance of regulations and technical standards, safety margins remain insufficient and residual risks are still significant.

In side of healthcare professional services, the distance between workplace design and health promotion seems even wider than the one from safety and design. Commonly, medical services have little connection with the work environment, even less with the designers and their considerations about human capabilities and skills during the design. The focus from the occupational health become also a reactive approach, based on treatment of occupational injuries and diseases. Doing a post-integrated healthy, the preventive policies can be limited to promote workstation exercises or implementation of a job rotation system.

As soon this sequential model of incorporating healthy and safety has shown some insufficiencies, integration of ergonomics in design phases seems to be a good key to promote safer and healthy workplace. In order to achieve this, both ergonomics and engineering design need to be articulated. Otherwise, ergonomics will continuously be seen as a difficulty or "barrier" to the design process.

3. SOME NEEDS FOR PROMOTING ARTICULATION BETWEEN ERGONOMICS AND ENGINEERING DESIGN

The engineering design process has some specific features. It is possible to say that it:

- is usually fragmented between different specialists (e.g. Wulff *et al.*, 1999b; Rouse, 1987; Burns and Vicente, 2000);
- is a multiple criteria decision process (e.g. Hasan *et al.*, 2003; Haslegrave and Holmes, 1994);
- happens in an iterative way (Burns and Vicente, 2000; Haslegrave and Holmes, 1994; Fadier and De la Garza, 2006);
- is inserted in a rich constraint environment (e.g. Broberg, 2007; Burns and Vicente, 2000).

As soon all this features has an impact over the engineering design process, they should be considered as an attempt to integrate ergonomics and design process. In the following paragraphs, an overview of each of these features is presented and some needs to promote the articulation of ergonomics into engineering design process is suggested.

3.1. Engineering design process is inserted in a rich constraint environment

The multiple constraints, which an engineering design process is subjected, derive from different sources. These sources can be financial, legal, contractual, political and social (Mekitiak and Neumannm, 2008). Broberg (2007) divides the constraints as technical and contextual. Burns and Vicente (2000) identify 3 categories: contextual constraints, constraints of parsing and distribution and constraints from other domains. Regardless the size of the company or project, time pressure and reduced budgets are usually the most common constraints in the design process. Burns and Vicente (2000) observe that designers and ergonomists must negotiate through a changing web of constraints from many sources, and constraints can justify why the 'best' ergonomic design is not always adopted.

As soon the environment in which engineering design process is inserted is a rich constraint, ergonomics proposals should be seemed as relevant by organization and feasible by design engineers.

To be viewed as relevant, ergonomics cannot be considered as an extra cost or time loss by the organization. The effort of including ergonomics in design process should start from top management; otherwise, ergonomists would be in a weak position to influence design engineers (Broberg, 2007). As stated by Hendrick (2003), one way to get this support is to being able to present the ergonomics proposals using typical business terms, which means showing a cost-benefits analysis of the considered ergonomic proposal.

The recognition of importance of ergonomic requirements is necessary by the designers also their perception of the formal organization of human factors (Wulff *et al.*, 1999a). Sometimes, within a company, people even do not perceive who is actually the designer of a workplace (Launis *et al.*, 1996). The study conducted by Broberg (2007) also suggests that engineers are even not aware that they influence the work environment of other people, and they do not consider ergonomics or work environment aspects in engineering projects. The introduction of ergonomics at design stages aims to place human activity in the forefront of designers´ decisions (Daniellou and Garrigou, 1992). To achieve this, ergonomic proposals should consider the environment constraints, so they could be seen as feasible and useful by design engineers.

3.2. Engineering design process is a multiple criteria decision-making process

In an engineering design process many decisions are made by taking multiple criteria into account. Each specialist involved in the design team has his own perception regarding the design problem, so they use specific criteria to propose solutions. Ergonomics criteria are placed as one of the multiple criteria established for designing the production process or other facilities. In a high constraint environment, they can easily lose its strength on the decision making process, as it will compete with criteria that are technically, legally or social imposed. So, ergonomic criteria provided by ergonomists should be competitive with other criteria. One of the main criticisms regarding ergonomics is related with the ergonomic guidelines. As stated by Campbell (1996), many existing human factors reference materials have been criticized by designers for being 'too wordy', 'too general' and 'hard to understand'. The consequence of this is the fact that designers seldom even thought of consulting ergonomics handbooks because they look for specific answers to specific questions (Meister and Farr, 1967).

To guarantee that the ergonomic criteria will be taken into account during the decision-making process in engineering design, ergonomists should be part of the engineering design teams. Although engineers and designers could have a training or education in ergonomics knowledge and methods, this does not necessarily imply ergonomics criteria will be applied. As stated by Broberg (2007), transferring ergonomics knowledge to the each individual engineer does not, *per se,* 'activate' them to integrate ergonomics into engineering. Haslegrave and Holmes (1994) defend that ergonomists have a longer and more directed training to develop the specialist skills needed in ergonomics analysis and in particular those needed for user evaluation. The study conducted by Wulff *et al.* (1999b) concludes that an active involvement of a Human Factors

specialist integrated in the design team was critical to ensure recognition of Human Factors and a positive outcome for ergonomic criteria in the design negotiation process.

3.3. Engineering design process happens in an iterative way

Even though models present engineering design as an orderly and rational process (Pahl and Beitz, 1996), some studies have showed a different perspective: they state that engineering is a complex and heterogeneous activity (Broberg, 2007) and the design process is highly iterative with frequent repeated cycles of analysis and several practical changes during its course (Burns and Vicente, 2000; Haslegrave and Holmes, 1994). Garrigou *et al*. (1995) classify design as an iterative process of complex coordination.

As the engineering design is considered as an iterative process with successive and consequent design changes and decisions made, ergonomic criteria should be integrated as early as possible and ergonomists must take part of design teams throughout all engineering design process.

The timing of inclusion the ergonomic criteria into the engineering design process is advocated to be done as early as possible. Haslegrave and Holmes (1994) state that ergonomics input should be applied from the very start of a project, near the concept design stage. To Meister and Farr (1967) ergonomists should be involved in the drafting of the initial design specifications. The early incorporation can also provide better results, since fewer decisions have been taken and the flexibility is larger. To Daniellou and Garrigou (1992) when basic studies have been completed, it is no longer possible to provide prior guidelines for design. Also, an early incorporation of ergonomics criteria can avoid later changes in the design that can be very costly. The earlier the ergonomics criteria are introduced to design, fewer changes at design will be needed. An early incorporation of ergonomics criteria increase chances of their acceptance. Hendrick (2003) affirms that the earlier professional ergonomics participation in the design team´s work, less costly is the effort needed.

After the initial integration, ergonomists participation should be continued during all stages of design process. As soon the level of uncertainty in design falls down during the engineering process, more refined and detailed ergonomic guidelines and requirements can be necessary to be offered, regarding the. Additionally, the solutions provided may also need to be reviewed, adapted and negotiated according to the consequent changes and decisions that are made during the design process. This means that it is necessary, but not sufficient, that ergonomists provide recommendations at initial phases of design. As stated by Haslegrave and Holmes (1994), recommendations provided early on may be provisional, and features of the designs are very likely to be changed at later stages. According to Fadier and De la Garza (2006), in most design cases, the specification, testing and validation phases remain the most important for collecting and identifying end-users needs and usages in different categories and trades. Daniellou and Garrigou (1992) suggest that the installation assembly phase is also important to keep ergonomic working groups, because minor changes may still be requested at this stage and it is possible to assess difficulties that could not be forecasted, or were not taken into account during the project. The lack of integration of ergonomists in some stages of the engineering design process can cause rework and knowledge discrepancy regarding aspects already discussed and defined.

The integration of ergonomists in the design process can also bring benefits to the engineers approach, regarding the utilization of ergonomics criteria. According to Haslegrave and Holmes (1994), when ergonomics was considered in the early stages of developing a design, the whole design team began to focus on the users' perspective. This changing of paradigms about work is stated also by Garrigou *et al*. (1995) when they say that the role of the ergonomist in design processes is then not simply to bring new 'bricks' of knowledge to the designers, is much more a case of modifying the representations of work that are involved in design. Cordiner and Graves (1997) see other benefits of a continuous involvement of an ergonomist. For them, the participation of an ergonomist is valuable in a transitional period, as it can provide an additional link between groups in the project, facilitating discussions in areas of uncertainty, focusing attention on the importance of personnel involvement and recognising their concerns.

3.4. Engineering design process is usually fragmented between different specialists

Usually, a large design problem is usually handled by a group of specialists. The design process is highly fragmented and each specialist works exclusively in his own field (Garrigou *et al*., 1995). The problem is broken up into subproblems and distributed across a wide range of participants, according to their expertise (Burns and Vicente, 2000) and background. As stated by Cross and Cross (1995), working as a member of a team introduces different problems and possibilities for the designer, in comparison with working alone.

As soon different perspectives and interests are involved in teamwork, the social feature of design process is relevant for the success of it (Wulff *et al.,* 1999b). According to Boff (1987) one of the greatest obstacle to a successful

interdisciplinary design is the inability of designers from different disciplines to understand and appreciate the different views of other design parties involved in the same project. For Wulff *et al.* (1999a) an active participation by ergonomics specialists in engineering design can help overcome these structural barriers.

To be influent, ergonomists must then understand how the engineering design team works. To Mekitiak and Neumannm (2008), the engagement within engineers depends on the ability of ergonomists to understanding the objectives, motivations and work routines of engineers. According to Kirwan (2000), the nature of the inter-relationships between human factors personnel and those who control the procedures is a crucial ingredient to a successful implementation of ergonomics. The organization inside a design team can vary according to the size of company and the specific project, the rate of change of technology that will be provided and the amount of available resources. Ergonomists should be able to understand his social and technical role in the group. Haslegrave and Holmes (1994) state that it is clear that it is unlikely that there is only a single 'best' model for collaboration between ergonomists and design engineers.

Ergonomists and other engineers not only hold different criteria according to the design, but also speak different languages. But inside teamwork, it is a necessity communicates and share concepts and ideas (Cross and Cross, 1995). The lack of a common language can be a barrier between ergonomists and engineers and a hindrance in the acceptance of ergonomics by engineers (Haslegrave and Holmes, 1994). Because of this, ergonomists must be able to communicate and influence all specialists involved in the project.

To be influential on the design process, ergonomists should gain some knowledge of technical design and manufacturing techniques, but also must be able to communicate with all specialists. Haslegrave and Holmes (1994) suggest that ergonomists should work with technicians and designers in order to understand and pick up their technical language and working methods in specific contexts, but also engineers should be trained to be familiar with ergonomics terminologies.

4. CONCLUSION

In terms of occupational safety and health criteria on design of workplaces, the traditional engineering approach is somehow limited. Today, health and safety issue is more than having general regulations, provision of personal protective equipments and effort of adjusting work place to prevent accidents and diseases as much as possible after a work place is set to work. Therefore, there is a need to develop new models, approaches and tools to integrate prevention of work related injuries and diseases into the design process.

In today's world, beside the aim of protecting human health and comfort, ergonomics is also a branch interested in sustaining proper and efficient operation of a work place, which includes the occupational health and safety. Articulating ergonomics and engineering design constitute a good approach to develop healthy and safe work environments.

However, this articulation is not always easy to be promoted. Ergonomic criteria are commonly considered by design engineers as being too broad and/or hard to understand. In a highly constraint environment, ergonomics criteria can easily lose its strength on the decision making process as it will compete with other criteria that are technically or legally imposed. Also, ergonomics are frequently considered by designers as an extra-cost or loss of time.

Considering some main aspects of engineering design process, strategies to promote and facilitate ergonomic articulation with engineering design is suggested. The needed actions and behaviours for this articulation cannot be exhaustive or conclusive, as soon each specific project has particularities depending on size of the company, scale of the projects, the constraints involved, number and coordination of specialists. They intend to aid ergonomics practices and facilitate their integration into engineering design process. The integration of ergonomics into the workplace design can contribute to develop healthier and safer work environments.

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