PROJECT MANAGEMENT, ERGONOMICS, HEALTH AND SAFETY: THE CASE OF THE DESIGN OF A QUEBEC PLANT

☐ Ergonomics
☐ Project management
☐ Industry
☐ Engineering

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This research[1] involves reconstituting, a posteriori, the activity of an ergonomist and two preventionists responsible for integrating ergonomics and occupational health and safety (OHS) into a Québec aluminium plant construction project. Their activity was documented through a methodology consistent with the theoretical line of thought on the cognition of situated action. Five intervention strategies were identified and documented: advancing step by step, as the project progressed; adjusting to the engineering process; legitimizing their actions; having the design choices tested by the users' activity; and constructing a «memory of their actions». With these strategies, the three professionals were able to influence work situation design, to reduce a large number of risks at source, and to develop the prevention program before the plant was started up. However, other gains could have been made if the organizational and project management contexts had been different. The research suggests ways to consider these contexts differently so as to achieve a more effective integration of ergonomics and OHS. These are related to the project phases; the relationship between ergonomics and OHS within the organization; the relationship between the model of intervention by specialists and the approach by which non-specialists take charge of ergonomics and OHS; the management of subcontracted projects.

1 - INTRODUCTION

A genuine approach to eliminating risks at source and taking users' needs into account requires that occupational health and safety (OHS) and ergonomics be successfully integrated into all stages of the design of production facilities and equipment. For more than 20 years, the literature has maintained that this integration helps to test the design choices which determine the work situations, where and when the margins of manoeuvre for affecting them are optimal [ex.: 1, 2, 3]. However, the means to achieve a successful integration remain to be developed [ex. : 4]. Research can contribute to this subject by producing and diffusing critical knowledge on the strategies and tools implemented in concrete situations by ergonomists and preventionists. In ergonomics, the goal of modelling the activity of professionals is shared by several researchers, including Daniellou [5 to 8], Falzon [9, 10] and Lamonde [11 to 14]. This type of approach can also be observed in a great variety of professions, including those of the preventionist [ex.: 15], the engineer [ex.: 16 to 22], the social worker [ex.: 23], the teacher [ex.: 24], the psychologist, the urban planner and the architect [ex.: 22], to name but a few. These research studies highlight the mechanisms through which professionals intervene and succeed or fail. Thus, they help to better equip professionals by identifying the

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determinants of their practices which are conducive or not conducive to effective action, by providing points of reference for action and for reflection in action and lastly, by suggesting ways to develop initial and continuous training programs to best support their practices. Although these research projects are most often based on case studies, they can lead to general benefits such as these through accumulation [ex.: 10].

The case study presented here is based on this approach since it consisted in modelling the activity of one ergonomist and two preventionists involved in the design of a Quebec aluminium plant. As regards methodology and the generalization of results, this case study draws on the knowledge acquired from a broader research program on professional practices which the principal author of this article has been developing for several years [12] (Section 2). The proposed modelling describes the intervention strategies used by these three professionals, the effects of their interventions (in particular in terms of eliminating risks at source) and lastly, the determinants of their practices as well as ways of transforming the work context that emerge for the participating organization (Section 3). Beyond the case study, general lessons are derived from the research which can be transposed to other types of companies and other types of design projects (Section 4).

2 - METHODOLOGY

The research program we have been conducting for several years provides a general theoretical and methodological framework for the analysis of a number of professional practices and the generalization of the lessons stemming from such case studies (2.1). However, in the case of the research presented here, as in each case study, it was necessary to take into account the specific work context of the professionals whose practices were being examined in order to develop a specific and appropriate methodology for data collection and analysis (2.2).

2.1 General research program on professional practices

Under this program, the professional practices we are focusing on are those of actors striving to modernize and design facilities, equipment and work and production systems. The goal of the research program is to identify ways to transform the work context of these professionals, which is often determined by corporate and project management. The general goal is to take better account (in terms of greater effectiveness and more safety) of users' needs (in operation and maintenance) in the design of work situations. To date, three studies of professional practices have been conducted under this program, including this one [12, 13, 25]; a fourth is underway [14]. *Table I* presents these studies, by type of practice and type of intervention.

Under this program, it is necessary to examine:

1) the question of which transformation process of the professional work context should be favoured;
2) the ontological, theoretical and methodological issues raised by the analysis of professional practices, and even of human activity in general;
3) the generalization of results of case studies.

It should be pointed out that the general transformation approach which underlies these case studies is borrowed from French ergonomics.

In fact, it involves determining the relationship between:

1) the activity of professionals;
2) the determinants of their activity;
3) the effects of this activity on the correction and/or design choices, project management (actors, structuring, etc.) and company management (policies, values, etc.).

Thus, for a given case study, it is possible to identify the characteristics of the participating company and, if applicable, of the project involved, which are conducive or not conducive to effective action by the professional or professionals whose practices are being examined. These characteristics indeed influence their activity. By remodelling them, their work can be improved and the results obtained can benefit future correction or design projects and the daily operation of production facilities and equipment.

The theoretical and methodological framework underlying the analyses of practices was set out in the book published on the library case (the first completed case study) [12]. It should be clarified that when this research program began, the various phenomena characterizing the professional practices of intervention were identified through a review of the literature on professional practices (in ergonomics and other disciplines) and on human activity in general (literature from disciplines as varied as cognitive psychology, cognitive anthropology, human ethology, ethno methodology, etc...). Let us review a few of the lessons drawn from this documentary analysis:

- professional practice, on the one hand, is part of the course of life, that is, a given intervention stems from all past actions and the entire cultural baggage of the professional (general culture, trade cultures, local and even personal cultures) and, on the other hand, this same intervention is an opportunity for the professional to build his culture;
- it is at all times linked with special circumstances, in the here and now. It is thus not an a priori given but is dependent on the context, which is characterized by the professional's situation (including his prescribed tasks), his state (emotions, values, etc.) and his culture;
- it is related to the professional himself i.e., it is not the same as the prescribed task or the formulated request. It is the professional who constructs the path of intervention as he discovers it. To understand the intervention, the meaning he gives to his actions and communications at all times must be understood.

This ontological position led us, among the theoretical perspectives on cognition, to choose situated cognition anthropology, a theoretical movement which has been given some consideration in the ergonomic analysis of work over the last 20 years [17, 26]. Consequently, the principles and methods of data collection and analysis used are largely drawn from those proposed by the theoretical framework related to the course of action [27, 28]. In concrete terms, this means that the analyses of practices are centred on the dynamic of an actor's interaction with what, in his environment, appears relevant to him in the here and now for his internal organization. The activity is analyzed from an intrinsic viewpoint, i.e., by focusing at all times on the meaning, for the actor, of his actions and communications. The modelling is based on data produced by continuous and in-real-time observation as well as on verbalizations, mostly in the context of self-confrontation or interruptive interviews. The observation data provide ample

TABLE I

Research Program on Professional Practices: four Case Studies

		Type of intervention		
		Ergonomist	Preventionist	Engineer
Type of intervention	correction	Library case [12]	—	—
	design	ISO-9002 Certification project [25]	—	—
		Aluminium plant design project [13]		
		—	—	Production process or equipment design pro- entrusted to a consul- ting

TABLE II

Project Phases and Research Stages

Project year	Project phases in which the professionals were involved	Period of data collection and analysis	
		Activity analyzed	Actual collection
1	I Predesign (feasibility study, comparison of financial implication and chances of success of various innovation options) I Design (final choice, determination of investment budget)		
2	II Preliminary engineering (clarification of project goals for select option in technical terms and in terms of quality, deadline and costs, division of project into subprojects, conducting a series of studies, producing general specifications))		
3	IV. Detailed engineering (distribution of responsibilities among subproject leaders, writing up book of specifications or technical specifications with supporting plans, drawings, technical files, etc.)		
4	V. Calls for tender and construction		
5	VI. Pre-operational checks (tests on parts of facilities)		
5 and following	VII. Start-up, including corrections		

traces of actions and communications and of the dynamic context in which the activity takes place. Special techniques for data collection using pen and paper were developed since video taping did not seem to be appropriate for studying professional activities [12]. Verbalization relies on these observation data to document the meaning at each moment. Observation, verbalization and modelling require a period of familiarization with the professionals whose activities are to be analyzed and with their work context; the requirements of this period have been set out previously [12]. The results of all analyses of practices are validated with the professionals involved, as is the usual practice in ergonomics.

The question of generalizing case-study results arises for two components of the study, that is, the transformation of the professional work context and the analysis of the practices. On the one hand, it is through the accumulation of case studies that the research program generates a body of knowledge which allows for the generalization of results relating to one or the other of these components [ex. : 10] since each case study benefits from the acquired knowledge of other case studies and in return sustains the research program. On the other hand, generalizing results also involves taking advantage of the literature which deals with professional practices and human activity in general and with the conditions for effective intervention by actors involved in the modification and design of facilities, equipment and production systems (for example, the literature on project management - in particular that stemming from studies in simultaneous engineering, socio-technics, Total Quality Management and design ergonomics – and the literature on the sociology and management of organizations).

2.2 Methodology specific to the case study: an a posteriori reconstitution of activity

Thus, the research program was initially designed to analyze professional practices "here and now". However, when this case study started, the design project in which the two preventionists and the ergonomist were intervening was already quite advanced (2.2.1). A special methodology therefore had to be developed in order to reconstitute the traces which could support self-confrontation verbalizations (2.2.2).

2.2.1 The project phases and research stages

The design project, which involved an aluminium plant with a production capacity of 400,000 tonnes, took place over approximately five years. The phases of this project corresponded to those normally found in engineering (see Column 2 of *Table II*).

When the researchers were asked to analyze the practices of the three professionals, Phase V (construction) was quite advanced and Phase VI (pre-operational checks) was just starting. Methodological and practical constraints led us to reject outright the idea of examining past and current activities at the same time. Although phases V to VII also included occasions on which the professionals had to influence design process and choices, the earlier phases were considered to be more crucial since the margins of manœuvre were greater during these phases [ex.: 29 to 33]. This case study thus focuses on the earlier phases. The collection of data on phases I to IV inclusively took place over a five-month period, of which 1/3 overlapped with the end of construction and 2/3 with the start of pre-operational checks.

2.2.2 Traces of past activity to support self-confrontation

Three special circumstances had to be taken into account: the analyzed professional activity was conducted over a three-year period; it took place, at the latest, four months before the research project started and, at the earliest, slightly more than three years earlier; it was conducted partly on an individual basis and partly on a joint basis since the three professionals were not appointed during the same phases of the project (see Section 3.1). Thus, the methodology implemented was as follows.

A means to replace real-time observation data was created to serve as a basis for self-confrontation. Following a period in which we got to know and understand the project outline (time, budget, phases, actors, etc.), the documents and tools used by the professionals were compiled in order to pick up the obvious traces of the activity left by the three professionals on these documents and tools: diary notes, comments on plans, minutes of meetings, successive versions of sections included in the general specifications at the request of the professionals, etc. With the help of the professionals, these traces were dated and put back in chronological order so as to create an account of the facts and also of their actions (including communications) as the project progressed. The self-confrontation interviews were conducted on the basis of these traces.

The self-confrontation was guided by two major concerns:

1) getting our interlocutors to recall both the decisions made at a given moment of the project and the contextual and knowledge elements that were meaningful to them at the time, "as if they did not know the end of the story";
2) validating and completing a coherent account of the meaning of these actions.

This methodology can be illustrated through the following example. During the first interviews (before the verbalizations), the three professionals referred to themselves as if they had been a team throughout the project: in their view, this was a key to their success. The chronological reconstitution of the traces showed that the ergonomist had received a call from the future plant director inviting him to be a member of the operation team (see Section 3.1) right at the pre-design phase; and that each individual had in fact been appointed at different times, with different mandates, in different (project and operation) teams. The ergonomist's recollections of this telephone conversation helped to fill in the account of actions and communications and to document their meaning for him. For example, afterwards, the ergonomist got in touch with the specialist in environment, health and safety, a member of the project team, so that they could form a subgroup and coordinate their actions, given that they had the same concerns.

TABLE III

Collected Interview Data

Interviews	Number	Duration	Total
Interlocutors : he two preventionists and the ergonomist Interviews : (putting in chronological order the traces of their actions and communications) and self-confrontation verbalizations (meaning of these actions and communications for them)	3/pers. individually or as a group	3 à 6 hours	27 hours 539 pages of verbatim
Interlocutors : six project actors, interlocutors of the professionals, involved in the project and operation teams Interviews : semi structured, on the work context of the professionals (the project)	1/pers. individually	1 1/2 to 2 hours	10 1/2 hours 181 pages of verbatim
Total	12		37 1/2 hours 721 pages of verbatim

In total, the activity of the professionals was reconstituted a posteriori based on 27 hours of interviews and verbalizations recorded and retranscribed (539 pages of verbatim) (*Table III*). In addition, 10 1/2 hours of semi-structured, complementary interviews (182 pages of verbatim) were conducted with six of their interlocutors (including the leaders of the project and operation teams described in 3.1); these interviews aimed to understand the dynamic underlying the establishment of the professionals' work context and at times helped to fill in the chronology of events.

The analysis and modelling were carried out based on the notion of "strategy," a grouping of the meanings of the professionals' actions and communications from their viewpoint, based on underlying issues (around which the actions and communications were structured) as well as the dynamic decision-making process related to each of these issues. These strategies were highlighted through an analytical-regressive process, that is, based on an analysis of the completed activity by, going back over the different steps of this completion rather than analyzing step by step the process of generating these actions in real time (synthetic-progressive method) [27, 28].

3 - RESULTS SPECIFIC TO THE CASE STUDY

Results are presented in three phases. Some data related to the project and the company complete the information on the work context of the three professionals provided to date (3.1). Then, the results obtained by the professionals are presented briefly since our goal is to show the interest in learning more about their activity (3.2). This description of their activity is then presented (3.3). Lastly, the recommendations formulated to the participant company on the basis of this diagnosis are listed (3.4). Thus, by the end of Section 3, all the data necessary for drawing general lessons will have been presented.

3.1 The work context of the two preventionists and the ergonomist

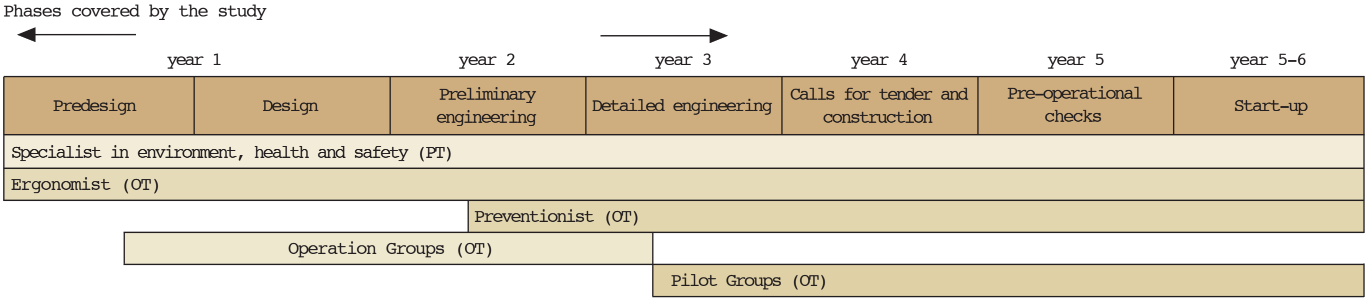
It is necessary to specify two elements of this work context to allow for an accurate modelling of the activity of the three professionals presented below: the variety and role of project actors depending on the phase (3.1.1); the degree and forms of OHS and ergonomics integration into the company at the outset of the project (3.1.2).

3.1.1 The project actors

The aluminium plant design project represented a formidable technological challenge, requiring innovations in various production sectors, including the pouring centre (with level pouring), the paste plant and the processing of anode butts. But it also involved designing a plant which complies with the company's

FIGURE 1

Actors in project team (PT) and operation team (OT), by time of arrival in the project and period during which they intervened (shaded areas)



fundamental values regarding ergonomics, OHS, environmental protection and human resources management. It should be noted that the director of the future plant was appointed at the same time as the project manager so as to influence the design and help to best take up this challenge. Each individual set up a team around himself called, respectively, the "operation team" (OT) and the "project team" (PT). Two of the three professionals whose activity was being analyzed were members of the first team and the other was a member of the second team; to make it easy to identify them, we have highlighted them in bold in the two following subsections.

The Project Team (PT)

During the predesign phase, the project manager brought together 10 « technological consultants »: nine individuals responsible for making decisions on the engineering process for a sector of the plant (centre of electrolysis, anodes, pouring, paste tower, high voltage, etc.) and **a specialist in environment and occupational health and safety**, appointed to influence them. They had to ensure that the project's time-budget was respected, to formalize the technical specifications and to manage external engineering since the company did not have an in-house team of engineers for major projects. During the phases of the project, contractual links were established with seven external firms in order to meet needs in engineering, architecture and project management. A total of 2 million engineering hours were needed and 700 to 1000 designers (engineers, technicians, draughtsmen, etc.) worked on the plant's detailed definition.

The Operation Team (OT)

In order to influence the design, the director of the future plant engaged the services of various groups and specialists during different phases of the project (*Figure 1*). First, right at the predesign phase, he engaged the services of **an ergonomist** who would follow the project until the end. Then, from the end of the preconcept phase to the 50% stage of detailed engineering, he created one operation group per sub sector of the future plant, each bringing together users (engineers, technicians, etc.) of existing plants in order to learn from their experience and avoid repeating the mistakes observed elsewhere. He also appointed **a preventionist**, at the 50% stage of preliminary engineering who was responsible for ensuring, until the end of the project, that the design choices would facilitate prevention management in the future plant. Lastly, he created pilot groups at the 50% stage of detailed engineering, made up of the future management team and whose mission was to "learn about" the new plant while it was being designed and thus to appropriate it easily. Their role obviously pushed them to challenge the project team and to influence the design.

3.1.2 Tools and Skills Available at Start of Project

After 20 years of experience and development by experts in the field of ergonomics and OHS, at the start of the project, the three professionals disposed of a number of elements forming their work context:

- a company policy that put the issues of ergonomics and OHS at the forefront;
- an "engineering process," that is, a project implementation methodology developed as of the early 1980s (therefore around 20 years prior to the project) which states the principle of "eliminating risks before they appear" (translation) and, since 1987, requires that critical OHS reviews be conducted, that is, that a checklist be revised by the designers in order to identify the risks related to the facilities, equipment or practices and involve, as needed, the operations staff and specialists (in OHS, ergonomics, occupational hygiene , etc.);
- a prequalification process for contractors which reserved the right to tender for those who met the criteria related to, in particular, ergonomics and OHS;
- a pool of contractors in the region who were familiar and had experience with the company's culture and practices related to OHS and ergonomics;
- a pool of engineers, technicians and other staff who worked in operating plants and had received basic training in ergonomics and OHS and had collaborated with specialists in these areas;
- results of research completed just before the project started, led by IRSST researchers together with, among others, the ergonomist whose activity was being analyzed in this study. This research led to the development of a methodology, referred to as "dynamic simulation," which improved the checklist-type critical OHS reviews, by drawing on the future activity approach which is prevalent in ergonomics [29, 34, 35].

Although benefiting from these gains, the three professionals had to innovate because this was the first experience of integrating OHS and ergonomics into such early phases of a large-scale project. Their work yielded the following results.

3.2 The effects of integrating OHS and ergonomics into the project

As regards prevention, a great number of dangerous situations for future workers were eliminated at the design stage (3.2.1). However, additional gains could have been made in terms of OHS prevention and ergonomics (3.2.2).

FIGURE 2

OHS risks eliminated at source

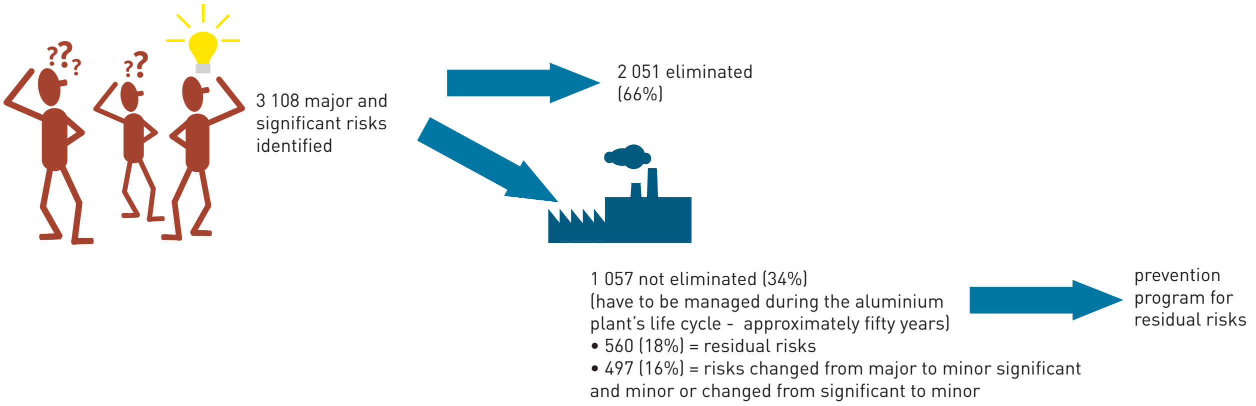
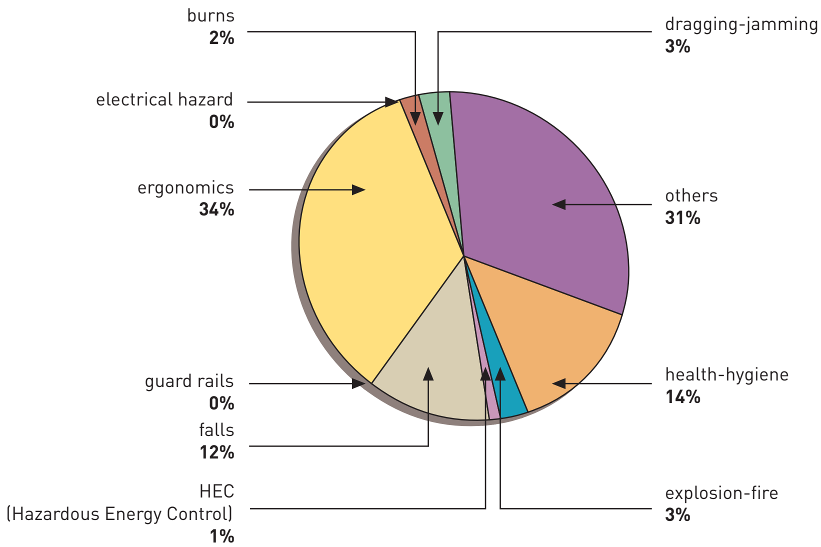


FIGURE 3

Significant risks identified at the engineering stage, by category



3.2.1 Positive effects, in particular in terms of prevention

These effects relate to the elimination of dangerous situations at source (a), the planning of the prevention program before the plant's start-up (b) and lastly, "secondary" positive results (c).

a) Dangerous situations identified and eliminated at source.

The two preventionists and the ergonomist were able to markedly reduce the risks in the workplaces and thus make significant financial gains in the short and long terms for the organization. Indeed, 3108 major risks were identified and brought to the attention of design engineers (*Figure 2*). Of this number, 2051 were eliminated and 497 were reduced at the engineering stage; the management of the 1057 residual risks was also planned before the start-up of the new plant.

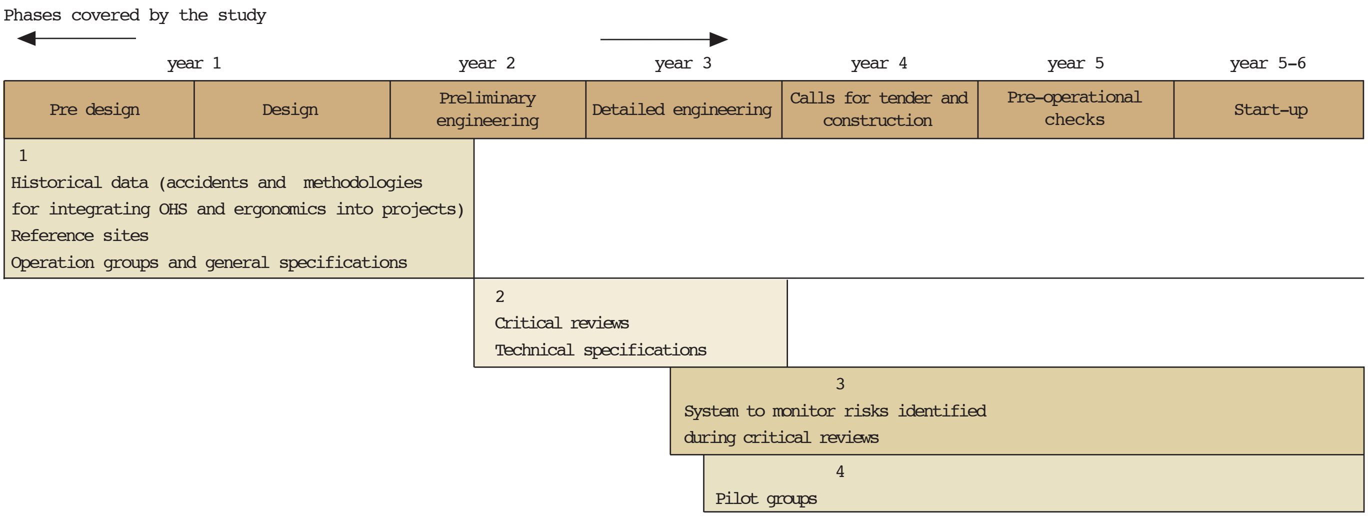
These high-risk situations were identified through critical reviews conducted as soon as 50% of the preliminary engineering was completed, and up until the end of the detailed engineering phase; this particular process is described in the section related to the professionals' activity. The "major" risks identified are divided as follows: circulation (57%), zero-point energy (18%), lifting equipment (10%), conveyors (8%) and confined spaces (7%). These five categories are considered to be a priority by the organization, given the indicators compiled in the operating plants, on which the professionals focused their action. *Figure 3* shows that a high proportion of "significant" risks (34%) are classified under the "ergonomics" category. Based on the definition in force in the organization, a risk is "ergonomic" if it can be attributed to postures and movements and if it is linked to the layout of the workplace.

A concrete example of an eliminated risk can be provided by reporting on the case of the aerial conveyor which sends the coke needed to make anodes to the top of the paste tower building. This 150-metre-long conveyor is situated quite high on an incline: 66 metres high at one end and 32 metres high at the other end. In the initial design, a roller bed was installed on a walkway providing access for maintenance. The circulation area, located next to the conveyor, was supposed to be 8 metres wide. The walkway was supposed to be equipped with a guard rail meeting the minimal standards, i.e., screen 1.1 metres high on the circulation side and 1.4 metres high on the conveyor side; a net structure was going to be placed above this walkway. When the critical reviews were conducted, four types of risk for workers ensuring maintenance of the conveyor were noted: risks related to dust emanation, ergonomic risks when changing the belt and rollers, risks of falling while working on the conveyor (neither the guard rail nor the net structure could have prevented the fall) and lastly, risks of being dragged along by the conveyor. Four categories of changes were made: installation of a belt conveyor supported by air (elimination of rollers and dust and reduction in maintenance and service needs), enlargement of the circulation area, design of a closed structure with windows (elimination of guard rail and net structure) and lastly, installation of an emergency handle.

Thus, were it not for the professionals' activity, 2051 risks would have generated compensation and manage-

FIGURE 4

Extrinsic Description of Professionals' Activity during the Project



ment costs during the entire life cycle of the new plant. In addition, 497 residual risks would have remained in the category of more serious risks which would also have had to be managed and compensated during the entire life cycle of the new plant.

b) Planning the prevention program before the plant start-up

A system which monitored whether or not changes to the design were made in order to take the identified risks into account was developed during the project; we will come back to this system in the section dealing with the professionals' activity. It should be mentioned here that at the end of the project, this system provided a clear idea of residual risks, i.e., not eliminated during the design phase. Hence, it was possible to plan the prevention program even before the plant start-up.

c) "Secondary" effects

The professionals also improved the overall engineering process. Indeed, the monitoring system was also developed to enable the operation team to locate the engineering plans at any time. Also, during the OHS activities in which the ergonomist participated, the latter was able to target equipment which was not essential to efficient operations and design choices which, while not representing OHS risks, would have caused inefficiency.

3.2.2 Lost potential

The figures which have just been presented are impressive. It is therefore not surprising that the professionals observed and the directors of the participating company were interested in participating in the research in order to formalize the approach implemented during the design of the aluminium plant, so that such intervention could become a "minimum standard."

However, with a view to continuous improvement, if we look at the potential that was not exploited, or the risks that were not eliminated:

- 1057 risks, despite being identified at the engineering stage, were not eliminated and thus will have to be managed throughout the entire life cycle of the plant;
- minor risks were not systematically dealt with during the project, due to lack of time and not lack of means;
- the professionals were not able to follow the design of certain parts of the plant, for all risk categories (for example, if the design was bought on a turnkey basis);
- some risks were identified only at the plant start-up;
- users' problems which generated inefficiency without creating OHS risks were not identified as a priority, since the approach implemented by the professionals was mainly devoted to identifying and controlling OHS risks. In particular, ergonomics was used as a technique to identify OHS risks, which is restrictive.

It is useful to consider this lost potential in terms of its causes as well as the means that would make the work of preventionists and ergonomists more effective, so as to increase the value added of their involvement in projects.

3.3 The real intervention activity of the two preventionists and the ergonomist

The reconstitution of traces and the verbalizations lead to a modelling of the activity of the three professionals from both the extrinsic perspective, by emphasizing the tools and means implemented for action (3.3.1), and the intrinsic perspective, by describing the intervention strategies deployed throughout the project (3.3.2).

3.3.1 The means of intervention implemented during the project (extrinsic description)

Four main means were implemented by the two preventionists and the ergonomist during the project, through close collaboration with the leader and members of the project team, the leader, operation groups and pilot groups of the operation team, the quality manager and external design engineers. *Figure 4* illustrates at which points in the project each of these means were put in place.

First, the professionals took stock of the major accident issues in existing plants and in reference situations, and then participated in operation groups at the end of the predesign phase in order to enrich the general specifications.

They then coordinated and participated in conducting critical reviews. This involved bringing together designers, operators and a preventionist or an ergonomist, depending on the type of critical review conducted, that is:

- "traditional" critical reviews led by the preventionist from the operation team, which consisted in identifying the risks based on a check list;
- "dynamic simulations" where the ergonomist implemented a process of projecting the future activity, such as is the practice in ergonomics.

Then, the professionals "invented" the computerized risk monitoring system (the "Critical Reviews and Intervention Plan" data bank) during the project in order to respond to the needs of the context (in particular, the great number of risks identified). This system worked as follows: when a risk was detected during a critical review, it was classified by the professionals (major, significant, minor) and the action required to correct it was assessed. The information was then input into the data bank. When the correction was made, the person in charge of this correction (a technological consultant or an engineer) indicated where it could be found (on which specifications, drawings, plans, etc.). Three types of correction were possible:

1) the design was changed to eliminate the risk;

2) the design was kept as is but the risk was reduced as a result of technical changes;

3) the risk could not be dealt with at the engineering phase and would thus have to be taken into account as a residual risk by the operation team by means of the prevention program.

This databank proved to be useful at several levels to monitor and control OHS and ergonomics integration. Indeed, it helped to record the risks and their treatment in a dynamic way (documenting successive states) on the one hand, and to monitor the corrections by means of a tracking system (management tool), on the other hand. Moreover, it was used to plan the prevention program before the plant start-up and to guide the pre-operational checks (Phase VI of project) systematically. Lastly, it was mentioned that it was developed in order to serve the interests of engineering and operation since it contained all the corrections by sequence of completion (chronology of plans where the changes can be found) so that the future plant operators, i.e., the pilot groups set up at the 50% stage of detailed engineering phase, could locate the engineering plans within a few minutes at any time.

Lastly, the professionals worked closely with the future plant operators. The pilot groups were an effective means to continue influencing the design.

3.3.2 The intervention strategies deployed by the professionals (intrinsic description)

An examination of the meaning that their actions held for the three professionals (as expressed in the self-confrontation verbalizations) reveals five main strategies deployed throughout the project. We will present an overview of these strategies (a) followed by a detailed example (b).

a) Intervention strategies: an overview

The strategies are as follows: (1) advancing step by step; (2) adjusting to the engineering demands; (3) legitimizing their actions in OHS and ergonomics; (4) having the design choices tested by the users' activity; and finally, (5) constructing a «memory of their actions». They can be summed up as follows:

- Highly experienced in their field, but isolated and appointed at different times, the three professionals intervened together for the first time in a project of this scale. The appropriate methodology was not known in detail ahead of time; it had to be adjusted and even created as rapidly as possible since this was a fast track project. In order to intervene where they were most useful to the design but without being in reaction mode, the professionals continuously analyzed the progress of the project and of their own activity: **they advanced step by step**.

- They were aware of the importance of staying as close as possible to the project and not establishing an OHS-ergonomics process that was parallel to that of engineering. All decisions they made – including that of getting together as a group of three –were thus designed to support the progression of engineering. They thus **favoured action that was integrated** into the project (rather than parallel action).

- However, the general design process did not really integrate OHS and ergonomic issues into its methods; this process was mainly programmed on the basis of the phases and needs of engineering. The professionals thus found themselves in an ambiguous situation, that is, they were appointed to intervene within the design process, yet they had to negotiate their methods, which were at times newly-created, and continuously demonstrate that these served the project: they sought to **legitimize their actions**.

- Their goal was to influence the design by expressing the engineering choices in terms of "work situations (production and maintenance)"; hence, they tried to detect the inefficiency and OHS risks caused by these choices in terms of "utilization." In order to detect these, the professionals could not make do with data on procedure and equipment. They tested the design choices by projecting in detail the future running of operations, that is, by **reasoning through dynamic simulation.** This joint strategy of the three professionals was mainly used by the ergonomist on a daily basis.

- As the project progressed over time, the volume of information increased exponentially. The project team included 11 people, and at the height of the project, there were 1000 designers but only three professionals. The latter thus developed a series of means to ensure that nothing was forgotten and to maintain control. Some of these means could become sustainable practices for future projects. The professionals were thus constructing a **memory of their actions** for the duration of the project and beyond.

The following example shows that these five strategies were interlinked and brought together more subtle strategies from which the links between the determinants of the professionals' activity and its effects emerged. It also highlights the fact that each strategy was rooted in a dynamic which went beyond that of the project, that is, the professionals constructed their intervention according to the context which was established gradually as interventions were carried out (in design and in correction) and strove to remodel their future intervention context.

b) An example of striking the right balance between expertise and the delegation of responsibility to non-specialists

The strategy "action integrated into the project" reflected the fact that in order to best influence the design (choices and processes), the professionals took into account the constraints of engineering and influenced them as needed, but mainly avoided implementing a parallel design process. Thus, to promote integrated action, they used three more subtle strategies, one of which involved arbitrating continuously between:

- doing the work themselves, or even resorting to a professional who was more specialized than themselves in OHS (an industrial hygienist or acoustician, for example) or in ergonomics (an ergonomist specialized in software design, for example); or
- delegating to non-specialists who had received basic training or information (design engineers, the quality control manager at the external engineering firm, etc.).

This division was possible because both types of skills were available. For 20 years, experts in ergonomics and OHS had increased the transfer of their know-how to internal ingineers and to external firms in the region (prequalification process) thus fostering consensus on the value of OHS, the acquisition of healthy practices (conducting critical OHS reviews, applying standards, etc.) and skills development to improve work situations. They had also developed training programs and intervention tools that were easy to transfer, thereby allowing for the initiation of the design engineers of external firms who had never worked for their organizations. In this case study, as there were only three professionals compared to the 700 to 1000 design engineers, these professionals could not deal with all the OHS and ergonomic issues. Therefore, the division between "expertise" and "transfer to non-specialists" allowed them to concentrate their efforts on areas where they had the highest value added and to ensure that OHS and ergonomics influenced the design choices even in their absence; this strategy certainly helped to eliminate risks at source.

The responsibilities which the specialists decided to keep for themselves and the criteria taken into account when arbitrating between "doing the work themselves" and "delegating" have been highlighted [9]. One of these criteria was the degree of expertise and open-mindedness of the non-specialist with whom they had to collaborate or to whom they had to delegate. However, it turned out that the three professionals did not necessarily associate "high level of skills and open-mindedness" with "decision to delegate." It was sometimes even the contrary, the professionals seeing this as an opportunity to favour action which could be integrated into engineering while at the same time reconfiguring their future intervention context:

- in terms of the project, spending time on somebody who had little training and was reluctant often did not yield better results than just applying standards... therefore, it was just as effective, in this case, to delegate by giving access to existing guides;
- on the contrary, working as an expert with somebody who was open and initiated was the only way to obtain greater value added in terms of the project and to implement more advanced ways of doing things, which would serve as an example for the future.

For example, the professionals decided to spend time working closely with one member of the project team in order to test, as early as the first critical review, the non-traditional process of "dynamic simulation (recently developed)." This project team member had gained relevant collaborative experience with the project's ergonomist through past interventions in correction and design. Working with this member helped to optimize the chances of success of the endeavour such that it could be used as an example to encourage other project actors to get involved in dynamic simulation in the current project and in future projects.

However, the approach by which non-specialists take charge, which had been much relied on over the last 20 years, also had its setbacks. Indeed, it had caused "expertise to be neglected," that is, the value added of interventions led by specialists in prevention and ergonomics and the characteristics of these interventions had not been highly valued, formalized and diffused. For example, the "engineering process" referred to above forced the designers to conduct critical reviews but:

1) left them with the responsibility of determining whether or not the involvement of an OHS or ergonomics specialist was necessary; and
2) did not provide for any other steps to be taken in the programming of projects, as if the work of these specialists, in design, was limited to conducting such critical reviews.

Thus, in the context of this project, the professionals had to come to terms with the feeling developed by some designers that they were able to practise ergonomics and OHS without a specialist since this merely involved sporadically applying a few simple techniques. A vicious cycle had thus taken hold, i.e., the specialists had simplified their knowledge and know-how in order to allow non-specialists to appropriate it easily; in return, several of these non-specialists had not developed a clear vision of the skills and the complexity of the experts' work. For example, unlike the specialists, some of the interlocutors interviewed mistakenly believed that *"meeting workers and operation employees is the best way to identify OHS and efficiency problems, their causes and the means to solve them"* (translation), which underestimates the skills used by the ergonomist to get round the difficulties that the operators have in describing the actual work they do and in establishing links between the problems, the activity and the design [36, 37, 47].

In the project examined in this article, the approach by which non-specialists take charge of these issues has, among other things, negatively affected the development of a project programming that can truly support multidisciplinary design. Thus, the three professionals lost a lot of time structuring the desired cooperation with the designers and building up margins of manœuvre for themselves during the project. This time, which was devoted to "legitimizing their role," was taken from the time that should have been spent on interventions with "direct value added." Moreover, compromises were made when it was impossible, without considerable effort, for them to legitimize their role; for example, the specialists often had to rely on the designers even though they knew that it would be better or even necessary for them to act as experts.

3.4 The factors involved in the effectiveness and lack of effectiveness of ergonomics and OHS integration

In a design process, taking OHS and ergonomics into account most often means coming up against the constraints of time, money and technology, the three main aspects governing projects. The value added of a study on the real activity of preventionists and ergo-

TABLE IV

Overview of determining factors of the professionals' activity which were conducive or not conducive to optimal action in the project

Categories of determining factors	Determining factors
Relating to project management and its continuous improvement	▶ Goals centred on overall performance of the project for the organization; Possibility to influence the project management and the operation early on; Preponderance of engineering at the level of project programming; OHS and ergonomics in correction and design viewed as a continuum; Existence of an organizational "standard" in terms of integrating OHS and ergonomics into the design process; Existence of formalized practices of continuous project improvement.
Relating to the role of ergonomics	▶ Testing design choices in terms of users' needs, not only for improving prevention, but also for efficiency; Distinguishing between the occupations of preventionist and ergonomist.
Relating to the role of expertise	▶ Flexibility to adopt type of intervention (with or without a specialist) having the highest value added; Valuing "expertise" in prevention and ergonomics (in relation to the opportunity for intervention by actors in other disciplines initiated in these fields).

nomists lies in its capacity to go beyond this rapid and widely used explanation.

Thus, four categories of determinants of the professionals' activity were revealed by the case study and led to recommendations made to the participating company. *Table IV* classifies these determinants according to their relation with project management, the role of ergonomics, the role of expertise or the links with subcontractors. It should be acknowledged that these determinants go beyond the time of the project and also involve the organization as a whole.

4 - OVERALL SCOPE AND LIMITATIONS OF RESULTS

Beyond the ways of transforming the work context identified for the participating company, the case study presented here contains lessons likely to influence the practices of other professionals involved in other types of design projects and organizations (4.1). However, some of its limitations regarding usefulness and the generalization of results must be underlined (4.2).

4.1 General scope of results

The case study provides a concrete example of the value added of integrating ergonomics and OHS into design projects (4.1.1). It also allows us to formulate some guiding principles which can help other companies develop a global strategy related to OHS and ergonomics management (4.1.2). Some of these principles are already part of the current state of knowledge on the integration of these disciplines into the design process, while others draw attention to elements which are less present in the literature (4.1.3).

4.1.1 The value added of integrating ergonomics and OHS into the design process

Without "putting a price" on it, our research gives an idea of the extent of the value added by integrating OHS and ergonomics into the design process. This value is described in terms of risks eliminated at source, which will never have to be compensated for or corrected during the plant's life cycle. The diffusion of these results completes the rare research efforts devoted to assessing the economic repercussions of integrating ergonomics and OHS into the design process [ex.: 38 to 42]. We believe that all these studies will help to promote a more widespread adoption of enriched approaches to project management. In fact, they all show that this type of approach to the design process is perfectly consistent with the various value-added programs (VAPs) that companies are increasingly implementing in order to eliminate activities which do not contribute to their profitability.

4.1.2 The principles of corporate OHS and ergonomics management

Guiding principles emerge from the case study which can help other companies develop a global strategy related to OHS and ergonomics management. These principles set out in *Figure 5*, support the pursuit of goals related to overall performance for the organization since they deal with the management of design projects, the linkages between operation and design activities and lastly, the balance to be created between the merging of specialties and expertise within an organization.

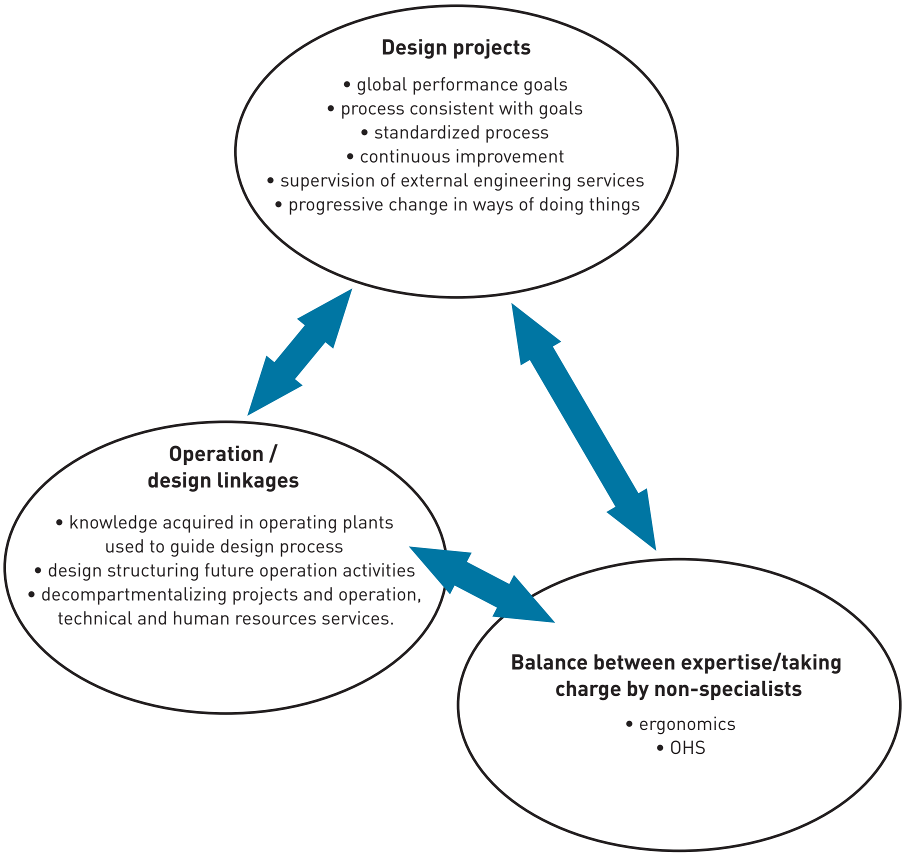
By their very nature, these principles are aimed at preventionists and ergonomists who intervene in work situations, those in charge of other functions (engineering, technical services, methods, etc.) and company directors. More generally, they concern organizations, regardless of their activity sector, size, resources and experience in OHS and ergonomics. However, they seem to be particularly relevant for organizations which are just getting started in these areas. Indeed, a company's 20 years of experience in integrating OHS and ergonomics in the design process has been examined in light of current scientific knowledge. The exercise thus helps to identify the pitfalls that a novice company can avoid, the "successes" that it can reproduce and, on the whole, the means to improve its ways of doing things while limiting trials and errors.

Some of these principles confirm those already put forward in the literature on simultaneous engineering, socio-technical management of projects, Total Quality Management and design ergonomics. Hence the need to formulate project goals in terms of global performance, implement a renewed design process consistent with such goals (which assumes doing more than simply involving specialists in other fields in a traditional engineering process), introduce continuous project improvement activities that link design with operation of facilities and systems, and structure multidisciplinary work such that it does not involve simple cohabitation or the merging of specialties [ex.: 42, 43, 44]. However, these principles are often formulated in ideological terms in much of the literature on project management. Our case study, on the other hand, shows how their effective implementation can concretely influence the ways of doing things of those who are involved in multidisciplinary projects and the results that they obtain.

To our knowledge, three of the guiding principles are less present in the literature or are hardly taken into consideration in the everyday reality of organizations. This is true of the component relating to the importance of having at one's disposal within an organization a standardized design process as an essential tool for continuous project improvement. One article produced in the context of our research project was moreover devoted to the project's record: the gains that can be expected from it, the methods of its construction (what and when to document and by whom), the way of exploiting it to ensure effective improvements in design projects and the role that preventionists and ergonomists can play in it [46]. Also, although the literature on multidisciplinary design often suggests that functions be decompartmentalized at the project level, it rarely emphasizes the importance of also decompartmentalizing them at the level of the organization's permanent structures. This nevertheless represents a major issue which involves, among other things, giving the "less classical" actors in the design process (preventionists, ergonomists, human resource managers, etc.) the opportunity to conduct strategic monitoring of projects so that they can prioritize their interventions based on the problems that they have to solve and manage on a daily basis in the organization. Lastly, the literature deals with the scope and limitations of participatory ergonomics while emphasizing one component -- the degree of appropriation that is possible by non-specialists of the intervention tools and skills of ergonomists (analysis of the activity, highlighting reference points of design, supporting changes, etc.) [ex.: 47]. Thus, it only indirectly addresses the pitfalls, highlighted in this case study, of an organizational strategy which is too strongly based on the model underlying participatory ergonomics, namely that of an approach by which non-specialists take charge.

FIGURE 5

Guiding principles for a global OHS and ergonomics management strategy within an organization



4.2 Limitations of results

The activity implemented by the two preventionists and the ergonomist in the context of the plant design project was not examined in its entirety because the phases subsequent to detailed engineering (calls for tender, construction, pre-operational checks and start-up) were not documented. As regards the earlier phases, an analysis in real time rather than a posteriori analysis would perhaps have allowed for even more detailed modelling. However, this does not in any way invalidate the results of the case study.

Moreover, the activity analyzed in this research relates to that of a specific group of professionals, in a particular design project conducted in a single company. Based on this fact, the general lessons which we have just set out may be liable to criticism. However, this limitation to the generalization of results remains relative since the research program is based on an accumulation of case studies and makes use of scientific knowledge derived from other sources (Section 2.1). Under these conditions, the professional practices examined cannot be considered to relate only to a specific case of engineering, and in fact it is possible to highlight general characteristics and lessons from a given situation which transcend the specificity of the case studied.

Lastly, the research reveals two ways to transform the work context of ergonomists and preventionists but for which it cannot provide indications and concrete means by which to achieve them. On the one hand, it borders on the field of organizational transformation, an area which ergonomic analysis cannot claim to occupy since the implementation of these changes relates to approaches belonging to the sociology of organizations and management [ex.: 48]. Although ergonomists have to date formalized means of action in collaboration with technical designers – engineers, architects and computer engineers –, they have developed many fewer methods of joint intervention with "organizational designers" [ex.: 49, 50]. On the other hand, this case study, along with others, raises [ex.: 31] the need to establish specific conditions to support the implementation of real multidisciplinary practices when the design is entrusted to an external company rather than conducted in-house. These conditions relate to managing service relations, that is, inserting a number of obligations into the contract, rethinking the composition of the firm selection panel, planning appointments to assess the services rendered during the project, etc. However, again in this case, this type of transformation requires that action be taken in a larger arena than that described and explained by the research, that is, the practice of consultant engineers and its organizational determinants.

5 - GENERAL CONCLUSION AND PROSPECTS FOR FUTURE RESEARCH

In our research program, the ergonomic analysis of activity is applied to the professional practices of actors working to modernize and design facilities, equipment and work and production systems. Our goal is to highlight the determinants of these practices and their effects. This involves better understanding the factors which are conducive or not conducive to taking users' needs into account (at operation as well as in maintenance) in the design of work situations, in order to improve their efficiency and safety. The case study set out here leads to at least two interesting prospects for future research.

First, ergonomic analysis could be advantageously enriched by approaches proposed by disciplines such as the sociology and management of organizations. This would involve giving us the means to play a role in the sphere of the organizational dynamics which determine the practices of actors, including but not only those deployed in a design context. In particular, it is necessary to identify the levers of action which ensure that the gains made in specific interventions will be realized in future practices. Similarly, it would be useful to better understand the linkages between the specific practices of projects and those of the "permanent organization." Indeed, the social dynamic which is expressed and built over the time of the project goes against a key principle, considered to be "natural" in the traditional organization, that is, the hierarchy (linear structure), which embodies the authority's power (the hierarchical leader assesses and can sanction) as well as the need for coordination (the hierarchical leader decides on the jurisdictions between the departments and links them up). In the case of multidisciplinary and matrix-based design projects, the principle of coordination is different [ex.: 50], that is, the projects bring together varied professional expertise from different departments; the projects actors, except for the project leader, share an equivalent status at the formal level; the formal authority, the hierarchy and the vertical design of supervision, while not disappearing, cohabit with other operating principles which are closer to the reciprocity of social exchanges and trust.

Moreover, research shows that it is highly necessary to learn more about the real activity of design engineers. This research theme is not new [ex.: 4, 16, 19]. However, the case study points to the need to focus on the particular case of those who work in consulting engineering firms. Moreover, it raises questions which have hitherto not been widely dealt with, such as how external design engineers consider the user's needs and minimize the impact of the "organizational distance" which separates design and operation? Or, given the particular characteristics of the practice of engineering in the Quebec context, how do design engineers from consulting firms arbitrate between "being responsible" for the consequences of carrying out their work for the environment and the life, health and property of every person [51] and "being able" to assess these consequences and remedy them; by extension, under which circumstances do they consult specialists in prevention and ergonomics or, on the contrary, do they decide to "do it themselves"? Answering these types of questions would help to target desirable changes, among others, regarding organization (for both the consulting engineering firms and the companies retaining their services) and training in engineering (so as to balance the techno centrist and human perspectives).

We believe that these two research avenues are important and have thus decided to focus on them. Indeed, they are at the centre of our fourth case study, which is already underway, conducted under the research program presented in Section 2.1 [14]. It goes without saying that the multidisciplinary research team will make the most of ergonomics, the sociology of organizations, engineering and applied ethics.

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