POLYTECHNIQUE MONTRÉAL

affiliée à l'Université de Montréal

New Process and Interface for Virtual Ergonomics Interventions

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RÉSUMÉ

L'utilisation des logiciels de modélisation humaine numérique (DHM : *Digital Human Modeling* en anglais) n'est pas encore généralisée dans l'industrie, ce qui peut entraîner une incidence élevée d'accidents du travail et de maladies professionnelles. Or la littérature en ergonomie et la pratique sur le terrain indiquent que ces logiciels ne sont pas faciles à utiliser et à comprendre par les non-ergonomes. L'intervention d'ergonomes auprès des ingénieurs et concepteurs qui utilisent des logiciels de design 3D n'est pas souvent sollicitée, car les interventions ergonomiques classiques sont perçues comme étant trop détaillées et trop longues par rapport au rythme de l'industrie. Dans ce contexte, l'utilisation de logiciels de DHM (ou l'application de l'ergonomie virtuelle) dans la conception des postes et d'environnements de travail pourrait être facilitée par un service de conseils en ergonomie qui permettrait de consulter rapidement et à distance un spécialiste d'ergonomie virtuelle.

La présente recherche visait à documenter la pratique actuelle des interventions d'ergonomie virtuelle (impliquant des logiciels de DHM), ainsi qu'à créer un processus d'intervention amélioré et pouvant se faire à distance, qui serait supporté par une nouvelle application Web nommée "Ask an ergonomist". Une première étude a été menée, au cours de laquelle quatre consultants expérimentés ont été interrogés sur cinq cas réels de consultations en ergonomie virtuelle. Les transcriptions des entretiens ont fait l'objet d'une analyse de contenu au moyen du logiciel Nvivo. Une deuxième étude reposait sur l'observation de trois cas réels d'interventions d'ergonomie virtuelle faits à distance. Les deux études ont permis de décrire et d'analyser finement le processus d'intervention d'ergonomie virtuelle actuel ainsi que de proposer une série d'améliorations. Ce travail nous a amenée à définir un nouveau processus d'intervention amélioré pouvant se faire à distance avec des outils d'ergonomie virtuelle. Pour supporter ce nouveau processus, nous avons conçu, développé et testé, en suivant une méthodologie de conception centrée sur l'utilisateur, un prototype de l'interface de l'application "Ask an ergonomist". Des études futures devraient tester l'utilisation réelle de cette nouvelle application sur le terrain et son impact sur la qualité des interventions d'ergonomie virtuelle.

ABSTRACT

Digital Human Modeling (DHM) software is still not extensively used in industry, which contributes to a high incidence of work accidents and occupational diseases. Literature and practice suggest that this software is not easy to use and understand by non-ergonomists. The intervention of ergonomists to support engineers and designers using 3D design software is not frequently sought because traditional ergonomics interventions are perceived as too detailed and too long for the dynamism of industry. In this context, the use of DHM in the design of workstations could be facilitated by a virtual ergonomics consulting service that can be accessed rapidly and remotely through the internet.

The present study aimed to document the current practice of virtual ergonomics interventions (interventions using DHM) as well as to create an enhanced virtual ergonomics intervention process and a web application to conduct it remotely. A first study was carried out where four experienced ergonomists consultants were interviewed about five real cases of virtual ergonomics interventions. The interviews' transcriptions were examined in a content analysis helped by the software Nvivo. A second study was about the observation of three real cases of free and remote virtual ergonomics interventions. The results of both studies are the description and representation of the current virtual ergonomics intervention process as well as a list of proposed improvements. A new virtual ergonomics intervention process to be conducted remotely was conceived considering these aspects. Finally, the interface of the application "Ask an ergonomist" (to facilitate the new process) was built to the stage of prototype following a user-centred design methodology. Future studies should test the use of the new application in practice and its impact on virtual ergonomics interventions.

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LIST OF SYMBOLS AND ABBREVIATIONS

CAD	Computer Aided Design
DHM	Digital Human Modeling
DS	Dassault Systèmes
EWD	Ergonomic Workplace Design software
IA	Information Architecture
MSD	Musculoskeletal Disorders
PDP	Product Development Process
R&D	Research and Development
UX	User Experience

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CHAPTER 1 INTRODUCTION

It has been pointed out by Dassault Systèmes that the users of their Digital Human Modeling (DHM) workstation design software do not use all the potential of this tool. This is a manifestation of a general fact: DHM has not been as extensively used in industry as it would be expected when taking into account its considerable advantages for this sector (Chaffin, 2009).

Two of the possible reasons for this situation are engineers' lack of ergonomics knowledge (Chaffin, 2009) and the absence of collaboration with ergonomists during the design process (Charland, 2016). Regarding the second point, it can be added that engineers do not usually work with ergonomists because of their tight work schedules that are not compatible with the deep analysis that ergonomists tend to do (Charland, 2016).

Despite this contradiction, there are reasons to affirm that the use of ergonomics' assistance in a well-shaped manner could be, in fact, a shortcut to a better final design solution.

In order to help Dassault's DHM software users to achieve their goal of designing safe products and workstations meeting their deadlines, a remote ergonomics intervention process conducted by an ergonomist specialist in virtual ergonomics (use of DHM) is proposed in this work. A new application will be conceived to allow the process to take place remotely and therefore, to provide immediate and ubiquitous access to virtual ergonomics professional assistance through internet connectivity.

Traditional models and processes of ergonomics interventions "in the field" described in literature cannot be applied directly in this case. The new intervention process needs to be adapted to the particularities of virtual ergonomics and the remote interaction between the client and the expert consultant. Since the scientific literature about virtual ergonomics consulting procedures is not abundant, a research will be conducted to describe ergonomics interventions based on the use of Digital Human Modeling tools.

The objectives of this work are:

1. To describe the current practice of virtual ergonomics interventions (based on the use of Digital Human Modeling).

2. To create an enhanced virtual ergonomics intervention process to be carried out remotely through the internet.
3. To create the interface of the application "Ask an ergonomist" that will support the new process of intervention and will be accessible through Dassault's workstation design software and Marketplace.

This document is organized into six chapters. The present one, Chapter 1 Introduction, contains the problematic and the objectives. Chapter 2 is dedicated to the literature review. Chapter 3 explains the methodology of the studies carried out to meet objective 1 of this work. Chapters 4, 5 and 6 correspond respectively to the three main results: the current process of virtual ergonomics intervention, the new process of virtual ergonomics intervention and the new interface "Ask an ergonomist". In the case of Chapters 5 and 6, they also contain the methodology used to obtain the results presented in the chapter.

Finally, in Chapter 7, the conclusions, limitations of the study and the recommendations are exposed.

CHAPTER 2 LITERATURE REVIEW

The present chapter contains an overview of the concepts and frameworks related to this research. First, it describes traditional ergonomics interventions in theory and in practice (section 2.1). Secondly, it presents the use of ergonomics in design (section 2.2). In the subsequent section (2.3), a virtual ergonomics intervention definition is proposed, and the challenges associated with manufacturing planning, DHM and collaboration are analyzed. Next, the user-centred approach for interface design is described, followed by a brief mention of persuasive design criteria (section 2.4). Finally, a review of the methodologies, methods and techniques to use in the research about the current practice of virtual ergonomics interventions is presented in section 2.5.

2.1 Traditional ergonomics intervention process

Folcher et al. (2017) define the ergonomics intervention as a process aimed at understanding and transforming a human activity (including work) in a concrete context and time, according to safety and efficiency criteria. Three propositions about the steps of this process will be described in the following paragraphs.

First, Denis et al. (2008) described the general process of Musculoskeletal Disorders Prevention interventions that they mentioned to be the "classical ergonomics intervention process". In its first step, *preliminary analysis,* the ergonomist should identify the problems to be solved. Then, in the *diagnosis,* he should describe the work to identify risk factors and possible causes. Finally, as part of the *solution development* step, the ergonomist should propose solutions to act on the causes and reduce the risk.

The second proposition of ergonomics intervention procedure is the one by St-Vincent et al. (2011). These authors propose an iterative process of five steps:

- *Request analysis*: once the ergonomist receives the request, he should get more information from the context and explore the views of other actors about the problem. Subsequently, the intervention's goals, scope and deliverables are defined in agreement with the different actors in the client organization, which could imply reshaping the initial request.
- *Preliminary research:* the ergonomist obtains the information to make the analysis.

- *Work situation analysis and pre-diagnosis:* the ergonomist uses activity units to delimit the part of the work to analyze. Work should be described and a pre-diagnosis should be done by stating hypotheses about the cause of ergonomics problems. These hypotheses should contain the **effect**, **the activity** and **the determinant** (element of the activity that causes the effect and should be modified).
- *Action plan*: the ergonomist explains the pre-diagnosis to selected stakeholders to gain their support for the necessary changes. The pre-diagnosis is then modified based on participants' suggestions and an action plan to transform the activity is proposed.
- *Solution*: the ergonomist carries out the transformation proposed in the action plan. Solutions are built with stakeholders. In some cases, the ergonomist will be in charge of implementing solutions; in others, he will only accompany the process.

The third intervention process is proposed by Folcher et al. (2017) and consists of the following steps: *request analysis and reformulation*, *open observations*, *pre-diagnosis*, *systematic observations*, *diagnosis* and *results* ("restitution" in French). Like St-Vincent et al. (2011), these authors give particular importance to the request redefinition after exploring the different actors' perceptions and gaining a deeper understanding of the problematic situation. According to them, the new request should be approved by all actors and become the intervention plan (Folcher et al., 2017).

The steps of the three approaches described before are presented in table 2.1.

Table 2.1. Steps of the intervention processes proposed by different authors.

Denis et al. (2008)	**St-Vincent et al. (2011)**	**Folcher et al. (2017)**
	Request analysis	Request analysis and reformulation
Preliminary analysis	Preliminary research	Open observations
	Work situation analysis and pre-diagnosis	Pre-diagnosis
		Systematic observations
Diagnosis	Action plan	Diagnosis
Solution development	Solution	Results (restitution)

Also like in St-Vincent et al. (2011), in Folcher et al. (2017), the pre-diagnosis contains hypotheses with the determinants of problems and some suggestions of change. Once the pre-diagnosis is accepted by the actors, the intervention process is less subject to the variability caused by different visions of the problem. From the description of these two processes it could be concluded that,

during the intervention, the ergonomist needs to make propositions that will be accepted or modified by other actors before he can move on.

In the Folcher et al.'s process, the meetings with actors during the *request analysis* as well as the steps *open observations* and *systematic observations* indicate that the ergonomist's comprehension of the target activity depends greatly on data collection in the client's organization, directly through observations and indirectly through the actors. The solutions that the ergonomist will propose, depend also largely on the possibilities of action in the client organization, which are only known by its people.

All these elements illustrate the important role that stakeholders (workers, engineers, managers, designers, health and safety professionals) play in interventions. They suggest that the ergonomist should build a good relationship with actors to get them involved. The actors' positive attitude towards the intervention will contribute to its success. But this and other conditions mentioned as necessary in the theoretical description of the intervention process are not always present in real contexts. It is therefore essential to analyze ergonomics interventions in practice.

2.1.1 Ergonomics interventions in practice

Ideally, a detailed intervention such as the processes described in the previous section, ensures the quality of the final ergonomics solution and the implementation of changes. However, all the steps proposed cannot always be applied, or alternative strategies need to be used.

Denis et al. (2008), in their exploration of 47 real interventions documented in scientific articles, found that more than half of them (30) skipped steps of the generally accepted process of intervention or reduced their scope. They identified three categories of interventions. The first, the *complete* process, contains full steps of Preliminary analysis, Diagnosis and Solution (the process by these authors described in the previous section). The second one is the *Shortened* type, where the Preliminary analysis is skipped and the Diagnosis is based on technical determinants. Finally, there is the *Turnkey* process (the shortest), where the existing problems are almost automatically addressed by known solutions without making a Diagnosis.

These findings give an idea of the gap between theory and practice in ergonomics interventions. For example, in the process proposed by St-Vincent et al. (2011), actors' implication in the *Action*

plan phase seems plausible, because the ergonomist can neither decide by himself what transformations carry on nor know their effect on different factors in the organization. However, the client might not be willing to have his employees involved and expects only to receive a diagnosis and solution from the ergonomist that his team will use later to make decisions on its own. Although this is not ideal, it might be preferable to a situation where the ergonomist does not intervene at all. A compromise could produce a better outcome for the application of ergonomics than the ideal way to proceed, but this is an arguable point.

Another particularity of interventions' practice is given by Folcher et al. (2017) when reporting that the young ergonomics Master's students in their first interventions in companies had more difficulties leading the intervention (dealing with the actors and interacting with them) than planning it. This could be a sign of the fact that, in ergonomics interventions, it is harder to deal with the human component than to figure out the right technical solutions.

In the theoretical definition of the steps of ergonomics interventions, the fact that the clients will facilitate ergonomist's work is taken for granted. In practice, stakeholders' engagement is not guaranteed.

Theberge & Neumann (2010) conducted interviews with 21 Canadian ergonomists about their practice. They concluded that a great part of the ergonomist's efforts is dedicated to gain stakeholders' support for the intervention and the implementation of changes. What these authors call "organizational work" is, in many cases, more challenging to ergonomics practitioners than the "technical work".

The following aspects of interventions' practice are conclusions from different studies where ergonomist practitioners were interviewed:

- Most clients request a corrective intervention instead of a preventive one. For those, the request of intervention was motivated by existing problems (Whysall et al., 2004).
- Ergonomists not only provide expert advice but also have an essential role in encouraging the use of ergonomics in the client organization (Theberge & Neumann, 2010).

- Interventions focus on the physical aspects of work and neglect psychological and psychosocial factors. A more systematic approach is necessary to take into account the multifactorial causes of MSD (Whysall et al., 2004).
- Once the ergonomists deliver a report, it is very rare that clients give feedback about the implementation of their recommendations (Whysall et al., 2004).
- A participatory approach (including the worker) increases the odds of implementing the results but sometimes clients don't allow their workers to participate (Whysall et al., 2004).
- The ergonomist obtains information from the main contact in the client site, which usually gives him an overview of the work and problems. He makes a tour of the workplace and gathers photos and videos of operators performing tasks. In some cases, he has a conversation with workers about frequency and repetition of actions, breaks, pain or discomfort and possible changes they would do for their own work (Whysall et al., 2004).
- Interventions don't follow a standard procedure (Whysall et al., 2004).

Different obstacles and facilitators of ergonomics interventions' practice are shown in Table 2.2

Table 2.2. Obstacles and facilitators reported by ergonomists and clients.

Author	**Point of view**	**Obstacles (-) and Facilitators (+)**
Whysall et al. (2004)	Ergonomist in the UK	- Contact in the client's organization not being the decision maker. - Lack of understanding of ergonomics in the client. + A business case for the proposed recommendations to convince managers (decision makers). + Range of possible solutions with associated costs-benefits, time requirements and pros and cons.
Whysall et al. (2006)	Clients	- Difficult to get managers authorization to implement changes. - Managers' lack of recognition of health and safety importance. - Difficulty to get workers to change their behaviour according to the intervention recommendations.
Eliasson et al. (2015)	Ergonomist in Sweden	+ Close relationships with client companies (which fosters credibility) + The clients' perception of ergonomists being useful in a wide variety of situations such as preventive work and efficiency improvement. + The use of standardized methods for the ergonomic analysis. + Ergonomist specialization in the client's industry. + Exchange of knowledge between different ergonomists consultants.
Theberge & Neumann (2010)	Ergonomists in Canada	+ Understand the particular needs or interests of the different stakeholders to adapt the propositions of change to them. + Supportive relationships with stakeholders. + To link the intervention with the client's goals.

The characteristics of ergonomics practice suggest that there are still improvement opportunities to explore. New strategies and approaches to gain stakeholders' support seem to be one of the keys to more successful interventions.

2.2 Ergonomics in design

Based on the Folcher et al.'s definition of ergonomics intervention presented in section 2.1, the participation of an ergonomist in workstation design is not considered an ergonomics intervention, because the human activity does not exist yet in a "concrete context and time".

Denis et al. (2008) also exclude ergonomists' involvement in the design of workplaces from the definition of MSD-preventive intervention used in their article. As it was said before, these authors selected 47 interventions for MSD prevention from a large group of interventions documented in scientific articles. As part of the inclusion criteria, they specified that the interventions selected should take place "in an actual workplace, at a specific workstation", indicating that they took place after the existence of a workstation and not during its design, which would have been even more "preventive". When these interventions are called preventive in the article they refer to the fact that they were made *before MSDs were problematic* and with the goal of "preventing" them or "curbing" them, not before the workstations were designed.

This shows that ergonomics practices called "interventions" take place in existing workstations during the production phase of the Product Development Process (PDP). When ergonomics is applied in design, the terms most frequently used for the activity are "ergonomics in design" or "ergonomic engineering design" instead of "intervention" and their protagonists are usually engineers and designers instead of ergonomists. However, it is possible to make a parallel between the two scenarios and assume that an evaluation and proposition of solutions similar to the ones made for existing workstations in interventions (production phase of PDP) can be made with the provisional definition of future workstations (during the production planning phase of the PDP). This point will be retaken for a definition of virtual ergonomics interventions in section 2.3.

Regarding the role of ergonomics in the design of a system, Chaffin (2009) mentions three possible scenarios. The first implies the use of traditional sources of ergonomic information such as tables, guidelines, books and standards, which is only successful if led by a person very knowledgeable in

ergonomics. When engineers with a poor understanding of human factors (which are the typical leaders of design) try to use these sources, the comprehension of the information is narrow and the results are deficient. The second approach is the testing of a physical prototype by users in order to observe and solve ergonomic issues. This fails to explore the design with all the variability of possible users and takes considerable time and money to be done. Finally, the third way is the use of Digital Human Modeling, which allows engineers to test design solutions with the workstation (or product) 3D model and be "immersed" in human use issues since the early stages of the process. With this tool, many tasks and many anthropometries can be tested and ergonomic adjustments can be made graphically and immediately (Chaffin, 2009). Moreover, the author says that DHM is the "only one means of addressing complex ergonomic issues". For all these benefits, the third approach, that is, the use of DHM for ergonomics application to design is recommended by the author (Chaffin, 2009). Although the use of this tool has grown since its introduction, there are still barriers to its generalization that will be discussed in section 2.3.1.2.

A procedure to conduct ergonomics studies based on the use of DHM is the one proposed by Schaub et al. (2012) (*adapted from Green, 2000; Lamkull et al., 2009 and Muhlstedt, 2012*) whose steps are the following:

1. Understanding the task
2. Understanding the environment
3. Understanding the population
4. Understanding the software limits
5. Performing the analysis
6. Analyzing and applying judgments to the results
7. Engineering of concepts and/or improvement proposals
8. Reporting the results

These authors suggest that a design or manufacturing engineer with ergonomics knowledge should conduct the process and receive support from an ergonomist for steps 5 to 7. In the same way, they recommend client's participation in steps 1 and 2 to provide information.

There are many differences between this way of proceeding and traditional ergonomics interventions. One of them is the presence of step 4, which is exclusive to the use of DHM. The process proposed by Schaub et al. (2012) is conducted by engineers with some assistance of an

ergonomist instead of conducted by an ergonomist as in traditional interventions. Finally, this process requires building the workstation's 3D model (though it is not reflected in the steps of Schaub it is an implicit condition), which is an additional step compared to traditional interventions. However, once the model is completed, it allows to run many different ergonomic analysis and to explore, compare and visualize alternatives with much more quality, precision and efficiency than in traditional methods.

Going back to the role of the ergonomist in an ergonomic analysis with DHM, it should be said that some DHM allow engineers to run an automatic ergonomic assessment to know if a deeper analysis and therefore the ergonomist support is necessary. Although it is not ideal, in practice, if the level of ergonomics knowledge of the engineer is good, an ergonomist may not be present and only called when a more complex analysis is required. The assistance of professional ergonomists in such situations can also be called ergonomics intervention, as it will be reflected in the definition of virtual ergonomics intervention in section 2.3.

2.2.1 Virtual ergonomics vs. Digital Human Modeling

The limits between Computer-Aided-Ergonomics, Virtual Ergonomics and Digital Human Modeling are sometimes blurred in scientific literature. Some of these terms are used as synonyms. Perez (2011) considers Virtual Ergonomics Tools as a group of computer aids to the application of ergonomics in product and process design that includes the following tools: Predetermined Motion Time Systems (PMTS), Discrete Event Simulation (DES), Digital Human Models (DHM) and Virtual Reality (VR). To this definition, we will add that these tools are not only useful in design but in any phase of the lifecycle of products and processes (i.e. in redesign, evaluation, etc.)

The most popular virtual ergonomics tool is Digital Human Modeling, which is defined by Adams & Berlin (2017) as follows: "DHM is a term that designates a software tool that enables digital models of humans to interact with virtual workplaces or products in a digital CAD environment". The human model is based on real anthropometric and biomechanical data that might vary to generate models of different populations and percentiles.

In most DHM tools, CAD models of the product, workstation and physical environment can be introduced. The possibility of changing the posture and animating the virtual human (task

simulation) allows to visualize work (or use) and subsequently predict performance and run ergonomic analysis (vision, reach, clearance, posture, RULA, OWAS, NIOSH, etc.) to evaluate physical load and risk. This allows to virtually modify the activity with almost no cost and time consequences and evaluate each option based on quantitative ergonomic criteria.

DHM and simulation are more extensively used in the automotive and aerospace industries. Some popular DHM software mentioned in Adams & Berlin (2017) are Jack, RAMSIS, SAMMIE, DELMIA Ergonomics Specialist and DELMIA V5 Human, Anybody, SANTOS and IMMA. Many DHM tools (ex. Jack and Delmia) are integrated into product lifecycle management (PLM) solutions, which facilitate the collaboration of different stakeholders during the design process. Motion capture is another technology that can be used together with DHM to facilitate the introduction of posture and task information (Joung & Noh, 2014).

Despite the many functionalities of DHM and its advantages for design, an ergonomic study based only on its use is incomplete because it does not guarantee the analysis of cognitive, psychological, psychosocial, anatomical and physiological factors. Even some biomechanical analysis might not be possible in certain DHM. Therefore, the presence of an ergonomist is essential (and recommended) to make a complete ergonomic analysis and use complementary methods when necessary.

2.3 Virtual ergonomics intervention

As it was mentioned in section 2.2, it is possible to expand the traditional definition of ergonomics intervention to include the ergonomic analysis of a future workstation made by an ergonomist during the design process. When the ergonomist uses virtual ergonomics tools to perform the analysis, such a practice could be called "virtual ergonomics intervention".

Although the use of DHM is more common in design, this software could also be used to facilitate the ergonomic analysis of existing workstations (as in traditional interventions) by ergonomists when these cannot go on-site or in cases where this tool can accelerate the analysis, exploration of solutions and redesign. Furthermore, DHM could help ergonomists visualizing and supporting decisions with quantitative analysis in order to effectively communicate with stakeholders during

a traditional intervention. Virtual ergonomics tools can be beneficial in phases of the PDP other than design.

Considering the views exposed in the previous paragraphs, a definition of virtual ergonomics intervention can be proposed. In the context of this work, a *virtual ergonomics intervention* is defined as the process of evaluation and requirements or solutions' elaboration for an existing or future product, workstation or system performed by an ergonomist in any phase of a PDP with the help of virtual ergonomics tools. Because DHM is the most common of these tools, in this work ergonomics interventions "with" or "in the context" of DHM will be synonyms of virtual ergonomics interventions. "DHM interventions" is another phrase that could be used to refer to the same activity.

To carry out a virtual ergonomics intervention, an ergonomist could use the steps proposed by Schaub et al. (2012) (section 2.2). However, a more detailed procedure would provide a better guidance. A new process of virtual ergonomics intervention should be defined to this end.

2.3.1 Challenges: manufacturing planning, DHM and collaboration

The obstacles and facilitators of traditional ergonomics interventions mentioned in section 2.1.1 can also be present in virtual ergonomics interventions. But there are additional challenges that are specific to this type of intervention. Some of them are related to the design phase of the PDP process, others to DHM use and others to the collaboration between ergonomists and stakeholders. These will be analyzed separately.

2.3.1.1 Manufacturing planning in the design phase of the PDP

Ergonomics should be taken into account in all phases of the PDP, but it is in design where the changes proposed will have the lowest cost impact (Schaub et al., 2012). For this reason, interventions in the design phase should be more frequent than in the production phase.

In the same way, inside the manufacturing planning that takes place during design, the earliest the ergonomic analysis is made, the more problems and extra costs are prevented. Even if, in the beginning, many design details are not yet defined (the workstation is defined only geometrically), it is recommended to perform an analysis and get deeper as more information (such as force, time and frequency) are added (Schaub et al., 2012).

Ergonomics interventions in the design phase of the PDP have considerable differences with the traditional ones that occur during the production phase. Some of them can be seen in table 2.3.

Table 2.3. Comparison of ergonomics interventions in the production phase of the PDP with those taking place in the design phase.

Characteristics	**Ergonomics interventions in**	
	production phase	**design phase**
Duration expected by the client	The problematic situation has existed probably for a long time already so there is less time pressure.	More time pressure because putting the product in the market first is a competitive advantage.
Possibility of immersion of the ergonomist in the company	It is possible.	It depends on the client but usually the information is in models and documents. No or little time for ergonomist's immersion in the company.
Existence of the work situation	It exists.	The work situation doesn't exist yet. There might be a simulation of the work but this is never as accurate as reality. In some cases, similar workstations might exist and the activity can be studied there.
Existence of a work problem such as MSD, pain, discomfort or complains.	In general, it exists and it is the reason for the request for an intervention.	Doesn't exist because the work situation doesn't exist. In some cases, there could be problems with similar workstations.

The challenge in manufacturing planning is the urgency to finish the workstation design. For engineers and production planners, used to work in dynamic environments, ergonomics might be seen as a complicated and time-consuming matter that can be overlooked using common sense and some basic principles. Sometimes the benefits of ergonomics are not obvious for them or their managers (Imbeau et al., 2006).

To promote ergonomics in such a context, ergonomists should be more adaptable to dynamic situations, provide quick and simple solutions whose effect on productivity and cost reduction is clear to stakeholders. Here, the traditional intervention process should somehow be compacted. The steps *preliminary analysis* in Denis et al. (2008) and *open observations* in Folcher et al. (2017) can be omitted, because there is no need to explore the problem and its causes by communicating with workers and stakeholders or to observe work directly in the workstation (there are still no real problems and no real workstation). But the ergonomist needs to clearly understand the task and imagine the more realistic postures that would be adopted by the worker. Its presence in the site

could help him communicate with stakeholders to obtain information and observe similar workstations if there were such. However, due to the need for rapid solutions, it becomes almost impossible to be long-time immersed in the organization and explore the work situation through observation, interviews and document analysis. Instead, the ergonomist should obtain the information from workstation's designers, workers or documents of similar existing workstations in much less time than in traditional interventions and sometimes without visiting the place.

2.3.1.2 Use of DHM

Despite the advantages of DHM, there are barriers to its generalization that might also get in the way of virtual ergonomics interventions. One of them is the difficulty to find professionals with a combination of competencies in engineering design, 3D modelling and ergonomics, all necessary to use this software. Contributing to this situation is the lack of ergonomics content in engineering and design study programs (Chaffin, 2009).

Other DHM problems mentioned by Chaffin (2009) are the poor accuracy of models and the large amount of time required to introduce information for task simulation. As a solution, the author suggests that future DHM should allow simulations based on the introduction of high-level task descriptors (Chaffin, 2009).

Perez & Neumann (2015) report ergonomists' and engineers' concerns about the considerable time and training required to use DHM. According to these authors, engineers (contrary to ergonomists) don't completely trust these tools because for example, they do not "consider human factors like learning curves, sickness and fatigue " which can lead to "costly mistakes".

Charland (2016) suggests that there is a gap between 3D design and ergonomics' practices, due, on one hand, to the engineers' lack of ergonomics knowledge and, on the other hand, to the ergonomists' inability to communicate and work in a 3D context. There is also a contradiction between the immediate results expected by 3D creators and the deep and long analysis usually performed by ergonomists (Charland, 2016). To encourage DHM use, the author proposes a change of paradigm in the design of these tools: they should make ergonomics accessible to the non ergonomists.

Another possible solution is the association of 3D designers and ergonomists to apply virtual ergonomics (like in the procedure proposed by Schaub et al., 2012). Here, the ergonomist should be able to use the DHM software and have a certain level of 3D modelling skills. This alternative corresponds to a virtual ergonomics intervention and is the approach supported in this work to stimulate the use of DHM.

2.3.1.3 Collaboration and remote interaction

The numerous and contradicting factors that have an influence in the design of a new product or workstation are usually optimized by a multidisciplinary team. Their members are frequently separated by disciplinary, organizational, geographical, cultural and temporal barriers that they need to overcome to collaborate and make decisions (Borsato & Peruzzini, 2015). Ergonomists are involved in this collaboration, and they similarly interact with stakeholders in other phases of the PDP (ex. production) during any type of ergonomics intervention.

In the particular case of virtual ergonomics interventions, the ergonomists capable of using the required tools are not as abundant as traditional ergonomists. They can be at a very distant geographical zone from the client. This, and the fact that clients sometimes try to avoid the ergonomist's presence in the organization, make it so that virtual ergonomics interventions frequently have to be conducted remotely.

Regarding the variations in temporal and geographical gaps, there are four types of collaboration (Germani et al., 2012): synchronous and co-located (face-to-face), synchronous and remote, asynchronous and co-located, and asynchronous and remote. The modality can be selected according to the situation. For example, in ergonomics interventions, the redefinition of the original request in negotiations between the ergonomist and the client might require some synchronous interaction to allow a richer information exchange and facilitate an agreement.

Another element having an influence on the efficiency of collaboration is the adjustment of the team members to the singularities of the unknown others, which frequently takes some time (Borsato & Peruzzini, 2015). In this sense, mature groups are better than newly formed groups. The cost and time required for preparation are also a drawback that hinders dynamic and quickly started collaborations (Borsato & Peruzzini, 2015). They can be reduced if actors have some

common ground rules and information about the other side's expectations and characteristics prior to their interaction (Borsato & Peruzzini, 2015).

Other disadvantages of collaboration are the possibility of losing control of the process actions and the risk of releasing confidential information. In design, there are knowledge representations that contain the results of the steps of the process and allow the understanding of the different stakeholders. They can be mostly linguistic and pictorial (such as concept sketches) in early phases of the process and symbolic, algorithmic and virtual (CAD model) in advanced steps. When there are restrictions to share these representations, collaboration is compromised. As Borsato & Peruzzini (2015) explain: "In a collaborative design process, product models need to be disseminated in a broad scope (..) companies are usually reluctant to share these models directly to avoid the leakage of the commercial secrets to competitors. This concern makes it difficult to realize the full potential and benefits of collaboration".

Some tools and file formats allow controlling the information shared to certain users to release the minimum required and protect the company know-how. Nevertheless, confidentiality remains a problematic point of collaboration with actors external to the organization, which is frequently the case of ergonomists consultants.

Another element influencing collaboration, in particular between designers and ergonomists is suggested by Lenté et al. (2014), who defend the visualization of use actions (storyboard) as the perfect support for cooperation between these professionals. In the particular case of virtual ergonomics interventions, sometimes clients have a DHM model containing the work tasks, which allows to visualize (and sometimes simulate) the activity as in a storyboard. When the client shares this file with the ergonomist, collaboration can be facilitated.

Based on these considerations and other ergonomics interventions' aspects analyzed in previous sections, the following suggestions are made:

- In many ergonomics interventions, actors form a new group, where they don't know the personalities, working routines and vocabulary of the others. Hence, an initial period of time is required to get familiar with these elements and consequently adjust to reach a certain group maturity. Synchronous and co-located collaboration is ideal at this time because it maximizes

the transmission of information (tone of voice, gestures) to quickly reach a state where all actors are "on the same page".

- Synchronous and co-located collaboration is also ideal when many factors are influencing a decision and a discussion should be established to reach an agreement.
- Agreements should be documented so they can be consulted in case of misunderstanding.
- Visualization of use actions (including a representation of the product or workstation and the physical environment) should be the basic support for collaboration between ergonomists and designers (engineers). In the case of virtual ergonomics interventions, the actions' information should be incorporated into the DHM model.

2.4 User interface design

The application of an ergonomics point of view to user interface design is usually put in practice through a human-centred design methodology. The basic human-centred design process is defined in the standard ISO 9241 part 210: Human-centred design for interactive systems (2010). This process proposes to repeat the following four activities in an iterative way until the user requirements are met: *Understand and specify the context of use, Specify the user requirements, Produce design solutions to meet requirements* and *Evaluate solutions against requirements*.

Many authors have enriched or modified this basic process to create other human-centred processes. Some of these processes are Contextual design, Goal-directed design, Scenario-based Design, Usage-centered Design, Usability engineering life cycle and recently, Lean UX. To the traditional techniques (interview, observation, task analysis, user test), new techniques have been added such as Persona, Scenarios, Card sorting, Flow diagram, Storyboard, etc. Frequently, a combination of techniques from different approaches is used on each design project.

Two essential concepts in human-centred design are usability and user experience.

ISO 9241-210 (2010) defines usability as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use". In other words, usability is a product quality that indicates the possibility of the

user to achieve his goals with the minimum mistakes, effort and time and the maximum satisfaction.

User experience, on the other hand, is not a product quality. The broader definition states that user experience is the set of "a person's perceptions and responses that result from the use or anticipated use of a product, system or service" (ISO 9241: 210). The user experience approach goes beyond usability, in that it takes into account aspects of the interfaces having an effect on users' emotions and subjective judgment.

For an application used in a consultation service (e-commerce) that should encourage the use of virtual ergonomics (as it is the case of the application of this work), design for the user experience is essential. For this reason, some important aspects of persuasive design that can influence user experience will be exposed in the following section.

2.4.1 Persuasive design

Mayhew (2012) defines five qualities of e-commerce websites' user experience: utility, functional integrity, usability, graphic design and persuasiveness.

Persuasiveness should be present in any tool or application that intends to encourage a user to do a certain action. It can be measured by the number of users who accomplish the intended action, that is, by the number of "conversions" (Mayhew, 2012). One essential aspect that contributes to persuasiveness, is the quality, place and importance that information about the product (or service) and the provider has in the interface and in the user flow. The capacity to inspire trust and help the user with his decisions at every step is also very important (Mayhew, 2012). In general, persuasive qualities should be present very early in the user flow (home page or entry page) to be able to keep him engaged.

Utility, functional integrity, usability and graphic design also have an influence in persuasiveness: No one will use a web site if it does not provide something necessary or wanted, that is, if it is not useful. The user would be easily discouraged if the site is malfunctioning or hard to learn and/or use. The graphic design could also influence the user's intentions on the site (Mayhew, 2012).

Behavioural science also give references for persuasive design. According to the description of the *Buying decision process* from this field of study, there are three major determinants of a user's

intention to buy. First, there is the *perceived utility* of the product or service that depends on its value for the user and its reliability. Secondly, there is *perceived self-efficacy*, which is about the users' perception of their capacity to understand and easily buy and use the product or service. Finally, there are the *social norms*, that is, other people, groups or institutions' positions regarding the product or service (Hamel & Bélanger, 2019). These three elements should be evident to the user in the first interactions with the site to persuade him to buy (or complete an intended action).

The persuasive design criteria mentioned in this section will be taken into account in the design of an application to facilitate remote virtual ergonomics consultation.

Based on the literature review made up to this point, this research will concentrate on encouraging the use of DHM tools by trying to reduce the gap between 3D design's and ergonomics' professionals. This will be achieved by proposing a new process of virtual ergonomics intervention led by an ergonomist with DHM skills and adapted to the needs of 3D engineers. The new process should simplify collaboration and make the advantages of DHM visible to clients.

2.5 Qualitative research

Qualitative research is a type of research that aims at "the development of concepts which help us understand social phenomena in natural (rather than experimental) settings, giving due emphasis to the meanings, experiences, and views of all the participants" (Pope & Mays, 1995). Table 2.4 helps to better understand this concept by comparing it to quantitative research.

Table 2.4. Quantitative vs. qualitative research.

Criteria	**Quantitative research**	**Qualitative research**
Research questions	Precise and invariable.	Wide and flexible.
Data	Measured quantitative data.	Observed situations, behaviours, opinions. Obtained from people.
Sampling	Statistically predetermined.	Purposive. Depends on results' saturation.
Process	Planned, Linear, Sequential.	Flexible, variable, iterative.
Researcher judgement influence	Minimized	Very important

Qualitative research is extensively applied in social sciences. Social research can be exploratory, descriptive or explanatory, or can combine these types (Neuman, 2011).

Another classification regarding the design of a qualitative study comprises ethnography, phenomenology, grounded theory, participatory action research and case study.

In particular, a case study is a detailed exploration of a single or small number of units that could be people, processes or others (Gustafsson, 2017). It allows for exploring a phenomenon and its context. In a case study, two types of analyses are possible: within-case and cross-case. The first is a deep analysis of a single instance of the phenomenon, whereas the second allows finding differences and similarities between instances.

The techniques to use in qualitative research analysis are just a few and the procedures for their application are usually not detailed nor agreed by scientific authors. As a result, the researcher has considerable freedom in their application, but he can also lack references to conduct a rigorous research.

According to Jolibert & Jourdan (2006), there are two main types of qualitative analysis techniques: summary and content analysis. The summary is the simplest and implies repeatedly reading the data and writing observations until a final report summarizing all conclusions is presented. The second one, more elaborated, is content analysis. In this case, the data are repeatedly classified following a set of categories that help to find patterns. A systematic procedure and detailed documentation make it easier for the researcher to leave traces of his reasoning during the interpretation of the text.

2.6 Data collection techniques in qualitative research

In qualitative research, there are three main methods to collect data: observation, individual interview, and group meetings (group interviews, focus groups, etc.) (Jolibert & Jordan, 2006). Document analysis should be added to these.

The choice of each technique for a study should be based on different factors. Observation should be chosen if it is essential to reduce the researcher's influence on the phenomenon studied. When problems and reasons behind people’s actions are important (their insights are required), the interview is preferable to observation. Observation is also not viable in complex business processes that have many actors. In these cases, the researcher can try to have access to documents or communications as well as participants of the process.

When the interaction between participants is important, a group meeting is better than an individual interview, whereas the latter is better when the influence of other people's presence in the participant's answer should be avoided. That is the case of subjects from competitive industrial domains where information should be kept confidential (Jolibert & Jordan, 2006). Data obtained in interviews and group meetings are more subjective than those obtained during observations.

Interviews can be used as an intensive technique that allows getting details of each participant's perception but cannot use a large sample size. According to the freedom given to the interviewee to talk about the topic, interviews can be classified in *structured*, *semi-structured* or *not structured*. In the first case, there is a predetermined list of questions that should be answered by all participants. In the second case, the interviewer has a list of general themes that should be covered, but there is freedom in the order and depth to do so. Finally, the unstructured interview has no predetermined themes or questions and the participant has almost full control of the conversation (Patton, 2002 in Jolibert & Jordan, 2006).

2.6.1 Sampling

White & Marsh (2006) mention that "since the object of qualitative research is not generalizability but transferability, sampling does not need to ensure that all objects being analyzed have an equal or predictable probability of being included in the sample (…) Instead, the sampling should be theoretical and purposive. It may have as its objective providing the basis for identifying all relevant patterns in the data or characterizing a phenomenon. It may even present the findings quantitatively through numbers and percentages but not through inferential statistics".

In terms of sample size, these authors propose to include as many cases as necessary to reach saturation, that is, to get to the point where new cases don't lead to new findings. They also state that, as the sample is purposive, the results produced by its analysis cannot be generalized to the population.

2.7 Content analysis

Content analysis is "a research technique for making replicable and valid inferences from texts (…) to the contexts of their use" (Krippendorff, 2004). In other words, it is the analysis of a group of documents or texts to draw conclusions that will answer the research questions. Another definition

says that content analysis is a procedure to reduce data from large amounts of text to a limited set of categories (Weber, 1985 cited in Jolibert and Jordan, 2006).

To facilitate inferences, the researcher revises the text repeatedly to classify every section according to a system of themes or categories. These themes or categories emerge from the text gradually during the repeated rounds of analysis and they should contribute to answer the research questions.

Texts to analyze with content analysis can be independent of the research or generated for its purpose. In the first case, there would be documents or conversations generated during real activity (people are unaware of the study). In the second case, there would be data from interviews and observations that took place during the study (White & Marsh, 2006).

Table 2.5 shows important elements of content analysis.

Table 2.5. Terms used in content analysis.

Concept	**Definition**
Research questions	Are the questions that should be answered with the content analysis and therefore they guide the whole process. White & Marsh (2006) define them as " open questions that guide the research and influence the data that are gathered ".
Theme	Labels that allow grouping the content relative to one specific idea.
Category	Labels that allow grouping content in different categories inside a theme around different specific ideas.
Categories instances	Parts of the text assigned to one theme or category.
Coding scheme	A set of themes and/or categories and/or subcategories and the instructions or rules used to classify parts of the text on each of them. Allows articulating the analysis. Synonyms: Analysis grid, Framework, Coding system, Code, Coding plan.
Memos	Analyst's notes with his interpretations of the text. They can be about emerging themes or relationships between themes to shape models (White & Marsh, 2006) or about the similarities and differences of the cases regarding one theme.
Cases	Instances of the phenomenon being studied.
Thematic synthesis	Discovering of themes emerging from the text.
Coding	Revise the content to assign parts of it to a certain theme or category.

As it is shown in the table, the coding scheme is the group of themes emerging from the text and the categories and subcategories inside each of them as well as the detailed explanation of how to classify the data into these themes and categories. By using a coding scheme, the text is codified (classified) and the frequencies on each category are considered for the results. A coding scheme can be developed during the study (which is called Thematic synthesis in Houghton et al., 2017) or can be taken from an existing source and used as a predetermined coding scheme. This

predetermined code would frequently need adjustment once the data are analyzed; themes and categories could be added or eliminated according to what arises from the text.

Memos are the way the researcher "records his reflections, decisions and comments" during the analysis. They help to keep track of the evolution of his interpretations of the text. There are two common types of memos: concept memos, which are about emerging concepts (themes) and theory memos, that describe relationships between concepts to build up a model (White & Marsh, 2006).

Other important elements of content analysis defined in table 2.5 are the research questions. According to White & Marsh (2006), they are not always invariable: as the researcher examines closely the data, new important aspects could be found that were not foreseen and the initial interest of the research (research questions) could change. The authors present content analysis as a flexible methodology that adapts according to partial findings. They make the distinction between qualitative and quantitative analysis and consider the first one much more flexible.

2.8 A framework to guide content analysis

Although there are no detailed guidelines for qualitative data analysis in literature, many authors consider that the researcher should define a framework for the analysis. "There must be logic behind the analysis and therefore a framework" (Houghton et al., 2015 citing Yin, 1998). A proper framework should lead to an objective and systematic way of proceeding and therefore contribute to the rigour and transparency of the study. The design of the study and the chosen techniques play a part in its definition. In this work, the research about the current practice of virtual ergonomics interventions will have a case study design. Content analysis will be the qualitative analysis technique.

The content analysis procedure (framework) that will be used in this work will be defined in the following sections. Three references will be used to that end: the framework proposed in Houghton et al. (2015) for multiple case study qualitative research, the steps for content analysis proposed in White & Marsh (2006), and the content analysis components proposed by Krippendorff (2004).

2.8.1 Framework for qualitative case study by Houghton et al. (2015)

Houghton et al. (2015) present a framework for qualitative case study analysis that combines elements from two works. On the one hand, they propose to use as a methodology the four stages of qualitative analysis suggested by Morse (1994): **comprehending**, **synthesizing**, **theorizing** and **re-contextualizing**. On the other hand, they suggest to apply the strategies proposed by Miles & Huberman (1994) as a guide to accomplish each of the four previous stages. These strategies are: *broad coding, pattern coding*, *memoing*, *distilling*, *ordering* and *testing executive summary statements* and *developing propositions*. The stages and strategies to use on each of them will be explained in more detail in the following paragraphs.

Comprehending implies the elaboration of a detailed description of the data (Houghton et al, 2015 citing Morse, 1994) and should be facilitated by an initial *broad coding* (general classification of text in themes or categories). Stakes (1995) (cited in Houghton et al., 2015) suggests the use of a predetermined code in this initial coding process that could be enriched during the analysis if necessary.

The next step is **synthesizing** which is the "merging of perception and cases to describe typical, composite patterns" (Houghton et al., 2015 citing Morse, 1994). This should be achieved by *pattern coding* and *memoing*. *Pattern coding* is the creation of further themes or categories that reflect the perception of participants and the interpretations of the analyst (Houghton et al, 2015). *Memoing* is the creation of memos or executive summary statements, which are summaries of themes made by the analyst after revision of the coded data. "They lay the foundation for further development of propositions regarding the data" (Houghton et al, 2015 citing Miles & Huberman, 1994). Memos can also be made for other elements than themes.

After synthesizing there comes **theorizing**, which aims at creating a deeper understanding of the phenomenon studied by looking for relationships between themes or categories. This implies *distilling*, *ordering* and *testing summary memos* (executive summary statements). Testing is done by tracing back in the data the propositions in memos. After this verification, more general explanations should be elaborated to create the results and conclusions of the study.

Finally, there is **re-contextualizing,** where the researcher can make propositions that could be transferable to populations or areas (*developing propositions*). In this step, the results of the

research can be compared to other studies to strengthen rigour (Houghton et al, 2015 citing Miles & Huberman, 1994).

Most elements of this framework will be used in the present study. Some of them will have a different denomination. For example, *broad coding* and *pattern coding* will be seen as just iterations of coding with no particular name.

2.8.2 Krippendorff's Content Analysis components (2004)

The following are the steps that according to Krippendorff (2004) should be followed by the researcher to go "from texts to results" in content analysis:

1. **Unitizing**: relying on unitizing schemes.
2. **Sampling**: relying on sampling plans.
3. **Recording/coding**: relying on coding instructions.
4. **Reducing data** to manageable representations: relying on established statistical techniques or other methods for summarizing or simplifying data.
5. **Abductively *inferring* contextual phenomena**: relying on analytical constructs or models of the chosen context as warrants
6. **Narrating the answer to the research question**: relying on narrative traditions or discursive conventions established within the discipline of the content analyst

In the first and second components: **unitizing** and **sampling**, the researcher decides what *units* (segments of text to analyze) and subset of units (*sample*) are more suitable to the analysis goals. **Recording/coding** (third component) implies recording the data to be available for future researchers but also coding the text according to coding instructions (coding scheme described in the previous section). This is the first transformation of the text by the analyst.

The fourth component transforms data even more, "**reducing**" it from the previous coded text to a simplified representation of it, which could be done in summaries in qualitative analysis or in diagrams, tables, or frequency percentages in a quantitative approach. The simplified representations allow the analyst to have a "big picture" of the texts, which is particularly useful when dealing with large amounts of data.

In the fifth component (**abductively inferring contextual phenomena**), Krippendorff (2004) considers that the analyst "moves the analysis outside the data" and extends it to the "unobserved phenomena in the context of interest". That is, conclusions about the context of the study are drawn from the content analysis' results and existing literature about the context.

Finally, in the sixth component: **narrating**, the analyst uses the previous conclusions to answer the research questions. He explains the contributions made by the study to the existing knowledge about the context. He can recommend how to use the results as well as mention its limitations and the need for future research.

Krippendorff (2004) declares that the six components should be applied with flexibility according to the needs of the study: there could be iterations, loops or sequential execution. There could also be a merge or addition of steps. The units of analysis, the sampled documents, even the coding instructions (coding scheme) can be adapted based on the analyst's perception of their compatibility with the texts.

An observation to make after the revision of Krippendorff's content analysis components (or steps) is the absence of the coding scheme development. The coding instructions are a reference for the third component (recording/coding) but it is not evident where this code is coming from. Additionally, a component to define the research questions should be added or at least mention them as a guide for the whole process. On the other hand, the author provides very useful guidance for text interpretation (components 4, 5 and 6) that will be used in the present study.

2.8.3 Steps for quantitative content analysis by White & Marsh (2006)

Although the steps proposed by White & Marsh (2006) are mainly for what they call a quantitative content analysis, some of them are also present in qualitative or mixed analysis methods. Therefore, they will be discussed here. The steps for a study using quantitative content analysis are as follows:

1. Establish a hypothesis or hypotheses
2. Identify appropriate data (text or other communicative material)
3. Determine the sampling method and sampling unit
4. Draw sample
5. Establish a data collection unit and unit of analysis

6. Establish coding scheme that allows for testing hypothesis
7. Code data
8. Check for the reliability of coding and adjust the coding process if necessary
9. Analyze coded data, applying appropriate statistical test(s)
10. Write up results

Some steps from this list will be taken into account here; others don't apply (those mentioning a hypothesis) because the present study does not follow a deductive approach. In this way, in steps 1 and 6, the hypotheses could be replaced by "research questions". For example: "Establish coding scheme that allows for testing hypothesis", can be adapted in an inductive approach to "establishing a coding scheme that helps answering the research questions".

From this procedure, it is particularly useful the distinction between *Establish coding scheme*…, *Coding the data* and *adjust coding* in steps 6, 7 and 8 respectively. Although in the execution of a qualitative content analysis, these three steps might overlap at times, to have them defined separately makes the process easier to understand by the researcher.

2.8.4 Steps of the analysis (Framework) assumed for the present study

The three approaches exposed have useful elements that were combined and adapted to define the steps that will be used in this study, which are the following:

1. Establish the research questions.
2. Design the study: select the data collection technique, the units of analysis, etc.
3. Define the preliminary coding scheme to answer the research questions.
4. Collect data and transcribe them.
5. *Codify the text according to the current coding scheme.*
6. *Write memos for each theme and for the relationships between them.*
7. *Adjust and/or modify the predetermined coding scheme if needed.*
8. Create results about each category and the relation between categories (using frequency percentages).

9. Elaborate conclusions.
10. Describe what was intended to be described with the content analysis (create a model that integrates the conclusions).
11. Verify propositions made in the conclusions by tracking them back in the text. (use CADCAQ query functions and re-reading of the text to look for text examples to back conclusions)
12. Elaborate answer to the research questions based on results (include here the transferability of the results, comparison with other studies and limitations or recommendations)

As content analysis is an iterative process that requires multiple revision of the data, steps 5 to 7 might be repeated many times before the researcher considers that is time to go to step 8.

2.9 Validity and reliability in content analysis

In quantitative content analysis, there are four types of validity: face validity, criterion validity, content validity and construct validity (White & Marsh, 2006). *Face validity* is the degree on which a concept is correctly measured. Subjectivity in its assessment can be reduced by having experts analyzing the measure to find out the concept that was trying to be measured (Neuendorf, 2016). *Criterion validity* is the correspondence between a measure and an external behaviour (Neuendorf, 2016). *Content validity*, "looks at the completeness of representation of the concept" (White & Marsh, 2006) whereas *construct validity* refers to "the extent to which a measure is related to other measures (constructs) in a way consistent with hypotheses derived from theory" (Neuendorf, 2016).

Reliability, on the other hand, can be enhanced by a complete coding scheme containing definitions, instructions and examples. "Categories or levels" in it, should be exhaustive and exclusive and should be measured at the highest possible scale (nominal, ordinal, interval, and ratio) (White & Marsh, 2006).

Some authors propose to quantify code reliability. To this end, different researchers should code the text in parallel. Then the code reliability can be determined as the ratio between the elements with agreement in its classification and the total number of elements classified with the coding scheme. More than 0,9 is considered good reliability (Jolibert & Jordan citing Carney, 1972).

In qualitative content analysis, on the other hand, validity and reliability are defined differently.

"Qualitative content analysis focuses on **creating a picture of a given phenomenon that is always embedded within a particular context**, **not on describing reality objectively (…)** In qualitative research, findings are confirmed by looking at the data, not the researcher(s), to determine if the data support the conclusions. The important criterion is not numeric correspondence between coders but conceptual consistency between observation and conclusion" (White & Marsh, 2006).

For this reason, in qualitative content analysis, validity and reliability are replaced by different qualities. Lincoln & Guba (1985) (cited in White & Marsh, 2006) described four criteria to assess the rigour of a qualitative study: credibility, transferability, dependability, and confirmability. They are defined as follows in White & Marsh (2006):

Credibility is **"**the equivalent of internal validity, calls for identifying all important factors in the research question and accurately and completely describing the ways in which these factors are reflected in the data gathered".

Transferability "or external validity, is essentially a judgment about the applicability of findings from one context to another".

Dependability is given by the extent in which a study can be replicated and the same (or very similar) results obtained.

Confirmability "relates to objectivity and is measured in quantitative content analysis by assessing inter-rater reliability."

Houghton et al. (2013) present different strategies to reinforce these qualities during a qualitative case study. To improve **credibility** they propose "*prolonged engagement*" of the researcher in the field and "*persistent observation*" of the phenomenon being studied. *Triangulation*, *peer debriefing* and *member checking* can also contribute to make the research more credible (Houghton et al., 2013). *Triangulation* is the use of different techniques or different sources to gather data about the same phenomenon. The use of observation and interviews to obtain information about the same aspects is an example of triangulation. Another example is to interview different types of actors to get diverse views about the same phenomenon.

Houghton et al. (2013) suggest that *peer debriefing* should be used to know if an external researcher agrees with the process followed by the main researcher instead of expecting both researchers to make the same decisions and obtain the same results independently.

Member checking can be done by asking participants to confirm codes, observations or findings or verify interviews' transcriptions. Houghton et al. (2013) recommend that participants check their own words instead of the constructions made by the researcher during the analysis.

Transferability can be enhanced by elaborating *thick descriptions* of the context, findings, and decisions that allowed the researcher to go from text to results. Quotations of the original text also help to understand the researcher's analysis and interpretations. This would give an external reader or researcher the elements to judge if the results of the study can be transferred to another context or not (Houghton et al., 2013).

Finally, **dependability** and **confirmability** can be obtained using *audit trail* and *reflexivity* strategies. The *audit trail* consists of a detailed description and explanation of the analysis steps. Computer-Assisted Qualitative Data Analysis Software (CAQDAS) such as Nvivo can help the researcher to build an audit trail.

Reflexivity is the recording of the researcher's personal contributions and reflections. This would leave a trace of the researcher's subjectivity influence in the analysis.

Audit trail, *reflexivity* and *thick description* contribute to make the process meticulously documented, so it can be replicable and easily evaluated by other researchers.

2.10 Use of Qualitative Data Analysis software: Nvivo

Computer-assisted qualitative data analysis software (CAQDAS) can help to manage, explore, interrogate and systematically annotate qualitative data. "It can also enhance transparency and rigour" (Houghton et al., 2015 citing Bringer et al., 2004; Crowley et al., 2002; Richards, 1999). If the software is properly used, the analysis will be more robust and well documented.

Nvivo is a commonly used CAQDAS software. Some of its most used functionalities and their description are presented in the table 2.6.

Table 2.6. Nvivo functions.

Nvivo function	**Description/use**
Nodes	Are used as an analogy to themes or categories
Node description (property)	It can be used to define the node to explain what content should be coded in this node.
Cases	A case is an entity of text selected by the analyst to code the text into the nodes and compare the results on each node. It is not the same as the cases of the case study but it can be coincident. Cases in Nvivo can be interviews, subjects, coders, etc.
Attributes	Attributes allow to register factual information about the cases (or participants), for example, gender, occupation, age range. This might facilitate the comparison of participants with different and similar characteristics. (Houghton et al., 2015 citing Richards, 1991)
Memos	Memos can be used to write the ideas of the researcher while and after reading the text. Memos could also be created to summarize the results on each node.
Queries	Queries can be used to check the results obtained by reading, in an automatic way.
Matrix	It can be used to summarized results and cross cases and nodes.

In Nvivo, node hierarchies and descriptions help to create and depict a coding scheme and memos help to keep a record of the analyst's interpretations associated with themes (nodes) or cases. This contributes to a better documentation of the analysis.

Another functionality whose use can contribute to improve rigour is the query function, that allows to interrogate the text and check propositions made during manual reading. The matrix function can also be used to find crossed relations between attributes and themes and therefore to check propositions about the data. However, many authors call to take into account that the software cannot "analyze" the data (Houghton et al, 2015 citing Bringer et al, 2004; Lathlean, 2010), it just provides tools to facilitate analyst's work. The best results are obtained when manual and automatic analysis are complemented (Welsh, 2002).

The definitions, frameworks and tools from qualitative research and content analysis that were examined in sections 2.5 to 2.10 were used to design the research carried out in this work to describe the current process of virtual ergonomics intervention. The next chapter contains the design and methodology of this research.

CHAPTER 3 METHODOLOGY FOR THE STUDY OF THE CURRENT PROCESS OF VIRTUAL ERGONOMICS INTERVENTIONS

This chapter presents the methodology of the research conducted to achieve objective 1 of this work, that is, to describe the current practice of virtual ergonomics interventions.

The methods, techniques and procedures used to accomplish objectives 2 and 3 are described in chapters 5 and 6 respectively along with the results.

The present chapter is structured in four sections. Section 3.1 describes the general design of the research. In sections 3.2 and 3.3 are described in detail the procedures and techniques used in Study 1 and Study 2 respectively. Finally, section 3.4 contains the limitations of both studies.

3.1 Design of the research

A qualitative research was conducted to achieve the first objective of this work, that is, to describe the current process of virtual ergonomics interventions and to find areas for improvement. As virtual ergonomics (DHM) intervention processes are not much documented in scientific literature, the research used an inductive approach and was exploratory and descriptive.

A case study was chosen as the design of the research since the number of virtual ergonomics interventions that could be studied is very limited. To our knowledge, this practice is less common than traditional ergonomics interventions. A case study was also suitable for the descriptive purposes of the research.

Two multiple case studies were conducted. Study 1 included five cases of past virtual ergonomics interventions. The data were obtained through semi-directed interviews with ergonomists consultants having experience in virtual ergonomics. Interviews' transcriptions were processed with a qualitative content analysis in NVivo. The interview is an intensive and flexible data collection technique ideal for exploratory and descriptive studies, hence its selection.

Study 2 covered three cases of virtual ergonomics interventions that took place during the research. The data were obtained through participant observation, directed interviews and documentary analysis.

Study 1 was the most important source of data, therefore its process of analysis is much more documented. Study 2 was carried out mainly for triangulation and verification of the previous findings (from Study 1).

There was also Study 1a, which is not a case study itself, but the content analysis of the part of the interviews (from Study 1) where participants talked about virtual ergonomics interventions in general and not about the main specific case described.

Twenty predetermined themes were established prior to the content analysis. Nine of them (activities, actors, inputs, outputs, tools, demand, duration, obstacles, facilitators) were confirmed by the analysis in Study 1, Study 1a and Study 2, in that order. Categories inside the themes were initially found in Study 1. Then, in Studies 1a and 2 they were confirmed and some new ones were added.

3.2 Study 1: five cases of past virtual ergonomics interventions described in interviews

Study 1 consisted in a multiple case study where five cases of past virtual ergonomics interventions were documented by interviewing the four ergonomists who conducted them (one of the participants gave two interviews about two different cases). A content analysis allowed to process the data obtained.

3.2.1 Content analysis

Study 1 aimed at describing the process of virtual ergonomics interventions as well as to find areas of improvement. These two goals generated two research questions for the content analysis:

1. What is the current process of virtual ergonomics interventions?
2. What are the aspects that can be improved in the process of virtual ergonomics interventions?

Previous to the analysis, a revision of literature was conducted to find existing themes and categories that would allow to describe the virtual ergonomics intervention process and identify problems. The sources found contributed to define more specific questions (tables 3.1 and 3.2) and general themes (table 3.3) that became the basis of the interview guide and the first attempt of coding scheme. The researcher's criteria also played a role in their definition.

Table 3.1. Specific questions for Research question 1 and references used.

Research question 1: What is the current process of virtual ergonomics intervention?	
References used	**Specific questions (to detail the research question)**
	In the process of virtual ergonomics interventions:
Definition of process by Hammer & Champy (1993) from the domain of Business Process Reengineering	What are the activities carried out?
	What are the inputs and outputs of the process and of the specific activities?
Activity interview by Duignan, Noble, & Biddle (2006)	What tools and methods are used?
Activity interview by Duignan, Noble, & Biddle (2006)	What are the main actors and what is their role in the process?
Researcher's criteria	How is coordination achieved?
	How are the interactions taking place?
	What types of documents and information presentation formats are used?

Table 3.2. Specific questions for Research question 2 and references used.

Research question 2: What are the aspects that can be improved in the process of virtual ergonomics interventions?	
References used	**Specific questions (to detail the research question)**
Researcher's criteria	What are the factors affecting the efficiency of the process from the ergonomist's perspective?
	What are the factors affecting the success of the process from the ergonomist's perspective?
Activity interview by Duignan, Noble, & Biddle (2006)	How can the process be facilitated with a computer tool from the ergonomist's perspective?

Table 3.3. Preliminary themes for interview guide and coding scheme.

References	**Themes**
" Grille d'analyse de la littérature francophone sur le déroulement d'interventions d'ergonomie participative " (St-Vincent et al., 2010) Activity interview (Duignan et al.,2006)	Activities Tools Methods Actors Documents
Definition of process by Hammer & Champy (1993) from the domain of Business Process Reengineering	Inputs Outputs
" Grille d'analyse de la littérature francophone sur le déroulement d'interventions d'ergonomie participative " (St-Vincent et al., 2010)	Context Client sector OSH in the client Request (Demand) Actors Results Clients satisfaction Obstacles Facilitators
Contextual Interview (Holtzblatt & Beyer, 2014) Activity interview (Duignan et al.,2006)	Problems with current tools New tool

In a second time, a guide for the interview (Appendix A) was created using the questions, themes and sources reflected in the previous three tables. The 20 themes in table 3.3 were used as a predetermined coding scheme. Once the interviews were completed and analysed, only nine of the original themes were verified in the text: activities, actors, inputs, outputs, tools, demand, duration, obstacles, facilitators. Different categories were found inside each theme as a result of the repeated analysis rounds and always using the research questions as a guide. The result is the final coding scheme of Study 1.

Tables with quotations of the participant's words were created for the nine themes as evidence of the categories, subcategories and their presence in each intervention case.

3.2.2 Interviews

The guide that was created to conduct the semi-structured interviews contains two parts. In Part 1, there are four sections: context, activities, actors and results. In Part 2 there is only one section about interventions in general.

In the first part, the participant is asked to describe one particular intervention that he carried out using DHM software (virtual ergonomics). In the second part, the subject is asked about the generic activity of intervention. The guide contains open questions to allow the subject to express himself freely avoiding bias from the researcher. A list of more specific questions was used to ask for details once the interview is very advanced. As mentioned previously, the guide is based on the questions, themes and sources reflected in tables 3.1, 3.2 and 3.3 in the previous section.

A pre-test interview with a very experienced subject was carried out and, in light of the results some questions were modified to focus on more relevant information (the final guide is presented in Appendix A). Then, a second interview was carried out with the same participant and three more interviews were completed with three other subjects. The pre-test interview was included in the analysis for a total of five interviews from four subjects (the first participant was interviewed on two occasions).

The interviews lasted between 60 and 90 minutes and were conducted by the same two interviewers. They took place mostly via Skype (4 out of 5); only one of them (the pre-test) was face to face. In all cases the sound was recorded with participants' permission and the audios were

transcribed. Four out of five interviews were conducted in English and one was conducted partially in English and partially in French. Part 2 of the interview was only completed in one case. In the other four, this part was very brief due to time limitations.

No participant was withdrawn from the study.

3.2.3 Sampling

Study 1's sample was purposive. Dassault's Systèmes specialists, familiar and up to date in the field of virtual ergonomics, helped to create a list of the very few ergonomists who have conducted virtual ergonomics consultations and therefore have the profile necessary for the study.

Seven subjects were contacted by email and asked to participate in the interviews. Six of them answered, but finally only four were available during the period of time of the study. Three subjects were interviewed about one real past intervention and one was interviewed twice about two different cases, which provided data about five interventions. As it was said before, the total number of participants was four.

The exclusion and inclusion criteria presented in table 3.4 helped to avoid bias in the sampling.

Table 3.4. Inclusion and exclusion criteria for the selection of participants and intervention cases.

Units	**Exclusion criteria**	**Inclusion criteria**
Participants	Participant non-ergonomist	Participant ergonomist
Intervention cases	Ergonomics intervention not using DHM.	Ergonomics intervention using DHM.
		Interventions made remotely or face-to-face.
		Ergonomist part of the client's company (internal ergonomists) or not part of it (external ergonomist).
		Interventions made in the manufacturing sector or in product design projects.

The participants were left to describe any intervention case (free choice) meeting the criteria they were given, that is, any case of completed ergonomics consultation where they used DHM tools to answer a client's request.

During discussions with some participants through email or in the first moments of the interview, when they were told the inclusion and exclusion criteria for selecting a case, they seemed to find difficult to identify a case with such characteristics that they could remember and describe. This discussion could be too long and affect their disposition and time for the interview. For these reasons, once the participant mentioned a case that met the criteria the researcher accepted it.

In fact, originally, an *internal ergonomist* and an *intervention conducted only face to face* were exclusion criteria (only interventions made remotely and for an external client were going to be included). As some of the participants did not have examples with these characteristics, it was decided to modify the criteria to be as reflected in table 3.4.

As a result of the more inclusive selection criteria, the five cases finally used for the study are very heterogeneous, as can be seen in table 3.5.

Table 3.5. Characteristics of the five cases of virtual ergonomics interventions in Study 1.

Characteristics	**S1_Case1**	**S1_Case2**	**S1_Case3**	**S1_Case4**	**S1_Case5**
DHM requested	Yes	If necessary	If necessary	No	No
Type of project	Product design	Manufacturing	Manufacturing	Manufacturing	Product design
Communication	Remotely	Remotely	Remotely- Face to face	Face to face	Face to face- Remotely
Ergonomist	External	External	Internal	Internal	External
DHM software	Yes	Yes	Yes	No (rudimentary)	Yes

Table 3.6 shows some characteristics of the participants.

Table 3.6. Characteristics of the participants in the interview.

Characteristics	**Participant1**	**Participant2**	**Participant3**	**Participant4**
Sex	F	M	M	M
Range of Age (years)	40-50	50-60	50-60	30-40
Country at the time of the interview	Canada	UK	US	UK
Years of experience as ergonomist	26	28	31	15
Years of experience in DHM	24	11	31	14
Years of experience as consultant	6.5	25	>11	11

As can be seen in the table, the participants have considerable experience in ergonomics and DHM.

3.2.4 Nvivo

The software Nvivo was used for content analysis. In table 3.7 are presented its main functions and their particular use in this study.

Table 3.7. Nvivo functions used in this study.

Nvivo function	**Use in this study**
Nodes	Themes, categories and sub-categories
Node description (property)	Definition of the theme, category or subcategory represented by the node. The ensemble of all these definitions is the coding scheme.
Cases	Every intervention case (interview) is a case.
Attributes	Characteristics of each case, such as the sector of the client of the intervention, the job position of the ergonomist and his/her external or internal condition regarding the client's company.
Memos	Memos were used to write the ideas of the researcher while and after reading the text. Memos would also be created to summarize the results on each node.
Queries	Queries were used to check the results of the analyst in an automatic way.
Matrix	The matrix was used to create the results and to find relations between themes.

3.2.5 Study 1a

During the five interviews about a case of intervention conducted in the past, the four participants also talked about their experience with virtual ergonomics interventions in general. These data were not abundant, but were also analyzed to verify the categories found in the analysis of the specific cases.

For most themes, this analysis confirmed the categories found in Study 1 and added very few new ones. Only for *obstacles* and *facilitators* it added many new categories. All the new categories were included for the subsequent Study 2.

3.2.6 Reliability and validity

Different strategies and elements enhanced the rigour of Study 1.

The interview guide was elaborated using interviews and methods for similar purposes established in scientific literature. Then it was adjusted based on the results of the pre-test with Participant 1.

A predetermined coding scheme formed by 20 themes was established as a result of a literature review. The changes and additions made to it during the content analysis were justified with

quotations supporting the presence of each theme and category. These two elements contribute to the validity of the coding scheme.

The software Nvivo allowed to leave trace of every step through the use of nodes, nodes description, memos and notes. The text codified on each node (category) can be easily verified by an external researcher using the Nvivo file. In the same way, for each theme, a quotation table was created in Word. It contains the excerpts from the text that justify the presence of each category on each case according to the main researcher. These elements provide transparency to the analysis.

To further improve the rigour of the research, external researchers (who are also experts in ergonomics) checked the coded content and approved most of the main researcher's decisions. In this application of *peer debriefing*, the few suggestions made by the external researchers were incorporated into the coding scheme until an agreement was reached.

With Nvivo, more than five iterations of analysis were made searching for new themes and categories and verifying the coded text. The systematic verification and the use of automatic queries allowed to detect researcher's mistakes and omissions and therefore helped reinforce validity. This quality is also backed by the participants' ample experience in ergonomics, DHM and consultation and the seven years of ergonomics experience of the main researcher.

In addition to all of the above, *member checking* was used as a strategy to reinforce validity. It consisted in the participants' verification of the activities present in each intervention case. They received by email a link to an electronic questionnaire containing all the activities (categories) that, according to the researcher's analysis, were part of the current process of virtual ergonomics interventions. They were asked to select the activities that were present in the case of intervention they had described before. The presence of activities previously decided by the researcher on each case wasn't shown. The questionnaires were made in Survey Monkey. Only three participants (participants 1, 3 and 4) completed them, confirming the data of four intervention cases (participant 1 confirmed the data of the two cases that she described). In general, they confirmed the categories and presence of activities initially found by the researcher, with very few exceptions that led to make adjustments to the final presence of activities in each case. The questionnaires and the results can be seen in Appendix P. They included a section for participants to add new information (not

related to the activities) and clarify aspects that were unclear in the interview. The new elements provided here were also incorporated into the analysis.

3.3 Study 2: three cases of free virtual ergonomics intervention

According to a triangulation strategy, a second multiple case study was conducted where the observation technique was used to collect data about three cases of virtual ergonomics consultations. The research questions of Study 2 are the same as in Study 1. Therefore, the themes and categories from the first study were also used in the second one.

The three virtual ergonomics interventions analyzed here took place at the same time as the research, contrary to Study 1, where the participants had to describe an intervention that took place months or years before the research. In addition to participant observation, document analysis and interviews were used to collect data.

3.3.1 Sampling

In Study 2, the sampling was purposive. During the research, Dassault Systèmes posted an offer of free virtual ergonomics evaluation in order to test the market for a future paid service. They published the offer with the title " Virtual Ergonomics Evaluation for SAFE & EFFICIENT workplaces " in different social network pages and sent it to their headquarters employees all over the world. The post contained a link to a Survey Monkey form where clients could request the service and provide contact information. The intention was to include in the sample all clients requesting and receiving the free virtual ergonomics evaluation service during the research. Finally, three clients completed the whole process during this period and were included in Study 2. They were all from the manufacturing sector because DS's offer concerned the evaluation of workplaces. Coincidentally, all clients knew about the offer through Dassault Systèmes employees that contacted them.

The three cases of intervention in Study 2 had many characteristics in common (in contrast with the heterogeneity of cases in Study 1) as can be seen in table 3.8.

Table 3.8. Characteristics of the three cases of virtual ergonomics interventions in Study 2.

Characteristics	**S2_Case1**	**S2_Case2**	**S2_Case3**
DHM requested	Yes	Yes	Yes
Type of project	Manufacturing	Manufacturing	Manufacturing
Communication	Remotely- Face to face	Remotely	Remotely
Ergonomist	External	External	External
DHM software	Yes	Yes	Yes

3.3.2 Participant observation

The main data collection technique in Study 2 was participant observation. Not every step of the intervention cases was observed, but some of the most important. These were: the DHM analysis made by the ergonomists team, the final presentation to the client (in 2 of 3 cases) and some Skype communications with clients.

The virtual ergonomics analysis of workstations in the three cases was performed during three days by a team of four people. The principal ergonomist in the team is very experimented in virtual ergonomics consultations (coincidentally participant 1 in Study 1). The other two ergonomists have many years of experience in virtual ergonomics software R&D and one of them was the head of the evaluators' team. Finally, there is the researcher, who has experience as an Ergonomics lecturer. During the three days of analysis (that included Skype communications) and during the final presentations, the researcher took notes using the form in Appendix C.

3.3.3 Document analysis and interview

The document analysis of the final reports delivered to clients was used as an additional data collection technique. In the same way, the researcher examined the files provided by each of the three clients.

Complementary information about the three interventions was obtained in interview with the head of the evaluators' team (an ergonomist with vast experience in virtual ergonomics software R&D), who was the person interacting with all clients and aware of all activities.

Table 3.9 shows the data collection techniques in Study 2 and their contributions to each theme.

Table 3.9. Data collection techniques and their contributions to each theme in Study 2.

#	Theme	Participant observation	Document analysis	Interview with the leader of evaluators
1	Activities	X		X
2	Actors			
3	Tools	X		
4	Inputs	X	X (files provided by clients and record of Skype meetings)	
5	Outputs		X (final report)	
6	Demand		X (final report)	X
7	Duration			X
8	Obstacles	X		
9	Facilitators	X		

3.4 Limitations of both studies

The small size of the sample in both studies makes it so that the results describing the current process of virtual ergonomics interventions cannot be generalized or transferred to a wider context. They can merely be used as a reference in a field that has limited bibliography (virtual ergonomics interventions) and as a starting point for deeper studies. Another limitation of both studies is that the data were obtained mostly from the side of the ergonomist conducting the intervention. Although other actors were observed (mainly listened to in a Skype call without video in Study 2), they were not interviewed. The client who requests the consultation would have been a key source of data about the problems. In this sense, it is recommended that future studies get information directly from the client.

Finally, it should be said that in Study 1, the participants had to describe a past intervention. In some cases, they could have conducted the intervention months or years ago, so they might have omitted details or changed elements of their story that they did not remember accurately.

In the next chapter, the results of Studies 1 and 2 will be discussed. They led to the description of the current process of virtual ergonomics intervention that will also be presented.

CHAPTER 4 CURRENT PROCESS OF VIRTUAL ERGONOMICS INTERVENTION

This chapter contains the results of the research conducted to describe the current practice of virtual ergonomics interventions and its areas for improvement. It is structured according to nine themes: *activities*, *actors*, *tools*, *inputs*, *outputs*, *demand*, *duration*, *obstacles* and *facilitators.* The themes were the same in Study 1, Study 1a and Study 2. The categories for each theme found in Study 1 were mostly confirmed and some new ones were added in the subsequent Studies 1a and 2.

The first nine sections of this chapter (4.1 to 4.9) correspond to the nine themes mentioned above. Each section presents the results of the three studies followed by the main conclusions and suggested improvements. Section 4.10 contains a summary of the results of all themes. Finally, in section 4.11, the graphical representation and the description of the current process of virtual ergonomics intervention are presented.

4.1 Activities

4.1.1 Activities in Study 1

Table 4.1 presents the activities (categories) in each of the five cases of intervention described in the interviews of Study 1.

"YES" means that, according to the participant, the activity was present in the case. "no" means that the participant said the activity wasn’t present in the intervention. An empty cell means that no information about the activity was given by the participant during the interview. The frequency of "YES" is reflected in the last column of the table. The same will apply to all themes' tables. The quotations of the participant's words justifying the presence of each category on each case were reflected in a table named "citation's table" for each theme. The citation's table of the theme activities can be seen in appendix D.

Table 4.1. Activities in the five cases of Study 1.

#	Activities	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Freq
1	Generic presentation by ergonomist	YES	no		no	YES	2
2	Request of intervention by client (not necessarily DHM)	YES with DHM	YES maybe with DHM	YES client expects DHM	YES ergonomist decides DHM	YES ergonomist decides DHM	5
3	Signature of NDA by ergonomist	YES	no	no	no	YES	2
4	Proposal elaboration by ergonomist and client	YES	no	no	no	YES	2
5	Proposal signature by ergonomist and client	YES	no	no	no	YES	2
6	Ask for information and files to client (and/or suppliers) by ergonomist	YES	YES	YES	no	YES	4
7	Waiting for information and files from client (and/or suppliers)	YES	YES		no	YES	3
8	Communication*	YES	YES	YES	YES	YES	5
9	Meetings*	YES	YES	YES	no	YES	4
10	Get information and files ergonomist from client (and/or suppliers)	YES	YES	YES	no	YES	4
11	Get information and files by ergonomist on his own	YES Get 3D model of equipment	YES Make 3D model of equipment	no	YES Make 3D model of equipment	YES Make 3D model of equipment	4
12	Make the DHM analysis and prepare snapshots/presentation/report by ergonomist	YES	YES	YES	YES	YES	5
13	Check that the path is good ergonomist with client	YES	YES	YES	YES	YES	5
14	Arrange meeting/Send invitation for presentation of analysis	YES	YES	YES	no	YES	4
15	Send snapshots of the DHM	YES	YES	YES	YES	YES	5
16	Give presentation/report and/or discussion by ergonomist and client (and or suppliers)	YES	YES	YES	YES	YES Selection of solutions	5
17	Request of further analysis by client	YES	no	no	no	no	1
18	Modification of proposal by ergonomist	YES	no	no	no	no	1
19	Make extra analysis by ergonomist	YES	no	no	no	no	1
20	Deliver extra analysis by ergonomist	YES	no	no	no	no	1
21	Paying by client to ergonomist	YES	no	no	YES	YES	3
22	Follow up by ergonomist	YES	no	YES	no	YES	3

*Communication and meetings are activities fragmented into actions that are part of the other activities.

The activity *Request of intervention* takes very different forms for the different cases and is better analyzed in the results of the theme Demand. Sometimes there is not an explicit request of virtual ergonomics intervention by a client. Instead, there are client's general expectations of the ergonomist's job declared before the intervention (mainly in the case of an internal ergonomist). The ergonomist, knowing these expectations, that sometimes have a wider or different scope than the virtual ergonomics analysis, decides then to carry on with it using a DHM tool, as the best way to satisfy the client's need.

In the five interventions there was a *Request of intervention by client (not necessarily DHM)* (activity 2). Only in three of them (cases 1, 2 and 3) the client mentioned the DHM analysis as part of its request.

In 4 out of 5 interventions, the ergonomist had to *Ask for information and files to client (and/or suppliers)* (activity 6), then he did *Get information and files from client (and/or suppliers)* (activity 10). The same proportion had to *Get information and files on his own* (activity 11), in particular 3D models (three of them had to build a model and one had to obtain it by himself). In 3 out of 5 interventions the ergonomists mentioned the need of *Waiting for information and files from client (and/or suppliers)* (activity 7).

Naturally, the activity *Make the DHM analysis and prepare snapshots /presentation/ report by ergonomist* (activity 12) was present in all cases.

In the five interventions, the ergonomists did *Check that the path is good with client* (activity 13) before delivering the results and finally, did *Give presentation/report and/or discussion by ergonomist and client (and or suppliers)* (activity 16).

In all cases, there were *Communications* (activity 8) between client and ergonomist as part of other activities. Four out of five interventions included *Meetings* (activity 9) that were not the final presentation.

We could assume that in all cases there was some kind of *Signature of NDA by ergonomist* (activity 3), a *Proposal elaboration* (activity 4) and *Signature by ergonomist and client* (activity 5), maybe a while before the intervention, but it was only mentioned in two cases (S1_Case1 and S1_Case5). In S1_Case3 and S1_Case4, the absence of these two activities could be justified by the fact that

the ergonomists were internal to the company. A contract probably has been signed long time before and regarding responsibilities much larger than the intervention.

Request of further analysis by client (activity 17) and the subsequent *Make* and *Deliver extra analysis by ergonomist* (activity 19) were only present in one intervention (S1_Case1). It is logical to think that these activities will be present only occasionally. *Check that the path is good with client* (activity 13) should contribute to avoid these extra activities, because any question the client wants to add can be asked before the delivery of the final results.

A *Payment* (activity 21) was present in S1_Case1, S1_Case4 and S1_Case5, but again, it is logical to think that in the other two cases, the ergonomists' work was somehow remunerated. This remuneration probably corresponded to all their work for the company and not only to the intervention, so they might have omitted it in their description of the intervention for this reason.

Finally, 3 out of 5 interventions had some kind of *Follow-up by ergonomists* (activity 22).

When participants talked about DHM interventions in general (Study 1a) during the interview, the activities mentioned were the same already identified in the analysis of the individual cases (Study 1). As a consequence, the content analysis of the text related to DHM interventions in general did not add new categories in the theme activities.

4.1.2 Activities in Study 2

No new activities (categories) were found in Study 2, but most of those found in Study 1 were present here too, which confirms the results. Table 4.2 shows the activities present in the three cases of Study 2.

Table 4.2. Activities in the three cases of Study 2.

#	**Activities**	**Description of the activity in the particular context of the free service**	**S2_Case 1**	**S2_Case 2**	**S2_Case 3**	**Freq**
1	Generic presentation by ergonomist	Post in social networks offering free Virtual Ergonomics evaluation and link of survey (on Survey Monkey) to request the service	YES	YES	YES	3
2	Request of intervention by client (not necessarily DHM)	Answer to survey (in Survey Monkey).	YES with DHM	YES with DHM	YES with DHM	3
3	Signature of NDA by ergonomist	The client only asks for their shared information to be confidential	no	no	no	
4	Proposal elaboration by ergonomist and client	As the evaluation is a free service no contract was required	no	no	no	
5	Proposal signature by ergonomist and client		no	no	no	
6	Ask for information and files to client (and/or suppliers) by ergonomist	Once ergonomist and clients have establish contact by email, ergonomist sends link for the client to upload files into a DS file transfer site (ergonomist company). Ergonomist also asks for information about the task in email and in Skype conversations.	YES	YES	YES	3
7	Waiting for information and files from client (and/or suppliers)		YES	YES	YES	3
8	Communication*		YES	YES	YES	3
9	Meetings*		YES	YES	YES	3
10	Get information and files ergonomist from client (and/or suppliers)		YES	YES	YES	3
11	Get information and files by ergonomist on his own			YES		1
12	Make the DHM analysis and prepare snapshots/presentation/report by ergonomist		YES	YES	YES	3
13	Check that the path is good ergonomist with client		no	no	no	
14	Arrange meeting/Send invitation for presentation of analysis		YES	YES	YES	3
15	Send snapshots of the DHM		no	no	no	
16	Give presentation/report and discussion by ergonomist and client (and or suppliers)		YES	YES	YES	3
17	Request of further analysis by client		no	no	no	
18	Modification of proposal by ergonomist		no	no	no	
19	Make extra analysis by ergonomist		no	no	no	
20	Deliver extra analysis by ergonomist		no	no	no	
21	Paying by client to ergonomist		no	no	no	
22	Follow up by ergonomist		no	no	no	

The absence of activities 4, 5, 17, 18, 19, 20, 21 and 22 in all cases can be explained by the fact that these three interventions were part of a free service offered just in one occasion by Dassault Systèmes as part of a market test. There was no need for a contract (activities 4 and 5) nor payment (activity 21) and clients couldn't ask for an extra analysis (17 to 20).

Clients could have asked for the signature of a NDA by the evaluators (activity 3) but they just asked them to keep the information confidential, without any signed agreement.

These three cases are similar in terms of activities because they were conducted as part of the same service (restricted to the virtual ergonomics evaluation of a workstation using its 3D model) by the same team of evaluators during the same period of time (in parallel).

Only for activity 11 (*Get information and files by ergonomist on his own*) there were differences between the three cases. In S2_Case2 ergonomists obtained information about the workstations from the company website, but in none of the cases the ergonomists built or obtained 3D models by themselves. One of the clients asked for the evaluation of a workstation based only in technical drawings but the service was not provided arguing that the 3D models were required.

Conclusions:

The fact that the same categories of activities found in Study 1 were present in the three cases of Study 2 and that there was no addition of new categories is a confirmation of the results that adds validity to the research.

All the activities mentioned seem important even if in some particular cases they might not be present. Therefore, they will all be included in the description of the current process of virtual ergonomics intervention in section 4.11.

Based on Study 1, it seems frequent that ergonomists build or obtain 3D models by themselves.

Improvements:

As for the improvement of the process, some activities could be eliminated, automated or merged in order to reduce the duration and increase the efficiency.

- Activities 7, 9, 17, 18, 19 and 20 could be absent in some particular interventions but it cannot be guaranteed that they will not be present in some interventions, therefore they cannot be eliminated from the process description.
- Activities 1, 4 and 6 could be totally or partially automated.
- Activities 1, 4, 6 and 14 could be combined. Also 13 and 15 could be combined in a single activity.

4.2 Actors

4.2.1 Actors in Study 1

Appendix E contains a table with the categories of actors present in the five interventions cases of Study 1. Actors categories were grouped in: ergonomist's company, client, supplier (which is considered an external organization) and other external actors.

Overall, 23 categories were found besides the ergonomist. Most of them were individuals but some organizations are also considered actors when the particular person from them wasn't specified by the interviewee. The minimum number of actors (besides the ergonomist) in a case was three for S1_Case1 and the maximum was nine for S1_Case2.

The Supplier is involved in 3 of the 5 interventions (S1_Case2, S1_Case3 and S1_Case5). Though the Supplier is the most frequent external organization, there might be others, like in S1_Case5 (*external funding organization* and *external organization interested in the results*). There could also be external actors indirectly linked to the intervention. That is the case of a "friend" or *professional contact of the ergonomist* who provided the human model in S1_Case4.

The professional profiles more frequent were managers, engineers/designers and ergonomists/OSH professionals.

In all cases, there is some kind of manager involved: *health and safety manager* and *engineer leader* in S1_Case1 and *health and safety manager* and *high level direction* in S1_Case2. In S1_Case3, there is a *health and safety manager* and a *manufacturing engineer* that acts as a manager. Then, in S1_Case4, there is *high level direction* amongst others. Finally, in S1_Case5, there is a *project manager*.

In all cases except S1_Case5 there are engineers involved. Designers were present in S1_Case2 (tool designers) and in S1_Case3 (designer_supplier).

The worker or future user of the product or equipment was not present in any of the cases.

When participants talked about DHM interventions in general (Study 1a) the actors mentioned were the same already identified in the analysis of the individual cases (Study 1), therefore, no new categories of actors were found.

4.2.2 Actors in Study 2

Study 2 wasn't about a traditional consultation service, instead it was about a free service offered as part of a pilot study to explore the market. The actors representing the client were not the ones who would typically have requested a paid service. For this reason, the actors of Study 2 won't be analyzed.

Conclusions:

The implication of a number of actors with different professional roles and backgrounds (managers, engineers and others) is a characteristic of the interventions. This implies that part of the process would be dedicated to coordination, communication and clarification tasks.

The worker or future user of the product or equipment wasn't involved in any of the cases.

It seems logical that the actor that will more directly use the virtual ergonomics' specialist assistance and the results of the intervention is the engineer or designer in charge of the workstation or product design, redesign or evaluation. It seems also logical that the nature of the information that the ergonomist will exchange with this actor is mostly technical. However , managers' profile is also very important and has generally more impact on the decisions made.

Improvements:

In a new process, the vocabulary and complexity of the deliverables and other materials produced should be easy to understand by all actors involved (from the engineering to the management domain). They should contain meaningful information for the different actors: for the engineers all technical aspects should be clear, whereas for the managers, there should be information about deadlines, costs, resources, etc.

4.3 Tools

4.3.1 Tools in Study 1

The tools used on each activity for the five cases of intervention of Study 1 are shown in Appendix F.

In the activities' analysis in section 4.1, it was clear that frequently the ergonomist needed to obtain or build models by himself (4 out of 5 cases). In the tools analysis, it was found that Grab CAD was used in S1_Case1 to get 3D models and it is logical to think that tools like this, with a large availability of models, could be useful to the ergonomist during virtual ergonomics interventions.

A variety of tools were used for communication in the different cases and in the same intervention. In S1_Case2, for example, four different communication tools were used (phone, WebEx, email, Sametime). In S1_Case1 there were three different communication tools.

Videoconference applications and Power Point are the main tools used for presentation.

To make the DHM analysis, a DHM software is used in 4 out of 5 interventions (S1_Case1, S1_Case2, S1_Case3 and S1_Case5). In S1_Case4 the software was a CAD tool where the ergonomist introduced a 3D model of a human.

In two cases: S1_Case2 and S1_Case5, besides the DHM software, a CAD software was used (CATIA and ROBOCAD respectively).

To make the analysis and prepare a presentation, frequently many applications were used at the same time and information had to be passed from one to the other.

In none of the cases was mentioned the use of a cloud service to send or access the files.

When participants talked about DHM interventions in general (Study 1a), the tools mentioned were the same already identified in the analysis of the individual cases in Study 1. No new tools were found in this part of the interviews.

4.3.2 Tools in Study 2

The tools found in Study 2 are shown in appendix G. Although there are similarities between these results and those of Study 1, there are also some differences. In Study 2, online information and services are used for the *Generic Presentation* and for the *Request of intervention*. This is somehow a partial automation of these activities that allows them to take place in an asynchronous way (client can do them without the ergonomist's presence). Although this cannot be considered typical because of its differences with the results of Study 1 (whose cases of intervention are more representative of the real practice), it gives a clue for improvement.

The tools used in Study 2 are practically the same in the three cases, probably because the evaluator was the same (the same team evaluated the three cases). Another new element of Study 2 that wasn't present in Study 1 is the use of a file Server to exchange the 3D files.

Conclusions:

- Many communication tools can be used in the same intervention.
- Many tools (more than 4) are used during the DHM analysis by the ergonomist.
- 3D model databases can facilitate the work of the ergonomist.
- The use of cloud-based services to transmit the files is not frequent.
- For some cases there were online information and services to facilitate tasks such as *Generic presentation* and *Request of intervention* in Study 2 that freed the ergonomist from participating and allowed for asynchronous communication.

Improvements:

- Use online services to partially automate some tasks and also to take advantage of asynchronous communications.
- Provide the client and the ergonomist with easy access to large 3D model databases.
- Provide a wide variety of communication tools sharing the same history of communication to avoid misunderstandings and duplicity of messages. The actors might then choose the communication tool to use each time according to the particular type of information or situation.

- Facilitate the integration of the applications used in one intervention.
- Use a cloud based application to keep and exchange the intervention files.

4.4 Inputs

4.4.1 Inputs in Study 1

The Inputs found in Study 1 are presented in appendix H. To facilitate its analysis, they were classified as file or information (FILE or INFO). Some inputs classified as information were contained in others classified as files.

The analysis of this theme allows to find the inputs required by the ergonomist to complete the intervention.

Obviously, the *3D models of the human, the equipment and the build-up (or product)* are necessary to the virtual analysis. However, other spatial and dimensional aspects could be necessary if they are not evident in the individual 3D models. These are the *Environment configuration* (relative positions of the models) and the *Specific postures*. In S1_Case1 this information was given by the client in *Pictures of human postures as example* and *Pictures of configuration of environment*. There are usually different postures that allow to accomplish a task: if the client doesn't specify the posture, the ergonomist will use his experience to propose the most probable and healthier posture.

The *Task information* was necessary in all cases and it was probably passed in communications with the client (e.g. communications to express the request). But other elements also gave task information: in S1_Case1 it was *Pictures of human postures as example*, in S1_Case2 it was *Spreadsheet with worker tasks, risks* and in S1_Case3 it was *Design proposal of a build-up*. In S1_Case4 the task information comes FROM 2_CLIENT IN GRAL whereas in S1_Case5 the participant knew everything about the task (i.e. driving) because he was a rally car driver himself. From this, it can be concluded that there is no standard way of transmitting the task information.

Now, returning to the *3D models (equipment and built-up*), ideally, the ergonomist would have them provided and that would allow him to accomplish the analysis sooner, but only in one of the interventions (S1_Case3) the ergonomist said clearly that he got these models from the client. In

the other four cases, the participant had to obtain models by himself. For S1_Case1, S1_Case2 and S1_Case4, it was the 3D model of equipment and for S1_Case5, it was the product (built-up) model. The human model in part of the DHM software but in S1_Case4 the ergonomist used a CAD to make the analysis, so he got a 3D human model by himself. In the three interventions where 3D models were build by ergonomists (S1_Case2, S1_Case4, S1_Case5), pictures, drawings and/or dimensions were necessary.

The fact that the ergonomist got some information and models by himself implies that he probably has personal sources like friends and literature, but also, that he might need to look for public resources on the internet such as libraries or databases.

S1_Case5 shows that the ergonomist could be given an economic constraint (*Price and budget for solution*) and *requirements* for the solutions.

Population and percentiles was mentioned in all cases but S1_Case4, where it had to be present as an input anyway, either given by the client in his request or decided by the ergonomist based on his understanding of client's needs.

Anthropometric information could have been given by the human model or taken from other sources by the ergonomist. Although this is an obvious input for any DHM intervention, it was only mentioned for S1_Case5. Here, when the participant was asked about the documents used, he said he used an anthropometric database external to the DHM.

When the four participants talked about DHM interventions in general (Study 1a), the inputs mentioned were mostly the same as the ones already identified in the analysis of the individual cases (Study 1). A few new inputs were mentioned and therefore added as categories. They are show in table 4.3

Table 4.3. Additional inputs mentioned by the participants when talking about DHM interventions in general (Study 1a).

Classification	**Additional inputs**
FILE	Screenshots of a simple DHM made by the supplier (which is partly the client of the intervention)
FILE	Video of the worker or user doing the task
FILE	Motion capture file of worker or user doing the task
INFO	Force and weight of tools
INFO	Repetition

4.4.2 Inputs in Study 2

Appendix I presents the inputs in the three cases of virtual ergonomics consultations of Study 2. Many of the inputs identified in Study 1 and Study 1a were also present in the three cases of Study 2 which confirms the results.

Here, the *3D models of equipment* were provided by the client in the three cases, against only one in Study 1. This can be explained by the fact that the evaluators asked for the 3D models as a condition to provide the free service. It was known through interviews with the evaluators' leader that one of the clients requested the analysis of another workstation, but as he didn't provide the 3D models (only technical drawings), the evaluation was not completed.

When comparing these results with those of Study 1, an interesting question stands out: should a virtual ergonomics intervention service include or not the construction of the 3D models by the ergonomist? This is obviously not part of the competencies of this profession. Ideally, companies should provide 3D models of their workstations or products to the ergonomist so he can perform the DHM analysis. It is only this last activity that corresponds to his expertise.

In S2_Case1, the client provided a *Video of the worker or user doing the task*, which is very useful to get postures and task information, but is only possible for existing workstations.

The input *Recorded Skype conversation* was new in Study 2 and allows the ergonomist to go back to the conversation to take notes or confirm some details. Although this is not an additional source of information (because it contains the same information transmitted in the meeting), it can contribute to save time from clarification of doubts or misunderstandings.

Conclusions:

As a conclusion of the analysis of this theme, the following lists summarize the inputs necessary to the ergonomist in a virtual ergonomics intervention. It seems pertinent to make a distinction between the information that depends on the client as a source and the information that ultimately can be obtained by the ergonomist on his own. This would allow some flexibility of the ergonomist when demanding information to the client.

In the group of information that could only be obtained from the client, there is a distinction between the information that needs to be transmitted in a file and the information that could be

transmitted by speaking. This determines the ways of transmission that will be proposed in the new process.

List of inputs necessary in a virtual ergonomics intervention:

Information and files depending on the client (if the ergonomist is external to the client):

Information that needs a support to be transmitted (files or hard copy):

- Environment configuration
- 3D models of equipment* OR Dimensions, pictures or drawings to build it.
- 3D models of Built-up (or product)* OR Dimensions, pictures or drawings to build it.

Information that could be transmitted by speaking (not necessarily needing a support):

- Population and percentiles
- Task information (Force, weight, repetition)
- Financial information (Price and budget for solution)
- Requirements

Information and files not necessarily depending on the client (they could be obtained from client or obtained or built by ergonomist):

- Human model
- Anthropometric information
- Specific postures
- Risks
- Identified problems
- 3D models of equipment*
- 3D models of Built-up (or product)*
- Specifications about products to modify the design

*These elements could be obtained or built by the ergonomist but this would imply extra effort and time, which could lead to a longer intervention and therefore be an inconvenient for client's satisfaction. In the same way, the construction of 3D models is not part of the ergonomist's competencies.

The following file formats were mentioned by participants in at least one of the studies: Excel spreadsheets, SPSS database, 3D files in general (JT files, Solidworks files, Delmia files), Videos, Simulation files, Power Point presentations, Images and PDF.

Improvements:

- The inputs should be shown as a list of information or files required since the first moments of the intervention and should be clear in the initial explanation of the service to the client. This list is not the same shown in this section, but should be based on it.
- Meetings and conversations should be recorded when possible so they can be used as references for the ergonomist without taking extra time from the client.
- The ergonomist should have tools to open and edit all the file formats found.

4.5 Outputs

4.5.1 Outputs in Study 1

Appendix J presents the outputs (or results produced during the intervention) in the five cases of Study 1. To facilitate the analysis, the outputs were classified as general information (INFO), specific ergonomics information (SEI), files (FILE) or ways of transmitting them (WAY). Some information (INFO and SEI) might be included in files and some information and files can be used in one way of transmission. *Number of tasks* is not a category of outputs but a measure of its AMOUNT.

In terms of information (INFO and SEI), the outputs are very heterogenic between the cases.

In all cases, there were *images of the DHM*, which obviously contain some *posture*, *reach* and *clearance information*. Nevertheless, the SEI categories *reach information* and *clearance information* will only be considered as an output (YES in the table of appendix J) if the information was explicitly pursued as an output of the analysis.

The intervention where the general information output (INFO) is the simplest is S1_Case4, because the ergonomist only had to confirm that one task met ergonomic compliance (*Confirmation of ergonomic compliance*). Regarding the SEI, this intervention produces *clearance information*.

In S1_Case2 the general information is *Recommendations* and the SEI is *reach information*, but these should be given for seven tasks.

Then, in S1_Case3, the general information transmitted is *Ergonomic problems of design*, whereas the SEI mentioned by the participant is *Force information* and *Load on biomechanical structures*. It is unknown how many tasks were analyzed.

In S1_Case1 there is more: *Different postures per task*, *Recommendations* and *Answer to questions* as general information and as SEI there is *vision, reach, joint moment, load on biomechanical* structures and *RULA* results. The number of tasks analyzed was 16.

Finally, S1_Case5 is completely different because new *Different solutions* to an ergonomic problem are proposed and the *Advantages and disadvantages* as well as the *Cost of each solution* are also given to help the selection. In terms of SEI only *Reach information* was mentioned by the participant. The number of tasks was four.

Regarding the files (FILE) the only common output are the *3D model of DHM analysis* (which is logical because they are all virtual ergonomics interventions) and *Snapshots of the DHM* (which is also expected because these are the support of the *images of DHM*).

The rest shows the variety of files that clients receive: in S1_Case1, S1_Case2 and S1_Case4 the results are delivered as a presentation/report. For S1_Case3 only snapshots are given as files. For S1_Case5 the clients get the CAD files of the solutions (which don't include the human model) and Power Point presentation is shown and used during a discussion but the file is not kept by the client.

In all cases the results were explained directly to the client, in a *Presentation with discussion* or a *Live DHM presentation.*

Finally, one output produced by the ergonomist in three cases (S1_Case2, S1_Case4 and S1_Case5) was the *3D model of equipment*. Even if the client didn't ask for it, the ergonomist had to build it to create the virtual environment. As it was mentioned in the previous section, ideally, in a virtual ergonomics intervention, the ergonomist would receive the 3D files from the client, but as it is evident in the three cases mentioned, the client do not always provide them.

When the participants talked about DHM interventions in general (Study 1a) the outputs mentioned were mostly the same as the ones already identified in the analysis of the individual cases (Study 1).

4.5.2 Outputs in Study 2

Appendix K presents the outputs in the three cases of DHM ergonomics consultations of Study 2.

In all cases, the outputs delivered to the clients were in a FILE containing the *Report/presentation document.* Also in all cases there was a *Presentation with discussion.*

Four types of information (INFO) produced as an output were common to the three cases: *Ergonomic problems of design, Images of DHM, Recommendations/Requirements* and *Confirmation of ergonomic compliance/Risk evaluation.* These similarities might be linked to a certain standardization of the intervention because the latter was provided by the same team of ergonomists at the same time to satisfy a very specific service offer.

However, there were considerable differences between the rest of the outputs in the categories SEI and INFO that were probably caused by the different clients' needs.

Two new specific ergonomics information (SEI) appeared as an output that were not present in Study 1 nor in Study 1a: *Repetition information* and *KIM indicator evaluation.*

Conclusions:

From the outputs analysis we can conclude that the clients have different information needs and files requests, so the ergonomist should be prepared to react to these differences.

Some outputs are requested more than one time so there is some repetition.

Improvements:

- In a new process all the possible outputs can be proposed to the client (with examples), as options to express the request. The possibility of expressing the request in their own words should be given as an alternative.
- The classification used in the analysis could be useful to organize the offer of outputs to the client in groups.

- For each output or group of outputs that the client can chose there should be a template of report or presentation to facilitate the ergonomist' work. This template can be used since the beginning of the intervention to facilitate communication and understanding between the parts regarding the final results.
- In the long term, a reduced number of standard outputs represented in templates could help to make virtual ergonomists services look more simple and be more known. New outputs found in future studies or future interventions can be added.
- Knowing the more probable requests he can get, the ergonomists can improve his preparation for the analysis.

4.6 Demand

4.6.1 Demand in Study 1

Appendix L presents the characteristics of the client's demand (or request that initiate the intervention) in every case of Study 1. The demand aspects analyzed were: *Actor that made the request*, *Goal of client with intervention*, *Demand initially expressed by client*, *Demand specified by ergonomist*, *Stage in design process* (of the client problem) and the *Corrective or preventive* intentions of the client with the intervention.

The *Actor that made the request* had in all cases a manager profile. In S1_Case3, the management is considered indirectly as the person making the request, because this intervention was a routine analysis that the internal ergonomist performs as part of the management expectations for his job position.

The initial demand of the client was always reshaped or more detailed by the ergonomist. This can be verified in the difference between the *Demand initially expressed by client* and the *Demand specified by ergonomist*.

One of the elements specified by the ergonomist was the use of DHM. Only in S1_Case1, "DHM use" was explicitly asked by the client. In S1_Case2 and S1_Case3, the client considered the use of DHM as a possibility, but relied on the ergonomist to decide if it was pertinent to use it. In S1_Case4 and S1_Case5 the client did not ask for DHM at all (didn't even know what it was) and

it was the ergonomist who decided to use it. Based on these results, it could be argued that to impulse the use of DHM when clients do not ask for it explicitly, the ergonomist should take the initiative of using this tool.

The goal of the client with the demand was generally linked to the pursuit of profit, cost reduction or legal compliance. For S1_Case1 and S1_Case5 (both product design projects) the client needed to adapt a new design to a human to reach a new market. The final goal was profit, because of more clients and/or more sales. In S1_Case2, S1_Case3 and S1_Case4, which are projects in the manufacturing context, the goals were to reduce costs (S1_Case2 and S1_Case3), meet OSH legal requirements (S1_Case3 and S1_Case4) or make a work task possible (S1_Case4).

Finally, in most cases, client's intentions were preventive (4 out of 5).

When participants talked about DHM interventions in general (Study 1a), the aspects related to the demand theme did not add new categories.

4.6.2 Demand in Study 2

Intervention cases in Study 2 were atypical because they were a product of a free service of virtual ergonomics workstation evaluation. When a free service is offered, the people that make the demand and their reasons could be different from those in typical cases, where the service is paid. In S2_Case3, for example, the demand didn't come directly from the company whose workstations were analyzed. Instead, it came from partners of DS that were interested in selling DS's virtual ergonomics software to Client 3.

For these reasons, the demand of the three cases of Study 2 won't be included in the analysis.

Conclusions:

In general, the final goal of clients in an intervention is not ergonomics design per se. The risk reduction is never their ultimate goal: the ultimate goal is a new design concept based on ergonomics (use), or save money, or make a task possible and/or meet the regulations.

Improvements:

From the demand analysis in Study 1 the following improvements for the process are proposed:

- To impulse the use of DHM in those cases where the client does not ask for it explicitly, the ergonomists should use it as part of their job of consultants.
- If one wants to encourage clients (in particular managers) to make ergonomic or DHM analysis (and therefore to request and pay for the service of Virtual ergonomics intervention) they need to know the advantages they can get in terms of cost, insurance, law, impossible tasks, etc.
- The clients' satisfaction with the results will also increase if the advantages mentioned in the previous point are evident in the final solutions.

4.7 Duration

4.7.1 Duration in Study 1

The intervention duration is important because the earlier the changes are made to design, the less costly is their implementation.

Appendix M presents the duration of the whole intervention and some activities in Study 1. The five cases lasted respectively 1 month, 3 weeks, 3 days, 1 week and 6 months.

Interventions S1_Case3 (3 days) and S1_Case4 (1 week) lasted much less than the other three. Coincidentally, in these two cases, the ergonomists worked in the client company. Although this cannot be generalized as a determinant of the duration reduction, a reflection about the possible advantages of internal ergonomists can be made. Ergonomists that are part of the client's company have most likely already signed contracts and NDAs, know what is expected of them and are familiar with the company and the actors. They should therefore need less time of preparation than an external ergonomist (only the proposal elaboration can last as long as one week, as in S1_Case1). On the other hand, these two subjects (S1_Case3 and S1_Case4) did not wait too long for information or files (activity 7) because they already had them, they could obtain them by themselves or the company had routines to provide them. Probably for all these reasons they could make the DHM analysis earlier in the process than the others.

In S1_Case5, which is the longest intervention (four to six months duration), the waiting times (activity 7: *Waiting for information and files from client*) were of one month sometimes. In contrast, the ergonomist took only one week for the actual DHM analysis (activity 12: *Make the DHM*

analysis / Prepare snapshots/presentation/report by ergonomist). Apparently what lengthened the intervention was waiting for client's decisions and information. This suggests that providing the ergonomist with the necessary inputs early is one of the keys to accelerate the intervention.

Another interesting finding in the theme duration is that is possible to have a virtual ergonomics intervention as short as three days (S1_Case3) which indicates that durations of six months (S1_Case5) or one month (S1_Case1) and even three weeks (S1_Case2) could be reduced. For example, one could think that there are methods and tools to make a proposal in less than one week (activity 4 *Proposal elaboration* in S1_Case1).

Conclusions:

The conclusions of this theme were included in the previous reflections.

Improvements:

Although the data about the duration of different activities in the process are not very rich, they suggest that the following improvements could contribute to reduce the overall duration:

- Have ergonomists familiar with the company to make the intervention.
- Accelerate the activities oriented to obtain inputs from the client. The client should have very early a list of information and files to provide. The ergonomist could be flexible about these requirements depending on the situation.
- Facilitate the proposal and report elaboration with the use of methods like templates, checklists, automatic generation and others.

Many improvements proposed in the rest of the themes can also contribute to reduce the duration.

4.7.2 Duration in Study 2

S2_Case1 and S2_Case 3 of Study 2 lasted two months whereas S2_Case2 lasted one month.

In these three cases there was no need of creating a proposal, the ergonomist didn't need to create 3D models (he got them from the client) and there was no payment, nor extra analysis requested. When compared to some cases in Study 1 it could be thought that these interventions could have lasted less than a month. However, as this was a free service, the evaluators offered to present the results by the beginning of April 2019 (2 months after the offer was published in the first days of February) and the clients agreed with that. For these reason, the results of the duration in Study 2 are not typical and will not be analysed.

4.8 Obstacles

Table 4.4 presents all the obstacles found in Study 1, Study 1a and Study 2. The frequency of each obstacle's presence in Study 1 and 2 appear in the fourth and sixth columns respectively. The fifth column contains the number of participants who mentioned each obstacle in Study 1a. Validity is reinforced by the confirmation of some obstacles found in Study 1 and 1a, in Study 2 (triangulation).

The obstacles were classified according to the possible influence of the new process on them in *Indirect*, *Direct* or *None* (eighth column). Regarding the intervention aspect they are related to, the obstacles classification was: *Client*, *Context*, *Tools*, *DHM tool*, *Strategy* and *Input* (seventh column). Appendix N contains a more detailed table about obstacles presence on each study.

Table 4.4. Obstacles of interventions in Study 1, Study 1a and Study 2.

#	All obstacles	Found first in	Frequency out of 5 cases in Study 1	Frequency out of 4 participants in Study 1a	Frequency out of 3 cases in Study 2.	Classification	Influence of the process in it
1	Lack of actors collaboration with the DHM intervention	Study1	1	2		Client	Indirect
2	Lack of coordination of actors	Study1	2	1		Client	Indirect
3	Lack of managers support for the DHM intervention	Study1	1	1		Client	Indirect
4	Designer not being the decision maker causes decision making to be longer and more complex	Study1	1			Client	None
5	The client is not ready for a Virtual Ergonomics intervention (they are too early in the conceptual phase of design)	Study1a		1		Client	Indirect
6	Clients don't want to get involved in deep or complicated analysis	Study1a		2		Client	Indirect
7	Clients might suggest postures that are not the most likely ones	Study1a		1		Client	Indirect
8	Different languages of actors	Study1	1	1	1	Context	Indirect
9	Holidays at the same time of the intervention make it so that it takes longer	Study1	1			Context	None
10	Ergonomist resistance to DHM	Study1a		1		Context	None
11	Posture subjectivity	Study1a		1	1	Context	Indirect
12	In new designs there is constant change to keep up to date and there is a lot of communication back and forth	Study1a		1		Context	None
13	DHM software doesn't allow to simplify data display for presentation	Study1	1			DHM tool	None
14	Specific DHM software doesn't allow to do certain biomechanical calculations	Study1	1			DHM tool	None
15	Human model lacking of the real human physical characteristics	Study1a		2		DHM tool	None
16	Lack of certain ergonomic analysis tools in the DHM software	Study1a		1		DHM tool	None
17	Bugs of the DHM software	Study1a		1		DHM tool	None
18	DHM is slower and less visually attractive than people's expectations of it	Study1a		1		DHM tool	None
19	Client doesn't express clearly what he wants (request)	Study1	1	1	2	Input	Indirect
20	Difficulties to know exactly where to position the models in the virtual environment	Study1	1	1		Input	Indirect
21	Receive too little information from client	Study1	1		2	Input	Indirect
22	Impossibility or difficulties to get the 3D models from client or supplier	Study1	3		1	Input	Indirect
23	Long time waiting for information, decisions or availability of the client	Study1	1			Input	Indirect
24	Find a time when many actors are free to participate in a meeting delays the meeting	Study1a		2		Strategy	Indirect
25	Many tasks or configurations make a long report	Study1a		1		Strategy	None

Table 4.4. Obstacles of interventions in Study 1, Study 1a and Study 2. (*Continued and end*)

#	All obstacles	Found first in	Frequency out of 5 cases in Study 1	Frequency out of 4 participants in Study 1a	Frequency out of 3 cases in Study 2.	Classification	Influence of the process in it
26	Ergonomist decisions are not justified	Study1a		1		Strategy	Direct
27	Making the proposal is not efficient	Study1a		1		Strategy	Direct
28	It takes time to make the proposal	Study1a		1		Strategy	Direct
29	Ergonomist need to change and position manikins of different sizes during a live DHM presentation	Study1a		1		Strategy	Direct
30	Difficult to differentiate the different sizes of human models	Study1a		1		Strategy	Direct
31	Slowness of presentation making people focus in the non important	Study1a		1		Strategy	Direct
32	Human model lacking of the real human physical characteristics COMBINED someone using the DHM who doesn't explore what would happen in reality PRODUCES a DHM analysis that doesn't represent reality MIGHT LEAD to take the wrong decisions	Study1a		1		Strategy	Direct
33	Ergonomist doesn't have access to a DHM software	Study1	1	1		Tools	None
34	Not having the required human model	Study1	1			Tools	Direct
35	Difficulties in the transfer and or importation of 3D models	Study1a		2		Tools	Indirect
36	Ergonomist computer not having the capabilities to run the DHM model software quickly	Study1a		1		Tools	None
37	Companies don't have DHM software	Study1a		1		Tools	None
38	Companies don't have CAD software	Study1a		1		Tools	None
39	Client and ergonomists not having the same tools to communicate	Study1a		1		Tools	Indirect
40	The DHM software being used might make some analysis longer than other software	Study2			1	DHM tool	Indirect
41	DHM software not having anthropometric data of the target population	Study2			1	DHM tool	Indirect

The obstacles that are out of the influence of the process (*None* in eighth column) will not be commented. Those that can be directly or indirectly influenced by the process will be analyzed according to their classification.

Client:

The most important obstacles linked to the client are 1, 2, 3, 4 and 6. The *Lack of actors collaboration* (Obstacle 1) or resistance to the intervention is an important one. It is generally caused by actors' poor knowledge or underestimation of DHM, as is expressed by the ergonomist describing S1_Case2: "They don't want to come to the meeting, they don't know what you are

doing when you are talking about human modeling, they don't know, they don't think it's useful". This is even more problematic if the management (Obstacle 3) is indifferent or resists the intervention, because they could reduce the first obstacle by exerting their leadership. Also, when managers (usually decision makers) don't have interest in the intervention, this one won't happen at all or its success will be compromised. For internal ergonomists with access to actors and information, some interventions might be possible without managers support if the changes proposed are minor. That is the case of S1_Case4 (see Appendix N), where this obstacle was present and yet the internal ergonomist was able to obtain information and complete the intervention. Although *Lack of coordination of actors* (Obstacle 2) could depend on many factors, it could be attenuated by the management too.

Designers not being the decision makers (Obstacle 4) is an obstacle even to the existence of the intervention because they might not get the approval to get external help. To get around this obstacle, the intervention advantages in terms of cost and benefits for the company should be emphasized to attract decision makers' interest.

Obstacle 6 partly confirms the problematic that originates this research: companies might avoid virtual ergonomics interventions because they see them as *deep and complicated analyses* that delay their goals' achievement. The new process should try to change this perception during the first interaction experiences (with the ergonomist or the application) showing an intervention process as simple, concise, transparent and advantageous as possible. Of course, the real process should keep up with those expectations to satisfy the client and change the image of virtual ergonomics interventions in the long term.

Inputs:

Obstacle 19 is about the difficulties of the client to express the request. Obstacles 20, 21, 22 and 23 show problems to receive information from the client. Specifically obstacle 22: *Impossibility or difficulties to get the 3D models from client or supplier* and obstacle 23 *Receive too little information from client* are very important because they were present in both Study 1 and Study 2.

The obstacles related to inputs confirm the results in the theme inputs. Although these five obstacles depend on the client company, the ergonomist and the new process should help actors to reduce

them. Ultimately, the new process should contribute to the client understanding of his own responsibility in the facilitation or delay of the intervention, so it is not all put on the ergonomist.

Context:

Different languages of actors (Obstacle 8) is a problem in verbal communication that was suggested to be alleviated by the use of email (can be seen in the facilitators in the next section).

Posture subjectivity (Obstacle 11) represents the ergonomist difficulties to find the most probable posture (among all the possible ones) that will be assumed for a task. In this sense, it seems important to obtain posture information from the client for existing tasks or reach consensus of actors on the most probable posture when the task doesn't exist yet. In any case, the ergonomist needs to explore posture reality to be able to adjust the model or base his decisions in the most realistic postures (even if the model cannot reflect them).

DHM tool:

Though DHM tools improvement is not an objective of this work, the limitations of this software found in the obstacles can be used as a reference for development companies. In the new process, the ergonomist should use other tools or methods to compensate current DHM limitations.

Tools:

These obstacles might be attenuated providing ergonomists access to certain tools. For obstacles 34, 35 and 39 for example, three respective solutions would be: to have rich databases of human models, to have software to open and convert different 3D formats and to have the most used free communication applications.

Strategy:

These are obstacles 24 to 32 and they are related to the way things are done during the intervention. They will be taken into account to suggest new strategies in the section concerning the process improvement in the next chapter (section 5.2).

4.9 Facilitators

Table 4.5 presents all the facilitators found in Study 1, Study 1a and Study 2. It has the same structure as table 4.4 in the previous section. Appendix O contains more detailed results.

Table 4.5. Facilitators in Study 1, Study 1a and Study 2.

#	All facilitators	Found first in	Frequency out of 5 cases in Study 1	Frequency out of 4 participants in Study 1a	Frequency out of 3 cases in Study 2.	Classification	Influence of the process in it
1	Experimented ergonomist who makes an evaluation just by looking at the work situation	Study1a		1		Strategy	None
2	Contact in the client who helps the ergonomist when he is remotely	Study1	1			Client	Indirect
3	Contact in the client who understands ergonomics and 3D	Study1	1			Client	None
4	Good work relationship with an actor	Study1	2	1		Client	None
5	Support of actors	Study1	1			Client	Indirect
6	Support of management	Study1	1			Client	Indirect
7	Actors that have experience working with ergonomists	Study1a		1		Client	None
8	Certain power of decision of engineers without escalating to managers	Study1a		1		Client	None
9	Contact in the client who is up to date and knows almost everything about project	Study1	1			Client	Indirect
10	Designer open to discussion about design	Study1	1			Client	None
11	Stability of the team of stakeholders	Study1	1			Client	Indirect
12	DHM facilitates changes, visualization, iterations, discussion of different solutions and trade-offs	Study1	1	1		DHM Tool	Direct
14	ADV_DHM allowing quick visualization of different solutions	Study1a		1	1	DHM Tool	Direct
13	Changes in the posture can be easily made	Study1a		1		DHM Tool	Direct
15	DHM graphic and quantitative analysis facilitates comprehension and avoids disagreement	Study1a		1		DHM Tool	Direct
16	To have many ergonomics tools combined in the DHM software	Study1a		1		DHM Tool	None
17	Use of catalogs	Study1a		1		DHM Tool	Direct
18	Ergonomist obtains information by himself	Study1	3		1	Inputs	Direct
19	Getting pictures from the client with environment configuration and posture	Study1	1	1	1	Inputs	Indirect
21	To have all the information necessary for the analysis	Study1	1	1		Inputs	Indirect
22	Well established proposal	Study1	1	1		Inputs	Indirect
24	General view or list of the assembly line workstations or tasks that might include the risks and the methods of analysis	Study1	1		1	Inputs	Indirect
20	To have a video of the human doing the task	Study1a		1	1	Inputs	Indirect
23	In some situations a very simple model of the virtual environment is enough to make a DHM analysis	Study1a		1		Inputs	Direct
25	Format of the models	Study1a		1		Inputs	Indirect

Table 4.5. Facilitators in Study 1, Study 1a and Study 2. (*Continued and end*)

#	All facilitators	Found first in	Frequency out of 5 cases in Study 1	Frequency out of 4 participants in Study 1a	Frequency out of 3 cases in Study 2.	Classification	Influence of the process in it
26	Changes proposed not having considerable cost and time implications	Study1	1			Strategy	Indirect
27	Give results the soonest possible and the earliest possible in the design process	Study1	1	1		Strategy	Direct
31	Live DHM presentation to facilitate discussion and exploration of options	Study1	1	1		Strategy	Direct
32	Use different clothing colors to differentiate percentiles in the DHM	Study1	1	1		Strategy	Direct
33	Have manikins prepared for the DHM live presentation	Study1	1	1		Strategy	Direct
35	Ergonomist interest in showing client how DHM can help them	Study1	1			Strategy	Direct
28	DHM still images allow to leave a trace and proof of ergonomic assessment	Study1a		2		Strategy	Direct
29	Ergonomist using the DHM to provide information to facilitate decision making rather than imposing decisions is more persuasive	Study1a		1		Strategy	Direct
30	Meetings where there is visual information	Study1a		1	1	Strategy	Direct
34	Ergonomist persuades another actor that a posture is very unlikely without repositioning the manikin	Study1a		1		Strategy	Direct
36	Email better that phone for clients not speaking the same language as ergonomists	Study1	1	1		Strategy/ Communication	Direct
37	Email being the fastest way to communicate because there is no need to find a common time for a phone call	Study1a		1		Strategy/ Communication	Direct
38	Ergonomist having access to DHM software (or 3D software)	Study1	1			Tools	None

Clients:

The 10 facilitators related to clients suggest that actors' positive attitude together with their DHM, ergonomics and 3D knowledge have an important influence in interventions success. They also confirm obstacles 1, 2 and 3 in the previous section (*Lack of actors collaboration*, *Lack of actors coordination* and *Lack of management support*). Although many of these facilitators cannot be influenced by the intervention process, for facilitators 5 and 6 (*Support of actors* and *Support of management*) there could be an indirect influence exerted in the first contact with the client to make him aware of the advantages of the intervention.

Facilitators 2 and 9 show that it could be advantageous for the new process to have one contact in the client company that collaborates with the ergonomist.

DHM Tool:

The facilitators related to the DHM tool are advantages of using the software. In the new process, the ergonomist could use them as a reference to make the most of this tool.

Inputs:

Facilitators 22 and 21, that confirm obstacles 19 and 21, are particularly important: a request expressed clearly and the inputs availability significantly facilitate the work of the ergonomist. Facilitator 18 shows that sometimes it is easier for the ergonomist to find information by himself than to obtain it from the client. Facilitators 19, 20 and 24 are useful inputs: pictures with environment configuration and postures, videos of the task and general view (or list) of the assembly line, workstations and tasks. The format of the 3D models provided by the client (facilitator 25) could facilitate or complicate its importation into the DHM software.

Strategy:

Facilitator 26 suggests that solutions with low cost and time implications are better accepted and applied by the client. It also confirms the results (in the theme demand) that showed the economic motivation being central in client's goals. Facilitator 27 confirms that a quick analysis in early phases of design could be very positive because one of the clients' goals is to anticipate risks to minimize costly modifications.

Facilitator 31 is about the advantage of DHM live presentations (presentations with the DHM software) to make modifications or analysis suggested by the discussion. But this kind of presentation could make DHM flaws more evident to the actors (obstacle 18). The situation could be worse if the ergonomist doesn’t have the necessary DHM skills: obstacles 29 and 31 could be accentuated.

Strategy/Communication:

The use of email instead of phone to talk to no native speakers of the ergonomist's language is a way to facilitate communication (facilitator 36). However, it is logical to think that other ways

might be useful in other circumstances. For this reason many ways of communications will be available for actors to chose.

Most obstacles and facilitators will be taken into account to elaborate requirements for the new process and interface. Some of them have solutions that are out of the scope of this work because they are technical, require company decisions or involve professional opinions from other domains than the ones of this work.

4.10 General conclusion of themes' results

In Study 2 the categories found in Study 1 were widely confirmed and just a few new ones were added (in the themes Tools, Inputs, Outputs and Obstacles). This adds validity to the results and suggests that the data collected allow to describe the main characteristics of the current virtual intervention process.

However, the results cannot be generalized due to the small sample size (five and three cases in Studies 1 and 2 respectively).

Some conclusions about the virtual ergonomics interventions studied will be discussed in the following paragraphs. The interventions were heterogeneous: some interventions were conducted by internal ergonomists whereas others were conducted by external ones, some interventions are in product design projects whereas some others are in manufacturing, some interventions were related to a new design whereas others corresponded to the modification or evaluation of existing workstations that ended up being virtual ergonomics interventions because the ergonomist decided to use this tool to support his work, some interventions lasted months and others just a few days.

Despite this variety there are points in common between cases. The following activities are present in most of them: *request of client*, *ask* and *receive information*, *make DHM analysis and arrange meeting/presentation appointment by ergonomists*, *check provisional results* with clients and *deliver final results*.

Actors present in interventions (excluding the ergonomist consultant) were in all cases more than three, they can be as numerous as nine, and they have different backgrounds such as engineering, management and OSH.

The information required by the ergonomist is mainly related to the physical description of the product or workstation and its environment (3D models being the ideal input) and the description of the activity (task information). It is transmitted in different ways to the ergonomist and there are usually difficulties and delays in this step. The outputs are also varied but always have in common the DHM analysis screenshots. The ergonomist has to use different tools that sometimes are not optimal nor integrated.

The low demand of DHM interventions (mentioned in the problematic and confirmed by the participants) can be explained by the fact that key actors in industry are not familiar with this tool and its advantages (which is verified in the obstacles). One of these actors are managers, who will not see ergonomics' benefits unless they are expressed in financial terms.

Another problem is that clients don’t want to get involved in deep and complicated analysis and their perceive ergonomics interventions like that. To change this situation, virtual ergonomics interventions need to be more efficient and brief than traditional ones and this should be evident to the clients. One possible approach is to produce significant results (even if they are not complete) for clients sooner (as in the Agile philosophy used in software development).

There are many disadvantages of using DHM that still keep these tools far from generalization in industry. One of them is posture subjectivity, that sometimes make results from DHM less convincing for clients than those made with real worker and a physical mock-up.

But even when a virtual ergonomics intervention is requested, there are obstacles to its success. An important obstacle is the fact that ergonomists don't receive the 3D models from the client, either because clients don't use a 3D software or because the design is in an early stage where the product or equipment is not completely defined. Depending on the case, the ergonomist could adapt and build reference elements in the 3D (such as rudimentary volumes) to make the DHM analysis or could ask for the 3D files as a condition to provide the service. The second option is recommended in the long term, because companies should evolve to the 3D and 3D modeling is not part of ergonomists’ expertise. The ergonomist could suggest to the client a 3D modeling service as an alternative. However, in some cases it could be pertinent to build the models (in case the ergonomist has the skills) to make some interventions possible, avoid losing clients and promote virtual

ergonomics. Ultimately, this decision resides in the company and/or ergonomist providing the service and can be adjusted strategically.

Other barriers to generalization and success of DHM interventions are communication problems. A clear request definition by the client and the transmission of information to the ergonomist are essential to reduce intervention time. The standardization of the possible requests (outputs) and required information (inputs) as well as a shared vocabulary can facilitate the communication between client and ergonomist for this purpose. Although the comprehension of both parts might take time and effort at the beginning, this standardization might be the key to shorter and efficient interventions in the future. Other professions have standardized their services and documentation so their communication with clients has a support and a vocabulary that facilitate understanding.

According to the results, the current virtual ergonomics interventions have some similarities with traditional interventions practice described in the literature review (Chapter 2). In both types of interventions there is no standard procedure, only physical aspects of the activity are taken into account while psychosocial and psychological factors are neglected. In both situations there are obstacles associated to the actors' lack of ergonomics knowledge and the managers' poor acknowledgement of ergonomics.

Similarly to the obstacle mentioned in literature for traditional ergonomics practitioners: *Contact in the client's organization not being the decision maker* (Whysall et al., 2004) there is *Designer not being the decision maker...* found in S1_Case3, where coincidentally the designer was an important contact in the client but didn't have the power to accept the changes on behalf of his organization. Also in both traditional (literature) and virtual (this study) ergonomics interventions, good and supportive relationships between the ergonomist and the stakeholders are mentioned as important facilitators.

As opposed to traditional ergonomics interventions where clients were reported to request mostly corrective actions, in the virtual ergonomics interventions of this study the clients requested mostly preventive analysis (4 out of 5 cases in Study 1). Another difference is the inclusion of the worker in the intervention, that is mentioned in the literature about traditional ergonomics practice but is not present in any case of this research.

4.11 Current process of virtual ergonomics intervention

Figure 4.1 shows the diagram that represents the current process of virtual ergonomics interventions based on the results of Studies 1, 1a and 2 for the themes *activities*, *actors*, *inputs*, *outputs* and *tools.*

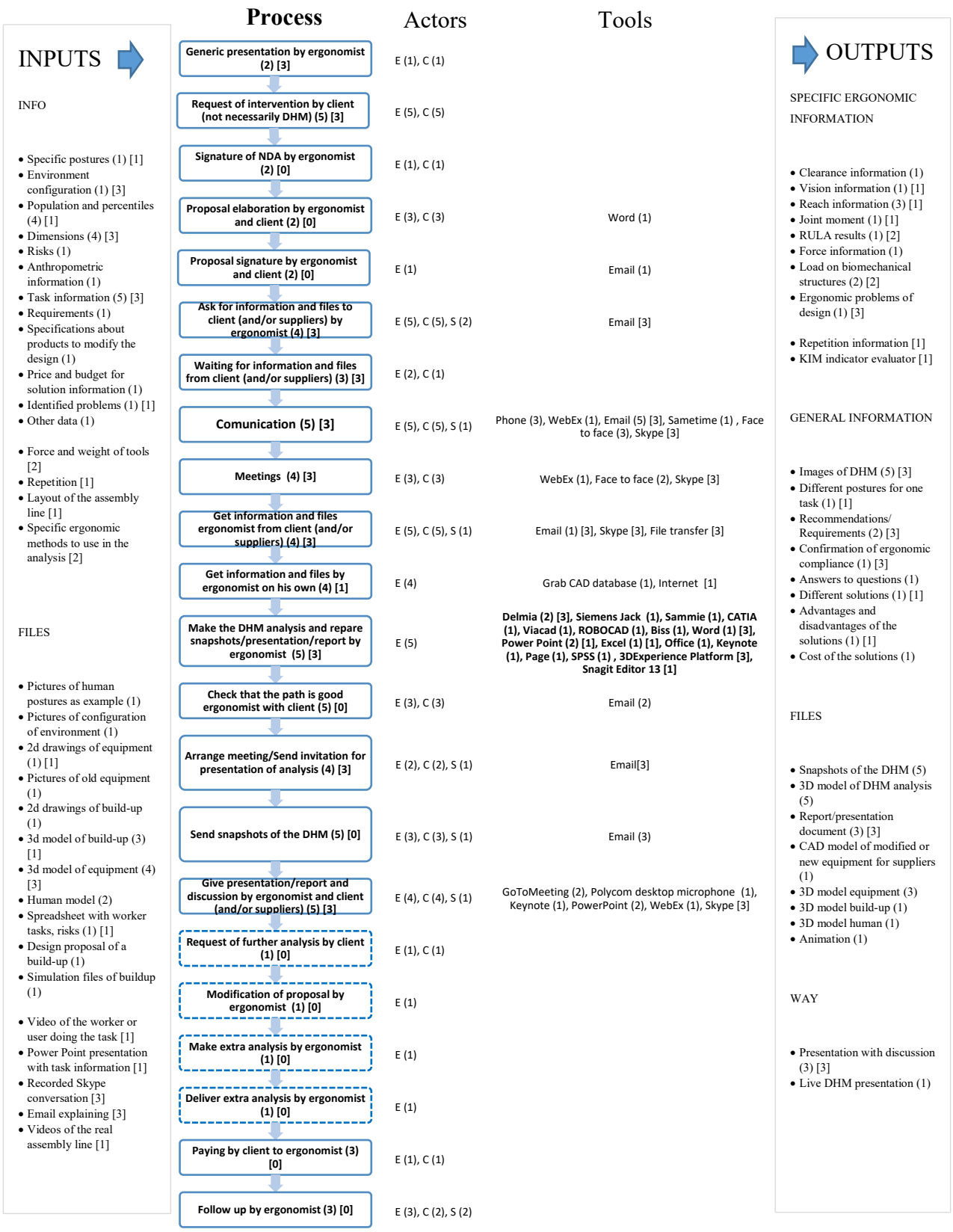


Figure 4.1. Current process of virtual ergonomics intervention.

The process contains 22 activities. It reflects all the activities, inputs and outputs present in the cases of Study 1 and Study 2. For each activity, the actors and tools mentioned are represented too. In the actors column, E represents the ergonomist and C and S represent client and supplier as general entities. The categories frequency is shown in parentheses for Study 1 (out of 5 cases) and in brackets for Study 2 (out of 3 cases).

The tools used for *Generic presentation* and *Request of intervention* in the three cases of Study 2 (see appendix G) were not included in the process because they were considered too specific to the free consultation and not likely to be used in typical services of ergonomics consultation. The use of these tools gives a lead to the process improvement, so it will be taken into account in that step.

This chapter (representation of current process and conclusions from the themes) constitutes the study and analysis of the current practice of virtual ergonomics interventions that is an essential step for the proposition of a new procedure. From these results, a list of requirements for the new process and the new process description were created as will be presented in Chapter 5.

CHAPTER 5 NEW PROCESS OF VIRTUAL ERGONOMICS INTERVENTION

The present chapter describes the conception of a new virtual ergonomics intervention process which is the second objective of this research.

The enhancement of virtual ergonomics intervention procedures should take into account the characteristics of the current practice and its improvements reflected in the results of Studies 1, 1a and 2 in the previous chapter. As the new process will become a real service provided through a web application by Dassault Systèmes, important elements of this context play a part in its definition. For these reasons, the methodology followed to create the new process involved the use of the current practice and context conclusions to propose requirements. A table was built where the current practice (themes) and context characteristics were associated with new requirements. The new process is defined through these requirements and a diagrammatic representation.

This chapter is organized in three sections. In section 5.1, the context of the new process and the conditions that it imposes to it are described. Sections 5.2 and 5.3 present respectively the requirements and the representation of the new process.

5.1 Context of the new process

The design of a new process of virtual ergonomics intervention responds to a general need in industry and also to a concrete demand. This demand is the request made by the virtual ergonomics division of Dassault Systèmes, to design a new service of remote virtual ergonomics consultation. The new service (that they will offer) is part of a prospective strategy: Dassault's virtual ergonomics vision.

To create this vision, the company analyzed the barriers to a more extended use of DHM in the manufacturing setting. Based on their experience with users and the DHM literature, they found two important problems. The first one is the time consuming task of positioning the manikins in existing DHM software. The second one is engineers' lack of ergonomics knowledge on one side and ergonomists' poor 3D skills on the other, which makes hard for these users to learn to use the software (DHM use requires a combination of ergonomics knowledge and 3D skills).

Dassault’s virtual ergonomics vision contains strategies to attenuate these two problems. Firstly, it contemplates the implementation of a Smart Posturing Engine that will automatically position the manikin and therefore reduce almost to zero the manual positioning times. The new software that will contain this feature is the Ergonomic Workplace Design (EWD), oriented to manufacturing planning.

Secondly, Dassault would try to make DHM software more usable for engineers lacking ergonomics knowledge by automating ergonomic analysis and simplifying results representation. This vulgarization of ergonomics in the EWD should allow engineers to eliminate on their own many of their workstation's problems.

However, there could be ergonomic problems that require a deeper understanding of the situation and engineers cannot solve, even with the new facilities. In order to assist engineers in such situations, Dassault intends to provide a new service of online virtual ergonomics consultancy, whose design is the purpose of the present work.

According to the company request, this consultation process (intervention) should be conceived to take place remotely because Dassault’s clients are all over the world and ergonomists are not likely to be in the same place to provide the service. The application that will allow this remote communication will be called "Ask an ergonomist".

The online service will be accessed mostly through a button named "Ask an ergonomist" that will be always visible in the EWD software interface. The characteristics of EWD users are summarized in a Persona created by Dassault and shown in figure 5.1.

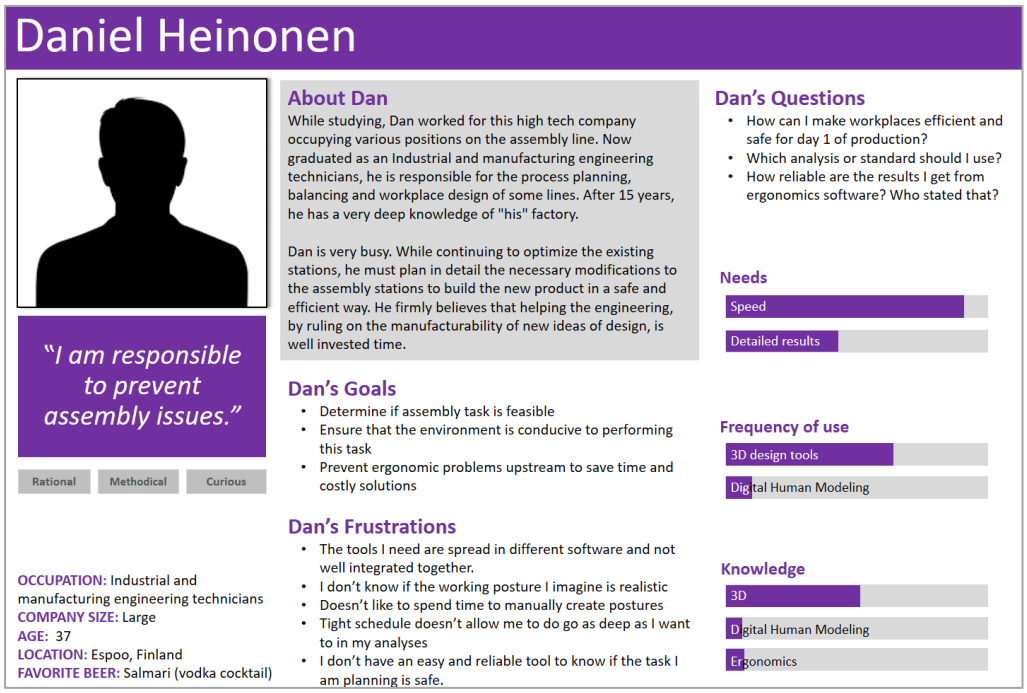


Figure 5.1. Persona of EWD main user created by Dassault before the present study.

Based on the EWD client (persona) the new process should:

- Privilege speed over detail in the results.
- Be adapted to a user with poor ergonomics and DHM knowledge.
- Enhance reliability in the analysis and the results.
- Improve tools integration to facilitate use (by the client of the process).
- Help the client to save time and reduce costs and make these advantages visible to him.

Although the main target public of the service are EWD users, Dassault will also aim at other clients with a similar profile that will access the service in the Marketplace of Dassault's 3DEXPERIENCE platform. The profile of these other users being similar to the EWD users' one, the requirements previously mentioned will be considered for them too.

Other organizational requirements expressed by Dassault are the following:

- DS could select for their service clients that provide the 3D models. In the case of clients without 3D models, DS could suggest them an external modeling service.
- The clients should be offered service packages that simplify the request specification.

- A Non Disclosure Agreement should be signed by the ergonomist to protect client's information.

5.2 Requirements for the new process

To define the new process, the current process (figure 4.1), the themes' conclusions (Studies 1, 1a and 2 in Chapter 4) and the context's characteristics (section 5.1) are taken into account.

Table 5.1 contains the new process requirements (second column), the elements from previous analyses that originated each of them (first column) and some possible solutions (third column).

Table 5.1. Requirements and possible solutions for the new process.

Theme or context conclusion/ Obstacle (-)/ Facilitator (+)	**Requirement for the new process**	**Possible solutions**
Context: DS clients are all over the world and ergonomists are not likely to be in the same place to provide the service.	Process will be conducted remotely by means of a web application in DS 3DExperience Platform.	
Context: Privilege speed over detail in the results. DURATION: Based on the short duration of some interventions it can be said that other cases take too long and the duration could be reduced. + 27 Give results the soonest possible and the earliest possible in the design process. - 24 Find a time where many actors are free to participate in a meeting delays the meeting. + 37 Email being the fastest way to communicate because there is no need to find a common time for a phone call.	Reduction of the duration of the process. Reduce the number of meetings.	Automatic email notifications about the state of the process and documents (reduces the need of writing emails, allows the actors to take action when it is their turn, reduces checking time). Ergonomist will have Report templates for each of the possible client requests. Proposal will be automatically generated based on the choices of the client in a form. Only two meetings will be part of the process in two key moments where a discussion to reach agreement can be established. The rest of the interactions can happen in an asynchronous way. Other solutions also contribute to reduce the duration of the process.

Table 5.1. Requirements and possible solutions for the new process. (*Continued*)

Theme or context conclusion/ Obstacle (-)/ Facilitator (+)	**Requirement for the new process**	**Possible solutions**
ACTIVITIES: All the activities (categories) found are important and none can be eliminated. DURATION: The times of some activities can be reduced by combining them with others, automating them or by using certain tools.	All the activities found in the study should be included in the process. Activities 1, 4 and 6 could be automated totally or partially. Activities 1,4,6 and 14 could be combined. Also 13 and 15 could be combined in one single activity.	Activity 1 (Generic presentation) will be replaced by the information available in the home page introducing the service to the client, who can read it according to his own interest and pace. Activity 4 (Proposal elaboration) will be simplified by automatically generating a proposal based on information entered in forms. Activity 6 (Ask for information and files to client or supplier) will be embedded in the interface, where the client will be prompted to enter these elements in a form. These 3 activities (1,4,6) could be done in a very short period of time (the same day) consecutively and followed by Activity 14 (Arrange meeting). In this way, the four activities are considered combined because they all should be done to submit a request of consultation to the ergonomist. Activities 13 and 15 combined means that the partial results shown by the ergonomist to the client to *check that he/she is doing what is expected* will include *snapshots of the DHM.*
ACTORS: Presence of many actors with different professional roles and backgrounds. - 2 Lack of coordination of actors in the client or supplier that might cause delays. - 1 Lack of actors collaboration with the DHM intervention. + 2 Contact in the client who helps the ergonomist when he is remotely. + 9 One person to communicate with that is up to date and knows almost everything about the project.	Coordination and communication with different people from different organizations should be facilitated. All actors should be able to keep up to date about the intervention. Vocabulary and documentation should be clear and meaningful for all actors.	One person in the client organization should be the main contact for the intervention. This person will make the request, provide information to the ergonomist and coordinate other actors in the client or supplier organization to provide information, make decisions or participate in meetings with ergonomists. The main contact can share (with other actors) access to the consultation in the application if necessary. The proposal and report can be shared with other actors and will contain sections with information about deadlines, time required and cost-benefits of the intervention and the different solutions, to help managers make decisions. The intervention progress will be reflected in the application, so users can track the project and have access to all the files, documents and information up to date in only one place.

Table 5.1. Requirements and possible solutions for the new process. (*Continued*)

Theme or context conclusion/ Obstacle (-)/ Facilitator (+)	Requirement for the new process	Possible solutions
ACTORS: The worker or future user of the product or equipment was never involved in the interventions described.	Include the worker in the process when possible.	The main contact in the client organization can coordinate worker's participation in the intervention (in meetings, to provide information, to check documents produced by the ergonomist).
TOOLS: The ergonomist needs to obtain or build models by himself. - 22 Impossibility or difficulties to get the 3D models from client or supplier. + 18 Ergonomist obtains information by himself. + 23 In some situations a very simple model of the virtual environment is enough to make a DHM analysis. VS Context: DS could choose only clients that already have 3D models. DS will receive requests from clients without 3D models and suggest an external modeling service.	Improve ergonomist resources to build or obtain the models by himself. VS: Request the 3D models of equipment or build-up from clients as a condition to provide the service of consultation. DS and ergonomist can decide case by case and adjust strategically.	Provide the client and ergonomist with easy access to large databases with 3D models of equipment, humans and build-ups that might facilitate the construction of the DHM analysis without modeling. DS should decide: The service includes the construction of the 3D model by the ergonomist. VS Declare clearly and early in the interface that providing 3D files is a condition and suggest a service of 3D modeling to the client. OR Use both approaches depending on the client.
TOOLS: Variety of tools used for communication + 36 Use email instead phone to talk to no native speakers of ergonomist's language.	Provide a wide variety of communication tools sharing the same history to avoid misunderstandings and duplicity of messages. The actors might then choose the communication tool to use at each time according to the suitability to the type of information to transmit.	Page that contains all the information, files and interactions corresponding to the intervention. Communication will be allowed through Skype application integrated in the main application and providing audio call, video call, videoconferencing, messaging and instant messaging. Comments associated to files and information can be added as annotations to generate different versions.
TOOLS: To make the analysis and prepare a presentation, frequently many applications are used at the same time and information should be passed from one to the other.	Facilitate the use of many tools to the ergonomist and the client during the intervention.	Allow integration and compatibility of tools in the new application (Skype, Doodle, EWD-Ask an ergonomist). Ergonomist will use the 3DExperience platform for the analysis who has already many tools integrated.

Table 5.1. Requirements and possible solutions for the new process. (*Continued*)

Theme or context conclusion/ Obstacle (-)/ Facilitator (+)	Requirement for the new process	Possible solutions
Context: Improve tools integration to facilitate use to the clients.		For EWD users: They will be able to open Ask an ergonomist from the EWD interface and the application will automatically take the information about the task, the workstation, the assembly line, the human and the risks from the EWD file, so the client is spared re-introducing it. Also, the way of representing the data in Ask an ergonomist will be similar to EWD so there is consistency and the client has a fluent transition between the two interfaces.
TOOLS: In none of the cases was mentioned the use of a cloud service to send the files. Context: 3DEXPERIENCE platform has a cloud storage service called 3D Drive. - 22 Impossibility or difficulties to get the 3D models from client or supplier.	Use a cloud based application to transmit and preserve the files related to the intervention.	Use the 3D Drive service of 3DEXPERIENCE platform of Dassault (integrated to the application) to keep and share all the files related to the intervention.
INPUTS: There are Information and files depending on the client (if the ergonomist is external to the client). There are Information and files not necessarily depending on the client (could be gotten from client or obtained or built by ergonomist). Context: Users of EWD DURATION: Provide the ergonomist with all the necessary inputs to execute the analysis very early is one of the keys to accelerate the process of intervention. - 21 Receive too little information from client. - 23 Long time waiting for information, decisions or availability of the client. + 21 Have all the information necessary for the analysis (ergonomist).	The process should make it so that the inputs necessary to make the analysis (the list of inputs) get to the hands of the ergonomist as soon as possible. Reduce the effort of the client to get information and files and to transmit to ergonomist.	The client should be asked the minimal information required. A clear list of all required information and files specified in a form (as a checklist) to the client from the very beginning (even before he makes the request). To have a meeting before the ergonomist starts the analysis where he can ask for missing information. For EWD users: Automatic transmission of information and files (along with the request) from the EWD software through the "Ask an ergonomist" application to the ergonomist.

Table 5.1. Requirements and possible solutions for the new process. (*Continued*)

Theme or context conclusion/ Obstacle (-)/ Facilitator (+)	Requirement for the new process	Possible solutions
INPUTS: The ergonomist receives different formats of 3D files as inputs. - 35 Difficulties in the transfer and or importation of 3D models.	The tools used in the process should allow to convert or open a wide variety of 3D files.	Dassault's 3DExperience platform has integrated tools to automatically convert 3D files to the format of their CAD and DHM software.
OUTPUTS: Clients expect different outputs (they have different information needs and files requests) that are listed in the results of this theme. Context: Outputs should be adapted to a user with poor ergonomics and DHM knowledge. To create service packages will simplify the task of request specification to the clients. DEMAND: DHM is not always known by clients and therefore not asked in the request of intervention (two cases).	In a new process, all the possible outputs (based on the research findings) can be proposed to the client (with examples) for him to choose what he wants to receive. But all this outputs will be grouped in packages of service, to reduce the number of decisions the client has to make and facilitate the task. To impulse the use of DHM in those cases where the client does not ask for it explicitly, the ergonomist should use DHM as part of their job as ergonomist consultants.	Predetermined service packages with a selection of the different outputs found in the research will be given to clients for them to specify the request (this packages can be also modified by DS decisions). A secondary option to create a custom package based on all the outputs found in the research will be provided to clients. Templates and examples of the reports corresponding to each package of outputs will be provided to the client in the step of request specification. As an alternative, the application will allow clients to contact directly the ergonomist and express their need in communications (preferably audio or video synchronous communication) and the ergonomist can select the options of the request in the interface to generate the proposal. In all cases the ergonomist will use DHM.
DEMAND: The risk reduction for clients is never the ultimate goal. The ultimate goal is a new design concept based on ergonomics, or save money, or make a task possible or meet the regulations and laws. - 6 Clients don't want to get involved in deep or complicated analysis.	Include informative elements to contribute to client conversion (Information tackling clients goals)	In the home page of the application there should be information about the general benefits of ergonomics and DHM in terms of cost, insurance, law, impossible tasks, etc. also about the steps of the process, the duration, visual representation of possible results in templates and examples that allows for a quick understanding of the process (that should look simple)
DEMAND: The satisfaction of clients with the results of the intervention will also increase if the advantages (in terms of cost, insurance, law, impossible tasks, etc.) are evident in the solutions proposed by the ergonomist.		As early as possible (proposal and first meetings) the client should be provided information about the benefits of the specific intervention in terms of cost, insurance, law, impossible tasks, etc. To give more than one solution to the client.

Table 5.1. Requirements and possible solutions for the new process. (*Continued*)

Theme or context conclusion/ Obstacle (-)/ Facilitator (+)	Requirement for the new process	Possible solutions
+ 26 Solutions proposed by the ergonomist have low cost and time implications.		Provide information about the cost and time associated to the implementation of each solution. The ergonomist should always prepare a solution that is the least costly and time consuming.
DURATION: Ergonomists internal to the company are more familiar with it and seem to need less time to complete the intervention. They have easier access to the information and key people.	Have ergonomists familiar with the company to make the intervention.	During the request elaboration, recommend to the client an ergonomist familiar with his/her company or industry, if there is one.
DURATION: Proposal elaboration times can be reduced (Proposal elaboration lasted one week in one of the cases). - 19 Difficulties of the client to express the request and the ergonomist to understand it. + 22 Well established proposal. - 27 Making the proposal is not efficient. - 28 It takes time to make the proposal.	Facilitate the proposal elaboration with the use of methods like templates, checklists, computer tools, and others.	Proposal template associated to the different services that the client can select. Proposal will be automatically generated based on the choices of the client in a form. Allow the manual adjustment of the proposal for particular cases.
Context: Privilege speed over detail in the results. + 31 Live DHM presentation to facilitate discussion and exploration of options	Have a DHM live presentation to present the results instead of preparing reports or images.	The DHM live presentation could be chosen in some cases as a method to give a quick answer to the client. The live presentation will be facilitated by the use of EWD as the DHM software by the ergonomist. This should be decided for each case by the ergonomist.
Context: The clients want to protect their information because it might constitute a competitive advantage. A NDA should be signed by the ergonomist.	Implement and make visible procedures to protect information (NDA).	Existence of an NDA by default that is already signed by all ergonomists. Clients will be able to upload their own NDA. The client will be shown the NDA options before he is asked to introduce files and information, which will contribute to create trust. The application will not allow the ergonomist to access files and information without signing the NDA selected by the client and this will be made clear to the client when he uploads his information.

Table 5.1. Requirements and possible solutions for the new process. (*Continued and end*)

Theme or context conclusion/ Obstacle (-)/ Facilitator (+)	Requirement for the new process	Possible solutions
Context: Enhance reliability in the analysis and the results.	Early experience of the client contributing to trust.	Information about the experience and certifications of the ergonomists in the home page. CV and picture of every ergonomist as well as link to the Linkedin profile available in the application.
Context: Be adapted to a user with poor ergonomics and DHM knowledge.		Use a vocabulary that is familiar to the user and less ergonomics specialized possible. Use tooltips to explain the meaning of specific terms in a familiar language. Give the option to the client to communicate directly with the ergonomist to express their need and collaborate to define the request.
+ 24 Use of General view or list of the assembly line workstations or tasks that might include the risks and the methods of analysis.		Have a view or list of all tasks under analysis (and risks associated) throughout the intervention and show the results based on that view. EWD users: use similar representations to those in the EWD software, like the operations and task tree.
- 1 Lack of collaboration due to underestimation and poor understanding of DHM. + 5 Actors collaboration.	Availability of materials to better understand DHM and ergonomics. Help to understand terminology.	Access to attractive and didactic material to understand ergonomics and DHM (Wiki) Glossary.
+ 32 Use different clothing colors to differentiate percentiles in the DHM.	Use different clothing colors to differentiate percentiles in the DHM.	
+ 29 Ergonomist using the DHM to provide information to facilitate decision making rather than imposing decisions is more persuasive.		Use a tone of advice in the report and interactions with the client. Give different solutions to the same problem and give elements to compare each solution in terms of cost, time, productivity but also injuries or stress on workers.
- 11 Posture subjectivity. - 32 Human model lacking of the real human physical characteristics COMBINED someone using the DHM who doesn't explore what would happen in reality PRODUCES a DHM analysis that doesn't represent reality MIGHT LEAD to take the wrong decisions.		Check with client that the postures proposed by the ergonomist are realistic as part of the activity *Checking results* before the final delivery.

The following characteristics desirable in the new process are based on collaboration aspects analysed in the literature review (Chapter 2):

- Two documents: Proposal and Report will contain the agreements of both parts (client and ergonomist) from the beginning and can be modified and completed during the process. The NDA will also define agreements but will not be modified during the process.
- In the first moments of the intervention, there should be some synchronous collaboration. This helps ergonomist and client to familiarize with each other (when they have never worked together before) and reach the first agreements in a contract or proposal. Communication should be as similar as possible to the co-located conditions so actors should listen and see each other and use product or workstation representations to support the explanations. A rich exchange of information is imperative at the beginning to quickly reach a state where all actors are "on the same page".
- The client will have acces to information to get familiar with the intervention procedure and the ergonomist before he makes the request. This information will be on the application site.
- To present the results, the contact should be synchronous, so any misunderstanding can be clarified and the final work of the ergonomist corresponds unequivocally to the client's expectations.
- The ergonomist should add a visualization of tasks to the report to facilitate communications in the rest of the intervention.

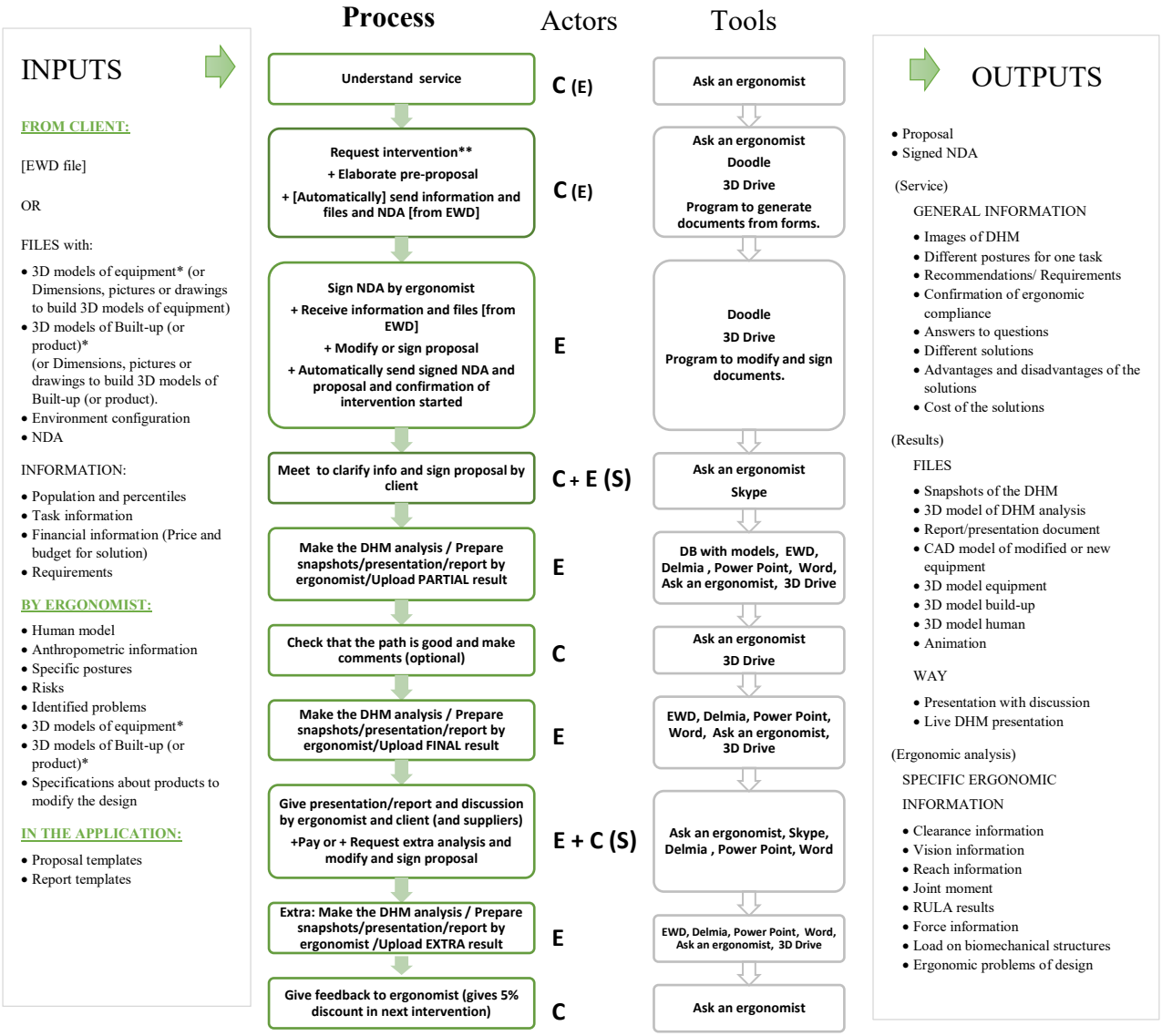
Finally, based on the Behavioral Change model explained in the persuasive design section of the literature review, the following requirements for the new application are proposed:

- The new application's home page should contain clear information about the utility of the service (*perceived utility*), the way to proceed to obtain the service (it should look simple to the user for a good *perceived self-efficacy*), other relevant companies using the service (*social norms*) and the qualifications of the ergonomist who provides the service (reliability for *perceived utility*).

All the requirements proposed were taken into account in the representation of the new process but some of them are more evident in the new interface prototypes presented in Chapter 6.

5.3 New process of virtual ergonomics intervention

The new process of virtual ergonomics intervention is shown in figure 5.2.



*3D models were included in the inputs that should be provided by the client as well as the inputs to be obtained by the ergonomist because they could be provided by any of both sides depending on the situation and DS decision.** Before the main contact makes the request in the application "Ask an ergonomist" he might need to consult other actors to obtain information or authorization to carry on with the demand. This communication does not involve the ergonomist so it is not reflected in the process diagram.

Figure 5.2. New process of virtual ergonomics intervention using the application "Ask an ergonomist" (C: Client; E: Ergonomist; S: Supplier)

Some activities of the current process were combined, which allowed to reduce the original 22 activities to 10 in the new process. The new intervention will be done remotely using the application ″Ask an ergonomist″ and other integrated applications such as Skype, Doodle and 3D Drive (3DS Experience platform) as mediators.

Although in the current process there were activities dedicated to Communications and Meetings, in the new process they are not represented because they are included in the rest of the activities: two meetings are proposed (one at the beginning and one at the end) and the exchange of files, its modification and verification by the two sides are implicit communications to reach agreement. The ergonomist will communicate mostly with the main contact in the client and will interact with the rest of actors during the two meetings. The main contact should mediate between the ergonomist and the rest of stakeholders. Communications that do not involve the ergonomist are considered internal and are not reflected in the process. Additional meetings and communication (with ergonomist) can take place if necessary, but should be minimized to make the intervention more efficient.

In figure 5.2, the elements between brackets are only for EWD users. For these users, there is a complete or partial model of DHM that can be sent automatically to the ergonomist, which reduces considerably the time and effort necessary for the transmision of information and files. Users that don't come from the EWD should fill or upload information in a form before submitting the official request (activity 2 in the diagram). The information asked in these forms will be determined by the results of the theme *inputs*. The specification of the outputs expected by the client should also be done by filling up a form before the request submission. This form will be based on the *demand* and the *outputs* results.

When an actor's participation in an activity is optional, it is represented between parentheses. For example, the ergonomist (E) can be present in the first two activities if the client decides to contact him by phone to ask about the service and/or make the request. In these cases it is recommended that the ergonomist suggests a Skype meeting in which he can show the client the information about the service and the choices he makes to submit a request. Another actor presented between parentheses is the supplier (S), who could be present at the first meeting (to agree about the proposal and sign it) and at the presentation of the results, if the client thinks that is convenient.

5.3.1 Validation of the new process

The new process was validated by 3 out of 4 participants. All four participants were sent an email with a link to an electronic questionnaire that showed the new process proposed. They were asked whether each of the activities present in the description should be in the new process of remote virtual ergonomics intervention. Then, they were asked to propose a sequence of the activities selected by them in the previous step. The questionnaires used for this purpose were made in Survey Monkey.

The three participants that answered the email and completed the questionnaires mostly agreed with the activities that described the process and suggested only minor changes that were incorporated (and are visible in figure 5.2). The results can be seen in Appendix Q.

The new process proposed in this chapter is based on the use of the web application "Ask an ergonomist" that will allow ergonomists and clients to collaborate remotely during the intervention. The user-centred methodology followed to design this application and the interface prototypes conceived as a result are described in the following chapter.

CHAPTER 6 DESIGN OF THE APPLICATION "ASK AN ERGONOMIST" TO FACILITATE VIRTUAL ERGONOMICS INTERVENTIONS

In order to achieve the third objective of this work, the user interface of the application "Ask an ergonomist" was designed to support the new virtual ergonomics intervention process. The present chapter describes in one section (6.1) the design methodology and results. Sub-sections 6.1.1, 6.1.2, 6.1.3 and 6.1.4 correspond to the four phases of the design process: Specification of context of use, Specification of user requirements, Design solutions and Evaluation.

6.1 Methodology and results of the design of the application "Ask an ergonomist".

A user-centred design methodology was followed to create the interface of the application "Ask and ergonomist". Table 6.1 shows its phases and the methods and techniques used in each of them.

Table 6.1. User-centred design process followed for the design of "Ask an ergonomist".

Phase	Methods and techniques	Name in this work
Plan the user centered design process		
Understand and specify the context of use	Interview (ergonomist)	Study 1. Multiple case study: content analysis of interviews describing five cases of virtual ergonomics interventions.
	Observation (ergonomist, client)	Study 2. Multiple case study: Participant observation, interview and document analysis on three cases of virtual ergonomics interventions.
	Activity interview	Study 1a. Interview four ergonomists about virtual ergonomics interventions in general.
	Contextual interview (ergonomist)	Contextual interview of one ergonomist (Appendix R)
	Current process diagram	

Table 6.1. User-centred design process followed for the design of "Ask an ergonomist". (*Continued and end*)

Phase	**Methods and techniques**	**Name in this work**
Specify the user requirements	Personas (client engineer, ergonomist, client manager)	
	Table of requirements and/or improvements New process diagram	
	Table of information and actions and possible future pages	
Produce design solutions	Information Architecture Tree	
	Paper mock-ups	
	Axure prototype	
	Informal evaluation with the organization (Dassault Systèmes)	
Evaluate design against requirements	User test 1 (client engineer)	

The actions carried out in each phase will be explained in the following sections.

6.1.1 Understand and specify the context of use

As can be seen in the last column of Table 6.1, Studies 1, 1a and 2 contributed to find information during the phase *Understand and specify the context of us*e. A qualitative content analysis of interviews with ergonomists having conducted virtual ergonomics interventions (Studies 1 and 1a) and a participant observation of virtual ergonomics interventions (Study 2) were completed. They provided the data to describe the current process of virtual ergonomics intervention and find areas for improvement (Chapter 4), which represents an application of task analysis.

One weakness of the first phase of design was the absence of clients' point of view about interventions; only the ergonomists' opinions were collected.

6.1.2 Specify the user requirements

Upon results of Study 1 (theme *actors*), actors in the client's organization have two main profiles: engineer or manager (a third but secondary profile is ergonomics or OSH specialist). In the particular case of "Ask an ergonomist", the main target is EWD users and according to Dassault they are mostly engineers. They would be creating a workstation in 3D and when they come across

an ergonomic problem they cannot solve on their own they will be expected to click on a button labeled "Ask an ergonomist" that leads to the application. As they would be the main source of technical information, they will probably interact the most with the ergonomist.

On the other hand, the results of the themes *demand*, *obstacles* and *facilitators* suggest that actors with a manager profile are in general the ones making the request and the decisions.

Based on these considerations, engineers (in charge of the ergonomic design) are recommended to be the main contact of the ergonomist in the client organization during interventions conducted with "Ask an ergonomist". Managers (or decision makers) would be a secondary contact.

These three main user profiles: *client manager*, *client engineer* and *ergonomist,* are defined as personas in Figures 6.1, 6.2 and 6.3 respectively. For the *client engineer*, the same persona created by Dassault's specialists for the EWD user is used. The persona for *client manager* was built from the information about these actors provided by ergonomists in Studies 1 and 1a.

Finally, the information about the ergonomist was obtained from the three studies (1, 1a and 2). A persona of the Ergonomist user of DHM software created in Dassault (Drouin, 2015) was also used as a reference.

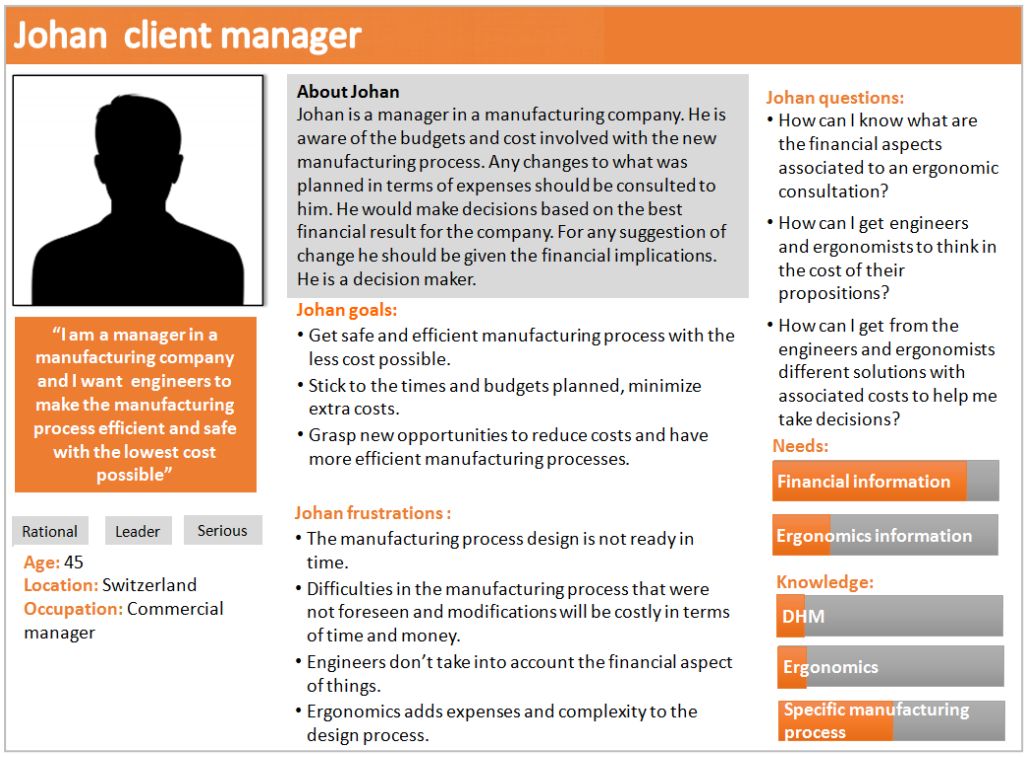


Figure 6.1. Persona of a client manager

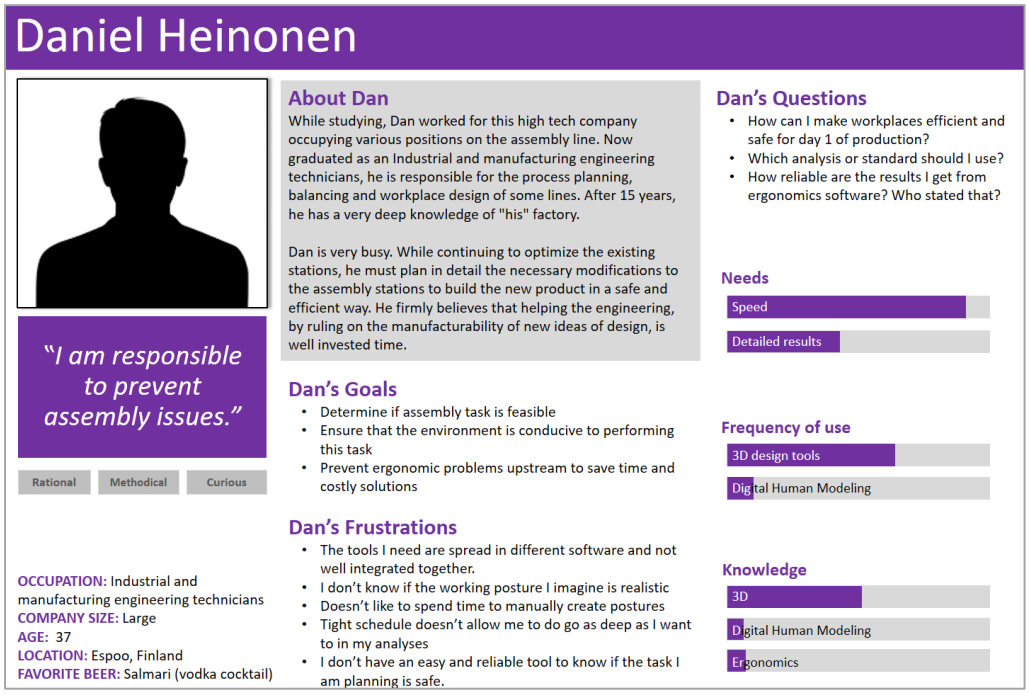


Figure 6.2. Persona of a client engineer (created by Dassault for the user of EWD)

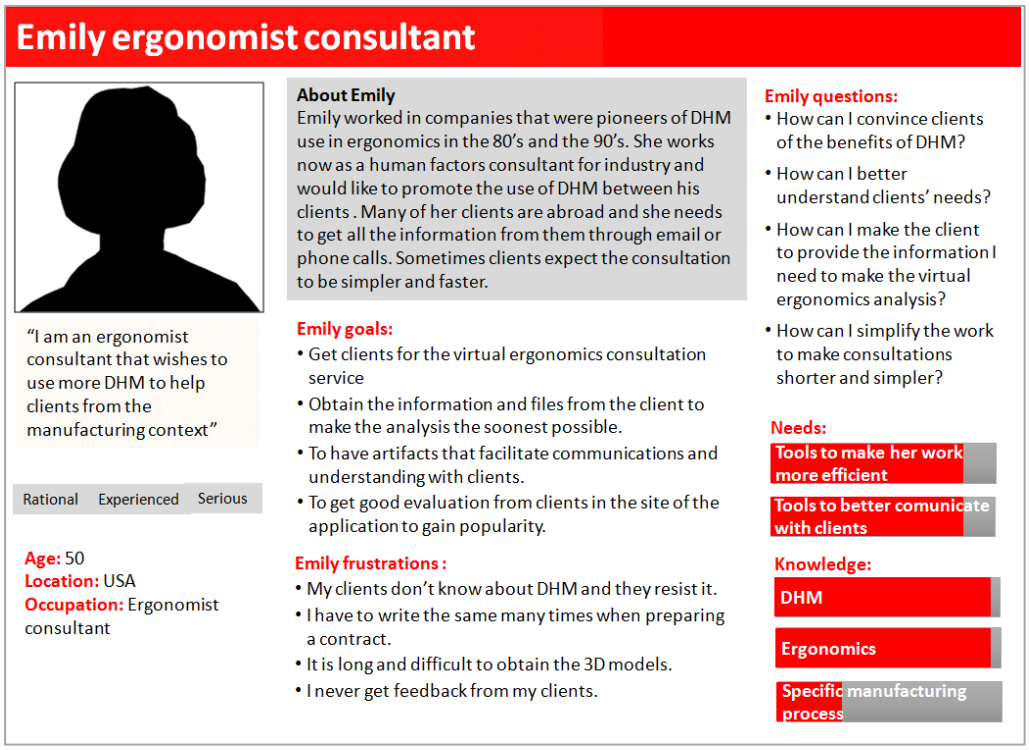


Figure 6.3. Persona of an ergonomist.

Since the design of "Ask an ergonomist" was requested by Dassault, some of the new process and interface requirements were obtained from their virtual ergonomics vision as well as from ideas they expressed during meetings with the researcher (section 5.1).

The main results of the phase S*pecify the user requirements* are presented in the requirements (section 5.2) and the description of the new process (section 5.3).

Using the new process activities as reference, the information needs and actions of actors were listed to determine the interface content and pages. This is shown in table 6.2, where information and actions (in third and fourth columns respectively) constitute the content of the pages indicated in last column.

Table 6.2. Information needs and actions for each of the activities in the new process and pages associated.

#	Activity	Information needed by the actor	Control actions by the actor	Pages
1	**Understanding of service (by client)**	Description of service.	Call the ergonomist Ask a question to ergonomist	*Home*** *Contact us*
		Steps the client should follow to request the service.		*Home* Start a consultation
		Examples of outputs he can receive (based on templates)		Specify request Report
		Ergonomists expertise		*Home* *Ergonomists*
2	**Request of intervention + Pre-proposal elaboration and sign (proposed presentation date) + [Automatic] sent of information and files and NDA [from EWD] (by client)**	Information about the services available (comes from OUTPUTS in the new process diagram): •Information the client can ask •Specific Ergonomics Information •Way of transmission of outputs. •Files	Select options for OUTPUTS: •Information the client can ask •Specific Ergonomics Information •Way of transmission of outputs. •Files Generate proposal	Specify request
		Non Disclosure Agreement	Upload NDA Read default NDA Accept default NDA (sign)	Provide information NDA
		Information to provide to the ergonomist (comes from INPUTS in the new process): [EWD file] OR FILES with: • 3D models of equipment or dimensions, pictures or drawings to build them. • 3D models of Built-up (or product) or dimensions, pictures or drawings to build. • Environment configuration • NDA INFORMATION: • Population and percentiles • Task information • Financial information (Price and budget for solution) • Requirements	Introduce or upload the following (comes from INPUTS in the new process): [EWD file] OR FILES with: • Dimensions, pictures or drawings • to build 3D models of equipment. • Dimensions, pictures or drawings to build 3D models of Built-up (or product). • Environment configuration • NDA INFORMATION: • Population and percentiles • Task information • Financial information (Price and budget for solution) • Requirements	Provide information
		Proposal Dates of availability of the ergonomist to have the final presentation.	Modify all previously entered options Modify proposal Sign proposal Save/discard entered information Select dates for the presentation based on ergonomist availability. Send request	Proposal

Table 6.2. Information needs and actions for each of the activities in the new process and pages associated. (*Continued*)

#	Activity	Information needed by the actor	Control actions by the actor	Pages
3	**Signature of NDA (by ergonomist) + Reception of information and files[from EWD] + Sign/Modify proposal + Automatically sent signed documents and confirmation of intervention started**	All the information and files (content) sent by the client. Services expected. Date proposed by client for presentation.	Download and open files (content) sent by the client. Open information sent by client. Confirm sufficiency of information sent by client to give the expected service/ Specify missing information. Send all the information about his/her actions. Send a message to the client.	Consultation
		Final proposal signed by client See the parts of the proposal that were manually modified by the client. Final proposal modified by him.	Confirm date proposed by client for presentation/ Specify a new date. Modify proposal Sign proposal	Proposal
		New Non-Disclosure agreement uploaded by client	Read New NDA Sign NDA	NDA
4	**Meeting and proposal signature by client and ergonomist**	Link to access meeting in Skype.	Open link to access Skype meeting	Consultation
		NDA signed by ergonomist Proposal signed by ergonomist/Modified proposal Confirmation of sufficiency of information sent by client to give the expected service/ Missing information. Information to do a secure payment (account, etc)	Open proposal	Consultation /NDA
			Modify presentation date Modify proposal Sign proposal	Proposal
			Introduce/upload missing information.(client)	Consultation/ Provide information
5	**Make the DHM analysis / Prepare snapshots/presentation/report* by ergonomist/Upload PARTIAL result**	Information and files provided by client. Template of the report corresponding to the request made by the client. (should appear in the consultation page as soon as the client makes the request)	Download and open files (content) sent by the client. Open information sent by client. Download report template.	Consultation Information
			Import files in DHM software. Use the DHM software to make the analysis.	3DExperience (outside of Ask and Ergonomist)
			Use snapshots and template to complete report.	3DExperience Software of the report (Word).
			Upload partially completed report Send confirmation to client.	Consultation

Table 6.2. Information needs and actions for each of the activities in the new process and pages associated. (*Continued*)

#	Activity	Information needed by the actor	Control actions by the actor	Pages
6	**Check that the path is good and make comments (optional)**	Information of the consultation.	Open/ download partially completed report file. Upload report with comments.	Consultation
		Partially completed report file.	Make annotations to partially completed report file.	Report page or Word
7	**Make the DHM analysis / Prepare snapshots/presentation/report by ergonomist/Upload FINAL result**	Information and files provided by client.	Download and open files (content) sent by the client. Open information sent by client. Download report with comments from client.	Consultation Information
			Import files in DHM software. Use the DHM software to make the analysis.	3DExperience Platform (outside of Ask and Ergonomist)
			Use snapshots and template to complete report.	3DExperience Platform Software of the report (Word). (outside of Ask an Ergonomist)
			Upload FINAL report file. Send confirmation to client.	Consultation
8	**Give presentation/report and discussion by ergonomist and client (and suppliers) + /Payment (by client)/ Request of extra analysis +Proposal modification and signature**	FINAL report	Download Open Report	Consultation
			Present Report.	Report page or Word
		Link to access meeting in Skype.	Open link to access meeting in Skype. (Connect to a meeting in Skype. Open and share outputs. Share screen. Record Skype meeting. Talk)	Consultation
			Pay the service. Download proof of payment.	*Payment*
		Information from client about additional analysis to do.	Modify presentation date Modify proposal Sign proposal	Proposal
9	**Extra: Make the DHM analysis / Prepare snapshots/presentation/report by ergonomist/ Upload EXTRA result**	IDEM AS IN PREVIOUS ACTIVITIES 5 and 7	IDEM AS IN PREVIOUS ACTIVITIES 5 and 7	IDEM AS IN PREVIOUS ACTIVITIES 5 and 7

Table 6.2. Information needs and actions for each of the activities in the new process and pages associated. (*Continued and end*)

#	Activity	Information needed by the actor	Control actions by the actor	Pages
10	**Feedback to ergonomist, gives 5% discount in next intervention by client**		Pay the service. Download proof of payment.	*Payment*
		Final results received.	Client: Download report.	Consultation
		Criteria to evaluate results (to give feedback to ergonomist).	Select options, introduce feedback/Evaluate intervention. Send feedback. Download proof of discount for next intervention. Delete all traces of intervention from the system.	*Feedback*

*Though the client has different options to select about the way he wants to receive the results, the ergonomist will always prepare a report or presentation to help himself prepare the results to be discussed with the client. In the table, every mention of a report open, created, uploaded, downloaded refers to this report or presentation.***Pages in italic font*: interface for client. Pages in normal font: interface that will have the same aspect for client and ergonomist with little variations.

The grouping of contents in the different pages uses as criteria the step of the process, the sequence of actions of each user and the inputs and outputs of the intervention.

6.1.3 Produce design solutions

The pages defined in the last column of table 6.2 were organized hierarchically to create the application's information architecture. Figures 6.4 and 6.5 show the information architecture trees for the client's and the ergonomist's user interfaces respectively. Both architectures are for connected users. A few new pages were added and the page *Specify request* was renamed as *Select service package*.

Each tree has three levels and a footer as indicated in the legend.

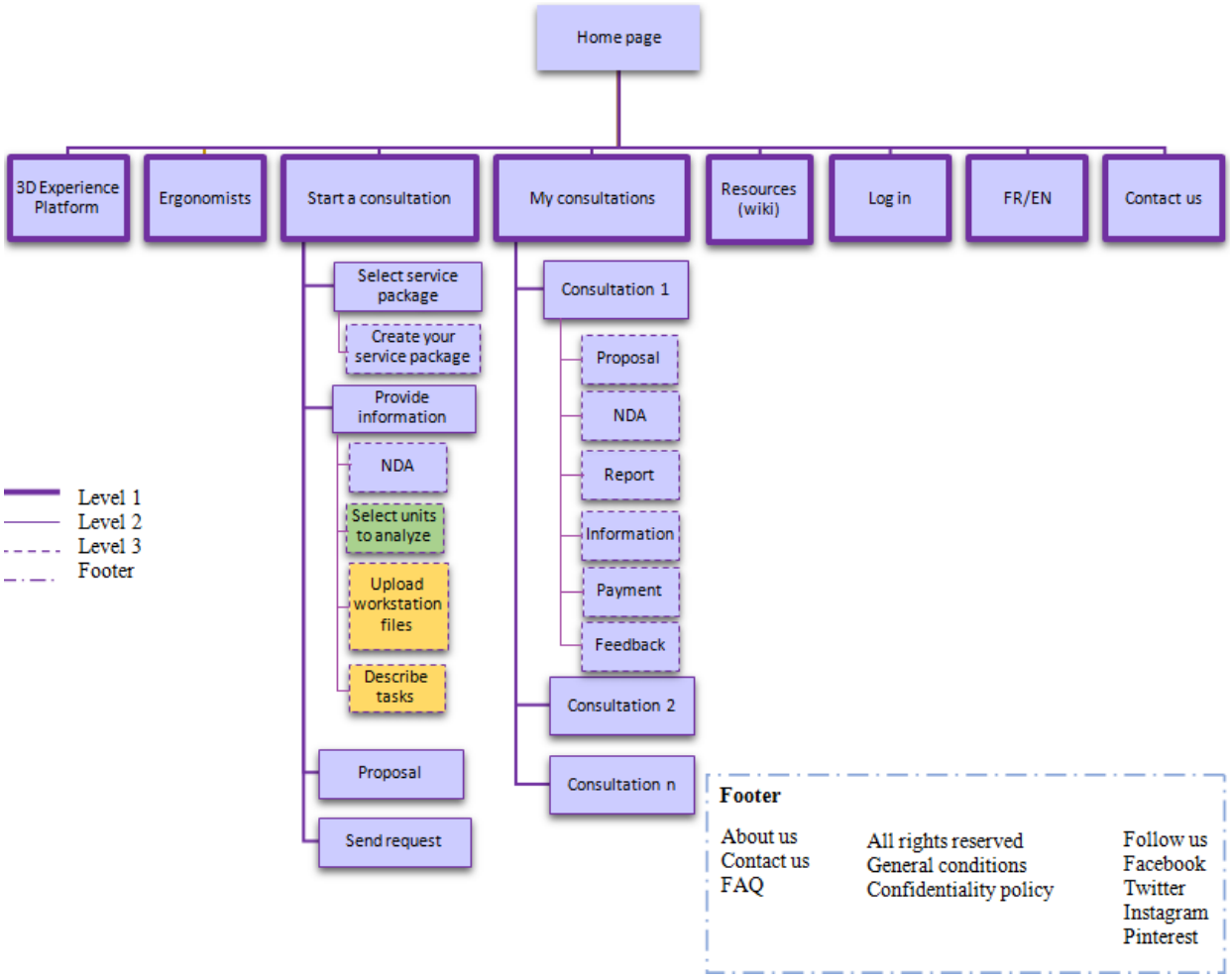


Figure 6.4. Information architecture tree of the user interface for the *client* connected.

In figure 6.4 the pages in green are specific to EWD users (access from EWD) and the pages in yellow are specific to a general user accessing from the Marketplace.

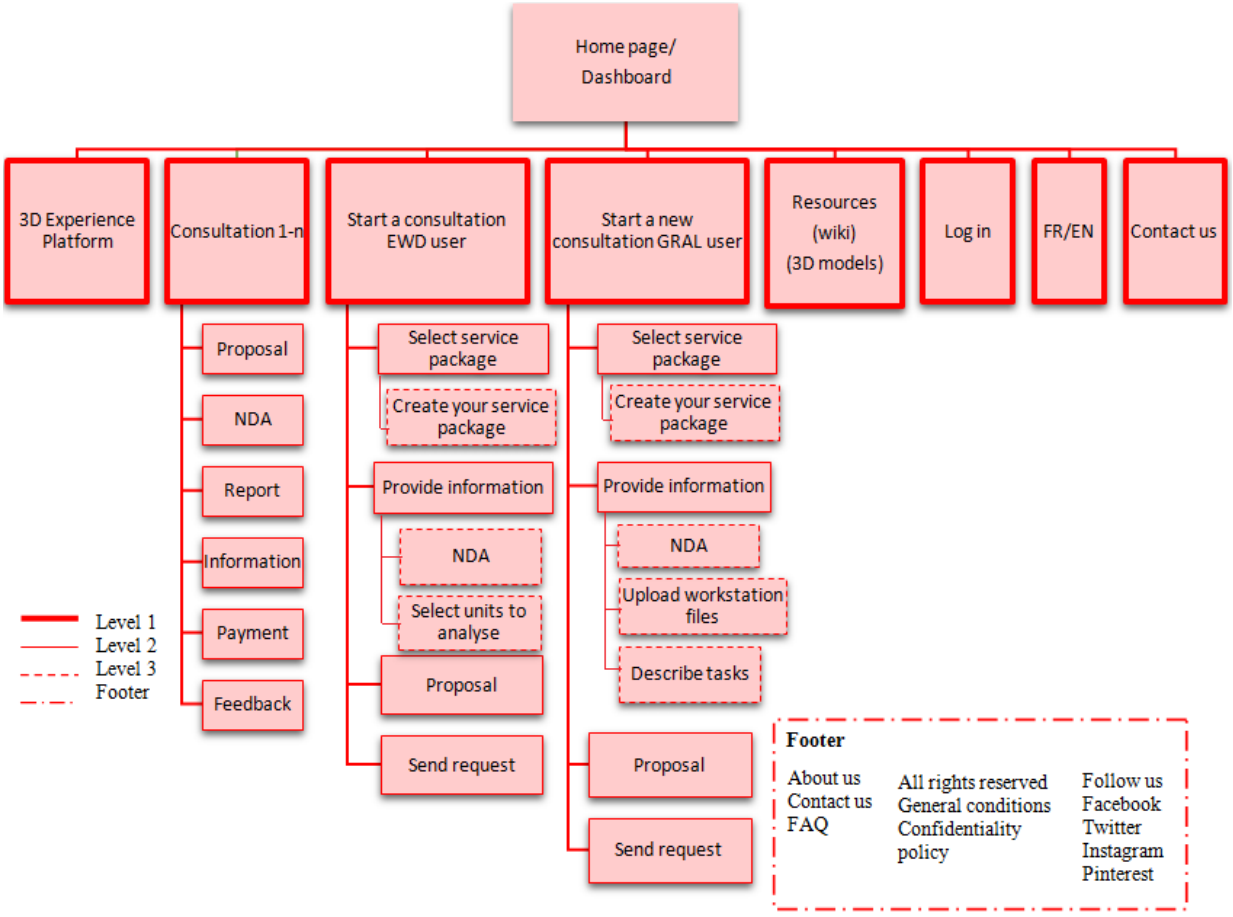


Figure 6.5. Information architecture tree of the user interface for the *ergonomist* connected.

In the information architecture, the *Specify request* page (table 6.2) is named *Select service package,* because "service packages" were created for the client to specify the request. This was a DS requirement and an attempt of reducing the number of options (Outputs) to facilitate decision making and avoid discouragement. The original elements to specify the request that can be seen in the activity 2 in table 6.2 are too many and too varied. To give references for comparison and still narrow down the choices, three service packages were created by the researcher. They should be adapted by a DS's marketing specialist in the future.

Later in the phase *Produce design solutions*, different paper mock-ups were created for the pages in the information architecture tree with the content specified in table 6.2. To increase consistency and facilitate learning, some elements of the interface design were taken from service applications already present in Dassault's Marketplace. These elements are: horizontal navigation menu for the main navigation, colors, structure of the home page and breadcrumb of steps to complete actions.

Three prototypes were produced in Axure:

- Prototype 1 (USER from EWD): interface for clients entering the application through the "Ask an ergonomist" button in the Ergonomic Workplace Design software.
- Prototype 2 (General USER): interface for clients accessing the application from the Marketplace.
- Prototype 3 (ERGONOMIST): interface for the ergonomist consultant.

Interface schemes of Prototypes 1, 2 and 3 can be seen in Appendices S, V and W respectively.

6.1.4 Evaluate design against requirements

Only Prototype 1 was tested with users. It was prioritized because it corresponds to the most important and frequent user: the client engineer from the EWD software. One round of tests with five users was conducted according to the methodology presented below. As a result, Prototype 1 was modified to produce the final version in this work, that is, *Prototype 1 final version*.

6.1.4.1 User test protocol

The goal of the test was to see if a new user would be able to complete a request of consultation on his own.

Participants:

All the participants in the user test have an occupation related to manufacturing engineering and have worked with 3D tools. Their characteristics are presented in table 6.3.

Table 6.3. Participants in the user test.

User	Sex	Occupation	Experience with 3D software
1	F	Manufacturing engineer	Yes
2	M	Industry process & manufacturing engineering consultant	Yes
3	M	Manufacturing engineer	Yes
4	F	Manufacturing engineer	Yes
5	F	Simulation engineer	Yes

User interface:

The interface schemes of Prototype 1 are shown in Appendix S.

Task:

Users were asked to complete a request of consultation starting at the EWD interface. The instructions given to the users are in Appendix T.

Procedure:

The main measure of the test was the completion of the task without intervention of the facilitator. The facilitator gave the scenario tasks to the participant and guided him during the test. As the user tests took place through Skype, they could hear each other and see the screen shared by the facilitator. Both had control of the actions showed on the screen. A group of observers from Dassault could see the screen and hear the participant's and facilitator's voices but the participant could not hear the observers during the test. At the end, they could all hear each other and the observers asked questions to the participant. Observers would take notes during the test and classify them as a positive aspect (+), a negative aspect (-) or a commentary (~). Once the test was over, they placed the notes (i.e. post-its) on a wall under the participant's name.

6.1.4.2 Test results

The tests lasted 30 to 45 minutes and they took place on the same day. All five users completed the task given in the test for a 100% of effectiveness. However, they encounter problems that might have been an obstacle to the task complextion in a real setting. These problems were registered in the notes that can be seen in Appendix U and led to the interface modification.

The problems present for more that 40% of users (in this case for two users or more) were selected as the most important ones. Some problems that were not frequent but that were considered as a source of improvement were also tackled in the modifications.

Table 6.4 contains the main problems and the modifications proposed.

Table 6.4. Main problems found during user test and modifications proposed.

Problems	**Modifications**
User doesn't have the information or authority to complete the task (request a consultation) and needs to consult a decision maker in his company. Needs information about financial aspects.	Allow the user to make most of the *Start a consultation* process except the final action where he sends the request to the ergonomist. Allow to generate the proposal and report with all the necessary information (including financial) for the user to share with decision makers. Allow to share consultation with decision maker.
Multiple interaction problems in the page *Select a service package* (packages are not easy to compare, is not clear how to select one package, the content of each package is not clear).	Make the packages incremental. Put the features inside each package. Make the information to show up when mouse over in the packages.
The selection of package before the section of tasks discourages the user, they prefer to select the task first.	Make the selection of tasks (which is the problem that the user have) the first page of the breadcrumb.

As in the user test it was found that the most important person that the user (client engineer) needs to consult before making the request is the decision maker, and the interface was modified to share a provisional proposal, report examples and a consultation link with this actor (first row of table 6.4), this activity should be added to the representation of the process. Accordingly, the second activity in the diagram from figure 5.2 in Chapter 5 will be replaced by the activities reflected in the following figure.

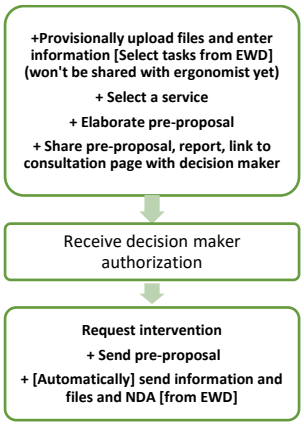


Figure 6.6. Activities that replace *Request an intervention* in the new process.

These modifications were added to the interface and are reflected in the final prototype *Prototype 1 final version*, whose interface schemes are shown in figures 6.7 to 6.20.

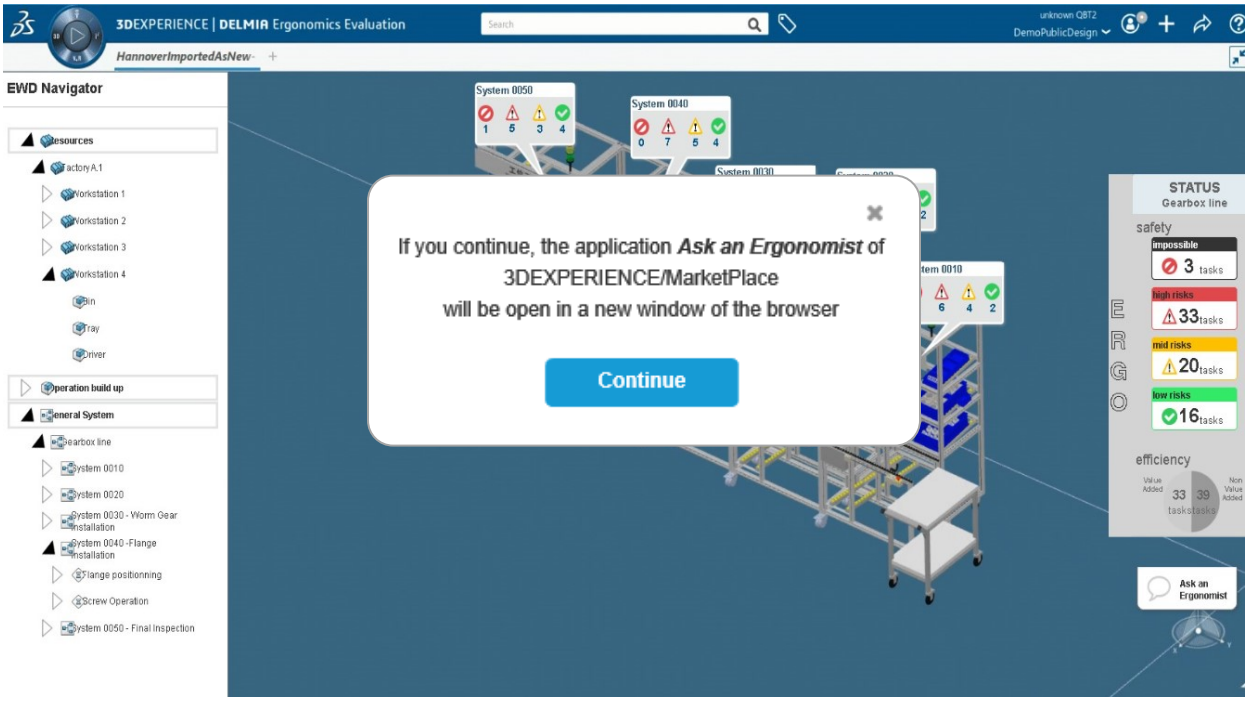


Figure 6.7. Message that appears when the user clicks on the button "Ask and ergonomist" in the EWD interface.

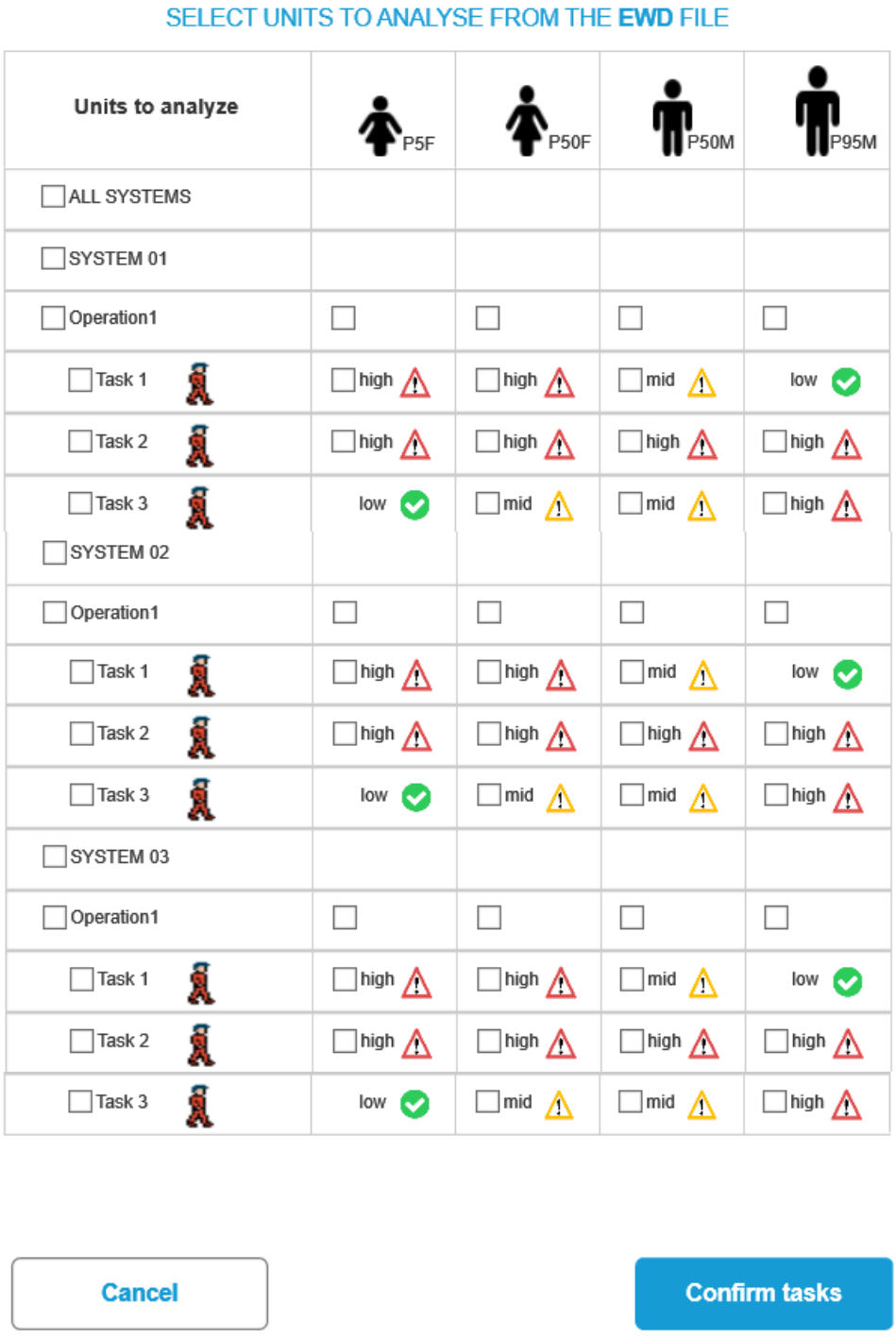


Figure 6.8. Page *Select units to analyze* of **Prototype 1 final version**.

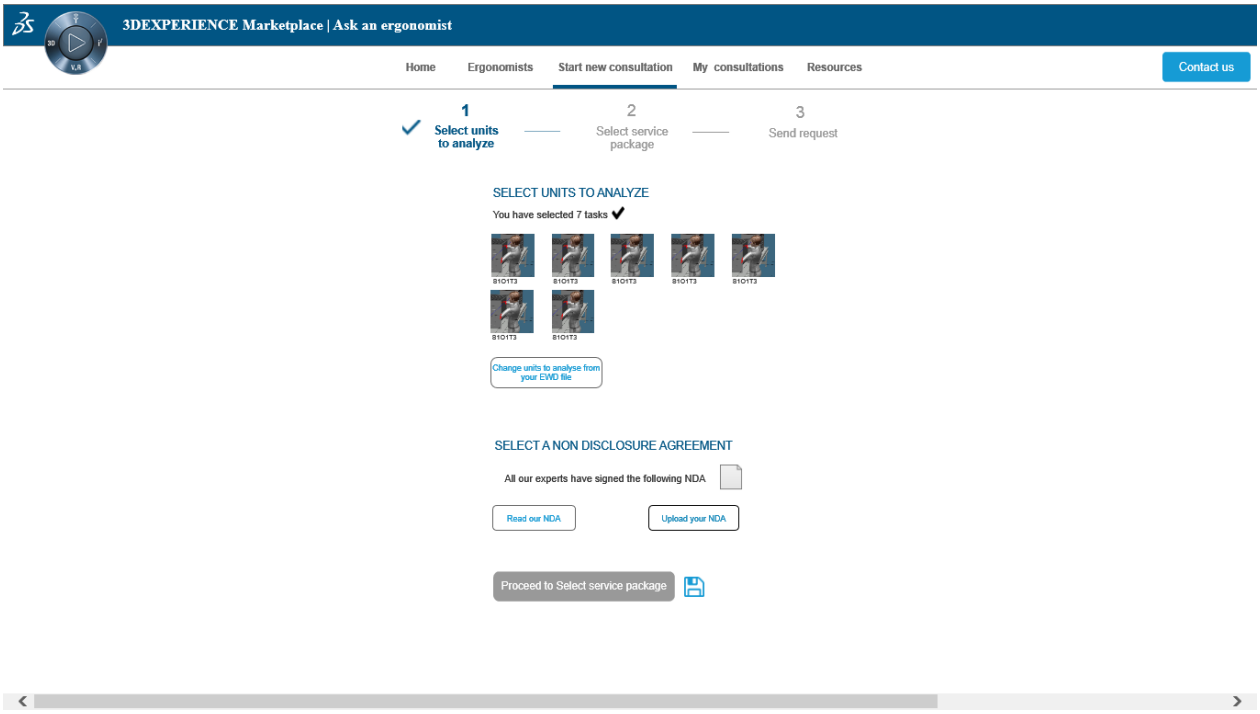


Figure 6.9. Page *Provide information* of **Prototype 1 final version**.

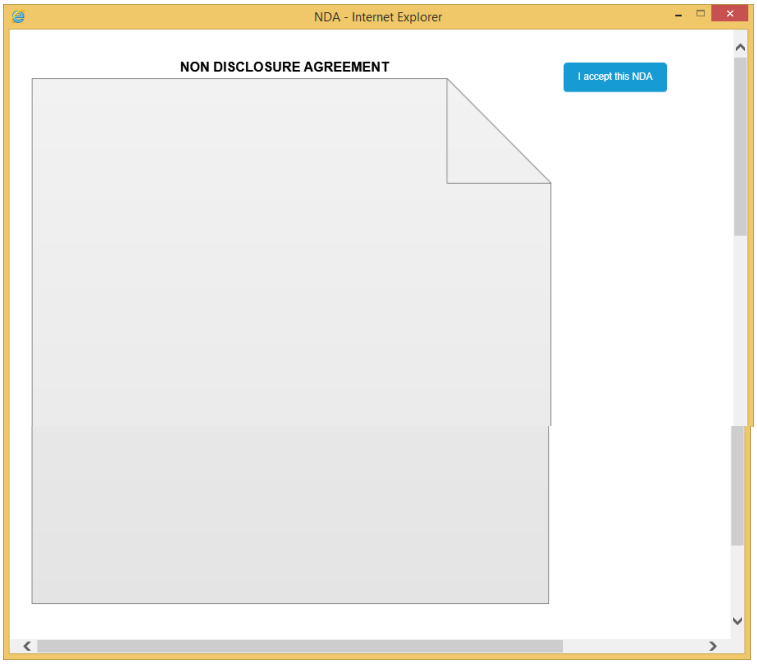


Figure 6.10. Page *NDA* of **Prototype 1 final version**.

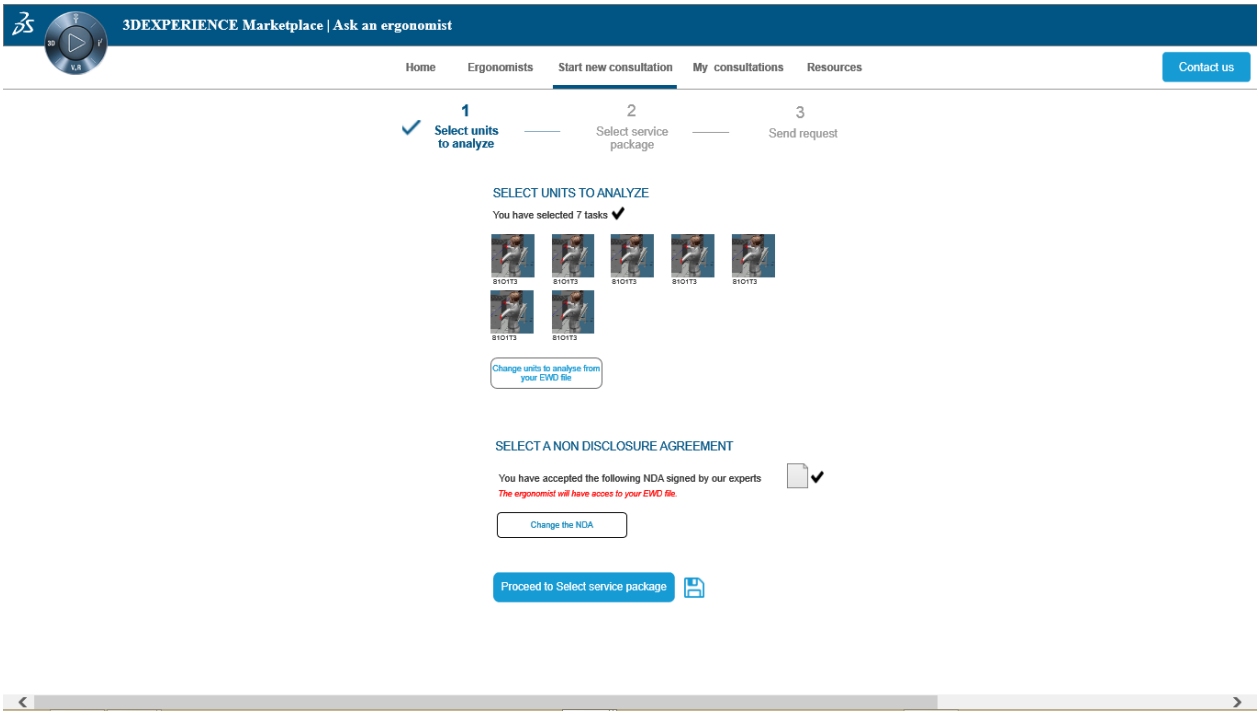


Figure 6.11. Page *Provide information (completed)* of **Prototype 1 final version**.

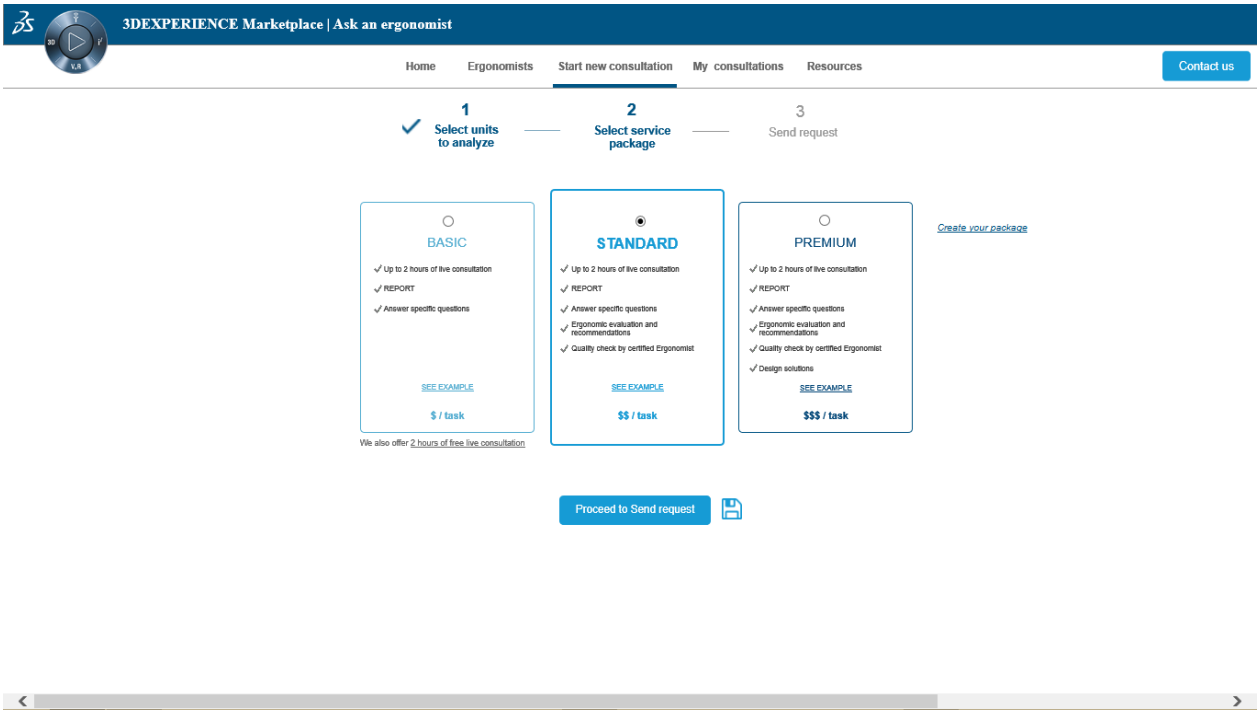


Figure 6.12. Page *Select service package* of **Prototype 1 final version**.

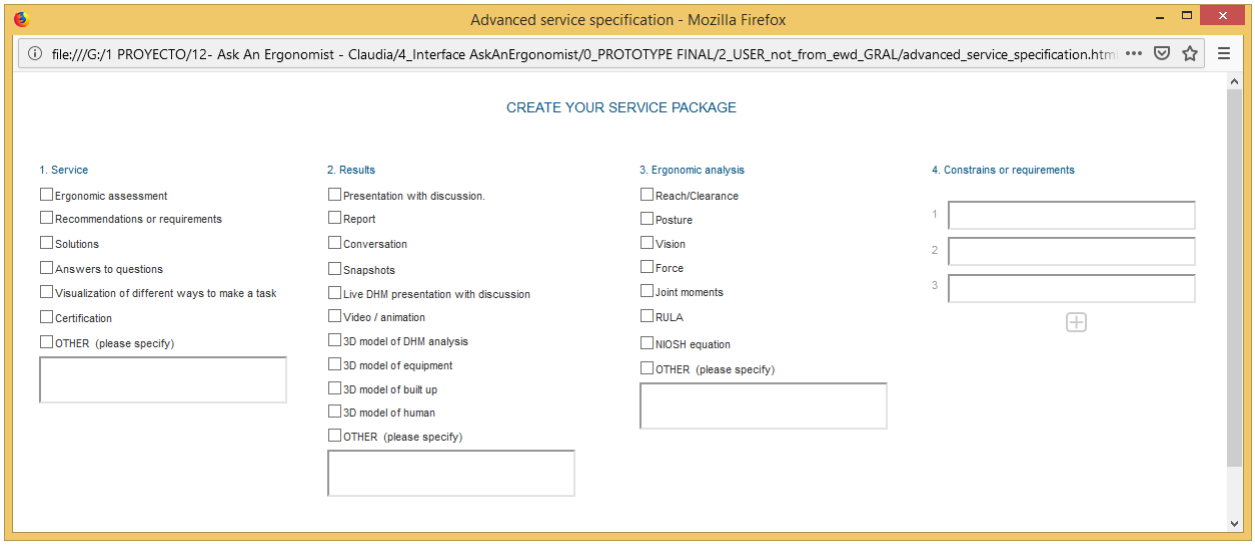


Figure 6.13. Page *Create your service package* of **Prototype 1 final version**.

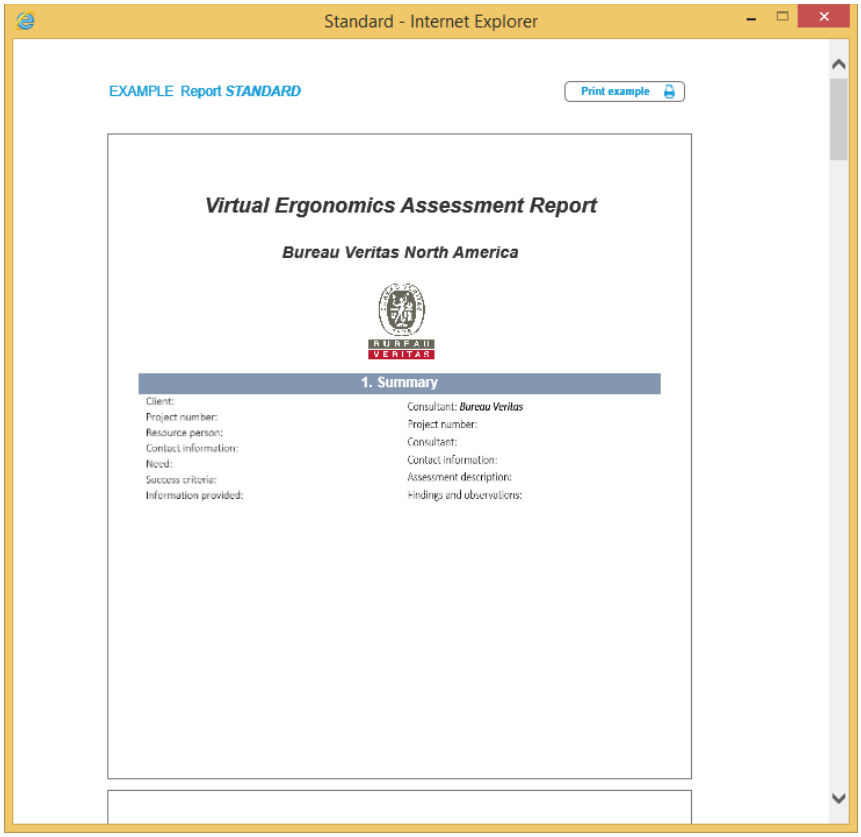


Figure 6.14. Page *Example of report* of **Prototype 1 final version**.

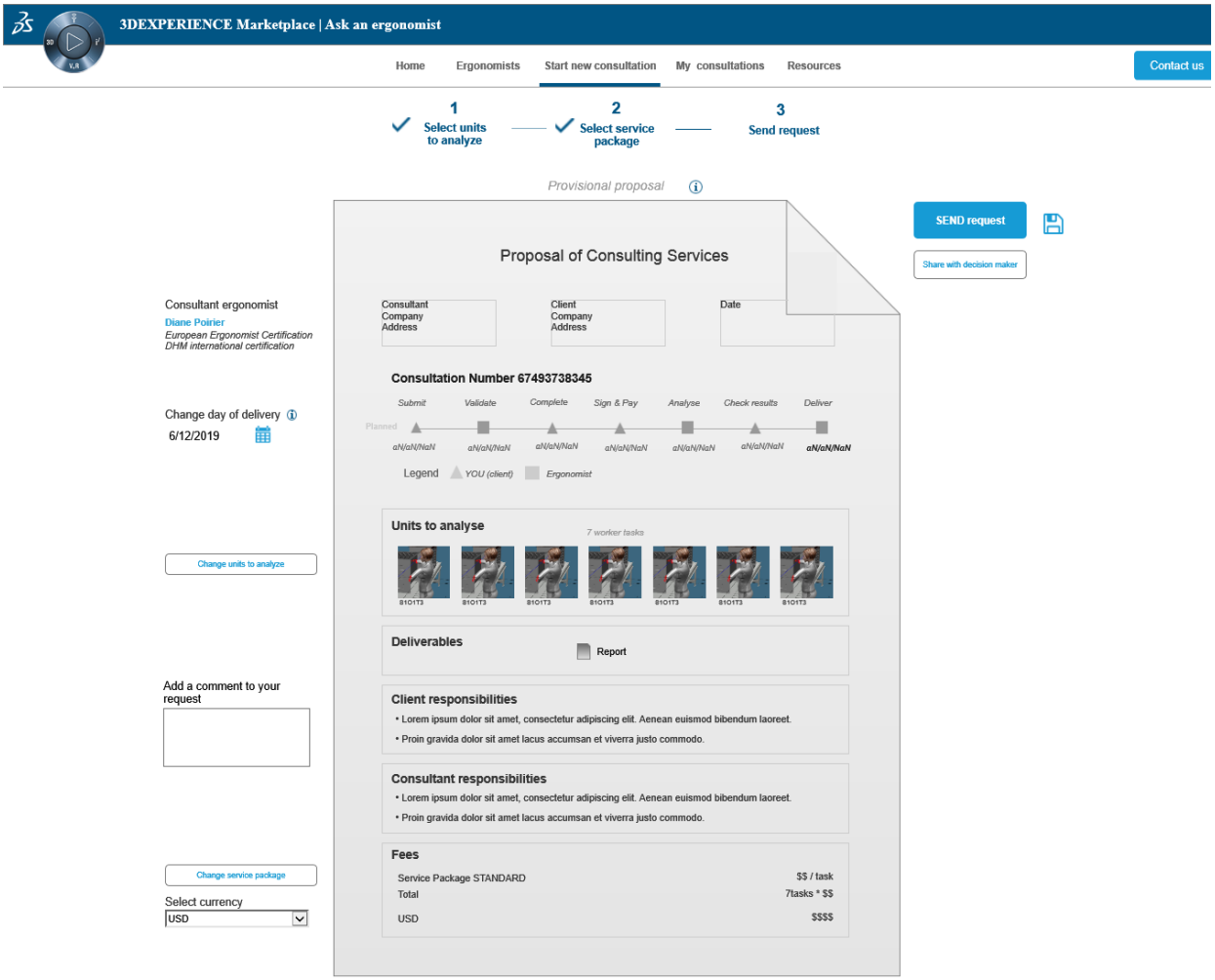


Figure 6.15. Page *Proposal* of **Prototype 1 final version**.

Figure 6.16. Dialog box *Share with decision maker* of **Prototype 1 final version**.

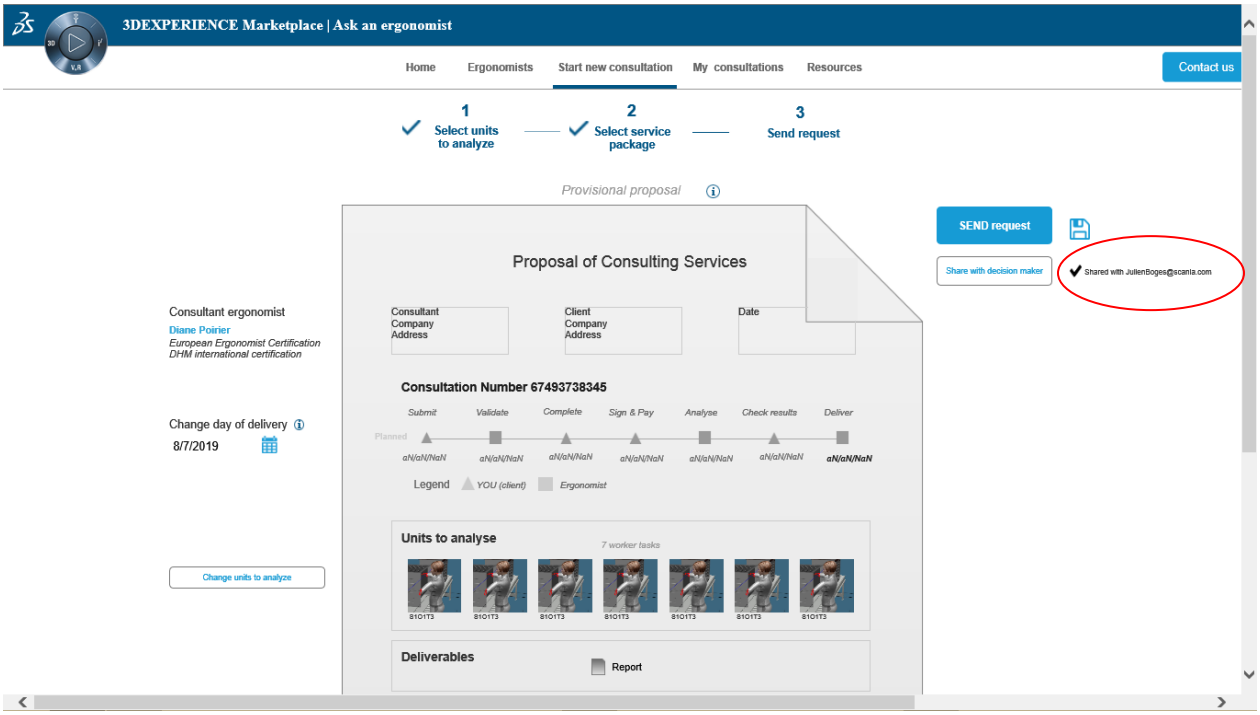


Figure 6.17. Detail of feedback when shared with decision maker in **Prototype 1 final version**.

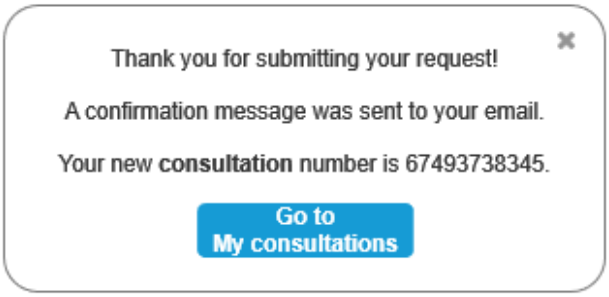


Figure 6.18. Submitting confirmation message in **Prototype 1 final version**.

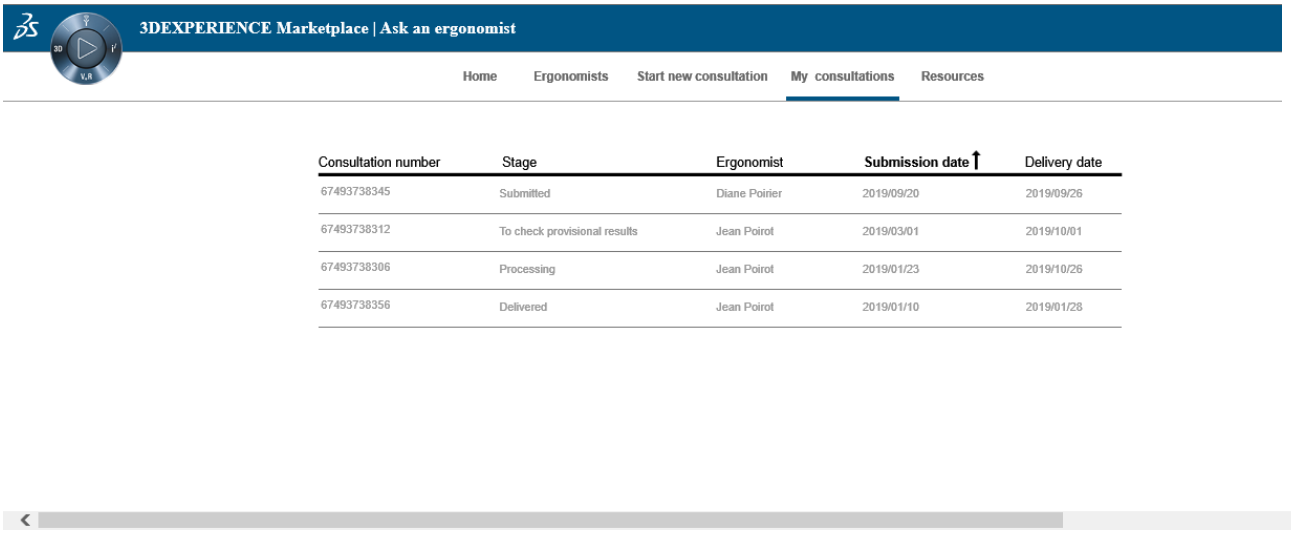


Figure 6.19. Page *My consultations* of **Prototype 1 final version**.

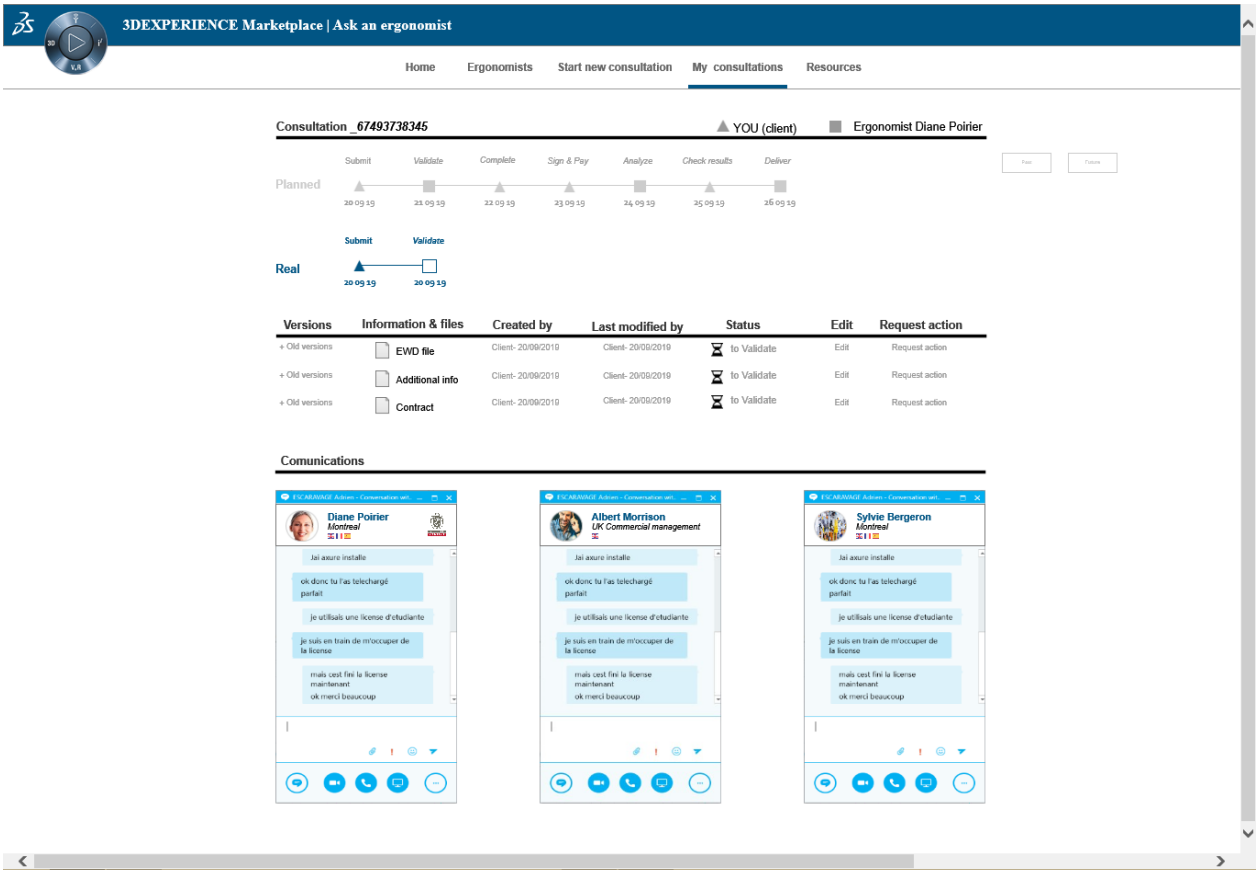


Figure 6.20. Page *Consultation* of **Prototype 1 final version**.

CHAPTER 7 CONCLUSION AND RECOMMENDATIONS

The three objectives of this research were achieved. The first contribution is the description of the current process of virtual ergonomics intervention and its possible improvements (objective 1) based on two multiple case studies (Study 1 and Study 2). The other important results of this work are the new process of virtual ergonomics intervention to be conducted remotely (objective 2) and the interface to support it (objective 3).

Current virtual ergonomics interventions were found to be heterogenous and similar in some aspects to the practice of traditional interventions described in literature. However, some characteristics are specific to the virtual ergonomics context like the difficulties to obtain the 3D models from the client.

The main improvements reflected in the new process are the combination of activities to reduce duration and the possibility for the client to familiarize with the service, the ergonomist, the process, the inputs and the results and create a proposal using "Ask an ergonomist" before officially requesting the service. This preparation allows the actors in the client organization to coordinate, make decisions and gather files and information before the ergonomist enters in the process, which should facilitate collaboration and reduce the intervention time. The automatic proposal generation is also a novelty of the new process that contributes to reduce duration and provides the main contact in the client's organization with a document to consult decision makers. Another innovation is the results' standardization through a list of possible services (outputs) with templates and examples.

Three interface prototypes were created for three different users: client entering from the EWD software, client entering from the Marketplace and ergonomist. A user test was carried out with the first prototype that corresponds to the most important user. Consequently, changes were made to produce the final prototype. A characteristic that contributes to the new interface usability is its integration with the EWD software that allows the automatic transmission of information to the "Ask an ergonomist" application, implying a considerable reduction of actions and cognitive load for client and ergonomist. Other aspects reinforcing usability are the interface consistency with other applications in Dassault's Marketplace and its integration with other 3DExperience platform applications such as 3DDrive. Dassault Systèmes will use these results to develop applications for their clients all over the world and promote the use of virtual ergonomics.

Additional contributions of this work are two instruments for future research: the *Guide of interview about virtual ergonomics interventions* and a coding scheme (implemented in an Nvivo file) for the analysis of virtual ergonomics interventions (that can be used to analyze interview's verbatim and observation notes).

In the ergonomics domain, this research might be one of the few studies of virtual ergonomics consultations practice that considers the interactions between ergonomists and clients and makes a detailed description of nine intervention variables: activities, actors, tools, inputs, outputs, duration, demand, obstacles and facilitators. This work can be a reference for researchers and practitioners trying to study and improve the practice of virtual ergonomics interventions. The requirements and description of the new process can be particularly useful to consultants.

Limitations of the research:

One of the research limitations is the small number of cases under study, which prevents the generalization of the results about the current practice of virtual ergonomics interventions. Another limitation is the absence of data collected from the interventions' clients; data was obtained mostly from ergonomists.

Future studies:

It is suggested to conduct other studies to explore clients' perspective on virtual ergonomics interventions. Future studies should also define metrics to evaluate the impact of the new application on virtual ergonomics interventions and contribute to its continuous enhancement. It is also recommended to evaluate the three final prototypes of "Ask an ergonomist" in further user tests to improve the interfaces before its implementation by developers.

BIBLIOGRAPHY

Albarello, L., Digneffe, F., Hiernaux, J.-P., Maroy, C., Ruquoy, D., & Saint-Georges, D. (1995). *Pratiques et méthodes de recherche en sciences sociales*. Paris: Armand Colin.

Berlin, C., & Adams, C. (2017). *Production Ergonomics: Designing Work Systems to Support Optimal Human Performance*. London: Ubiquity Press.

Borsato, M., & Peruzzini, M. (2015). Collaborative Engineering. In *Concurrent Engineering in the 21st Century* (pp. 165-196): Springer.

Bubb, H., & Fritzsche, F. (2009). A scientific perspective of digital human models: past, present, and future. In V. G. Duffy (Ed.), *Handbook of Digital Human Modeling: Research for Applied Ergonomics and Human Factors Engineering* (Vol. 3, pp. 3.1-3.30). Boca Raton, FL: CRC Press.

Burns, C. M., & Vicente, K. J. (2000). A participant-observer study of ergonomics in engineering design. *Applied Ergonomics, 31*(1), 73-82. doi:10.1016/s0003-6870(99)00017-4

Carney, T. F. (1972). *Content analysis: A technique for systematic inference from communications*. Winnipeg, Canada: University of Manitoba Press.

Chaffin, D. B. (2009). Some requirements and fundamental issues in digital human modeling. In V. G. Duffy (Ed.), *Handbook of Digital Human Modeling: Research for Applied Ergonomics and Human Factors Engineering* (Vol. 3, pp. 2.1-2.10). Boca Raton, FL: CRC Press.

Charland, J. (2016). Virtual Ergonomics- Vision of the Future. In M. J. Bullinger-Hoffmann A. (Ed.), *Homo Sapiens Digitalis - Virtuelle Ergonomie und digitale Menschmodelle* (pp. 279-284). Berlin: Springer Vieweg.

Demirel, H. O., & Duffy, V. G. (2007a). *Applications of digital human modeling in industry.* Paper presented at the International Conference on Digital Human Modeling (pp. 824-832).doi:https://doi.org/10.1007/978-3-540-73321-8_93

Demirel, H. O., & Duffy, V. G. (2007b). *Digital Human Modeling for Product Lifecycle Management.* Paper presented at the International Conference on Digital Human Modeling (pp. 372-381).doi:https://doi.org/10.1007/978-3-540-73321-8_43

Denis, D., St-Vincent, M., Imbeau, D., Jette, C., & Nastasia, I. (2008). Intervention practices in musculoskeletal disorder prevention: a critical literature review. *Applied Ergonomics, 39*(1), 1-14. doi:10.1016/j.apergo.2007.02.002

Drouin, H. (2015). *Spécification des usagers des logiciels d'ergonomie virtuelle*. Rapport de stage de maîtrise professionnelle. Polytechnique Montréal.

Duignan, M., Noble, J., & Biddle, R. (2006). *Activity theory for design from checklist to interview.* Paper presented at the IFIP Working Conference on Human Work Interaction Design (pp. 1-25).doi:https://doi.org/10.1007/978-0-387-36792-7_1

Eliasson, K., Lind, C., & Nyman, T. (2015). *Facilitators for the implementation of ergonomic interventions.* Paper presented at the The 47th International the Nordic Ergonomics Society Conference, NES2015, in Lillehammer, Norway, November 1-4th, 2015.

Folcher, V., Bationo-Tillon, A., & Duvenci-Langa, S. (2017). Construire et conduire une intervention en ergonomie. Questions pour la formation professionnelle. *Activités, 14*(14-1). doi:10.4000/activites.2956

Germani, M., Mengoni, M., & Peruzzini, M. (2012). An approach to assessing virtual environments for synchronous and remote collaborative design. *Advanced Engineering Informatics, 26*(4), 793-813. doi:10.1016/j.aei.2012.06.003

Gustafsson, J. (2017). Single case studies vs. multiple case studies: A comparative study.

Hamel, M.-L., & Bélanger, L. (March 2019). [Design et sciences comportementales].

Hammer, M., & Champy, J. (2009). *Reengineering the Corporation: A Manifesto for Business Revolution*. New York: Zondervan.

Holtzblatt, K., & Beyer, H. (2014). *Contextual Design: Evolved*: Morgan & Claypool Publishers.

Houghton, C., Casey, D., Shaw, D., & Murphy, K. (2013). Rigour in qualitative case-study research. *Nurse Researcher, 20*(4), 12-17. doi:10.7748/nr2013.03.20.4.12.e326

Houghton, C., Murphy, K., Meehan, B., Thomas, J., Brooker, D., & Casey, D. (2017). From screening to synthesis: using nvivo to enhance transparency in qualitative evidence synthesis. *Journal of clinical nursing, 26*(5-6), 873-881. doi:https://doi.org/10.1111/jocn.13443

Houghton, C., Murphy, K., Shaw, D., & Casey, D. (2015). Qualitative case study data analysis: An example from practice. *Nurse researcher, 22*(5). doi:10.7748/nr.22.5.8.e1307

Imbeau, D., Bellemare, M., Courville, J., Bergeron, S. Desjardins, L. . (2006). Ergonomics in a Design Engineering Environment. In W. Karwowski (Ed.), *International Encyclopedia of Ergonomics and Human Factors-3 Volume Set* (pp. 1233-1235). Boca Raton, FL: CRC Press.

Jolibert, A., & Jourdan, P. (2006). *Marketing Reseach: méthodes de recherche et d'études en marketing*. Paris: Dunod.

Joung, Y.-K., & Noh, S. D. (2014). Integrated modeling and simulation with in-line motion captures for automated ergonomic analysis in product lifecycle management. *Concurrent Engineering, 22*(3), 218-233. doi:10.1177/1063293x14537002

Krippendorff, K. (2004). *Content analysis: An introduction to its methodology* (2 ed.). Thousand Oaks, California, US: Sage Publications.

Lenté, C., Berthelot, S., & Buisine, S. (2014). *Scénariser l'usage pour améliorer la collaboration entre ergonomie, design et ingénierie*. Paper presented at the ErgoIA, Bidart-Biarritz, France. Retrieved from http://stephanie.buisine.free.fr/publis/ErgoIA14b.pdf

Mayhew, D. J. (2012). -Usability+ Persuasiveness+ Graphic Design= eCommerce User Experience. In J. A. Jacko (Ed.), *Human computer interaction handbook: Fundamentals, evolving technologies, and emerging applications.* (pp. 1181-1193). Boca Raton, FL: CRC Press.

Neuendorf, K. A. (2016). *The content analysis guidebook* (2 ed.). Cleveland State University, USA: Sage Publications.

Nigatu, T. (2009). *Qualitative data analysis* [Power Point Presentation]. Retrieved from https://www.slideshare.net/tilahunigatu/qualitative-data-analysis-11895136

Patton, M. Q. (1990). *Qualitative evaluation and research methods*. Thousand Oaks, California, US: Sage Publications.

Perez, J. (2011). *Virtual human factors tools for proactive ergonomics: Qualitative exploration and method development.* (Master's Thesis, Ryerson University, Toronto, Ontario, Canada).

Perez, J., & Neumann, W. P. (2015). Ergonomists' and Engineers' Views on the Utility of Virtual Human Factors Tools. *Human Factors and Ergonomics in Manufacturing & Service Industries, 25*(3), 279-293. doi:10.1002/hfm.20541

Pope, C., & Mays, N. (1995). Qualitative research: reaching the parts other methods cannot reach: an introduction to qualitative methods in health and health services research. *Bmj, 311*(6996), 42-45. doi:https://doi.org/10.1136/bmj.311.6996.42

Robert, J.-M. (2017). [IND6407 Analyse ergonomique du travail mental: Introduction].

Schaub, K. G., Mühlstedt, J., Illmann, B., Bauer, S., Fritzsche, L., Wagner, T., . . . Bruder, R. (2012). Ergonomic assessment of automotive assembly tasks with digital human modelling and the ergonomics assessment worksheet (EAWS). *International Journal of Human Factors Modelling Simulation, 3*(3-4), 398-426.

St-Vincent, M., Vézina, N., Bellemare, M., Denis, D., Ledoux, E., & Imbeau, D. (2011). *L'intervention en ergonomie [Ergonomic intervention]*. Québec, QC: Éditions Multimonde.

St-Vincent, M., Vézina, N., Laberge, M., Gonella, M., Lévesque, J., Petitjean-Roget, T., . . . Dubé, J. (2010). *L'intervention ergonomique participative pour prévenir les TMS: Ce qu'en dit la littérature francophone* (Report No. R-667). Montréal: IRSST. Retrieved from https://www.irsst.qc.ca/media/documents/PubIRSST/R-667.pdf?v=2019-10-28

Stephens, A., & Jones, M. (2009). Workplace methods and use of digital human models. In *Handbook of Digital Human Modeling* (Vol. 6, pp. 1-6). US: Taylor & Francis.

Theberge, N., & Neumann, W. (2010). Doing 'organizational work': expanding the conception of professional practice in ergonomics. *Applied ergonomics, 42*(1), 76-84. doi:https://doi.org/10.1016/j.apergo.2010.05.002

Weber, R. P. (1990). *Basic content analysis* (2 ed.). Thousand Oaks, California, US: Sage Publications.

Welsh, E. (2002). Dealing with data: Using NVivo in the qualitative data analysis process. *Forum qualitative sozialforschung/Forum: qualitative social research, 3*(2).

White, M. D., & Marsh, E. E. (2006). Content analysis: A flexible methodology. *Library trends, 55*(1), 22-45.

Whysall, Z., Haslam, C., & Haslam, R. (2006). Implementing health and safety interventions in the workplace: An exploratory study. *International Journal of Industrial Ergonomics, 36*(9), 809-818.

Whysall, Z., Haslam, R., & Haslam, C. (2004). Processes, barriers, and outcomes described by ergonomics consultants in preventing work-related musculoskeletal disorders. *Applied Ergonomics, 35*(4), 343-351.

Wulff, I. A., Westgaard, R. H., & Rasmussen, B. (1999). Ergonomic criteria in large-scale engineering design—II Evaluating and applying requirements in the real world of design. *Applied Ergonomics*, 30(3), 207-221.

APPENDIX A GUIDE OF THE INTERVIEW ABOUT VIRTUAL ERGONOMICS INTERVENTIONS

To the interviewer:

For details, the interviewer can use the questions Who, What, When, Where, Why (5W) or How at different points in the interview.

Introduction:

Thank you for taking your time to give us this interview and for sharing your experiences with us.

With these series of interviews, we seek to better understand the current practice of ergonomics interventions that involved the use of DHM (virtual ergonomics) tools.

There will be two parts of the interview: the first one is about one specific case and the second would be about this type of interventions in general.

Part 1:

General open question

Now we would like you to describe an intervention that you conducted in the past, where you used DHM to help a client.

Specific questions

CONTEXT:

1. Who was the **client**, did they have **ergonomics as a priority** for the company in a **reactive or proactive** approach?
2. Do they have people working on **ergonomics and Health and safety**?

Now we would like to talk about the initial request from the client:

3. **What** was it?
4. For what human **population**?
5. For what **percentiles** or manikins?
6. Was it **clear** or had to be **redefined**?
7. **Who** did the request and **how**?
8. What were you given as **INPUT** in terms of Materials and information?
9. Was there a **format** they request for the solutions, what was the **OUTPUT** expected?
10. **What will they do** with the solutions?
11. **Why** were they asking you this? (**Reasons)**
12. In what **stage of the design process** were they?

ACTIVITIES:

Describe (with as much detail as possible) the development of the intervention through **time and places** from the very first contact with the client (for the initial request). If possible, try to say what was the **goal** of doing each step.

(+SEQUENCE)

For every step:

- Talk about the **people** involved, their **role**, their **interactions** and **communications**.(+COORDINATION)
- Talk about the **tools, methods and documents** used on every step.
- Talk about the **INPUTs and OUTPUTS** of every step in terms of documents, files, information or decisions.
- What **sources of information** were used?

ACTORS:

1. Mention all the **people** that were involved directly or indirectly in the intervention (INCLUDING YOUR SELF) and what was their **role** (what is it that they did in the intervention), their **power of decision** and their **background**.

For each of them:

- What was their **attitude** towards ergonomics, DHM and the intervention?
- **Why** were they participating in the intervention, what was their **goal**?
- How were they **related to the designer**?
- Did they have **contradictions** of any sort?
- Did they already **knew** the **company**, the **project** and the **other people** in the intervention?

RESULTS:

1. What **solutions** did you propose? In what **format**? (**OUTPUT**)
2. What was the **impact** of the solutions?
3. How did the client **perceive this impact**? (Was the client **aware** of it?)
4. What **obstacles** to the success of the intervention (weaknesses) can you mention? (Sources of contradictions, misunderstandings, time consuming, difficulties, communication problems) (Was there a frequent need for clarification to be on the same page?)
5. What **facilitators** (strengths)?
6. Were the **clients satisfied with the intervention**? Why
7. Were the **clients satisfied with the solution**? Why

8. What was the **added value** to them and what was not?)
9. And the other **actors**?
10. Have their goals, emotions and attitudes **changed**? (Ex. perception of the importance of ergonomics, perception of DHM) Why?

Part 2:

Now I will ask you questions about the intervention activity in general, which is different from the first part of the interview where the questions were about a specific case.

When I say interventions (activity), I will be referring to all the ergonomic consultations where the client was using a 3D software and you used DHM tools.

INTERVENTIONS IN GENERAL:

1. What are the sub-**activities or steps** of interventions in general? Which are more frequent and which are rarer? (actions)
2. Comment on the different **types of interventions** that you identify so far in your experience in this activity. (Comment on the different types of requests from clients) Which are more frequent and which are rarer?
   a. Are there cases where the **client quits** the intervention early, before completing the analysis, for example after the first contact, before signing the proposal? Why?
   b. What do you think that makes the difference between clients that sign the proposal and go to the end or quit?
3. What different **people** can be involved? Which are more frequently involved and which are rarely involved?
4. What **tools** are used? Which are more frequent and which are rarer?
5. What **documents** are used? Which are more frequent and which are rarer?
6. What **methods** are used? Which are more frequent and which are rarer?
7. Comment on the **obstacles and facilitators** of interventions in general and which are more frequently or rarely present.

After processing the interview in more detail if we need to clarify something or ask a supplementary question, may we contact you by email? Thank you very much for your time.

APPENDIX B CODING SCHEME STUDY 1

This file was exported as a Codebook from the Nvivo file (***Study1_5 files_Specific)***. Some modifications were made after.

The nine themes (demand, actors, activities, inputs, outputs, duration, tools, obstacles and facilitators) are in the rows with grey background and the categories are below, in the rows with white background. The themes and categories correspond to the nodes in the Nvivo file. For some categories there are subcategories that are also in rows with white background but have a bigger indexation.

The files are five in total and they correspond to the five intervention cases described in the interviews.

The references are the overall number of text references about the theme or category.

To keep small the size of this document, only the part of the coding scheme corresponding to the theme activity will be presented in this appendix.

Table B.1. Coding scheme Study 1.

THEMES AND CATEGORIES (NODES IN NVIVO)	DESCRIPTION (NODE DESCRIPTION IN NVIVO)	FILES	REFERENCES
3.1 activities*	Here is the text about all the activities related to the intervention case from the first contact established with the client for the request to the delivery of the solutions and feedback sent to the ergonomist.	5	96
1_Generic presentation by ergonomist	The ergonomist gives the client a general presentation about the consultancy service that he can provide. This is a presentation previous to the client official request.	1	1
10_Get information and files ergonomist from client (and or suppliers)	The ergonomist receives information and/or files from the client and/or supplier.	5	9
11_Get information and files by ergonomist on his own	The ergonomist obtains information and/or files by his own effort (not from the client and not from the supplier).	4	5
12_Make the DHM analysis and prepare snapshots and or presentation and or report by ergonomist	The ergonomist recreates worker (or user) tasks in the 3D environment including the equipment, build-up and human. To do this, the ergonomist uses a DHM or a 3D modelling software. AND/ OR The ergonomist uses automatic ergonomic analysis available in the DHM software to assess the situation represented in the 3D environment. AND/ OR The ergonomist prepares a presentation, report, snapshots, documents or images to show to others the results of the analysis made.	5	6
13_Check that the path is good ergonomist with client	The ergonomist shows partial or final results to the client before the final delivery of the results to make sure what he has done is what the client wants (he is on the good path). The goal is to make the client react if there is something to change without waiting to the final presentation.	4	4
14_Arrange meeting and or Send invitation for presentation of analysis	The ergonomist proposes a meeting to the clients and/or suppliers and arranges all the details.	2	4

Table B.1. Coding scheme Study 1. (*Continued*)

THEMES AND CATEGORIES (NODES IN NVIVO)	DESCRIPTION (NODE DESCRIPTION IN NVIVO)	FILES	REFERENCES
15_Send snapshots of the DHM	The ergonomist sends snapshots of the DHM to the client and/or suppliers.	3	5
16_Give presentation and or report and discussion by ergonomist and client (and or suppliers)	The ergonomist presents the results to the client or suppliers while they can also talk or have a discussion. This discussion could be face to face, in the telephone or in a video conference but it should happen at the same time as the presentation of the results.	4	8
17_Request of further analysis by client	The client requests further analysis after the final delivery of the results was made by the ergonomist.	3	4
18_Modification of proposal by ergonomist	The ergonomist modifies the original contract (or proposal) to include the additional analysis requested by the client after the final delivery of the results (of the original request).	2	3
19_Make extra analysis by ergonomist	The ergonomist makes the additional analysis requested by the client (this additional analysis was requested after the delivery of the results established in the first contract).	2	3
2_Request of intervention by client (not necessarily DHM)	The client makes an explicit (or tacit) request to the ergonomist that starts the intervention. This request doesn't necessarily include the use of DHM. The client can ask for a DHM intervention or another intervention in which is the ergonomist who decides to use the DHM.	5	7
20_Deliver extra analysis by ergonomist	The ergonomist delivers the results of the additional request made by the client after the delivery of the initially requested results.	2	3
21_ Paying by client to ergonomist	The client pays to the ergonomist exclusively for the services provided during the intervention. The payment of a salary for a long-term contract of the ergonomist that is internal to the client's company is not considered here.	1	1
22_Follow up by ergonomist	After the delivery of the results, the ergonomist asks the client about their subsequent use in terms of applications, changes or decisions. AND/OR The client gives information to the ergonomist about the subsequent use of the results of the intervention in terms of applications, changes or decisions. AND/OR After the delivery of the results, the ergonomist might be asked for a brief evaluation of the changes done by the client, there might be several back and forth exchanges by email until the evaluation o	4	5
3_Signature of NDA by ergonomist	The ergonomist signs a Non-Disclosure Agreement for the client related to the intervention or to a contract with a larger scope that includes what is done during the intervention. This could take place during the period of time of the intervention or before, as long as it concerns the information exchanged during the intervention. *It is logical to think that in all cases there was some kind of NDA signed, but here it will only be considered present when the ergonomist mentions it.	2	2
4_Proposal elaboration by ergonomist and client	Ergonomist and client discuss the number of hours that the work of the ergonomist will take, the payment (or budget to pay the ergonomist) and the details of the service that the ergonomist will provide, amongst other contractual aspects. These elements are reflected in a document that could be a contract or something similar.	2	2

Table B.1. Coding scheme Study 1. (*Continued and end*)

THEMES AND CATEGORIES (NODES IN NVIVO)	DESCRIPTION (NODE DESCRIPTION IN NVIVO)	FILES	REFERENCES
5_Proposal signature by ergonomist and client	Ergonomist signs a document containing the number of hours that his work will take, the payment (or budget to pay the ergonomist) and the details of the service that the ergonomist will provide, amongst other contractual aspects.	1	1
6_Ask for information and files to client (and or suppliers) by ergonomist	The ergonomist asks for information and/or files to the client and/or supplier.	5	10
7_Waiting for information and or files from client (and or suppliers)	Ergonomist waits for the client and/or supplier for information, files or for a meeting.	2	4
8_Communication	The ergonomist and the client communicate during the intervention. *Communication actions are part of other activities of the intervention, therefore this is considered a fragmented activity.	5	6
9_Meetings	The ergonomist and the client (and or supplier) have meetings before the final presentation. * Here is not considered the meeting where the ergonomist presents the final results, instead, this meeting is part of the activity Give presentation/report and discussion by ergonomist and client (and suppliers). *Meetings is included or contains other activities of the intervention; therefore, it is considered a fragmented activity.	3	3

*Comments to the coding scheme in the theme *activities*:

The intention of the researcher was to define activities showing the similarities between the five cases of virtual ergonomics interventions. For this reason, some of the activity names have the wording of the participants; for others, the researcher uses words that try to include the actions described by the participant in a more general activity that could be common to all cases.

Another goal of the researcher when using the activities to define the process is to be as exhaustive as possible. This means to include all the activities from the five cases of intervention.

Each of these activities is not completely independent of the others and is not a unique occurrence; this means that one activity in the table can have many small actions happening at different moments and overlapping with actions of other activities. For example "Ask for information and files to client by ergonomist" could include many different contacts of the ergonomist to the client to ask for different information such as a simple answer to a question, a decision, a dimension, a 3D model or others. These requests are not happening all at one moment and place but they could happen even during the DHM analysis "Make the DHM analysis / Prepare presentation/report by ergonomist".

The activity "Request of intervention" takes very different forms for the different cases and is better analyzed in the results of the theme Demand. Sometimes there is not an explicit request of virtual ergonomics intervention by a client. Instead, there are client's general expectations of the job of the ergonomist declared before the intervention (mainly in the case of an ergonomist internal to the client's company). The ergonomist, knowing these expectations, that sometimes have a wider or different scope than a virtual ergonomic analysis, decides then to carry on a DHM or virtual ergonomic analysis as the best way to satisfy the need of the client.

Although Actors are a theme itself, most of the activity labels mention the actor's role. This helps identifying and comprehending the activity.

APPENDIX C FORM USED IN OBSERVATION IN STUDY 2

Observation Protocol	
Date: Time: Length of activity: Site: Participants:	
Activity:.	
Questions:	
Descriptive notes	Reflexive notes

APPENDIX D CITATION'S TABLE OF *ACTIVITIES* IN STUDY 1

This table contains the quotations that justify the presence of each activity (as presented in Table 4.1) in the five cases of interventions of Study 1. In bold (green and red) are the results of the member checking carried out with a questionnaire after the content analysis. When these results contradicted the quotations, they were taken as the final answer of the participant.

Citation's tables were produced for each of the themes but only the activities' one is presented here to avoid an excessive size of the document.

Table D.1. Citation's table of activities in Study 1.

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Generic presentation by ergonomist	**YES (Member checking)** " Researcher2: When was the generic presentation done? Sujet1_int1: Before the NDA "	**NO (Member checking)**		**NO (Member checking)**	**YES (Member checking)**
Request of intervention by client (not necessarily DHM)	**YES (Member checking)** "first I got contacted by this person, so the first thing is communication, what do they need, what's the project and then there is the proposal"	**YES (Member checking)** "bon premièrement la demande est venue, est venue de mettons d'un directeur"	"all designs proposals, came to me anyway, so my job was automatically to look at the documentation with each design proposal and to decide myself weather it justifies additional assessment" "One of my job expectations was that I would routinely use Digital methods to evaluate new products."	**YES (Member checking)** "we needed to show a person inside a mechanical power press euh… doing a task and euh…. for obvious safety reasons, we we… you can go inside a press to do maintenance but nobody would have been interested in me putting people in the press to use as scale figures in an analysis of access to some machinery inside the press and so I thought hey I've already got a solid model of this press I had already drawn the press in a simplified form and I said I will just use this little manikin, this solid modeling little human inside the press and it will be cool and they'll like it and we will have avoided the hazards to the humans. " "Most likely it was a matter of them saying: is there room? and I would said: yeah there's room and I can prove it."	**YES (Member checking)** "It was probably just a discussion that I had with somebody from that Motor Sport club and yeah they said you know we are… we want to do that, and we have a car and we want to make it suitable for disabled people to be able to drive very fast basically. Yeah, it just happened… the discussion and I didn't have to go through any bidding competitions, you know… Researcher Ah ok. It was… Sujet4 Word to mouth probably the best…you know… "

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Signature of NDA by ergonomist	**YES (Member checking)** Researcher2: When was there non-disclosure agreement signed? Sujet1_int1: Oh before the proposal.	**NO (Member checking)** "Researcher Ok parfait, parfait. Et en termes, est-ce que vous, est-ce qu'il a eu besoin de signer un non disclosure agreement? Sujet1_int2: Ah mais non mais ça s'est déjà fait avec B là, c'est une entente, comme je dis ça fait 20 ans qu'on travaille avec eux autres là."	Not considered because it wasn't mentioned. "I was the ergonomics lead for assembly production"	**NO (Member checking)** Not considered because it wasn't mentioned. "they hired me on a consulting basis and I was their acting Health and Safety manager for a year or two"	**YES (Member checking)**
Proposal elaboration by ergonomist and client	**YES (Member checking)** "we made a proposal"	**NO (Member checking)** "Researcher: Ok. And from that time, it was you who created the proposal? Sujet1_int2: No, because with this company we had like a budget, a used budget and its divided by project, so I had a certain amount of time between me and the other person that I said at the beginning helped me to... kind of third party, she pass along the project to me, so we had a budget for both of us, so I used some of the hours, we had so many hours for example, so I used some of the hours for that."		**NO (Member checking)**	**YES (Member checking)**
Proposal signature by ergonomist and client	**YES (Member checking)** "The signature of the proposal was onto email with that person"	**NO (Member checking)**		**NO (Member checking)**	**YES (Member checking)**

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Ask for information and files to client (and/or suppliers) by ergonomist	**YES (Member checking)** "I asked the client to give me some pictures of how they see the project, what exactly they needed" "So at that point I started working with the CAD technicians, because I needed the models"	**YES (Member checking)** "Ensuite on a voulu identifier l'ingénieur qui a les modèles CAD, bon à ce moment-là ça été un petit peu plus compliqué parce que y'avait pas vraiment, les modèles CATIA venaient d'un sous-traitant, c'était le sous-traitant qui avait les modèles de la nouvelle plateforme, mais y'avais un problème de communication entre les deux"	"In terms of how it went from there, well it was simply left to me to generate… by… requesting from the supplier the JT file for the product… well the assembly component"	**NO (Member checking)** IDEM as in Getting information….	**YES (Member checking)** IDEM as in Waiting for information…. And Getting information….
Waiting for information and files from client (and/or suppliers)	**YES (Member checking)**	**YES (Member checking)** "j'attendais qui m'envoie les modèles du sous-vendeur, du third party, j'attendais après ça puis ça n'arrivait pas, ça n'arrivait pas"			**YES (Member checking)** "Well I don't think there was so much wait before I started, but there was a lot of wait, you know, after I... You know I….Well, first of all taking the… some vehicle measurements, the data from the car and then maybe running a first analysis with the first type of equipment that had data, and euh yeah then getting the specs for other maintenance layout and different controls. So, it was more time around communication getting the data than actually doing the technical work" "And also the time to get you know… because it was a one-man band, the time to the next available meeting with ____… you know wouldn't be____ and then as I said there was a lot about confirmation of budgets… so that… you know… accelerated or slowed down things." "sometimes a month between the first step and getting a solid answer and move on to the next"

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Communication	" Yeah, that was through email. And then, we had a phone call, you know, and then we talked about the needs for the project over the phone call, and then after that I put together a proposal and that was onto email. The signature of the proposal was onto email with that person, so at the beginning was all with the manager and the lead oon the project so I was introduced to her at that point ...and then we discussed all the details and that at that point I requested the pictures so she sent me the pictures, put it on the proposal you know to make it complete for the contract and then after that you know we just started working. So at that point I started working with the CAD technicians, because I needed the models, the baby the ... children, and we don't have the human models for that, so that was a big deal and transferring the models so we communicated back-and-forth through email all through email and transferring the data through email um and then after that I worked and gave them.. you know, presented my report and that was through Webex kind of a presentation."	" Researcher: So every time you got in contact for example with the ergonomist that you said that was there, and he help you gather information from other people you got in contact with the ergonomist through email through WebEx or through both? Sujet1_int2: both and also you know the...what is it the little? What is it called? Is a little bit like...Its a little windows that pop up, that you can talk to them… it's like a text that you have on your screen that pop up, on my Lotus Notes its called Sametime, on Outlook is something, it's like a little window that pops up and says, you are available to talk over here instead of email. Researcher: So it was like a chat conversation. Sujet1_int2: Yes like chat."	" Hum well the presentation meeting was remote because it was with people in Germany but the other meetings hum. Ok all right the initial meeting with the assembly engineer was face-to-face hum obviously, when I was in the room, the assembly engineer was there so were other members of my clients engineering team, then on the Internet we would have been connected with the German supplier and then the subsequently discussions if there was any backwards and forwards it would all be done by Email between myself… usually between myself and the designer hum kind of going through thinks. "	" So the interaction would have been, I probably did nothing more than take screen shots in PDF format you know, and send them to my colleagues via email." "if I had a question, I would have gone out to the person and say hey… you know, what is the answer to this question? "	**YES (Member checking)** " Researcher Ok. So you would say that during these months the way you communicated was sometimes euh you were face to face Sujet4 Yeah. Researcher Sometimes you were on the phone Sujet4 Yeah. Researcher And maybe email? Sujet4 Very little email but only to show you know some progress and some images of ideas before we sit down face to face. "

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Meetings	**YES (Member checking)**	**YES (Member checking)** " Sujet1_int2: I had a spreadsheet and I needed to have the fields, so on the spreadsheet I needed all the steps that its you know closed for all the process, I needed the steps to be completed, and I needed a score and then at_____. So we try to have a meeting every two weeks and have them, you know, until the sheet was never work out. So I decided to do meetings more regularly at a faster pace, like weekly and during that meeting I wanted to keep it short, like look, that's is where we are we did that and that, and that but I was working remotely you know in briefing the meeting, so to organize the meeting, so that way when we go to the meeting it's all clear on a sheet, so they can just talk and take decisions. It was very hard to do... so each person I would talk this I Would call or email and that person in between the meetings"	IDEM to Communication	**NO (Member checking)**	**YES (Member checking)** " And also the time to get you know… because it was a one-man band, the time to the next available meeting with ____… you know wouldn't be____ …"

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Get information and files ergonomist from client (and/or suppliers)	**YES (Member checking)** "I requested the pictures so she sent me the pictures"	**YES (Member checking)** "Ensuite on a voulu identifier l'ingénieur qui a les modèles CAD, bon à ce moment-là ça été un petit peu plus compliqué parce que y'avait pas vraiment, les modèles CATIA venaient d'un sous-traitant, c'était le sous-traitant qui avait les modèles de la nouvelle plateforme, mais y'avais un problème de communication entre les deux" "Donc y'est allé, y'a pris des dimensions pour moi puis il m'a envoyé l'information. Moi j'ai bâti la plateforme en 3D euh" " ils m'ont envoyé le modèle de l'hélicoptère finalement "	"requesting from the supplier the JT file for the product… well the assembly component, and they are always very happy to do this…the regular supplier to my client. And as soon as I received it, I imported that into my Human Modeling software and started to analyze it in my desktop. I also, of course, asked for dimension drawings, so I had the detailed drawings of the product that the supplier had provided"	**NO (Member checking)** "I seem to recall that I didn't know how tall the press was and I didn't want to get a man lift in, go through all the trouble of measuring it and so… I think I might have asked the…. either a euh…. we had one engineer and we had one maintenance manager, I might have asked one of those guys how tall is the press? Do you have a drawing of the press? You know, I may have gotten a few dimensions euh… from those guys in that way." "I would not have known about that task, so I would have talked to the production manager and the supervisors and the maintenance manager about the task. They would have…. just through my interactions with the other managers, I would have become aware of the issue, I would have become aware of the issue from the plant manager, the manufacturing manager and the maintenance manager, and they would have filled me in on the details of where the person is, and why they're even having to get into the press." "if I had a question, I would have gone out to the person and say hey… you know, what is the answer to this question? "	**YES (Member checking)** "Well, first of all taking the… some vehicle measurements, the data from the car and then maybe running a first analysis with the first type of equipment that had data, and euh yeah then getting the specs for other maintenance layout and different controls. So, it was more time around communication getting the data than actually doing the technical work" "

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Get information and files by ergonomist on his own	**YES (Member checking)** "because I had to bring the car model, they didn't have a car model "	**YES (Member checking)** "I'm saying is like a platform, this thing in grey I modeled it myself because I couldn't get the people... the tool designers to send me the models "		**YES (Member checking)** "I took a tape euh and I went out and did some basic measurements of one of the press that I was concerned about and I took enough measurements to where I… could make some gross volumes in solids modeling, you know… and so I made…and the beauty of it, is I can make a little press that I can moved the ram up and down and then… I took that human figure that I had gotten from the guy in Arizona" "I just googled Human Models, you know, I got on the Internet and tried to find Human Models and of course you see all these artist models, all this stuff that's not analytical, on the Internet, all these scale figures, just crazy stuff but somehow I managed to run across this guy in Arizona who had euh he had built a Human Model"	**YES (Member checking)** "so I looked at different configurations from commercially _____ for… with very small changes…. controls that they would fit euh, in that car" ***The 3D model of the car he build it by himself (Member checking)***
Make the DHM analysis and prepare snapshots/presentation/report by ergonomist	**YES (Member checking)** "I built a report as I go, so don't do the report at the end, I do snapshot of the screenshot, you know, I position the model I do analysis like biomechanical or RULA and then I place that directly in the PowerPoint so nothing is lost."	**YES (Member checking)** "j'ai toute mis mes manikins puis je les ai colorés de différentes couleurs pour qu'on puisse identifier si c'était un modèle euh de 5% ou 95% " "Donc j'ai fait ça puis là je les ai placés à la bonne hauteur pour qu'ils aient une bonne posture pour effectuer la tâche puis là ensuite je leur ai dit ben là il vous manque tel chose comme par exemple euh 24 pouces pour que lui puisse rejoindre"	"I imported that into my Human Modeling software and started to analyze it in my desktop"	**YES (Member checking)** "I took that human figure that I had gotten from the guy in Arizona, whose name is John, I can find that for you, and I put it in there and I just did an anthropometric analysis "	**YES (Member checking)** "Researcher Euh you were using Digital Human Modeling for that? Sujet4 Yes, I used that for the assessment of the designs options. "

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Check that the path is good ergonomist with client	**YES (Member checking)** "I did go back-and-forth with them to make sure I gave them like for example pictures and I said well that's what I have so do you agree on that? Because I made them agreed because it can change if it's not the right posture and if for example this is just a CAD model of a seat, but when you install a baby seat on a cushy... a cushion and you tie the anchors it will deflect the material of the seat the cushion, so it does changed a little bit of the... so that took a while, I wanted to make really sure that they agreed on that, so we got together and had a couple of communication back-and-forth with pictures through email with them with them, to make sure that the seat was exactly where they needed it."	**YES (Member checking)** "Sujet1_int2: Yeah they had a drawing, a 2D drawing. So I took the 2D drawing and I build...Like it's a crook model but that's all I needed, I just need...it is the human that is important in this case right, so I had the human position and then I had the platform where it is supposed to be and I was saying well look you know there are missing 16 inches or 24 inches. And so when I built it, I built it...I was missing some information obviously. So when I asked does it make sense, they said, well yeah I think so, it's a little too low, so I changed it...you know...with the..."	"No I'd already completed the analysis and from the Human Factors point of view I wasn't happy with the outcome. So when I contacted the clients assembly engineer it was simply to say, come and look"	**YES (Member checking)**	**YES (Member checking)** " Very little email but only to show you know some progress and some images of ideas before we sit down face to face."

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Arrange meeting/Send invitation for presentation of analysis	**YES (Member checking)**	**YES (Member checking)** " … so to organize the meeting, so that way when we go to the meeting it's all clear on a sheet, so they can just talk and take decisions. It was very hard to do... so each person I would talk this I Would call or email and that person in between the meetings "	"From the client's side… sorry from the supplier's side then, it was simply a matter of sending an email, inviting them to a meeting to discuss it … to discuss this issue … and I would have put in that invitation, it would have been an enhanced invitation that would of have the screenshots and my initial concerns over the usability of that particular piece of equipment. " "Researcher: It's ok. It's ok. When you were talking about the senior designer and the supplier… you interact with him previous to the final presentation? Sujet2: Oh yeah. Yes, but…it would have been when I sent the invitation hum I sent him euh, I sent him screenshots of what I had done " "So, that way he would have an agenda for the discussions, I'd be able to participate meaningly, and we would as a courtesy always send off my initial thoughts to the stakeholders that would be interested in attending and, what I would generally do is send that out to a significant number of peoples, so although it sounds like a lot of people are involved I've might have sent that out to 50 people and they would have been almost … they would have been all people who could have a potential interest in the outcome of this.. for my working for my client. So that would have been finance people, planning people etc… etc…. And then, and that would have gone out at the same time to the supplier with an invitation to participate in the discussion. "	**NO (Member checking)**	**YES (Member checking)**

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Send snapshots of the DHM	**YES (Member checking)**	**YES (Member checking)**	IDEM to Arrange meeting/Send invitation for presentation of analysis	**YES (Member checking)** "So the interaction would have been, I probably did nothing more than take screen shots in PDF format you know, and send them to my colleagues via email. "	**YES (Member checking)** IDEM to Check that the path is good ergonomist with client
Give presentation/ report and discussion by ergonomist and client (and suppliers)	**YES (Member checking)** " And .so I got to different summaries with the data and then I presented that to them and then we discuss if they had any question and everything "	**YES (Member checking)** " Researcher La présentation que vous nous avez montré la dernière fois est-ce que ça allait être utilisé par qui? Qui allait recevoir ça? Sujet1_int2: Ben moi, l'équipe toute l'équipe là. Tsé l'équipe qu'on avait la grosse équipe qu'on avait pour regarder toutes, toutes les solutions puis la réduction des risques ben je l'ai présenté à cette équipe-là. Puis là ben après ça bien c'est sûr que c'est la personne en ergonomie puis la personne en Santé et Sécurité " "j'ai donné les résultats à l'ergonome et à la personne en Santé et Sécurité" "Researcher Et finalement au bout de ces 2-3 semaines vous avez livré le rapport et vous avez donné une présentation? Sujet1_int2: Hum je ne m'en souviens plus. Oui, probablement oui."	" So we simply would have connected my screen and we had a Polycom desktop microphone and we have a conversation with them, and then after a brief introduction of who was in the room, we would then engaged in sharing my screen and presenting the problems that we'd found and as we went through them there was sort of a general discussion of different points. " "So I had several engineers from the supplier, were in the meeting probably 3 or 4 at that time if I remember rightly and at least 6 or 7 engineers from my client were sitting in the room with me."	**YES (Member checking)**	**YES (Member checking)** "Sujet4 for the Human CAD Solution was in the selection process, after we selected the best option then that option was only delivered as a product not as a Human CAD solution. Researcher Ok. Sorry if I understood well you at least showed them images of the Digital Human Modeling analysis? Sujet4 Yes, maybe animations as well. Yeah." "Euh for the selection there was a presentation yes; it was a Keynote or a PowerPoint."

Table D.1. Citation's table of activities in Study 1. (*Continued*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Request of further analysis by client	**YES (Member checking)** " Researcher2: I heard you say that they ask for some things towards the end. Did you have to adjust the contract? Sujet1_int1: Oh, yes actually. I did a little bit more work than planned so yeah so… Researcher2: So you add a few hours and stuff like that? Sujet1_int1: Yeah so we just requested an adjustment. " "then they add question and they wanted to have some little clarification so I might if I remember well I did some little checking different things you know and then gave them the report and that was it."	**NO (Member checking)**IDEM as in Follow up…	"we didn't get any push back from the supplier"	**NO (Member checking)**	**NO (Member checking)**
Modification of proposal by ergonomist	**YES (Member checking)** IDEM to Request of further analysis by client	**NO (Member checking)** IDEM as in Follow up…		**NO (Member checking)**	**NO (Member checking)**
Make extra analysis by ergonomist	**YES (Member checking)** IDEM to Request of further analysis by client	**NO (Member checking)** IDEM as in Follow up…		**NO (Member checking)**	**NO (Member checking)**
Deliver extra analysis by ergonomist	**YES (Member checking)** IDEM to Request of further analysis by client	**NO (Member checking)** IDEM as in Follow up…		**NO (Member checking)**	**NO (Member checking)**
Paying by client to ergonomist	**YES (Member checking)** Confirmed after with participant	**NO (Member checking)**		**YES (Member checking)**	**YES (Member checking)**

Table D.1. Citation's table of activities in Study 1. (*Continued and end*)

ACTIVITY	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Follow up by ergonomist	**YES (Member checking)** "Researcher2: So, you did a follow up but they did not answer? Sujet1_int1: Yeah."	**NO (Member checking)** "Researcher Et après ça, après cette présentation qu'est-ce qui s'est passé. Il y a eu, est-ce que c'était fini les contacts avec eux, après ça? Il y a eu des retours d'informations? euh il y a eu des follow up, des suivis? Sujet1_int2: Non, parce que ils nous ont dit à ce moment-là d'arrêter de travailler sur le projet, ben c'est souvent comme ça être comme consultant, le budget a été épuisé donc on a dû arrêter, fac ils ont arrêté. Y'on arrêter ça. J'ai pu retouché à rien pas le restant de l'année. "	"So he would then send something back to me and that's what happened in this case where he said I think I've captured your requirements please let me know what you think. I'd look them over and on this occasion he'd captured them perfectly well there was no need to go back and forth. " "they reworked the design and the subsequent design was not only acceptable but I visited the supplier when it was fabricated and ran force tests on it, and approve it. It was an acceptable design"	**NO (Member checking)**	**YES (Member checking)** " Researcher Ok. Euh so do you remember if the client was satisfied with your solutions? Sujet4 Yeah… I think he was because it was quite a big success for a very small budget and, you know, it was in the news, it was advertised in the Motor Sport nationally. Actually, the cars were used for demonstration for a few years. There was a competition around the back of it so there was a…I think a very good publicity for a long time. "

APPENDIX E TABLE OF ACTORS IN STUDY 1

Table E.1. Actors in Study 1.

Actors	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
1_ERGONOMIST CONSULTANT	YES	YES	INTERN	YES/INTERN	YES
1a_account manager in consultant company		YES			
2_CLIENT IN GRAL	YES	YES	YES	YES	YES
2a_high level direction		YES		YES (plant manager)	
2b_ergonomist_client		YES	YES (himself)		
2c_health and safety engineer/manager	YES	YES	YES	YES (himself)	
2d_project manager					YES
2e_engineer leader	YES				
2f_CAD technician	YES				
2g_manufacturing and or assembly engineer		YES	YES		
2h_person in simulation and motion capture		YES			
2i_maintenance manager				YES	
2j_production manager				YES	
2k_worker					
2l_engineer specialized					
2n_tool designers		YES			
2o_Human Resources					
2p_Funding source for the project from the company					YES
2q_Other projects managers		YES			
3_SUPPLIER designing and producing the equipment or built up under analysis_gral		YES	YES		YES
3a_designer_supplier			YES		
3b_engineer_supplier			YES		
3c_comercial manager_supplier			YES		
external funding organization					YES
external organization interested in the results of the project					YES
Professional contacts of the ergonomists				YES	
Approximate total of types of actors besides the ergonomists*	3	9	5	4	5

* When there are specific actors from the client, this count excludes ***2_CLIENT IN GRAL*** because this entity is represented by the particular actors. When there are no particular actors mentioned but the client was mentioned in general in the interview, the category ***2_CLIENT IN GRAL*** is included in this count. The same applies for particular actors from the supplier and the general category ***3_SUPPLIER designing and producing the equipment or built up under analysis_gral.***

APPENDIX F TABLE OF *TOOLS* IN STUDY 1

For the activities with no tools assigned, the participants didn't give information during the interview.

Table F.1. Tools in Study 1.

Activities	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Generic presentation by ergonomist					
Request of intervention					
Signature of NDA by ergonomist					
Proposal elaboration by ergonomist and client	Word				
Proposal signature by ergonomist and client	email				
Ask for information and files to client (and/or suppliers) by ergonomist					
Waiting for information and files from client (and/or suppliers)					
Communication	phone email WebEx	phone WebEx email Sametime (on Outlook …)	Face to face Email	Face to face email	face to face phone Very little email
Meetings		WebEx	Face to face		Face to face
Get information and files ergonomist from client (and/or suppliers)	Email, STEP file no IGES				
Get information and files by ergonomist on his own	Grab CAD database	CAD software (maybe DELMIA)			
Make the DHM analysis and prepare snapshots/presentation/report by ergonomist	Delmia Word PowerPoint	DELMIA CAD in Delmia or CATIA	Siemens Jack 7.1 Biss Excel	Viacad	Sammie CAD Excel PowerPoint Office suite Keynote Page SPSS ROBOCAD
Check that the path is good ergonomist with client	email		Face-to-face		email
Arrange meeting/Send invitation for presentation of analysis			email		
Send snapshots of the DHM			email	email	email
Give presentation/report and discussion by ergonomist and client (and suppliers)	GoToMeeting	PowerPoint WebEx	Polycom desktop microphone Go to meeting		Keynote or PowerPoint.
Request of further analysis by client					
Modification of proposal by ergonomist					
Make extra analysis by ergonomist					
Deliver extra analysis by ergonomist	email				
Paying by client to ergonomist					
Follow up by ergonomist					

APPENDIX G TABLE OF *TOOLS* IN STUDY 2

Table G.1. Tools in Study 2.

Activities	**S2_Case1**	**S2_Case2**	**S2_Case3**
Generic presentation by ergonomist	Survey Monkey Social Network: Linkedin Email: DS	Survey Monkey Social Network: Linkedin Email: DS	Survey Monkey Social Network: Linkedin Email: DS
Request of intervention	Survey Monkey	Survey Monkey	Survey Monkey
Signature of NDA by ergonomist			
Proposal elaboration by ergonomist and client			
Proposal signature by ergonomist and client			
Ask for information and files to client (and/or suppliers) by ergonomist	Email	Email	Email
Waiting for information and files from client (and/or suppliers)			
Communication	Skype email	Skype email	Skype email
Meetings	Skype	Skype	Skype
Get information and files ergonomist from client (and/or suppliers)	DS file transfer Email Skype	DS file transfer Email Skype	DS file transfer Email Skype
Get information and files by ergonomist on his own		Internet	
Make the DHM analysis and prepare snapshots/presentation/report by ergonomist	DELMIA Ergonomics Evaluation App 2019 3DExperience platform Word Snagit Editor 13	DELMIA Ergonomics Evaluation App 2019 3DExperience platform Word Excel	DELMIA Ergonomics Evaluation App 2019 3DExperience platform Word PowerPoint
Check that the path is good ergonomist with client			
Arrange meeting/Send invitation for presentation of analysis	email	email	email
Send snapshots of the DHM			
Give presentation/report and discussion by ergonomist and client (and suppliers)	Skype	Skype	Skype
Request of further analysis by client			
Modification of proposal by ergonomist			
Make extra analysis by ergonomist			
Deliver extra analysis by ergonomist			
Paying by client to ergonomist			
Follow up by ergonomist			

APPENDIX H TABLE OF *INPUTS* IN STUDY 1

Table H.1. Inputs in Study 1.

Classification	Inputs	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Frequency
INFO	Other data	"the targets flesh and cushion compression"					1
INFO	Hours of ergonomist work and cost per hour	YES					1
INFO	Specific postures	YES BY HIMSELF FROM 2e_engineer leader					1
INFO	Environment configuration	YES FROM 2e_engineer leader (Problems with information precision)					1
INFO	Population and percentiles	YES FROM 2_CLIENT IN GRAL	YES FROM Who?	YES BY HIMSELF		YES FROM 2_CLIENT IN GRAL	4
INFO	Dimensions		YES FROM 2b_ergonomist_client FROM 2_CLIENT IN GRAL (Problems with information precision)	YES FROM 3_SUPPLIER And in 2D drawings of build-up	YES BY HIMSELF	YES FROM who?	4
INFO	Risks		YES FROM 2_CLIENT IN GRAL				1
INFO	Anthropometric information					YES BY HIMSELF	1

Table H.1. Inputs in Study 1. (*Continued*)

Classification	Inputs	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Frequency
INFO	Task information	YES FROM 2_CLIENT IN GRAL And in Pictures of human postures as example	YES FROM 2_CLIENT IN GRAL And in Spreadsheet with worker tasks, risks	YES FROM 3_SUPPLIER designing and producing the equipment under analysis_gral And in Design proposal of a build-up	YES FROM 2_CLIENT IN GRAL	YES BY HIMSELF	5
INFO	Requirements					YES FROM 2_CLIENT IN GRAL	2
INFO	Specifications about products to modify the design					YES FROM Who?	1
INFO	Price and budget for solution information					YES FROM 2_CLIENT IN GRAL	1
INFO	Identified problems		YES FROM HSE FROM 2_CLIENT IN GRAL FROM Who? And in Spreadsheet with worker tasks, risks And in Simulation files of buildup				1
FILE	Pictures of human postures as example	YES FROM 2e_engineer leader					1
FILE	Pictures of configuration of environment	YES FROM 2_CLIENT IN GRAL					1
FILE	2D drawings of equipment		YES FROM 2_CLIENT IN GRAL				1

Table H.1. Inputs in Study 1. (*Continued and end*)

Classification	**Inputs**	**S1_Case1**	**S1_Case2**	**S1_Case3**	**S1_Case4**	**S1_Case5**	**Frequency**
FILE	Pictures of old equipment		YES FROM 2_CLIENT IN GRAL				1
FILE	2D drawings of build-up			YES FROM 3_SUPPLIER			1
FILE	3D model of build-up	YES FROM 2f_CAD technician	YES FROM 2n_tool designers	YES FROM 3_SUPPLIER designing and producing the equipment under analysis_gral		YES BUILT BY HIMSELF	4
FILE	3D model of equipment	YES BY HIMSELF	YES BUILT BY HIMSELF	YES (not sure) FROM 3_SUPPLIER	YES BUILT BY HIMSELF		4
FILE	Human model	YES (the baby model) FROM 2f_CAD technician			YES BY HIMSELF (from a friend)		2
FILE	Spreadsheet with worker tasks, risks		YES FROM 2_CLIENT IN GRAL				1
FILE	Design proposal of a build-up			YES FROM 3_SUPPLIER			1
FILE	Simulation files of buildup		YES FROM who?"				1

*The source of the input is indicated in the cases where the participant mentioned it.

APPENDIX I TABLE OF *INPUTS* IN STUDY 2

In the second column (Inputs), all the categories of inputs found in Study 1, Study 1a and Study 2 are present. The third column (Category first found in) shows the specific study where the category was found first.

Table I.1. Inputs in Study 2.

Classification	Inputs	Category first found in	S2_Case1	S2_Case2	S2_Case3	Frequency
INFO	Other data	Study 1				
INFO	Hours of ergonomist work and cost per hour	Study 1				
INFO	Specific postures	Study 1	YES (from client)			1
INFO	Environment configuration	Study 1	YES (from client)	YES (from client)	YES (from client)	3
INFO	Population and percentiles	Study 1			YES (guessed by ergonomist on his own)	1
INFO	Dimensions	Study 1	YES (from client)	YES (from client)	YES (from client)	3
INFO	Risks	Study 1				
INFO	Anthropometric information	Study 1				
INFO	Task information	Study 1	YES (from client)	YES (from client when asked 2nd time)	YES (from client when asked 2nd time)	3
INFO	Requirements	Study 1				
INFO	Specifications about products to modify the design	Study 1				
INFO	Price and budget for solution information	Study 1				
INFO	Identified problems	Study 1	YES (from client)			
FILE	Pictures of human postures as example	Study 1				
FILE	Pictures of configuration of environment	Study 1				
FILE	2D drawings of equipment	Study 1		YES (from client)		1
FILE	Pictures of old equipment	Study 1				
FILE	2D drawings of build-up	Study 1				
FILE	3D model of build-up	Study 1			YES (from client)	1
FILE	3D model of equipment	Study 1	YES (from client)	YES (from client)	YES (from client)	3
FILE	Human model	Study 1				
FILE	Spreadsheet with worker tasks, risks	Study 1		YES (from client) *without risks		1
FILE	Design proposal of a build-up	Study 1				
FILE	Simulation files of buildup	Study 1				
FILE	Screenshots of a simple DHM made by the supplier (which is partly the client of the intervention)	Study 1a				
FILE	Video of the worker or user doing the task	Study 1a	YES (from client)			1

Table I.1. Inputs in Study 2. (*Continued and end*)

Classification	**Inputs**	**Category first found in**	**S2_Case1**	**S2_Case2**	**S2_Case3**	**Frequency**
FILE	Motion capture file of worker or user doing the task	Study 1a				
INFO	Force and weight of tools	Study 1a	YES (from client when asked 2nd time) (in email)		YES (from client when asked 2nd time)	2
INFO	Repetition	Study 1a			YES (from client when asked 2nd time)	1
FILE	Power Point presentation with task information	Study 2	YES (from client)			1
FILE	Recorded Skype conversation	Study 2	YES (from client when asked 2nd time)	YES (from client)	YES (from client when asked 2nd time)	1
FILE	Email explaining	Study 2	YES (from client when asked 2nd time)	YES (from client when asked 2nd time)	1st email YES (from client) 2nd email YES (from client when asked 2nd time)	2
INFO	Layout of the assembly line	Study 2		YES (from client)		1
FILE	Videos of the real assembly line	Study 2		YES (ergonomist by himself on the internet)		1
INFO	Specific ergonomics methods to use in the analysis	Study 2	YES (from client)		YES (from client)	2

APPENDIX J TABLE OF *OUTPUTS* IN STUDY 1

In the cases where the participant mentioned what was done with the output once produced, this information was also put in the table.

Table J.1. Outputs in Study 1.

Classification	**Outputs**	**S1_Case1**	**S1_Case2**	**S1_Case3**	**S1_Case4**	**S1_Case5**	**Freq**
AMOUNT	Number of tasks	16	7	?	1	4	-
SEI	Clearance information				YES SHOWN TO 2_CLIENT IN GRAL		1
SEI	Vision information	YES PART OF THE PRESENTATION/REPORT FILE					1
SEI	Reach information	YES PART OF THE PRESENTATION/REPORT FILE	YES PART OF THE PRESENTATION/REPORT FILE			YES SHOWN TO 2_CLIENT IN GRAL	3
SEI	Joint moment	YES PART OF THE PRESENTATION/REPORT FILE					1
SEI	RULA results	YES PART OF THE PRESENTATION/REPORT FILE					1
SEI	Force information			YES SHOWN TO 2_CLIENT IN GRAL AND 3_SUPPLIER			1
SEI	Load on biomechanical structures	YES PART OF THE PRESENTATION/REPORT FILE		YES SHOWN TO 2_CLIENT IN GRAL AND 3_SUPPLIER			2
INFO	Ergonomic problems of design			YES GIVEN TO 2_CLIENT IN GRAL AND 3_SUPPLIER			1

Table J.1. Outputs in Study 1. (*Continued*)

Classification	**Outputs**	**S1_Case1**	**S1_Case2**	**S1_Case3**	**S1_Case4**	**S1_Case5**	**Freq**
INFO	Images of DHM	YES	YES	YES	YES	YES	5
INFO	Different postures for one task	YES PART OF THE PRESENTATION/REPORT FILE					1
INFO	Recommendations/ Requirements	YES PART OF THE PRESENTATION/REPORT FILE	YES PART OF THE PRESENTATION/REPORT FILE				2
INFO	Confirmation of ergonomic compliance/ Risk evaluation				YES GIVEN TO 2_CLIENT IN GRAL		1
INFO	Answers to questions	YES GIVEN TO 2_CLIENT IN GRAL					1
INFO	Different solutions					YES SHOWN TO 2_CLIENT IN GRAL	1
INFO	Advantages and disadvantages of the solutions					YES SHOWN TO 2_CLIENT IN GRAL AND 3_SUPPLIER	1
INFO	Cost of the solutions					YES SHOWN TO 2_CLIENT IN GRAL AND 3_SUPPLIER	1
FILE	Snapshots of the DHM	YES USED TO CREATE PRESENTATION	YES USED TO CREATE PRESENTATION	YES GIVEN TO 2_CLIENT IN GRAL AND 3_SUPPLIER	YES GIVEN TO 2_CLIENT IN GRAL	YES USED TO CREATE PRESENTATION	5

Table J.1. Outputs in Study 1. (*Continued and end*)

Classification	Outputs	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Freq
FILE	3D model of DHM analysis	YES USED TO CREATE PRESENTATION KEPT BY ERGONOMIST	YES USED TO CREATE PRESENTATION KEPT BY ERGONOMIST	YES SHOWN TO 2_CLIENT IN GRAL AND 3_SUPPLIER DURING PRESENTATION	YES USED TO CREATE SNAPSHOTS KEPT BY ERGONOMIST	YES USED TO CREATE PRESENTATION KEPT BY ERGONOMIST	5
FILE	Report/presentation document	YES GIVEN TO 2_CLIENT IN GRAL	YES GIVEN TO 2_CLIENT IN GRAL	NO	NO	YES SHOWN TO 2_CLIENT IN GRAL DURING PRESENTATION	3
FILE	Spreadsheet analysis						
FILE	CAD model of modified or new built-up/ equipment for suppliers (solution)					YES GIVEN TO 2_CLIENT IN GRAL AND 3_SUPPLIER	1
FILE	3D model equipment	YES GIVEN TO 2_CLIENT IN GRAL	YES BUILT BY ERGONOMIST, USED TO CREATE DHM, KEPT BY ERGONOMIST		YES BUILT BY ERGONOMIST, USED TO CREATE DHM, KEPT BY ERGONOMIST		3
FILE	3D model build-up					YES BUILT BY ERGONOMIST, USED TO CREATE DHM	1
FILE	3D model human				YES FOUND BY ERGONOMIST, USED TO CREATE DHM, KEPT BY ERGONOMIST		1
FILE	Animation					YES SHOWN TO 2_CLIENT IN GRAL DURING PRESENTATION	1
WAY	Presentation with discussion	YES	YES	YES	YES	YES	5
WAY	Live DHM presentation			YES			1

APPENDIX K TABLE OF *OUTPUTS* IN STUDY 2

In the second column (Outputs), all the categories of outputs found in Study 1, Study 1a and Study 2 are listed. The third column (Category first found in) shows the specific study where the category was found first.

Table K.1. Outputs in Study 2.

Classification	Outputs	Category found in	S2_Case1	S2_Case2	S2_Case3	Frequency
AMOUNT	Number of tasks	Study 1	2	3	3	-
SEI	Clearance information	Study 1				
SEI	Vision information	Study 1			YES (in report)	1
SEI	Reach information	Study 1			YES (in report)	1
SEI	Joint moment	Study 1			YES (in report)	1
SEI	RULA results	Study 1		YES (in report)	YES (in report)	2
SEI	Force information	Study 1				
SEI	Load on biomechanical structures	Study 1	YES (in report)		YES (in report)	2
INFO	Ergonomic problems of design	Study 1	YES (in report)	YES (in report)	YES (in report)	3
INFO	Images of DHM	Study 1	YES (in report)	YES (in report)	YES (in report)	3
INFO	Different postures for one task	Study 1	YES (in report)			1
INFO	Recommendations/ Requirements	Study 1	YES (in report)	YES (in report)	YES (in report)	3
INFO	Confirmation of ergonomic compliance/Risk evaluation	Study 1	YES (in report)	YES (in report)	YES (in report)	3
INFO	Answers to questions	Study 1				
INFO	Different solutions	Study 1	YES (in report)			1
INFO	Advantages and disadvantages of the solutions	Study 1			YES (in report)	1
INFO	Cost of the solutions	Study 1				
FILE	Signed NDA	Study 1				
FILE	Proposal	Study 1				
FILE	Snapshots of the DHM	Study 1				
FILE	3D model of DHM analysis	Study 1				
FILE	Report/presentation document	Study 1	YES	YES	YES	3
FILE	Spreadsheet analysis	Study 1				

Table K.1. Outputs in Study 2. (*Continued and end*)

Classification	**Outputs**	**Category found in**	**S2_Case1**	**S2_Case2**	**S2_Case3**	**Frequency**
FILE	CAD model of modified or new built-up/ equipment for suppliers (solution)	Study 1				
FILE	3D model equipment	Study 1				
FILE	3D model build-up	Study 1				
FILE	3D model human	Study 1				
FILE	Animation	Study 1				
WAY	Presentation with discussion	Study 1	YES	YES	YES	3
WAY	Live DHM presentation	Study 1				
SEI	Repetition information	Study 2		YES (in report)		1
SEI	KIM indicator evaluation	Study 2	YES (in report)			1

APPENDIX L TABLE OF *DEMAND* IN STUDY 1

Table L.1. Demand in Study 1.

Characteristic	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Actor that made the request	2c_health and safety manager	2a_high level direction	Job expectations from 2_CLIENT IN GRAL	2a_high level direction (plant manager) 2i_maintenance manager 2j_production manager	2d_project manager
Goal of client with intervention	•Get visualization and analysis of a task to help conceptualization based in use for a new design.	•Anticipate risks in early stages of equipment design. •Save money from later changes and risks. •Save money paid to insurance company.	•Anticipate risks in early stages of equipment design. •Save money from later changes and risks. •Meet the legal requirements for factory OSH.	•Meet the legal requirements for factory OSH. •Make a maintenance task.	•Get new design adapted to disabled people (to get publicity and reach a new sector in the market)
Demand initially expressed by client	• Visualize and assess a task to see if it is possible. • Visualize different postures for the same task. • Use DHM.	•Detect risk and impossibilities in manufacturing operations before production. •DHM use is a possibility.	•Detect risk and impossibilities in manufacturing operations before production. •Use DHM if deeper analysis is required.	•Visualize a task to see if it is possible.	•Design product or part of it to fit a human.
Demand specified by ergonomist	•Visualize and assess 90 configurations (based on variations of posture, humans and other) of the same task. •Use DHM.	•Visualize and assess manufacturing operations and propose requirements for new equipment. •Use DHM.	•Visualize and assess manufacturing operations and propose requirements for new equipment or build-up. •Use DHM.	•Visualize and assess a task. •Use DHM.	•Design equipment or part of it to fit a human. •Give and visualize different design solutions. •Provide information to evaluate solutions. •Use DHM.
Stage in design process	•Conceptualization. (new product)	•Requirements analysis. (redesign of equipment)	•Solution (design proposal) (new equipment)	•Use (existing equipment)	•Conceptualization (new product) •Redesign (product modification)
Corrective VS preventive goals	•Preventive	•Preventive	•Preventive	•Corrective	•Preventive

APPENDIX M TABLE OF *DURATION* IN STUDY 1

Table M.1. Duration in Study 1.

Activity	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Whole intervention (from first request of client to delivery of results by ergonomist)	3 weeks - 1 month	2- 3 weeks	2 - 3 days	1 week Ergonomist work: few hours	4-6 months Ergonomist work: 4-5 days a week
Generic presentation by ergonomist	YES				
Request of intervention	YES by client with DHM	YES by client maybe with DHM	YES by client maybe with DHM	YES by client ergonomist decides DHM	YES by client ergonomist decides DHM
Signature of NDA by ergonomist	YES	YES Part of agreement between companies			
Proposal elaboration by ergonomist and client	YES	YES Define hours of predefined budget			YES Define budget and outputs
	1 week				
Proposal signature by ergonomist and client	YES				
Ask for information and files to client (and/or suppliers) by ergonomist	YES	YES	YES		
Waiting for information and files from client (and/or suppliers)		YES			YES
					Sometimes 1month
Get information and files ergonomist from client (and/or suppliers)	YES	YES	YES	YES	YES
	3 days				
Get information and files by ergonomist on his own	YES	YES Make 3D model of equipment	NO	YES Make 3D model of equipment)	YES
Make the DHM analysis / Prepare snapshots/presentation/report by ergonomist	YES	YES	YES	YES	YES
	2 weeks				1 week (core time)

Table M.1. Duration in Study 1. (*Continued and end*)

Activity	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5
Check that the path is good ergonomist with client	YES	YES	YES		
Arrange meeting/Send invitation for presentation of analysis		YES	YES		
Send snapshots of the DHM			YES	YES	YES
Give presentation/report and discussion by ergonomist and client (and suppliers)	YES	YES	YES	YES	YES Selection of solutions
	1 day		40-45 minutes		
Request of further analysis by client	YES	NO	NO	NO	
Modification of proposal by ergonomist	YES	NO	NO	NO	
Make extra analysis by ergonomist	YES	NO	NO	NO	
Deliver extra analysis by ergonomist	YES	NO	NO	NO	
Paying by client to ergonomist	YES		NO	NO	
Follow up by ergonomist	YES	NO	YES		YES

APPENDIX N OBSTACLES IN STUDY 1, STUDY 1A AND STUDY 2

Table N.1. Obstacles in Study 1, Study 1a and Study 2.

Number	All obstacles	Study where category was found	Classification	Influence of the process in it	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Study1	Participant 1	Participant 2	Participant 3	Participant 4	Study1a	S2_Case1	S2_Case2	S2_Case3	Study2
1	Lack of actors collaboration with the DHM intervention	Study1	Client	Indirect		YES				1	YES		YES		2				
2	Lack of coordination of actors	Study1	Client	Indirect		YES			YES	2	YES				1				
3	Lack of managers support for the DHM intervention	Study1	Client	Indirect				YES		1			YES		1				
4	Designer not being the decision maker causes decision making to be longer and more complex	Study1	Client	Indirect			YES			1							YES		
5	The client is not ready for a Virtual Ergonomics intervention (they are too early in the conceptual phase of design)	Study1a	Client	indirect							YES				1				
6	Clients don't want to get involved in deep or complicated analysis	Study1a	Client	Indirect							YES		YES		2				
7	Clients might suggest postures that are not the most likely ones	Study1a	Client	Indirect								YES			1				
8	Different languages of actors	Study1	Context	Indirect			YES			1		YES			1			YES	1
9	Holidays at the same time of the intervention make it so that it takes longer	Study1	Context	**None**	YES					1									
10	Ergonomist resistance to DHM	Study1a	Context	**None**									YES		1				
11	Posture subjectivity	Study1a	Context	Indirect								YES			1		YES		1
12	In new designs there is constant change to keep up to date and there is a lot of communication back and forth	Study1a	Context	Indirect							YES				1				
13	DHM software doesn't allow to simplify data display for presentation	Study1	DHM tool	Indirect			YES			1									
14	Specific DHM software doesn't allow to do certain biomechanical calculations	Study1	DHM tool	**None**			YES			1									
15	Human model lacking of the real human physical characteristics	Study1a	DHM tool	**None**							YES	YES			2				
16	Lack of certain ergonomic analysis tools in the DHM software	Study1a	DHM tool	**None**							YES				1				
17	Bugs of the DHM software	Study1a	DHM tool	**None**							YES				1				
18	DHM is slower and less visually attractive than people's expectations of it	Study1a	DHM tool	**None**								YES			1				

Table N.1. Obstacles in Study 1, Study 1a and Study 2. (*Continued*)

Number	All obstacles	Study where category was found	Classification	Influence of the process in it	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Study1	Participant 1	Participant 2	Participant 3	Participant 4	Study1a	S2_Case1	S2_Case2	S2_Case3	Study2
19	Client doesn't express clearly what he wants (request)	Study1	Input	Indirect	YES					1	YES				1		YES	YES	2
20	Difficulties to know exactly where to position the models in the virtual environment	Study1	Input	Indirect	YES					1	YES				1				
21	Receive too little information from client	Study1	Input	Indirect		YES				1							YES	YES	2
22	Impossibility or difficulties to get the D models from client or supplier	Study1	Input	Indirect	YES	YES		YES		3							YES		1
23	Longtime waiting for information, decisions or availability of the client	Study1	Input	Indirect					YES	1									
24	Find a time when many actors are free to participate in a meeting delays the meeting	Study1a	Strategy	Indirect								YES		YES	2				
25	Many tasks or configurations make a long report	Study1a	Strategy	**None**							YES				1				
26	Ergonomist decisions are not justified	Study1a	Strategy	Direct								YES			1				
27	Making the proposal is not efficient	Study1a	Strategy	Direct							YES				1				
28	It takes time to make the proposal	Study1a	Strategy	Direct							YES				1				
29	Ergonomist need to change and position manikins of different sizes during a live DHM presentation	Study1a	Strategy	Direct								YES			1				
30	Difficult to differentiate the different sizes of human models	Study1a	Strategy	Direct							YES				1				
31	Slowness of presentation making people focus in the non important	Study1a	Strategy	Direct								YES			1				
32	Human model lacking of the real human physical characteristics COMBINED someone using the DHM who doesn't explore what would happen in reality PRODUCES a DHM analysis that doesn't represent reality MIGHT LEAD to take the wrong decisions	Study1a	Strategy	Direct								YES			1				
33	Ergonomist doesn't have access to a DHM software	Study1	Tools	**None**				YES		1			YES		1				
34	Not having the required human model	Study1	Tools	Direct	YES					1									
35	Difficulties in the transfer and or importation of 3D models	Study1a	Tools	Indirect							YES	YES			2				
36	Ergonomist computer not having the capabilities to run the DHM model software quickly	Study1a	Tools	**None**							YES				1				

Table N.1. Obstacles in Study 1, Study 1a and Study 2. (*Continued and end*)

Number	All obstacles	Study where category was found	Classification	Influence of the process in it	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Study1	Participant 1	Participant 2	Participant 3	Participant 4	Study1a	S2_Case1	S2_Case2	S2_Case3	Study2
37	Companies don't have DHM software	Study1a	Tools	**None**									YES		1				
38	Companies don't have CAD software	Study1a	Tools	**None**									YES		1				
39	Client and ergonomists not having the same tools to communicate	Study1a	Tools	Indirect							YES				1				
40	The DHM software being used might make some analysis longer than other software	Study2	DHM Tool	None												YES			1
41	DHM software not having anthropometric data of the target population	Study2	DHM Tool	Indirect														YES	1

APPENDIX O FACILITATORS IN STUDY 1, STUDY 1A AND STUDY 2

Table O.1. Facilitators in Study 1, Study 1a and Study 2.

Number	All facilitators	Study where category was found	Classification	Influence of the process in it	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Study1	Participant 1	Participant 2	Participant 3	Participant 4	Study1a	S2_Case1	S2_Case2	S2_Case3	Study2
1	Experimented ergonomist who makes an evaluation just by looking at the work situation	*Study1a*	Strategy	None								YES			1				
2	Contact in the client who helps the ergonomist when he is remotely	*Study1*	Client	Indirect		YES				1									
3	Contact in the client who understands ergonomics and 3D	*Study1*	Client	None		YES				1									
4	Good work relationship with an actor	*Study1*	Client	None		YES with ergo	YES			2	YES				1				
5	Support of actors	*Study1*	Client	Indirect			YES			1									
6	Support of management	*Study1*	Client	Indirect		YES				1									
7	Actors that have experience working with ergonomists	*Study1a*	Client	None								YES			1				
8	Certain power of decision of engineers without escalating to managers	*Study1a*	Client	None								YES			1				
9	Contact in the client who is up to date and knows almost everything about project	*Study1*	Client	Indirect					YES	1									
10	Designer open to discussion about design	*Study1*	Client	None			YES			1									
11	Stability of the team of stakeholders	*Study1*	Client	Indirect		YES once reac hed				1									
12	DHM facilitates changes, visualization, iterations, discussion of different solutions and trade-offs	*Study1*	DHM Tool	Direct			YES			1	YES				1				
14	ADV_DHM allowing quick visualization of different solutions	*Study1a*	DHM Tool	Direct										YES	1	YES			1
13	Changes in the posture can be easily made	*Study1a*	DHM Tool	Direct							YES				1				

Table O.1. Facilitators in Study 1, Study 1a and Study 2. (*Continued*)

Number	All facilitators	Study where category was found	Classification	Influence of the process in it	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Study1	Participant 1	Participant 2	Participant 3	Participant 4	Study1a	S2_Case1	S2_Case2	S2_Case3	Study2
15	DHM graphic and quantitative analysis facilitates comprehension and avoids disagreement	*Study1a*	DHM Tool	Direct							YES				1				
16	To have many ergonomics tools combined in the DHM software	*Study1a*	DHM Tool	None							YES				1				
17	Use of catalogs	*Study1a*	DHM Tool	Direct							YES				1				
18	Ergonomist obtains information by himself	*Study1*	Inputs	Direct	YES	YES		YES		3							YES		1
19	Getting pictures from the client with environment configuration and posture	*Study1*	Inputs	Indirect	YES					1	YES				1	YES			1
21	To have all the information necessary for the analysis	*Study1*	Inputs	Indirect			YES			1	YES				1				
22	Well established proposal	*Study1*	Inputs	Indirect	YES					1	YES				1				
24	General view or list of the assembly line workstations or tasks that might include the risks and the methods of analysis	*Study1*	Inputs	Indirect		YES				1							YES		1
20	To have a video of the human doing the task	*Study1a*	Inputs	Indirect							YES				1	YES			1
23	In some situations a very simple model of the virtual environment is enough to make a DHM analysis	*Study1a*	Inputs	Direct									YES		1				
25	Format of the models	*Study1a*	Inputs	Indirect							YES				1				
26	Changes proposed not having considerable cost and time implications	*Study1*	Strategy	Indirect			YES			1									
27	Give results the soonest possible and the earliest possible in the design process	*Study1*	Strategy	Direct			YES			1		YES			1				
31	Live DHM presentation to facilitate discussion and exploration of options	*Study1*	Strategy	Direct			YES			1		YES			1				
32	Use different clothing colors to differentiate percentiles in the DHM	*Study1*	Strategy	Direct		YES				1	YES				1				
33	Have manikins prepared for the DHM live presentation	*Study1*	Strategy	Direct			YES			1		YES			1				
35	Ergonomist interest in showing client how DHM can help them	*Study1*	Strategy	Direct				YES		1									

Table O.1. Facilitators in Study 1, Study 1a and Study 2. (*Continued and end*)

Number	All facilitators	Study where category was found	Classification	Influence of the process in it	S1_Case1	S1_Case2	S1_Case3	S1_Case4	S1_Case5	Study1	Participant 1	Participant 2	Participant 3	Participant 4	Study1a	S2_Case1	S2_Case2	S2_Case3	Study2
28	DHM still images allow to leave a trace and proof of ergonomic assessment	*Study1a*	Strategy	Direct								YES	YES		2				
29	Ergonomist using the DHM to provide information to facilitate decision making rather than imposing decisions is more persuasive	*Study1a*	Strategy	Direct								YES			1				
30	Meetings where there is visual information	*Study1a*	Strategy	Direct								YES			1			YES	1
34	Ergonomist persuades another actor that a posture is very unlikely without repositioning the manikin	*Study1a*	Strategy	Direct								YES			1				
36	Email better that phone for clients not speaking the same language as ergonomists	*Study1*	Strategy/Communication	Direct			YES			1		YES			1				
37	Email being the fastest way to communicate because there is no need to find a common time for a phone call	*Study1a*	Strategy/Communication	Direct								YES			1				
38	Ergonomist having access to DHM software (or 3D software)	*Study1*	Tools	None				YES		1									

APPENDIX P RESULTS OF MEMBER CHECKING

S1_Case1 (participant 1)

Collector:	Web Link 1 (Web Link)
Started:	Wednesday, April 17, 2019 2:33:40 PM
Last Modified:	Thursday, April 18, 2019 12:32:11 PM
Time Spent:	21:58:31
IP Address:	83.145.101.131

Page 1: CAS 1. Siège de bébé

Q1

Veuillez classer les activités suivantes selon la séquence qu'elles ont eu lors de l'intervention CAS 1. Siège de bébé. Si vous considérez une activité non présente dans l'intervention, cochez la case Non présent.

Présentation générique (par l'ergonome)	1
Demande d'intervention (par client)	2
Signature du NDA (par un ergonome)	3
Élaboration de contrat (par l'ergonome et le client)	4
Signature de contrat (par l'ergonome et le client)	5
Demander des informations et des fichiers (au client et / ou aux fournisseurs par l'ergonome)	7
En attente d'informations et de fichiers (du client et / ou des fournisseurs)	9
Réunions *	6
Obtenir des informations et des fichiers (ergonome du client et / ou des fournisseurs)	8

Obtenir des informations et des fichiers (ergonome par lui-même)	10
Analyser avec DHM / créer prises d'écran, présentation ou rapport (par un ergonome)	11
Vérifier que le chemin est bon (ergonome avec client)	12
Organiser une réunion / envoyer une invitation pour la présentation	14
Envoyer des captures d'écran (par un ergonome au client)	13
Donner présentation avec discussion (par l'ergonome et le client et / ou les fournisseurs)	15
Demande d'analyse supplémentaire (par client)	16
Modification de contrat (par ergonome)	17
Faire l'analyse supplémentaire (par ergonome)	18
Fournir l'analyse supplémentaire (par un ergonome)	19
Payer (par le client à l'ergonome)	20
Suivi (par l'ergonome)	21

Q2

Quelles autres activités non mentionnées dans la question précédente faisaient partie de l'intervention? (veuillez spécifier chaque activité supplémentaire dans une ligne différente)

je crois que tout est là

Q3

Combien de tâches de travail (de l'usager) vous avez analysées lors de cette consultation?

Nombre de tâches	16

Q4

Les modèles 3D des bébés, vous les avez obtenus

des techniciens CAD du client

Q5

Le modèle 3D de siège de bébé, vous l'avez obtenu

des techniciens CAD du client

Autre (veuillez préciser):
Automobile dans GrabCad

S1_Case2 (participant 1)

Page 2: CAS 2 Micro-projet de la plateforme

Q6

Veuillez classer les activités suivantes selon la séquence qu'elles ont eu lors de l'intervention CAS 2. Micro-projet de la plateforme. Si vous considérez une activité non présente dans l'intervention, cochez la case Non présent.

Présentation générique (par l'ergonome)	Non présent
Demande d'intervention (par client)	1
Signature du NDA (par un ergonome)	Non présent
Élaboration de contrat (par l'ergonome et le client)	Non présent
Signature de contrat (par l'ergonome et le client)	Non présent
Demander des informations et des fichiers (au client et / ou aux fournisseurs par l'ergonome)	2
En attente d'informations et de fichiers (du client et / ou des fournisseurs)	3
Réunions *	4
Obtenir des informations et des fichiers (ergonome du client et / ou des fournisseurs)	5
Obtenir des informations et des fichiers (ergonome par lui-même)	6
Analyser avec DHM / créer prises d'écran, présentation ou rapport (par un ergonome)	7
Vérifier que le chemin est bon (ergonome avec client)	8
Organiser une réunion / envoyer une invitation pour la présentation	9
Envoyer des captures d'écran (par un ergonome au client)	10
Donner présentation avec discussion (par l'ergonome et le client et / ou les fournisseurs)	11
Demande d'analyse supplémentaire (par client)	Non présent
Modification de contrat (par ergonome)	Non présent
Faire l'analyse supplémentaire (par ergonome)	Non présent
Fournir l'analyse supplémentaire (par un ergonome)	Non présent
Payer (par le client à l'ergonome)	Non présent
Suivi (par l'ergonome)	Non présent

Q7

Quelles autres activités non mentionnées dans la question précédente faisaient partie de l'intervention? (veuillez spécifier chaque activité supplémentaire dans une ligne différente)

N/A

Q8

Combien de tâches de travail (de l'usager) vous avez analysées lors de cette consultation?

Nombre de tâches	7

Q9

En considérant le projet de la plateforme que vous avez dit qui a duré 2 ou 3 semaines, diriez-vous qu'il y a eu des réunions qui ont eu lieu pendant ce micro-projet? Combien et quel était leur objectif?

Respondent skipped this question

Q10

Veuillez fournir les informations personnelles suivantes

Années d'expérience en tant qu'ergonome	26
Années d'expérience en tant que consultant	6.5
Années d'expérience avec DHM	24

S1_Case4 (participant 3)

Collector:	Web Link 1 (Web Link)
Started:	Monday, April 15, 2019 10:05:00 AM
Last Modified:	Monday, April 15, 2019 10:15:48 AM
Time Spent:	00:10:48
IP Address:	107.77.237.95

Page 1: CASE Maintenance task into press

Q1

Please order the following activities according to the sequence they had in the CASE Maintenance task into press. If you consider an activity not present in the intervention select the checkbox Not present.

Generic presentation (by ergonomist)	Not present
Request of intervention (by client)	1
Signature of NDA (by ergonomist)	Not present
Contract elaboration (by ergonomist and client)	Not present
Contract signature (by ergonomist and client)	Not present
Ask for information and files (to client and/or suppliers by ergonomist)	Not present
Waiting for information and files (from client and/or suppliers)	Not present
Meetings*	Not present
Get information and files (ergonomist from client and/or suppliers)	Not present
Get information and files (by ergonomist on his own)	2
DHM analysis / snapshots, presentation or report (by ergonomist)	3
Check that the path is good (ergonomist with client)	4
Arrange meeting/Send invitation for presentation	Not present
Send screenshots (by ergonomist to client)	5
Give presentation and discussion (by ergonomist and client and/or suppliers)	6
Request of further analysis (by client)	Not present
Modification of contract (by ergonomist)	Not present
Make extra analysis (by ergonomist)	Not present
Deliver extra analysis (by ergonomist)	Not present
Paying (by client to ergonomist)	7
Follow up (by ergonomist)	Not present

Q2

What other activities not mentioned in the previous question were part of the intervention? (please specify every additional activity in a different line)

Respondent skipped this question

Q3

Approximately how many worker tasks you analyzed in this consultation?

Number of tasks	1

Q4

The dimensions of the press to built the model you got them

By measuring it directly by yourself

Q5

The DHM analysis that you made

You showed it personally to your client

You sent it by email as snapshots to your client

Other (please specify):
Trained workforce

Q6

Please, provide the following personal information

Respondent skipped this question

Q7

Please add any comments that you have

This project used a human model (Ergo-Link) to show conditions under which a die plug (interlocked safety device that prevents ram motion) is required to be inserted into the press.

S1_Case5 (participant 4)

Collector:	Web Link 1 (Web Link)
Started:	Monday, May 06, 2019 4:05:06 PM
Last Modified:	Monday, May 06, 2019 4:13:34 PM
Time Spent:	00:08:28
IP Address:	79.66.247.202

Page 1: CASE Rally car adaptation

Q1

Please order the following activities according to the sequence they had in the CASE Rally car adaptation intervention. If you consider an activity not present in the intervention select the checkbox Not present.

Generic presentation (by ergonomist)	2
Request of intervention (by client)	3
Signature of NDA (by ergonomist)	6
Contract elaboration (by ergonomist and client)	4
Contract signature (by ergonomist and client)	5
Ask for information and files (to client and/or suppliers by ergonomist)	7
Waiting for information and files (from client and/or suppliers)	9
Meetings*	1
Get information and files (ergonomist from client and/or suppliers)	10
Get information and files (by ergonomist on his own)	8
DHM analysis / snapshots, presentation or report (by ergonomist)	12
Check that the path is good (ergonomist with client)	11
Arrange meeting/Send invitation for presentation	14
Send screenshots (by ergonomist to client)	13
Give presentation and discussion (by ergonomist and client and/or suppliers)	15
Request of further analysis (by client)	Not present
Modification of contract (by ergonomist)	Not present
Make extra analysis (by ergonomist)	Not present
Deliver extra analysis (by ergonomist)	Not present
Paying (by client to ergonomist)	17
Follow up (by ergonomist)	16

Q2

What other activities not mentioned in the previous question were part of the intervention? (please specify every additional activity in a different line)

There were many informal/unarranged short catchup discussions over a cup of coffee during a regular recreational activity I shared with the client (motorsport). For others, this could be the golf club meeting, or the sunday football match etc.

Q3

Approximately how many worker (user) tasks you analyzed in this consultation?

Number of tasks	4

Q4

The 3D model of the car that you used in the DHM

you built it by yourself

How and from who you got the model or the information to build it?:
actual in-vehicle measurements with H mannequin

Q5

Can you enumerate all the information and files that you needed during the consultation? How and from who you got each of them?

about a dozen. Very thin files though...

Q6

Please, provide the following personal information

Years of experience as ergonomist	15
Years of experience in DHM	14
Years of experience as consultant	11

Q7

Please add any comments you have

It's been a long time since, so I might be missing some fine detail.

APPENDIX Q VALIDATION OF THE NEW PROCESS WITH PARTICIPANTS

Participant 1

Collector:	Web Link 1 (Web Link)
Started:	Wednesday, April 17, 2019 2:14:41 PM
Last Modified:	Wednesday, April 17, 2019 2:33:12 PM
Time Spent:	00:18:31
IP Address:	83.145.101.131

Page 1

Q1

Select the activities that you think are NOT important in a process of Digital Human Modeling ergonomic intervention that takes place remotely through an online application. For the important activities change the sequence if you think the proposed sequence is not ideal.

Understanding of service (by client in the website)	1
Request of intervention (by client in the website)	2
Send information, files and NDA (by client in the website)	4
Read and modify auto-generated contract (by client in the website)	3
Signature of NDA (by ergonomist in the website)	5
Validation of information and files (by ergonomist in the web site)	6
Sign/Modify contract (by ergonomist in the web site)	7
Send signed documents, confirmation of intervention started and request of completing information and files if necessary (by ergonomist in the website)	8
Signature of contract (by client in the website)	9
Payment (by client in the website)	10
Make DHM analysis / Prepare snapshots, presentation or report /Upload PARTIAL RESULTS to web site (by ergonomist)	11
Check that the partial result is good and make comments (by client in the website)	12
Make DHM analysis / Prepare snapshots, presentation or report /Upload FINAL RESULTS to web site (by ergonomist)	13
Give presentation/report and discussion (by ergonomist and client and or suppliers)+ Request of extra analysis (by client if necessary)+ Contract modification and signature (if extra analysis requested)	14
Make DHM analysis / Prepare snapshots, presentation or report /Upload EXTRA RESULTS to web site (by ergonomist)	15
Feedback to ergonomist (by client in the website)	16

Q2

What other activities not mentioned in the previous question do you think should be part of a remote Digital Human Modeling ergonomic intervention? (please specify every additional activity in a different line)

Data collection. Il se peut que le client ait a fournir des données comme la force, les répétitions, la fréquence, la durée, etc. Je me demande si un genre de mini questionnaire ne devrait être fait à propos des renseignements requis pour que le client sache à quoi s'attendre et pour accélérer le processus d'échange d'information.

Q3

Please add any comment that you have

voir no.2

Collector:	Web Link 1 (Web Link)
Started:	Monday, April 15, 2019 3:10:33 PM
Last Modified:	Monday, April 15, 2019 3:20:47 PM
Time Spent:	00:10:14
IP Address:	107.77.237.183

Participant 3

Page 1

Q1

Select the activities that you think are NOT important in a process of Digital Human Modeling ergonomic intervention that takes place remotely through an online application. For the important activities change the sequence if you think the proposed sequence is not ideal.

Understanding of service (by client in the website)	1
Request of intervention (by client in the website)	2
Send information, files and NDA (by client in the website)	3
Read and modify auto-generated contract (by client in the website)	4
Signature of NDA (by ergonomist in the website)	5
Validation of information and files (by ergonomist in the web site)	6
Sign/Modify contract (by ergonomist in the web site)	7
Send signed documents, confirmation of intervention started and request of completing information and files if necessary (by ergonomist in the website)	8
Signature of contract (by client in the website)	9
Payment (by client in the website)	16
Make DHM analysis / Prepare snapshots, presentation or report /Upload PARTIAL RESULTS to web site (by ergonomist)	10
Check that the partial result is good and make comments (by client in the website)	12
Make DHM analysis / Prepare snapshots, presentation or report /Upload FINAL RESULTS to web site (by ergonomist)	13
Give presentation/report and discussion (by ergonomist and client and or suppliers)+ Request of extra analysis (by client if necessary)+ Contract modification and signature (if extra analysis requested)	14
Make DHM analysis / Prepare snapshots, presentation or report /Upload EXTRA RESULTS to web site (by ergonomist)	15
Feedback to ergonomist (by client in the website)	11

Q2

What other activities not mentioned in the previous question do you think should be part of a remote Digital Human Modeling ergonomic intervention? (please specify every additional activity in a different line)

Include some way to personalize the process with a face-to-face introductory meeting. Skype or something similar would work. The value of the human aspects of business cannot be overstated.

Q3

Please add any comment that you have

My clients don't pay until they have results they like. I don't pay consultants until I have results I like.

Collector:	Web Link 1 (Web Link)
Started:	Monday, May 06, 2019 4:13:42 PM
Last Modified:	Monday, May 06, 2019 4:16:50 PM
Time Spent:	00:03:08
IP Address:	79.66.247.202

Participant 4

Page 1

Q1

Select the activities that you think are NOT important in a process of Digital Human Modeling ergonomic intervention that takes place remotely through an online application. For the important activities change the sequence if you think the proposed sequence is not ideal.

Understanding of service (by client in the website)	1
Request of intervention (by client in the website)	3
Send information, files and NDA (by client in the website)	2
Read and modify auto-generated contract (by client in the website)	5
Signature of NDA (by ergonomist in the website)	6
Validation of information and files (by ergonomist in the web site)	4
Sign/Modify contract (by ergonomist in the web site)	7
Send signed documents, confirmation of intervention started and request of completing information and files if necessary (by ergonomist in the website)	8
Signature of contract (by client in the website)	9
Payment (by client in the website)	15
Make DHM analysis / Prepare snapshots, presentation or report /Upload PARTIAL RESULTS to web site (by ergonomist)	10
Check that the partial result is good and make comments (by client in the website)	11
Make DHM analysis / Prepare snapshots, presentation or report /Upload FINAL RESULTS to web site (by ergonomist)	12
Give presentation/report and discussion (by ergonomist and client and or suppliers)+ Request of extra analysis (by client if necessary)+ Contract modification and signature (if extra analysis requested)	13
Make DHM analysis / Prepare snapshots, presentation or report /Upload EXTRA RESULTS to web site (by ergonomist)	14
Feedback to ergonomist (by client in the website)	16

Q2

What other activities not mentioned in the previous question do you think should be part of a remote Digital Human Modeling ergonomic intervention? (please specify every additional activity in a different line)

Video conferencing/live presentation

Q3

Please add any comment that you have

Respondent skipped this question

APPENDIX R CONTEXTUAL INTERVIEW GUIDE

Accomplishment + Directly in action:

1. What things do you want to **accomplish quickly** that you cannot, what are the **intentions** that you usually **give up** because of the limitations? What would you like to happen more **immediately**?

(Things that could be facilitated by technology)

Connection:

2. What promotes a **good connection and understanding with other** roles or makes it difficult?

Identity:

3. **What aspects of the activity have to do with your identity** or what aspects don't?

Sensation:

4. What do you **love or hate** about this activity? What are sources of pleasure, joy or fun?

The Hassle factor + The Delta:

5. What **annoys** you, takes **too much time** or requires **too much learning**?
6. How could a **new tool** help you?
7. Which **tools** would you **integrate** to facilitate this activity?

APPENDIX S PROTOTYPE 1 IN USER TEST

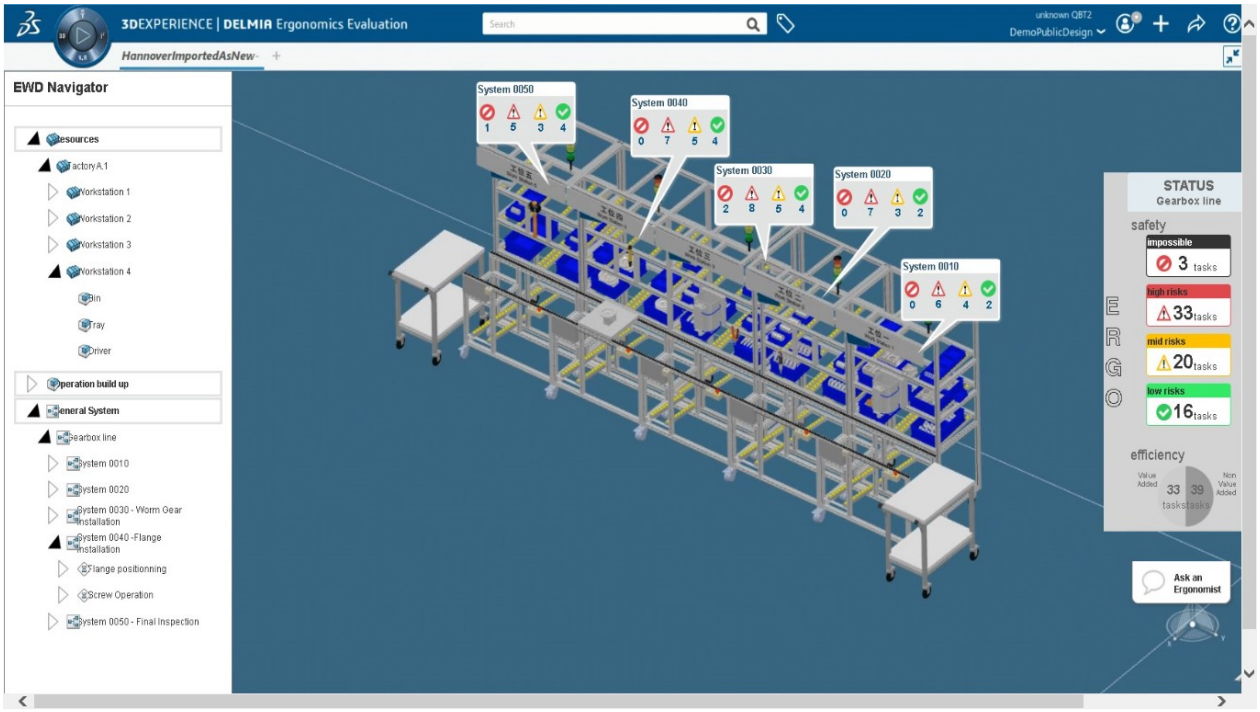


Figure S.1. Button "Ask and ergonomist" in the EWD interface.

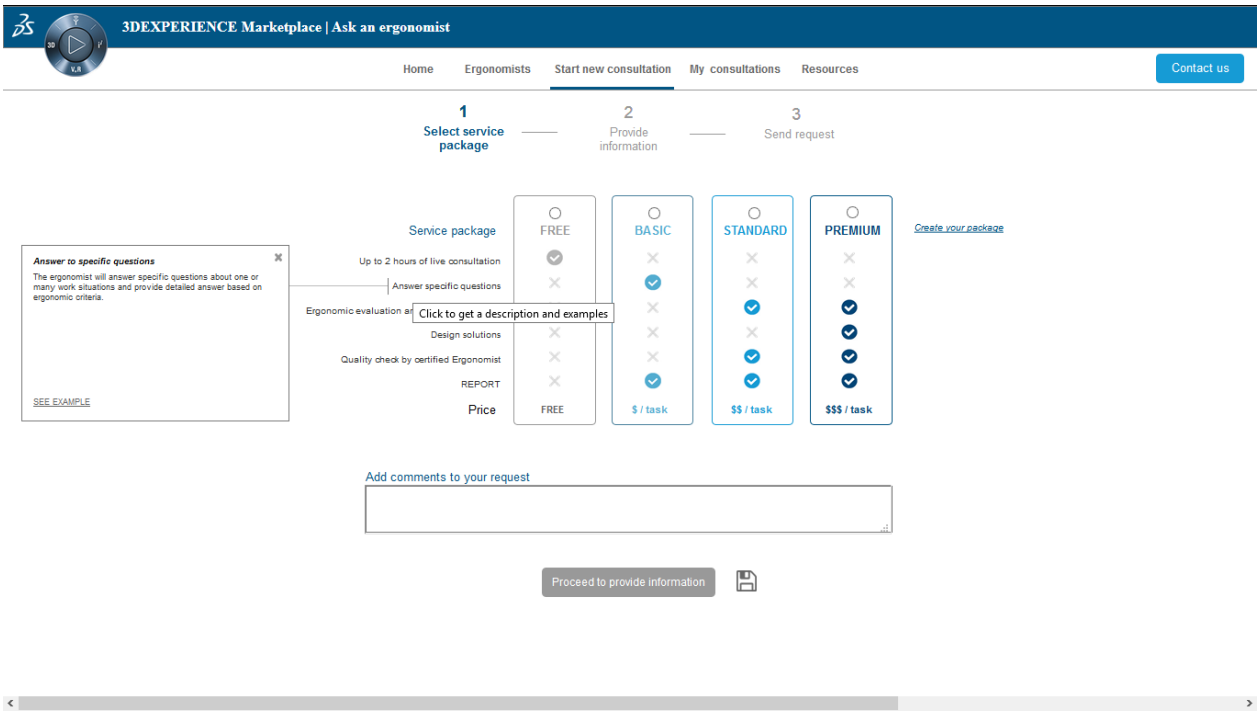


Figure S.2. Page *Select service package* of **Prototype 1** in user test.

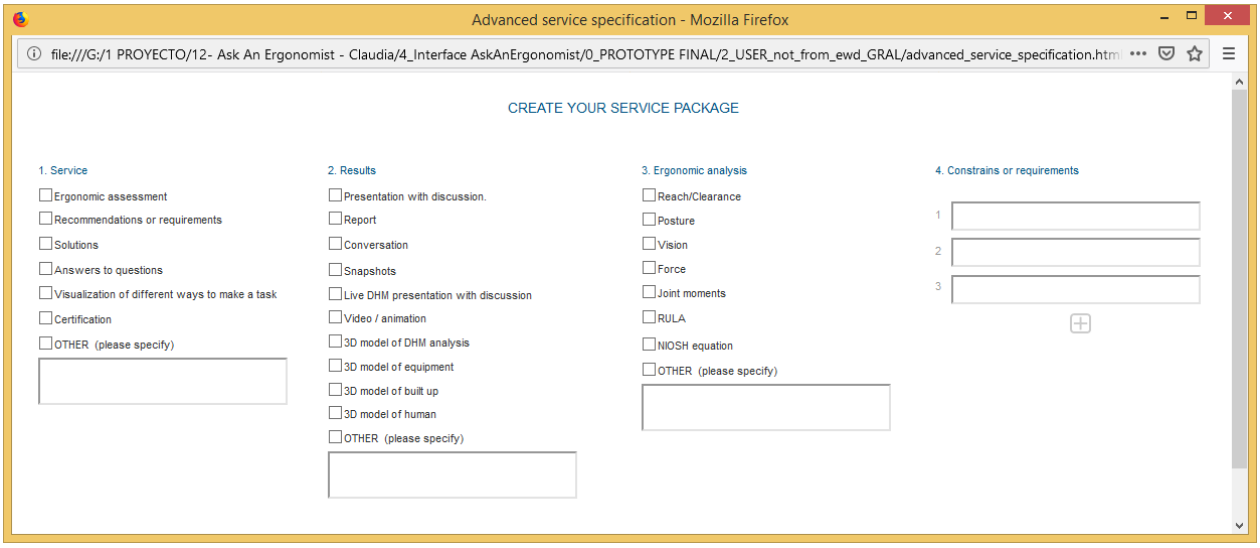


Figure S.3. Page *Create your service package* of **Prototype 1** in user test.

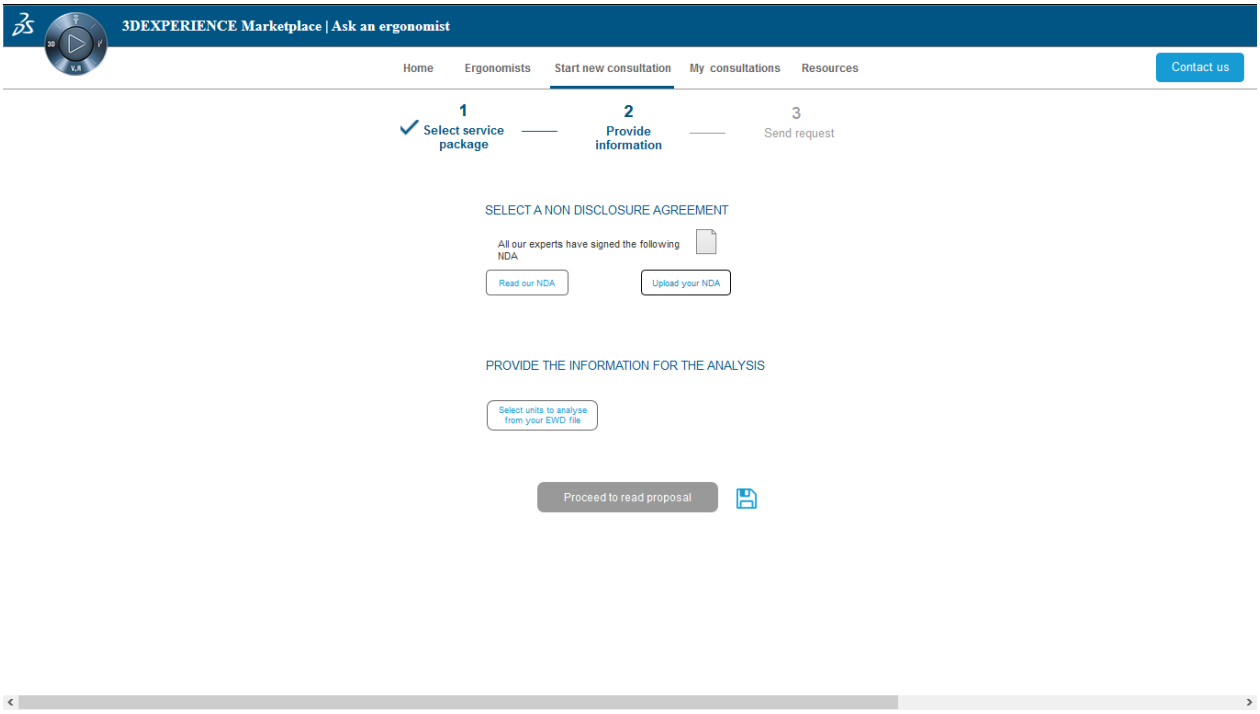


Figure S.4. Page *Provide information* of **Prototype 1** in user test.

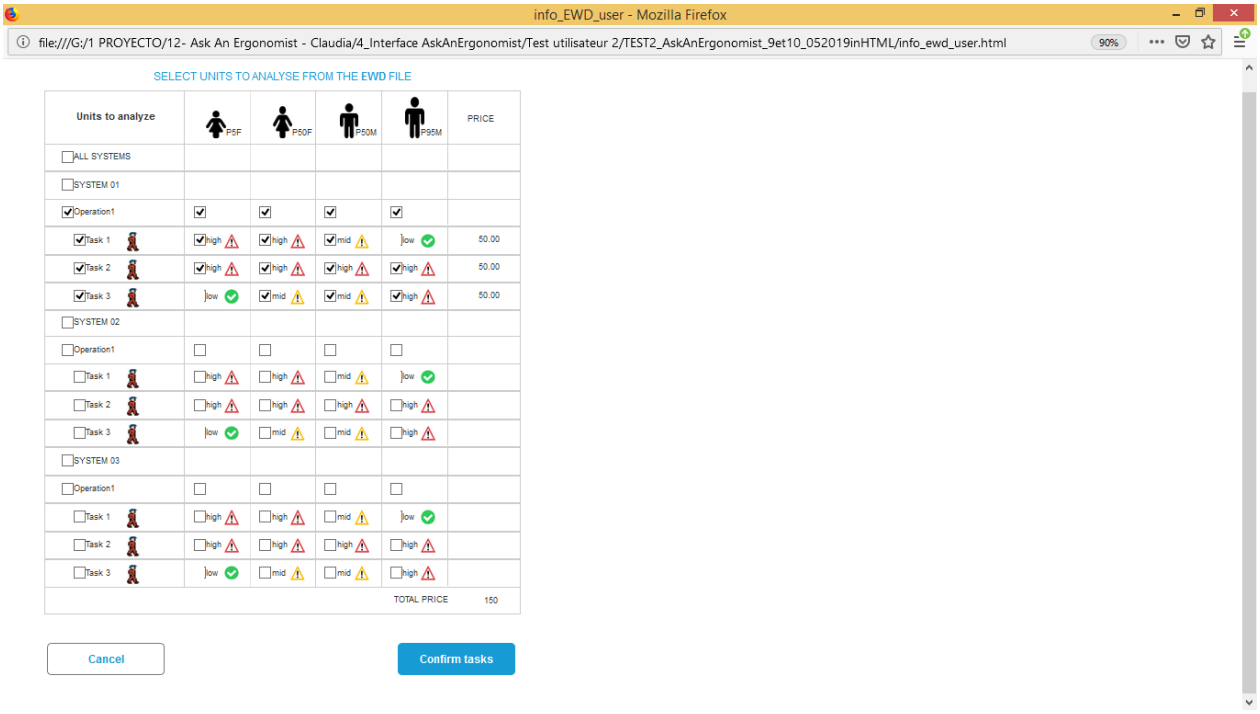


Figure S.5. Page *Select units to analyze* of **Prototype 1** in user test.

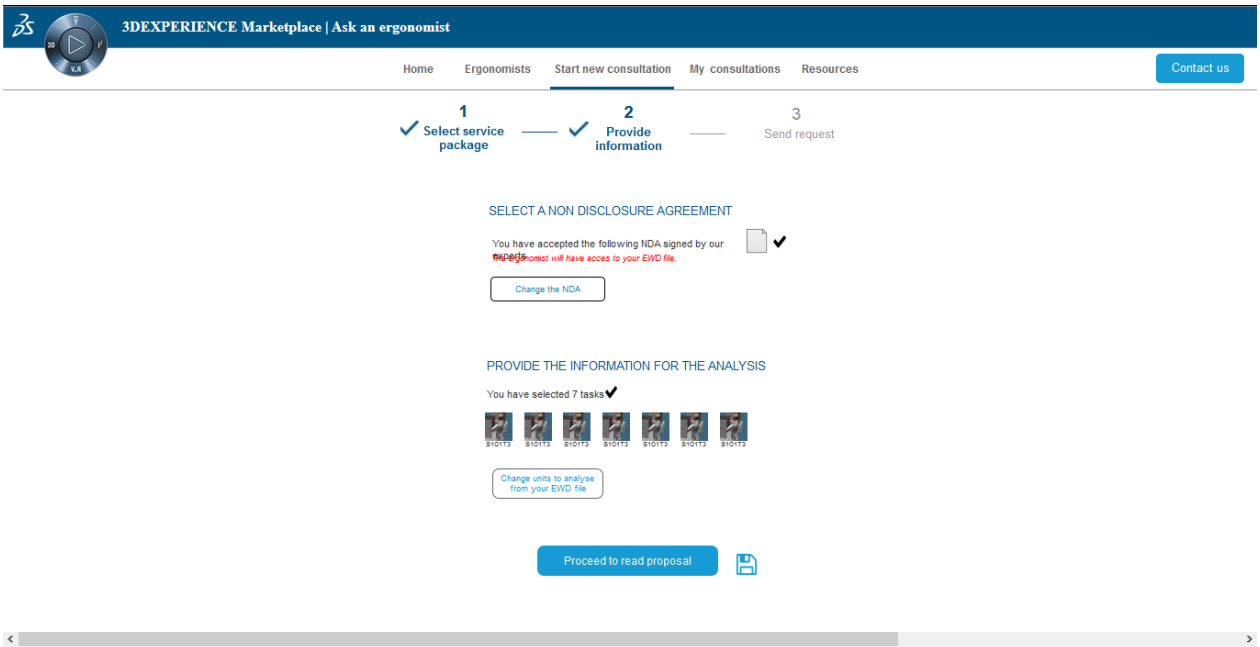


Figure S.6. Page *Provide information (completed)* of **Prototype 1** in user test.

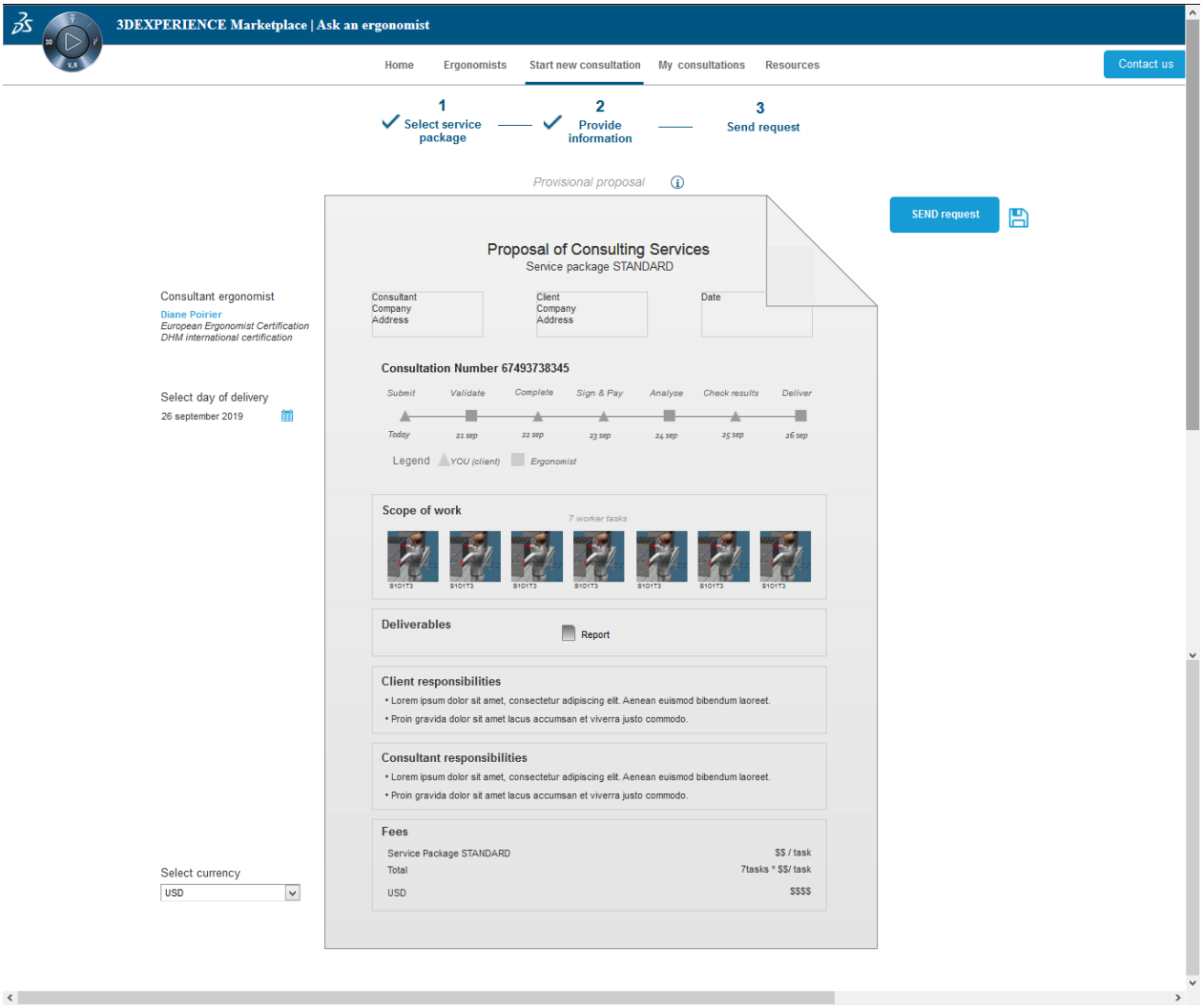


Figure S.7. Page *Proposal* of **Prototype 1** in user test.

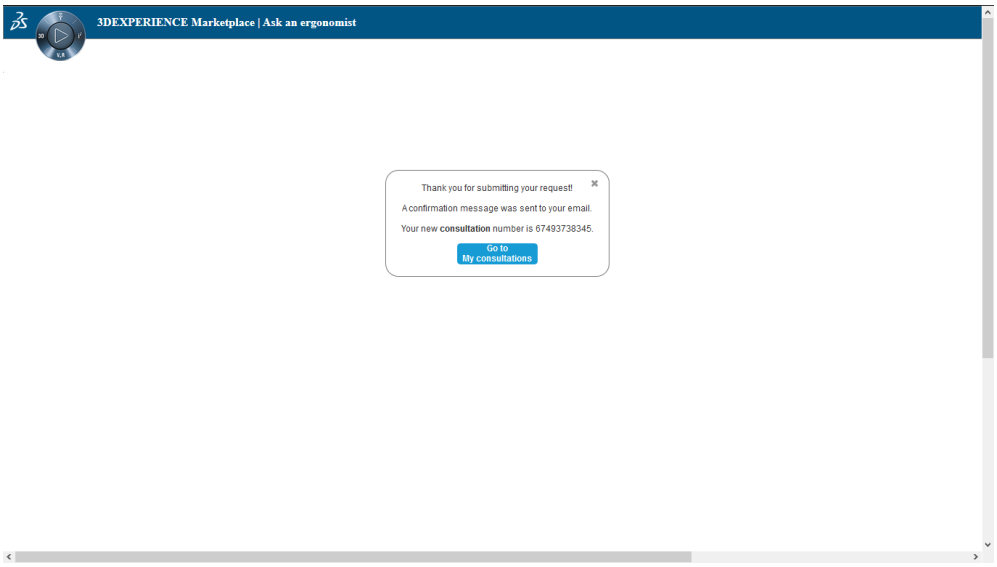


Figure S.8. Submitting confirmation message in **Prototype 1** in user test.

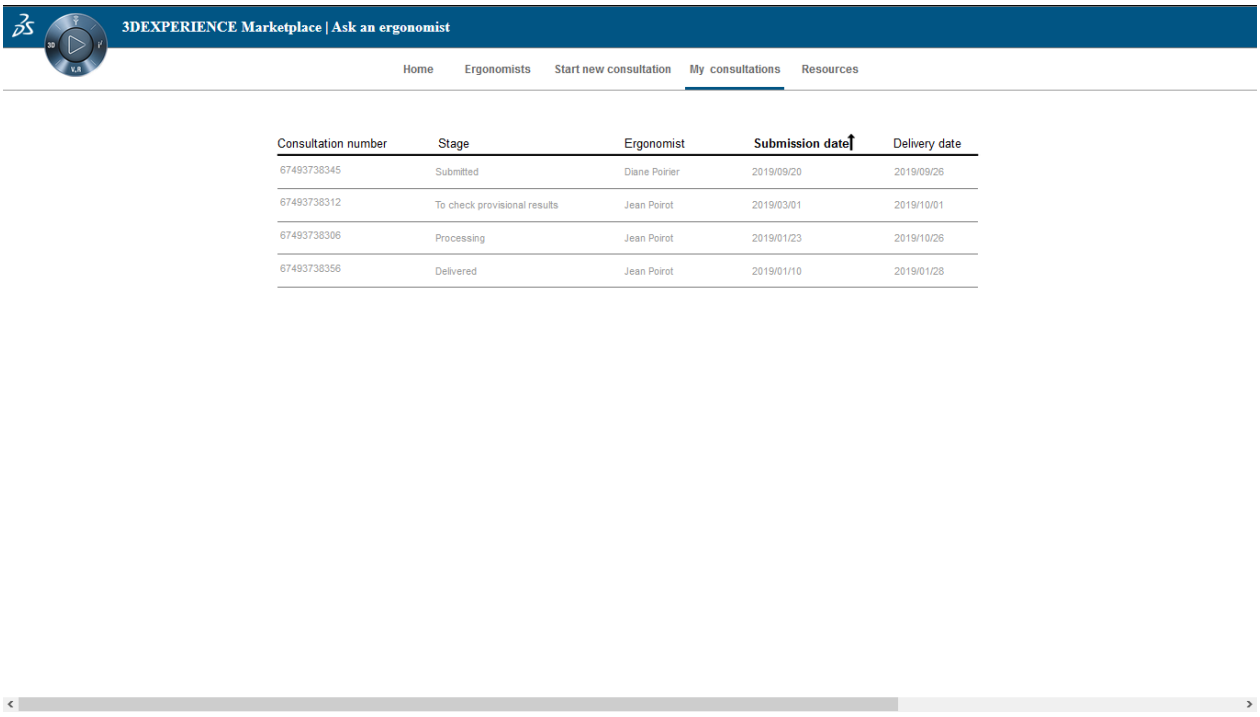


Figure S.9. Page *My consultations* of **Prototype 1** in user test.

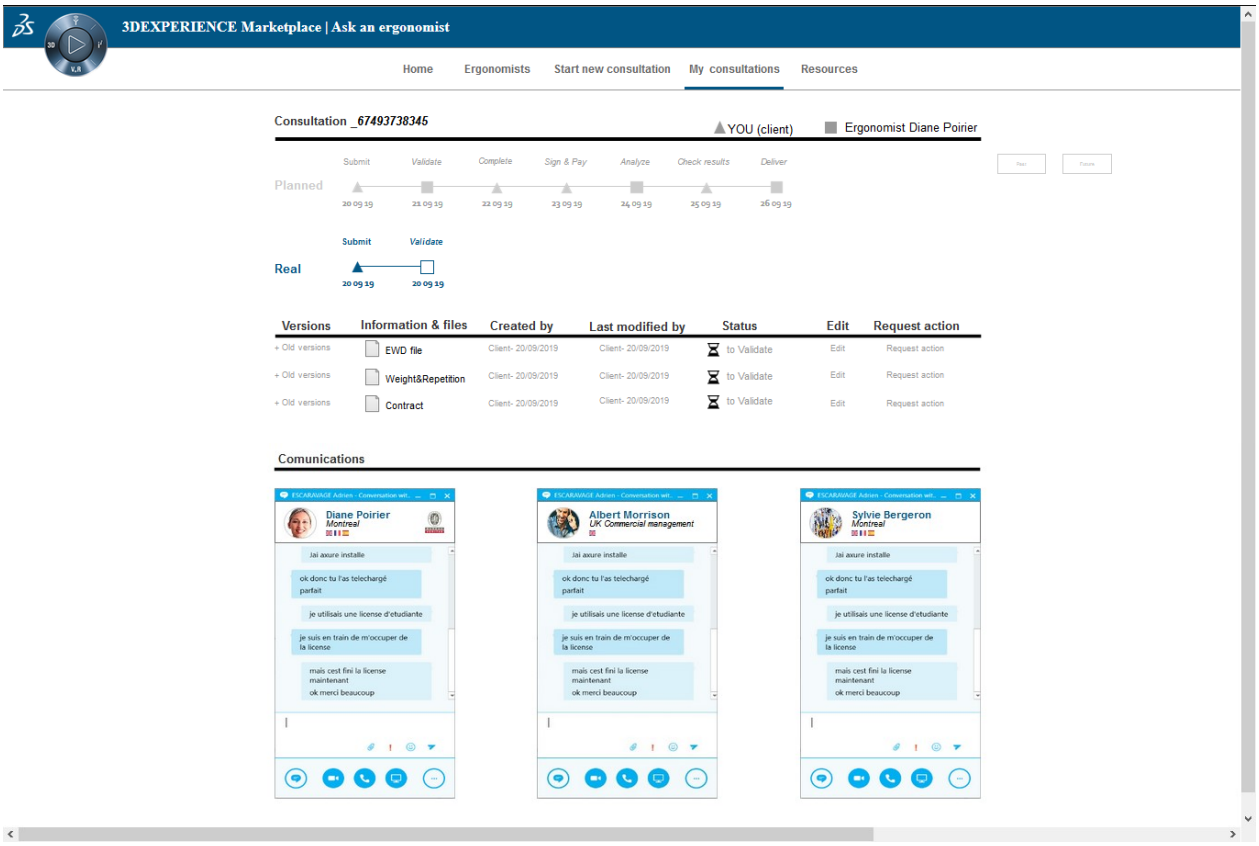


Figure S.10. Page *Consultation* of **Prototype 1** in user test.

APPENDIX T DIRECTIONS FOR USER TEST

You are using EWD and have SYSTEMS (stations), OPERATIONS and TASKS. You know the risk level for all your tasks.

There are seven tasks where you don't know how to reduce the risk.

What you should do is:

Submit a request of consultation to know how to reduce the risk of all tasks in SYSTEM01 and SYSTEM02 and Task 1 in SYTEM03 from high to low.

IF USER DOESN'T FIND WHAT TO DO BY HIMSELF

HINT1: You need to start a consultation

IF USER STILL DOESN'T FIND WHAT TO DO BY HIMSELF

HINT2: You need to follow the 3 steps indicated on top of the page

APPENDIX U NOTES FROM USER TEST

USER 1 Jessica
- Use doesn't know the budget for the ergonomics intervention.
- User tries to click in the check mark instead of clicking in the radio button of the package.
- User doesn't know what EWD is.
- OBSERVER ADVICE: the features on each package are not present in different packages, the features are not a point of comparison, so they should be written for each package, and the information should appear as a property of each package.
- OBSERVER ADVICE: Add indentation for tasks and operations in the selection of tasks.

USER 2 Loren
- Mouse over with information would help to have an idea of packages.
- User said he probably wouldn't be authorized to decide the price to pay. He won't have the decision capability to choose the package and complete the request.
* thought that AskAnErgonomist could have created an ENOVIA task that would have been assigned to someone.
* To put package selection at the end because at the beginning we don't know exactly what we want. In addition, if we enter the data and at the end, we are asked to select a package we would probably buy a bigger package.

USER 3 Axel
- User wants to select the task to analyze before clicking in AskAnErgonomist.
- User didn't click in the button Send request to finish, instead he clicked on Save.
- About the page to select a package "I don't know what options I have"
-Doesn't look at the options inside the packages.

USER 4 Anna
- In the add a comment part at the beginning: "I don't know…is a comment required?"
- User has doubts about what would happened when she selects a delivery date. User said impossible days should be impossible to select.

USER 5 Alexandra
-The more expensive services should include the cheaper services.
- In the task selection user said: "They would just send the machine that has the problem"
- Once submitted the request: "How do I get back to EWD"
-"What if I select dates that are not possible" in the select date option.
-The thumbnail pictures of selected tasks are too small.

APPENDIX V PROTOTYPE 2 (GENERAL USER FROM THE MARKETPLACE)

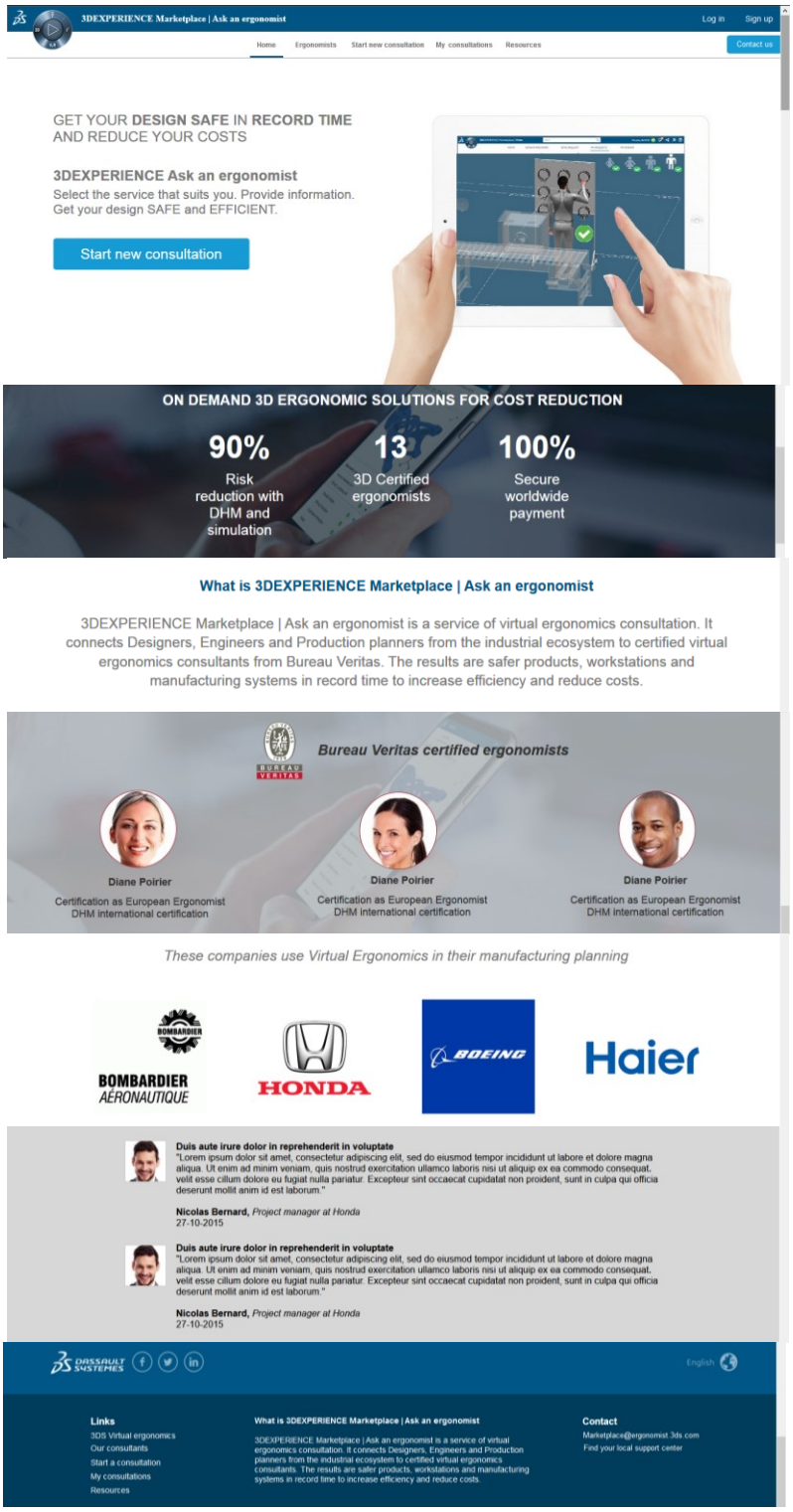


Figure V.1. *Home page* of **Prototype 2**.

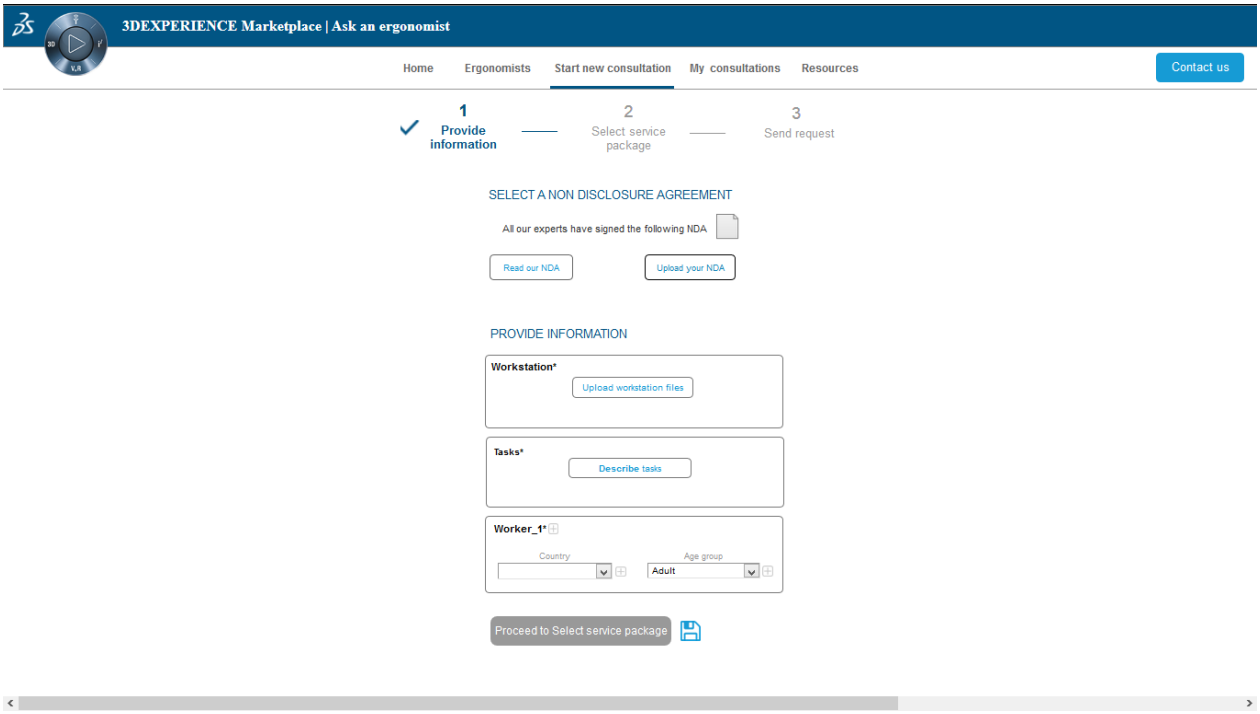


Figure V.2. Page *Provide information* of **Prototype 2**.

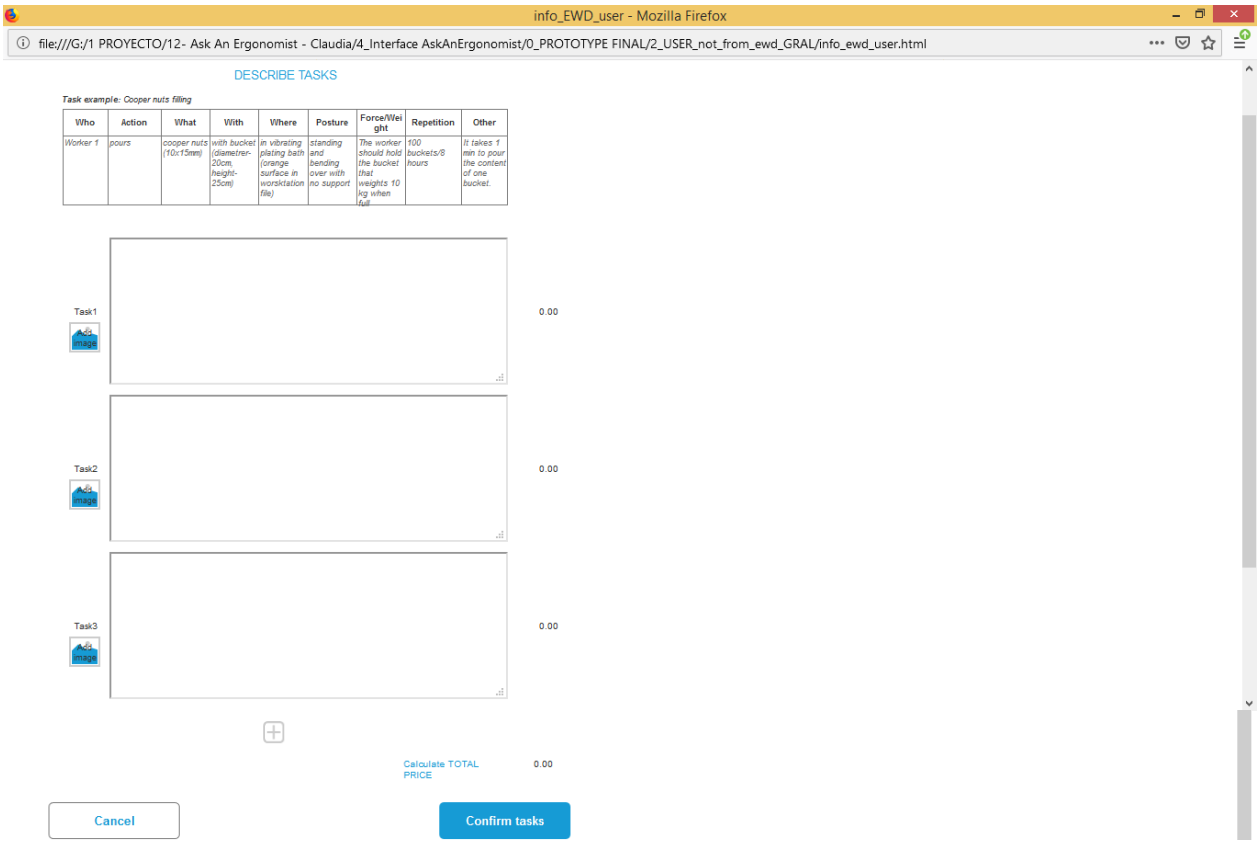


Figure V.3. Page *Describe tasks* of **Prototype 2**.

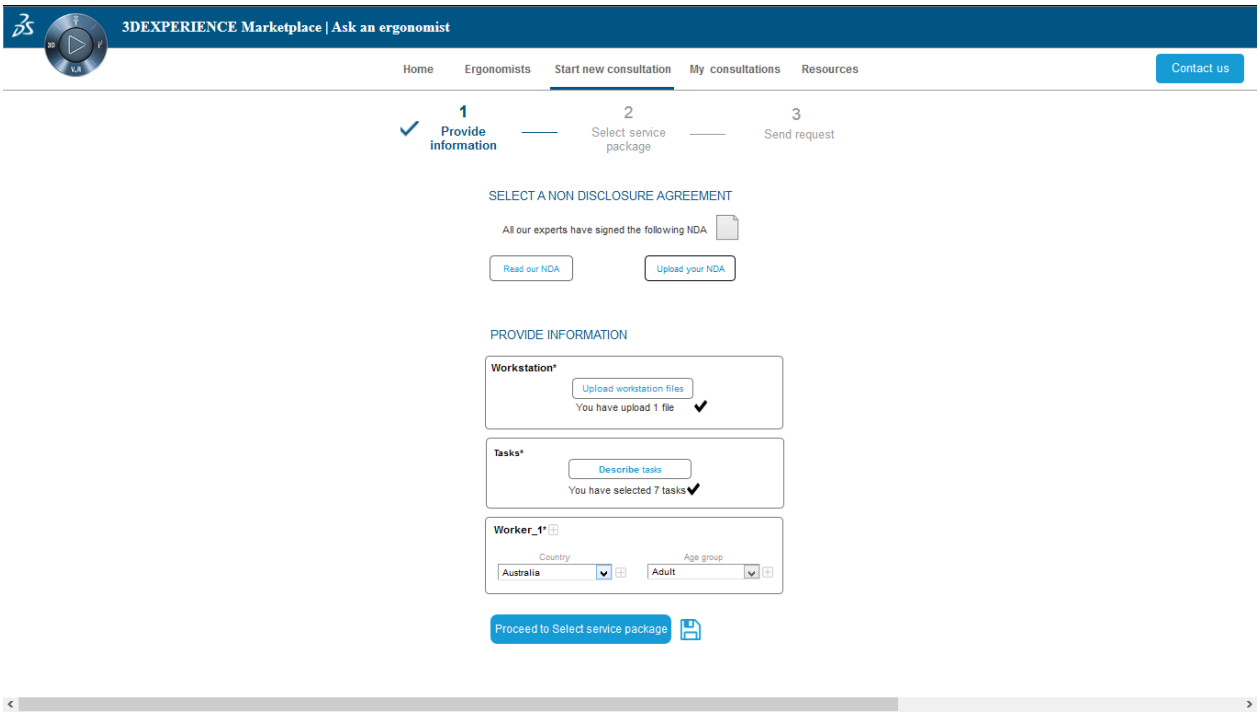


Figure V.4. Page *Provide information (completed)* of **Prototype 2**.

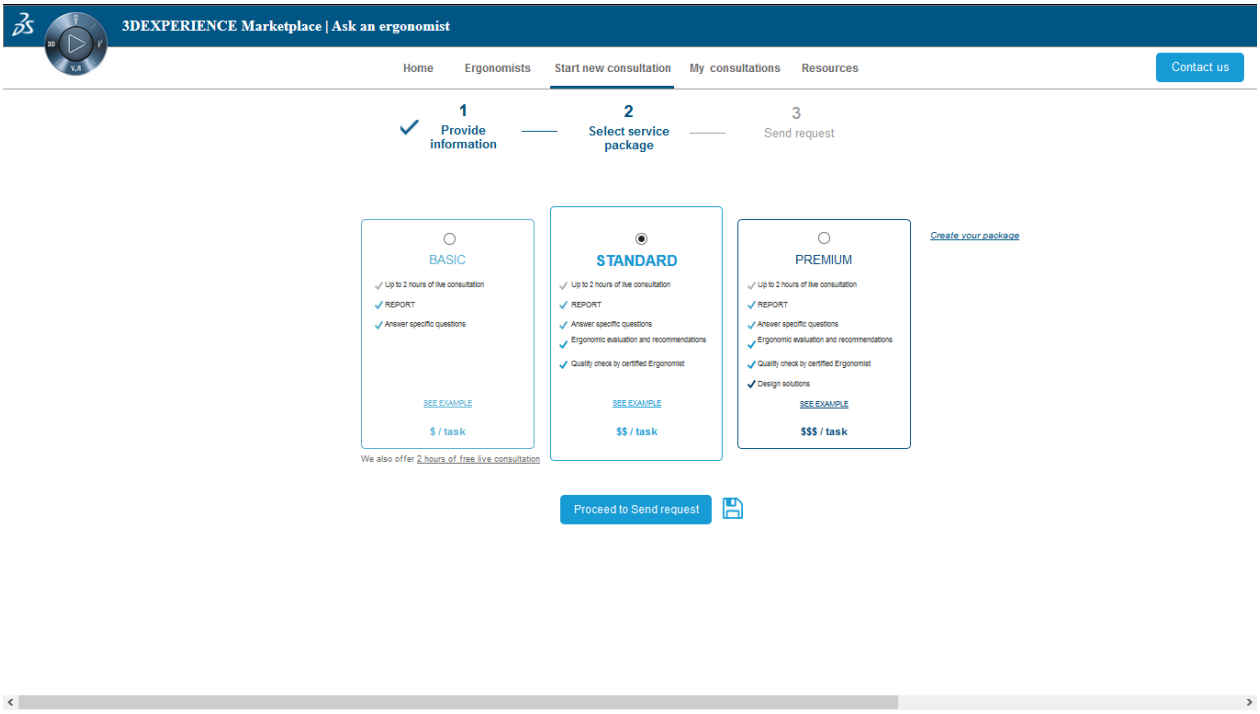


Figure V.5. Page *Select service package* of **Prototype 2**.

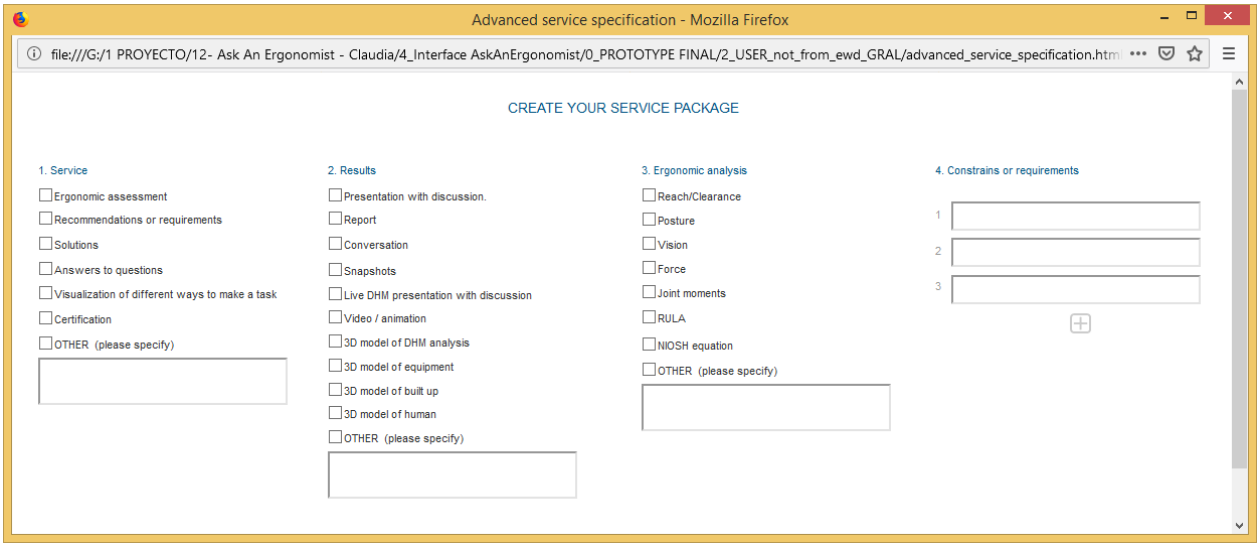


Figure V.6. Page *Create your service package* of **Prototype 2**.

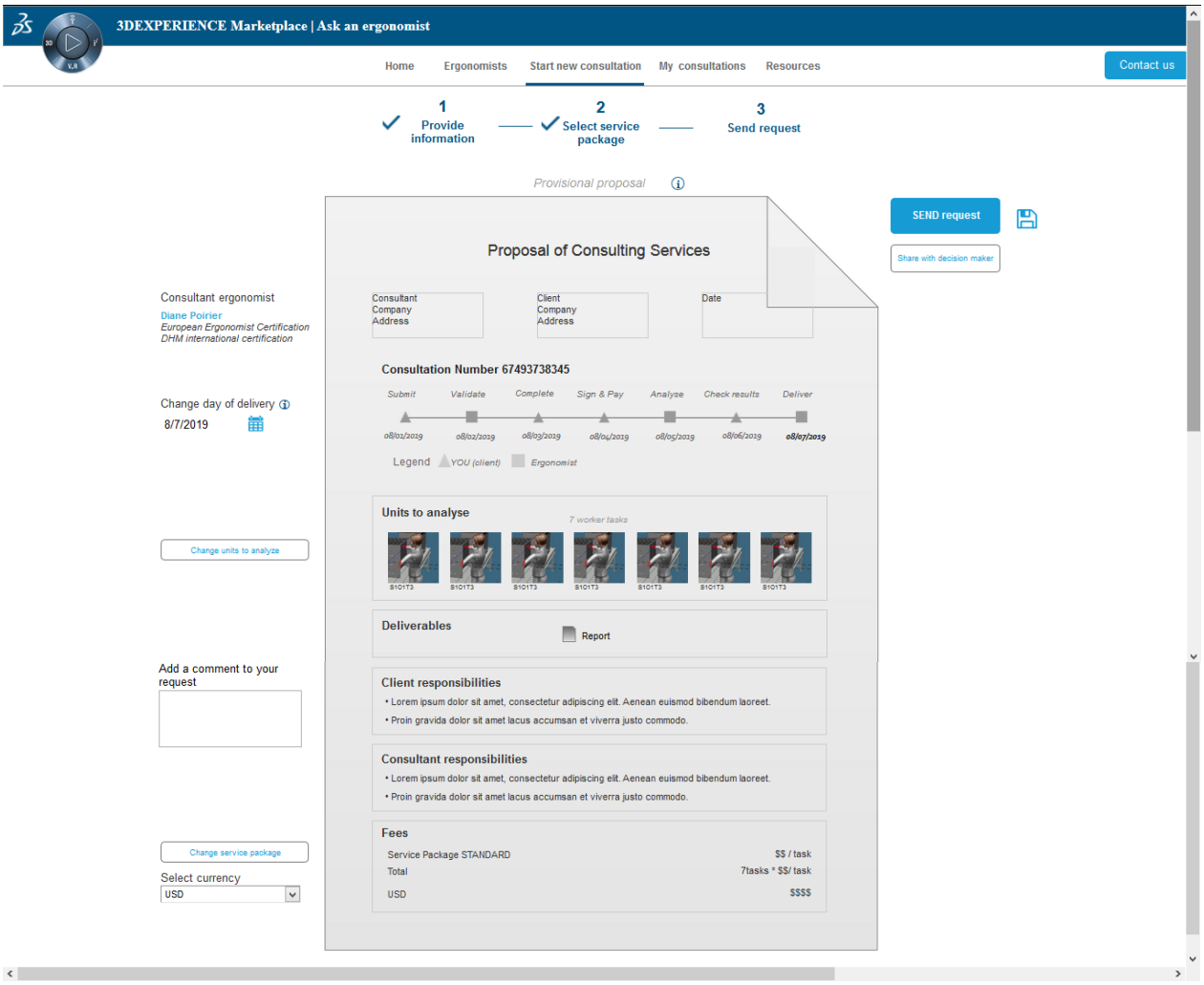


Figure V.7. Page *Proposal* of **Prototype 2**.

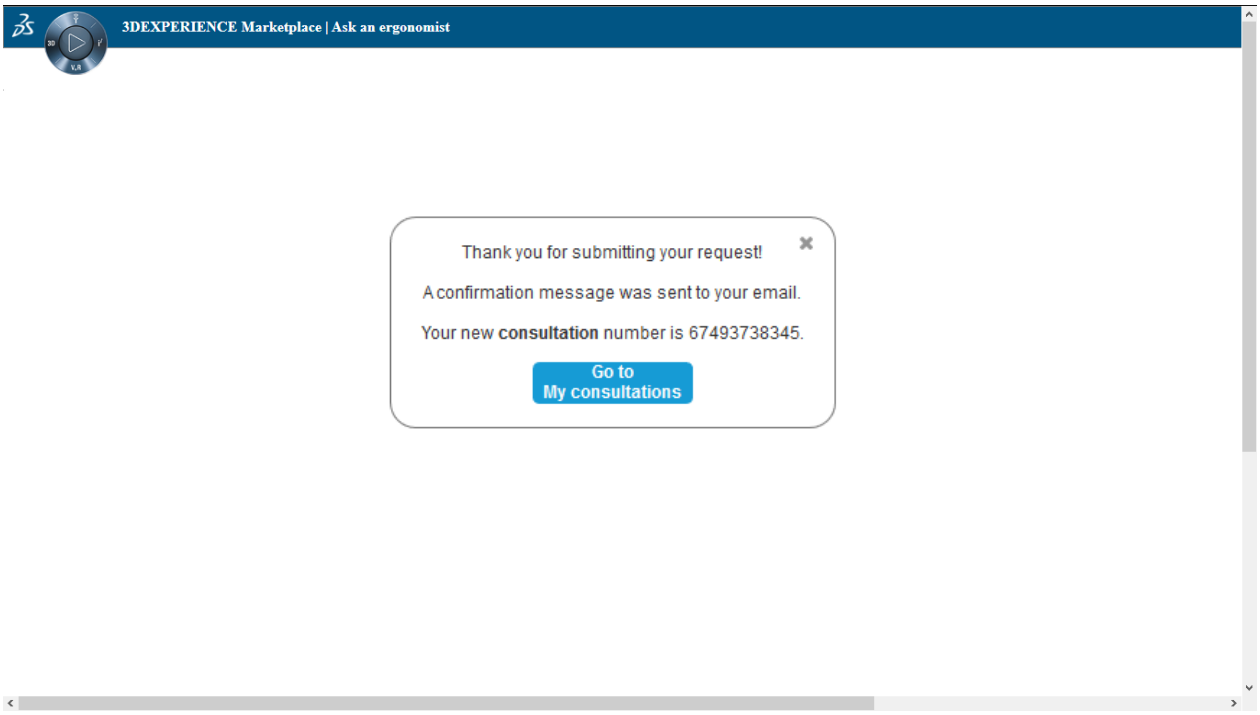


Figure V.8. Submitting confirmation message of **Prototype 2**.

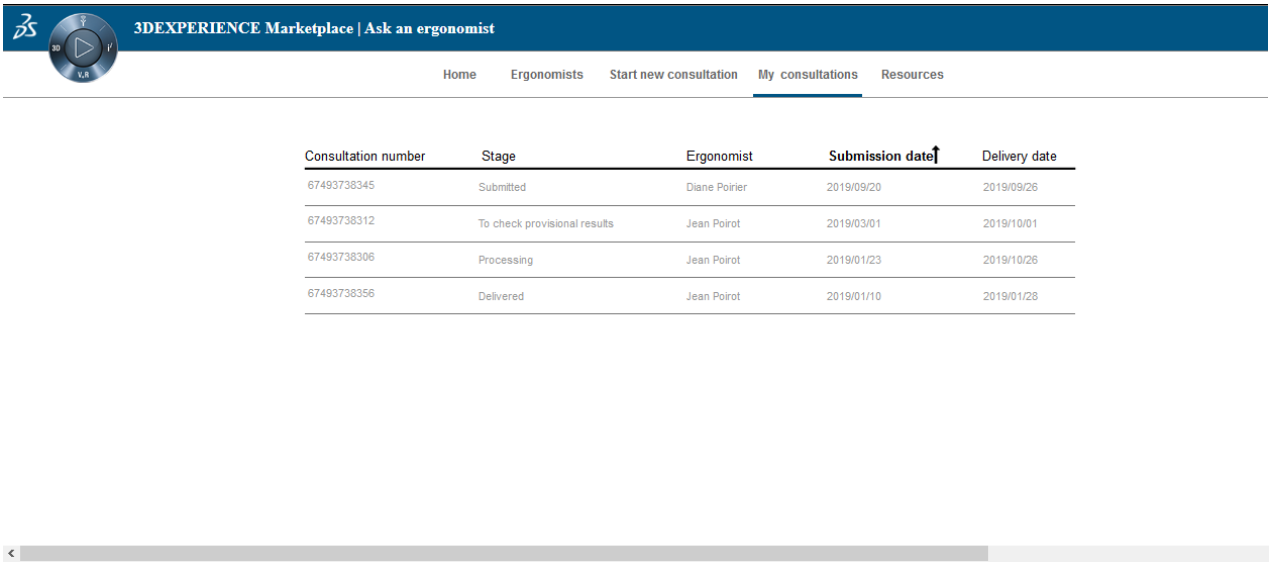


Figure V.9. Page *My consultations* of **Prototype 2**.

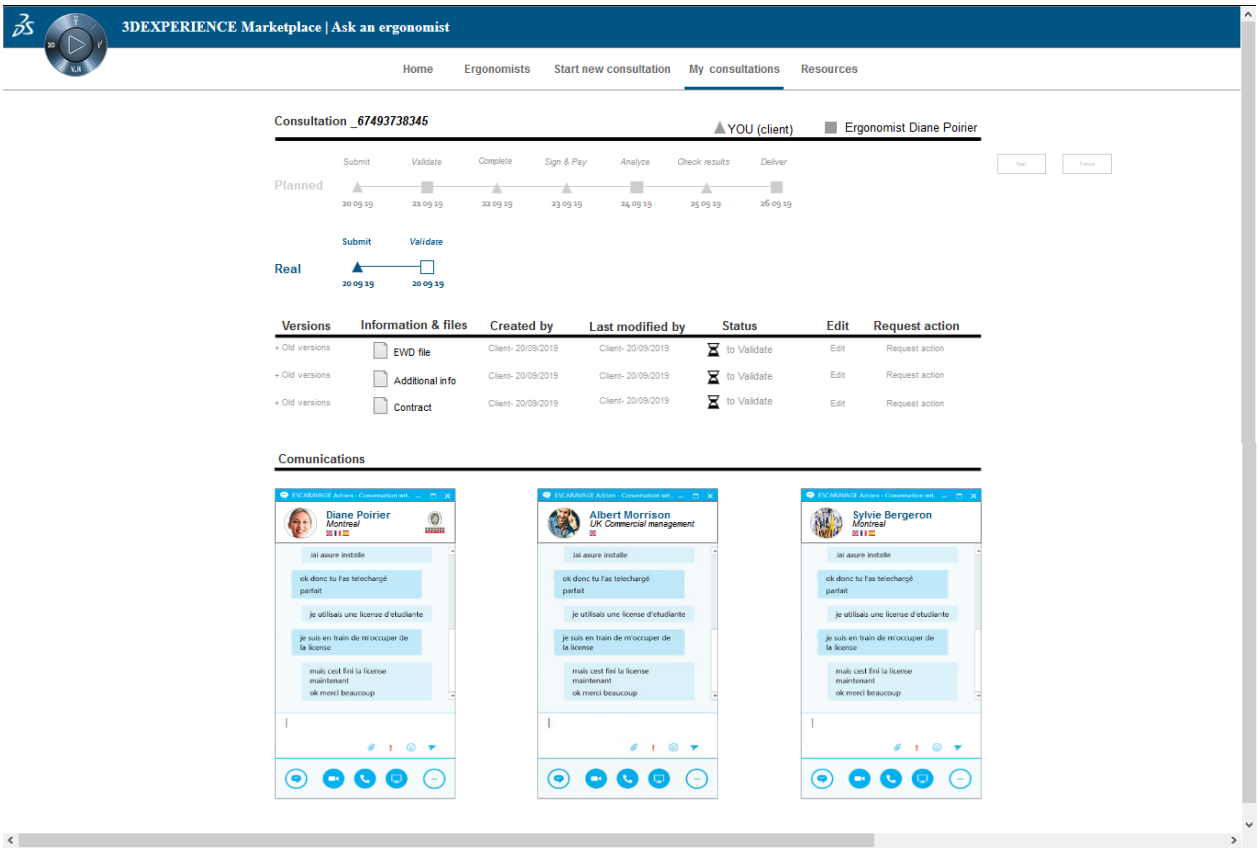


Figure V.10. Page *Consultation* of **Prototype 2**.

APPENDIX W PROTOTYPE 3 (ERGONOMIST)

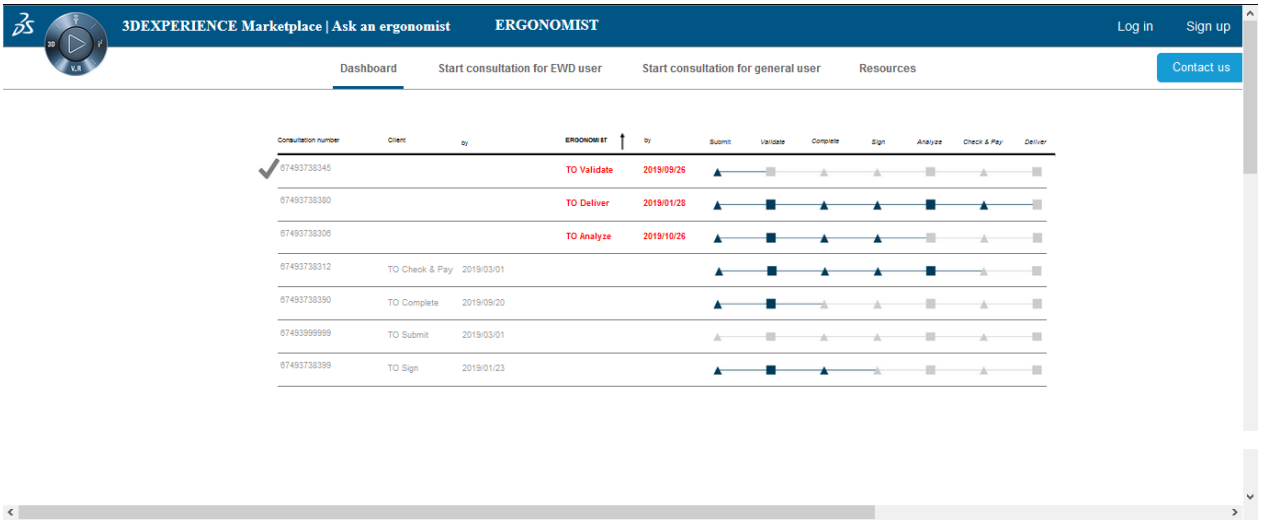


Figure W.1. Page *Dashboard* of **Prototype 3**.

* by clicking in **Start consultation for EWD** the interfaces (and flow) are the same as in Prototype 1 final version.

* by clicking in **Start consultation for general user** the interfaces (and flow) are the same as in Prototype 2.

This options are given to the ergonomist to make a requests for clients that did not want or were not able to create it by themself.

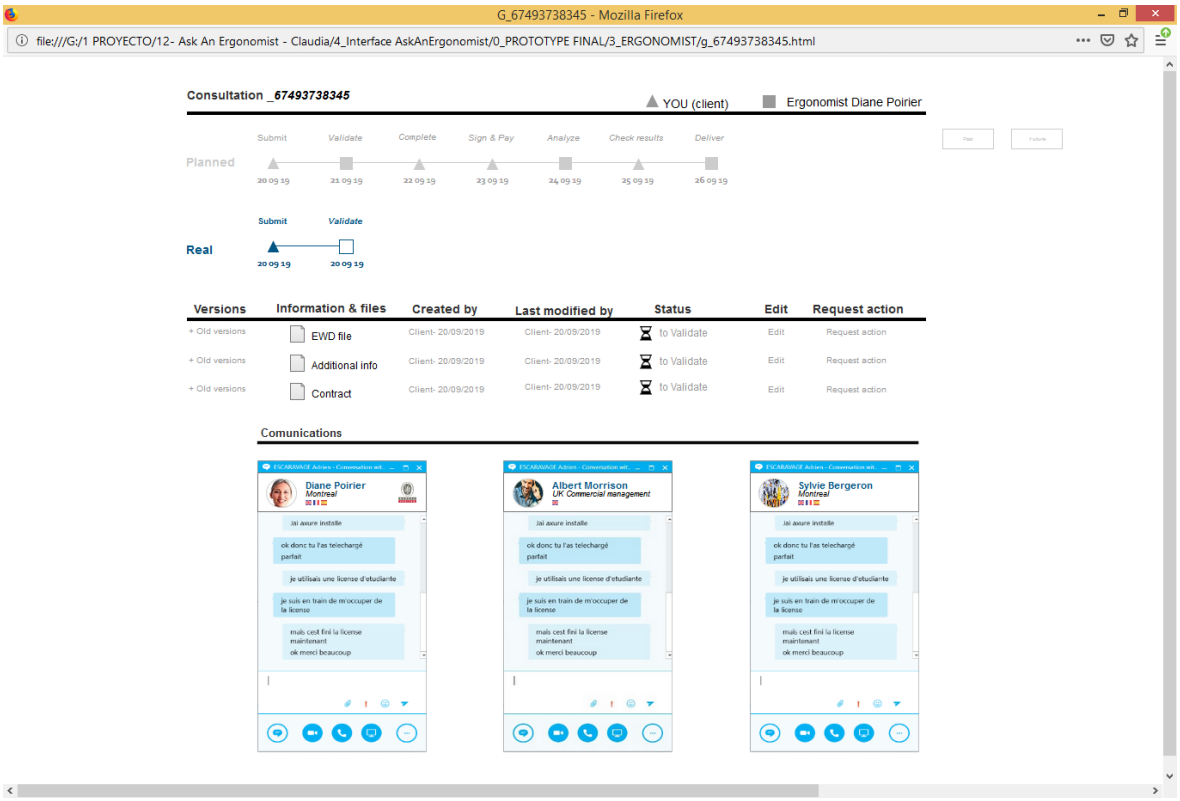


Figure W.2. Page *Consultation* of **Prototype 3**.

APPENDIX X ETHICS CERTIFICATE

POLYTECHNIQUE MONTRÉAL
LE GÉNIE EN PREMIÈRE CLASSE

CERTIFICAT DE CONFORMITÉ

Montréal, le 26 octobre 2018

M. Daniel Imbeau
M. Jean-Marc Robert
Mme Claudia Gordillo Paneque
Département de mathématiques et de génie industriel
Polytechnique Montréal

N/Réf : Dossier CÉR-1819-26

Madame, Messieurs,

J'ai le plaisir de vous informer que les membres du Comité d'éthique de la recherche avec des êtres humains (CÉR) ont procédé à l'évaluation en comité restreint du projet de recherche intitulé « *Conception d'un processus d'intervention en ergonomie virtuelle* ».

Les membres du CÉR ayant examiné votre projet en ont recommandé l'approbation sur la base des précisions que vous nous avez fait parvenir ainsi que des réponses aux questions et commentaires du CÉR.

Veuillez noter que le présent certificat est valable pour une durée d'un an, soit du **26 octobre 2018 au 25 octobre 2019**, pour le projet tel que soumis au Comité d'éthique de la recherche avec des êtres humains.

Veuillez noter que conformément aux exigences des organismes subventionnaires, il est de **votre responsabilité de nous soumettre un rapport annuel ou un rapport final avant l'expiration du présent certificat** afin de nous informer de l'avancement de vos travaux. Le formulaire à remplir est disponible à l'adresse suivante : (http://www.polymtl.ca/recherche/formulaires-et-guides).

La coordonnatrice du CÉR devra aussi être informée de toute modification qui pourrait être apportée ultérieurement au protocole expérimental, de même que de tout problème imprévu pouvant avoir une incidence sur la santé et la sécurité des personnes impliquées dans le projet de recherche (sujets, professionnels de recherche ou chercheurs).

Je vous souhaite bonne chance dans la poursuite de vos travaux.

Yuvin Chinniah, Président
Comité d'éthique de la recherche avec des êtres humains

cc: Céline Roehrig (DFR); Sylvie Proulx (Service des Finances)

Comité d'éthique de la recherche avec des êtres humains
Céline Roehrig; Coordonnatrice
Yuvin Chinniah, Président
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