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USER-CENTERED APPROACH IN INNOVATIVE ENERGETIC DESIGN: A CASE STUDY

Alexandre COLLANGE[1, 2], Frédéric SEGONDS[1], Julien NELSON[3], Thomas WIART[2], Christopher LAUG[2]
[1]Arts et Métiers ParisTech, LCPI, 151 Boulevard de l'hôpital, 75013, Paris, France
[2]Assystem AE&I, Pôle Innovation, Futura III – 23 Place de Wicklow, 78067, Saint-Quentin-en-Yvelines, France
[3]Université Paris Descartes, LATI, 71 avenue Edouard Vaillant, 92100 Boulogne Billancourt, France

Summary:

This study aims at elaborating a User-Centered Design (UCD) procedure that permits to include end-users (people who have knowledge on how the product could be used) in the innovation process. This research is led with Assystem, an engineering and innovation consulting company, along with the energetic design of one of Assystem's innovative products.

This paper consists in a literature review of the innovation process and of methods and tools related to a UCD approach. The proposed procedure is inspired from the Contextual Design method but adapted to a goal of technical performances maximization. It includes a dual inquiry phase, an interpretation phase, a creativity phase and an evaluation phase. The tools used are described in the paper as well as the results drawn from testing the procedure with an industrial case study.

Keywords: Contextual Design, UCD, Evaluation, Creativity, Innovation

1 INTRODUCTION

This study is led with the engineering and innovation consulting company Assystem along with the energetic design of an innovative wheelchair intended for paraplegic employees. This wheelchair is convertible into a "self-balancing vehicle" like a *Segway*, and into an exoskeleton. This product is supposed to give paraplegic collaborators access to construction sites in order for them to fully practice their profession (See Figure 1).

Figure 1: HANDROÏDE, the case study of this research

The author's goal is to design and optimize the energetic performances of the product. The main challenge faced by the author during the design process is the difficulty to generate innovative ideas for the energy storage systems layout and battery regeneration. Indeed, these systems are associated with precise technical constraints and depend on the way the product is going to be used and where.

The key to innovation in energetic design is thus a precise understanding of the product's future usage environment and of the user's behavior. Designers cannot imagine that themselves and need to include potential end-users to the design process. This external involvement is expected to enrich the idea generation phase as well as to provide relevant evaluations and help come up with innovative, effective and acceptable solutions to increase the performances and the overall quality of the product.

The purpose of this article is therefore to adapt and mix existing data collection, creativity and evaluation methods to develop a procedure that can be transposed on any product design. This document is a presentation of the elaborated methods and the results drawn from tests on our case study.

2 LITERATURE REVIEW

2.1. Innovation

2.1.1. Definition

In 1939, Schumpeter [13] was the first to define innovation as the successful entry into the market of a new product, service or process. The current reference definition of product innovation is the one cited in the Oslo manual (2005) [12] from the OECD (the Organization for Economic Co-operation and Development): "A technological product innovation is the implementation or commercialization of a product with improved performance characteristics such as to deliver objectively new or improved services to the consumer".

2.1.2. The innovation Process

According to Kline and Rosenberg (1986) [7], Innovation is linked to the design process: reference can be made to "Innovation Process". The efficiency of the innovation process is enhanced when a multidisciplinary expertise is included as it reinforces creative competencies and allow for rich combinations of otherwise disconnected pools of ideas (Hatchuel and Weil, 2002). In fact, Innovation is part of the design process and has to be organized and steered. A. Aoussat proposed in 1990 the following model [1] which summarizes the multidisciplinary Innovation process (see Figure 2):

From this point of view, the industrial product is the materialization of an idea. According to Staudenmaier (1985) [23], designers lose control over their product once it reaches a market and are forced to pass it on to the users. In order to minimize the risks associated with this loss of control it is necessary to include end-users in the innovation process. This model indeed proposes a "feedback loop" right before industrialization in order to rethink the need identification phase based on user tests results. This is the least one can do in terms of user-involvement and we will thus describe more advanced user-centered design approaches.

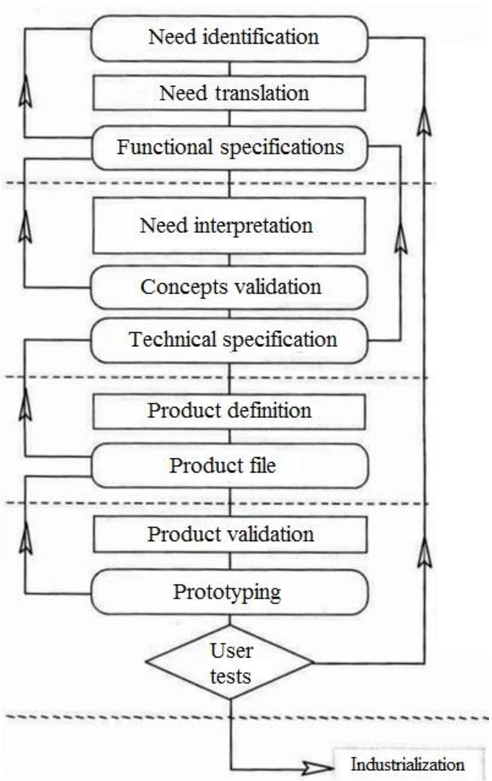

Figure 2: Innovation Process, extracted and translated from [1]

2.2. The UCD Approach

2.2.1. A brief history of User-Centered Design

User-Centered Design (UCD) is an approach which aims in including the user in the product design process. It was first summarized by Nickerson in 1969 [9] as the potential of computers was being recognized: *"the need for the future is not so much computer oriented people as for people oriented computers".* UCD indeed took its origins with the development of computer technology and showed great interests in software design. Based on Card's (1983) [4] theoretical studies on psychological responses applied to HMI (human user interfaces), Norman and Draper [10] proposed the first coherent reflexion on the subject in *User-centered system design* (1986). Norman then extended his research about UCD to the functional aspects of physical products in *the psychology of everyday things* (1988) [11], adopting a cognitive and emotional approach. UCD was later taken to another level by Nagamachi (1995) who created the concept of *Kansei Engineering [8]*. This method permits the comprehension of the user's emotional responses towards a product's technical and physical attributes in order to design solutions that can actually stir emotions. This method was proven relevant with the commercial success of the Mazda Miata and is widely used in the automobile industry since then. The integration of the user in the design process is today a key asset, and thus several methods have been elaborated.

2.2.2. The UCD approach nowadays

The ISO 9241-210 (2010) standard [6] summarizes the UCD approach along with the entire design process. It is considered today as the UCD reference model and is illustrated by the following diagram (See Figure 3):

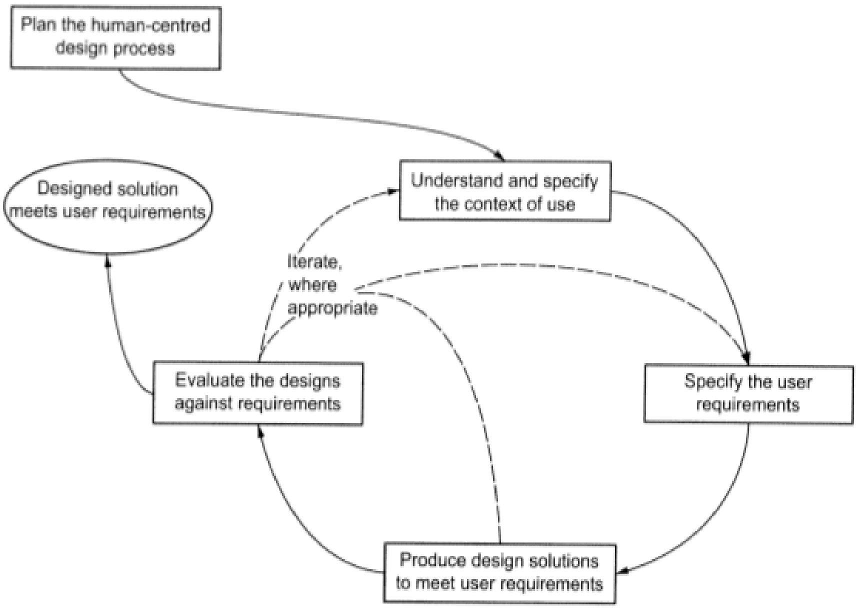

Figure 3: User-Centered Design, extracted from [6]

This gives an interesting overview of the UCD process which includes the following steps:

- Thoroughly describe the physical and social context of use (environment, human interactions, tasks performed…),
- Specify the user requirement precisely enough to provide guideline to designing solutions,
- Design solutions accordingly,
- Perform user tests on a prototype in order to evaluate the designed solutions,
- Iterate back to the appropriate steps to redesign solutions taking the test results into account…
- …until the designed solutions are validated by the user tests.

Compared to the model described earlier [1], this one clearly shows end-user evaluations can influence the whole innovation process instead of consisting in a final evaluation.

2.2.3. Participatory Design

In order to limit iterations due to negative evaluations from end-users, reference is made to *Participatory Design*, which aims at including them as much as possible throughout the process even to the point that they become part of the design team. For Olsson (2004) [14], (diagram extracted from Nelson, 2011) [24], the different levels of involvement are sorted as such (See Figure 4):

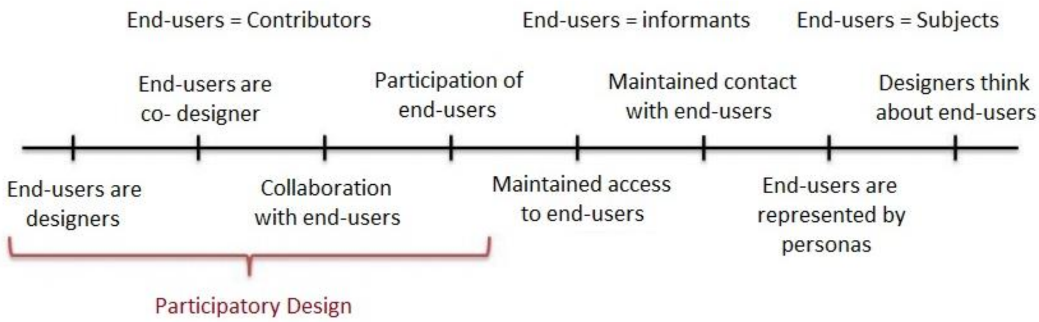

Figure 4: Levels of end-user involvement adapted from [24]

According to Salomo (2003) [15], *Participatory Design* not only increases the potential of acceptability in a product, but can also increase its technical performances. This is exactly what this study aims at achieving: use and adapt UCD methods in order to optimize the energetic performances of an innovative product.

2.3. Existing methods and tools

2.3.1. Contextual Design

Contextual Design (CD) by Beyer and Holtzblatt (1997) [2] is a UCD method that is primarily used for the design of computer information and IT systems, but has been adapted to other fields of study including consumer products, automotive and medical devices designs. It is very interesting for our case of study because this design method aims at describing and analyzing the *"work practices"*, a term which *"refers to the complex and detailed set of behaviors, attitudes, goals and intents that characterize a set of users in a particular environment"* [2].

CD consists in the following top-level steps: *contextual inquiry, interpretation, data consolidation, visioning, storyboarding, user environment design, and prototyping [2]* (See Figure 5):

Figure 5: Contextual Design Process, extracted from [2]

As explained earlier, this method is primarily intended for software design. In this field of study, the iterations can be fast since quick mock-ups of the designed interface are enough for user tests. Due to the nature of our product, we can't perform user-tests until the product file is validated and our product physically prototyped [1]. A way to adapt this method is to use scenarios as prototypes (Carroll, 2000) [19] in order to communicate our design to end-users so that they can evaluate it. Also this method is used to point-out problems in existing systems and redesign better solutions. Our objective is to design a new product from scratch so we don't have any problems to identify on an existing one. We however need a method to describe and understand the "work practice" and will thus use parts of this method to collect data and generate ideas by including end users in our process.

2.3.2. Contextual Inquiry

2.3.2.1. Target Population

One of the main difficulty that one faces during the design of a break-through innovation is that no one is familiar with the use of a perfectly similar product and designers can only perform a prospective analysis of the usage [16], which is only possible with a clear comprehension of end-users needs.

Before collecting data from end-users, it is necessary to define and identify them (Hostgaard and al., 2011). At first, we can define the term "end-user" as someone who is expected to use the product. In our case, Handroïde will permit paraplegic collaborators access to a profession they have never practiced. So even if paraplegic collaborators are seen as potential end-users, they don't really know what functions they might need for their work on the field. They are however indispensable for the design process because the product has to be adapted to their handicap. On the other hand, non-disabled collaborators who are used to working on construction sites have knowledge on work practices and have indispensable experience for the designers as well. No one has at once knowledge on these two aspects and both of these social groups have thus to be included in the design process. The designer team has to juggle between both points of view to provide a coherent and complete understanding of the needs the product has to meet. So in our case, our source of information are "end-user representatives" who have specific knowledge about our concepts' context of use that allow them to imagine better than others how the product will be used.

Once the target population is identified, there are different methods to collect data from them: interviews, questionnaires, brainstormings…

2.3.2.2. Interviews

Interviews can either be directive, semi directive, or non directive. The semi-directive interview is both framed and open. The interviewer needs to have an interview guide prepared but the conversation can diverge if it seems interesting to the interviewer, who has to keep in mind the objectives of the interview to avoid useless discussions (Wuillemin, 2006).

2.3.2.3. Questionnaires

Questionnaires can either be interview guides used by the interviewer or intended to be completed by a sample of the target population. It is a very inexpensive way to collect data but hard to use because the results are not always as good as expected compared to an interview. In fact, it is impossible to adapt the questions in response to the answers in a questionnaire.

2.3.2.4. Brainstorming

This method is very common and can be used throughout the whole design process to generate ideas (Jones, 1992) [21] or to understand activities and needs. It is adapted to describe the "work practices" needed for the contextual design method: people from the target population can be invited to brainstorm with the designers in order to describe as precisely as they can their work environment, tasks, habits, etc…and respond to each other's ideas.

2.3.3. Interpretation phase

The data is collected in the form of written texts or phrases and is hard to communicate or use. The CD method includes an interpretation phase intended to edit the data and make it more easily usable. The following tools can be used for this step.

2.3.3.1. Sequence model

The sequence model is a tool directly extracted from the Contextual Design method. It is a representation of the detailed steps performed to accomplish each tasks important to the work. It is supposed to show difficulties, goals, strategies, etc… [2]

2.3.3.2. Scenarios

The interesting part of scenarios made from collected data is that it can help visualize situations and help creativity. For Carroll [5], scenarios are a concrete description of an activity in which the end-user performs a specific task. It has to be precise in order to be useful for designers, who can then make decisions based upon real situations. It can also be used as prototypes for concept evaluation from the target population. Hanington (2003) [18] makes reference to "speculative scenarios" in this case.

2.4. Positioning of this study

2.4.1 Synthesis of our case study

- Assystem wants to generate innovative solutions to maximize the energetic performances of the product. These solutions need to be adapted to the end-users "work practices" and handicap.
- Paraplegic collaborators have never worked on the field and are unable to describe work practices. Non-disabled collaborators on site have knowledge on work practices but are unable to put themselves in the place of a paraplegic person. We therefore have to include both social groups in our procedure to understand the needs linked to handicap and working on the field.

2.4.2 Positioning of this paper

The previous state of the art about UCD approach in innovative design provides an overview of methods and tools that could be adapted to our case of study. However, figure 1 and 2 show processes that include end users as evaluators whereas we aim at developing a method in which the target population is consistently consulted as participants, or even integrated within the designer team. On the other hand, Contextual Design provides a method that includes users throughout the whole process but again as evaluators for problems identification from existing products. Based on this literature review, this study aims at developing a method that permits to include both collaborators who have knowledge on the usage environment and work practices and paraplegic people who can help designers produce concepts that are adapted to their handicap.

3 PROPOSED METHODS AND RESULTS

3.1. Proposed method

This section is intended to describe the proposed method. We will later discuss the results drawn from the testing of this method on our case of study and specify the tools that we used. The proposed method is the following (See Figure 6):

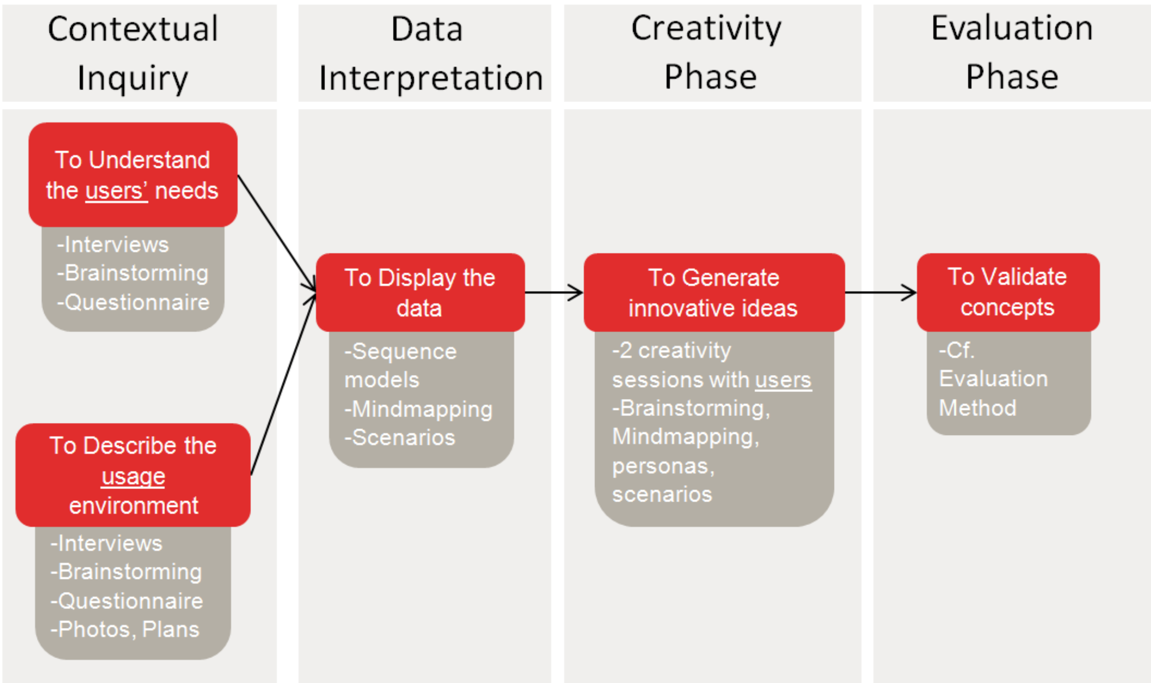

Figure 6: Proposed UCD procedure

The first step is "Contextual Inquiry". It consists in the collection of data from end-users on the context of use: Collaborators who work on sites and paraplegic persons. Both provide information about their needs as persons, or knowledge about work practices and work environment. These set of information are complementary and in our case have to come from two different social groups as explained earlier.

The data interpretation phase is important to display the collected information. It is necessary to make the data usable and communicable to the rest of the team or to the participants of a workshop.
The ideas are produced during the creativity phase. End-users are again invited to the workshops and the results from the data interpretation phase can be used to enable creativity.

The evaluation phase again included end-users. But our research led to an adapted evaluation method.

The evaluation phase was structured the following way (See Figure 7):

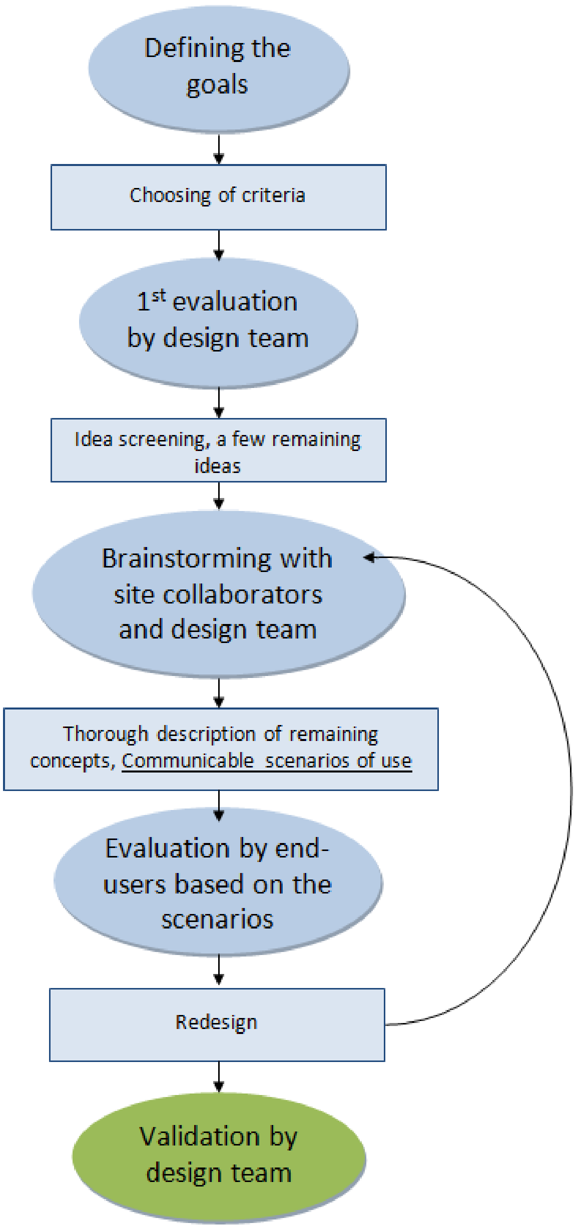

Figure 7: Proposed evaluation procedure

This proposed method aims at reducing the number of ideas with a first evaluation by the design team based on the project's industrial goals.

Once only a few interesting concepts remain, they are described more thoroughly with the help of site collaborators during a brainstorming session.
The goal is to generate illustrated scenarios of use to communicate the concepts to end-users (both paraplegic people and site collaborators) and use them as prototypes for evaluation as explained earlier in paragraph *2.3.1 Contextual Design*.
The results of their evaluation can either lead to the validation of the concept by the design managers, or to the redesigning of the concept.

3.2. Results

3.2.1 Contextual Inquiry

3.2.1.1 Brainstorming

The first tool we used to collect data was a brainstorming. A manager who had experience on the field was invited and we discussed about the work practices on a construction site.

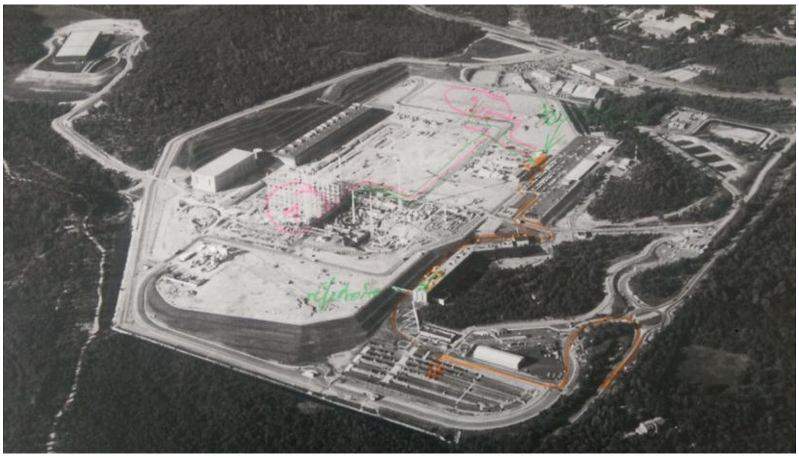

Figure 8: ITER site map with drawing of the path covered

We used an aerial photo of the ITER site and asked the collaborator to describe as precisely as possible a "typical day" as site supervisor.
The results drawn from this workshop were a drawn map (See Figure 8) and a text. This was by far the most efficient tool in view of the quantity and preciseness of the collected information. This success was due to the fact that the "end-user representative" was a manager of the team who knew what we were expecting from him. Also, the brainstorming allowed participants to respond to each other's ideas; the collected information was thus enriched.

3.2.1.2 Questionnaires

The questionnaires were created after the brainstorming, once we had a clear idea of what questions we should ask. It was in the form of two charts. The first one asked to describe each tasks with the time taken, the difficulties faced, the distances covered, etc… and the second one described the distances covered between two tasks, the difficulties faced, the equipment carried etc… We sent questionnaires to 5 collaborators in 4 different professions. These questionnaires were very useful because far less time-consuming than the brainstorming. It was helpful to explain orally the goal of the inquiry and our expectations to the collaborators.

3.2.1.3 Interview

We conducted two 1 hour-long semi-directive interviews over the phone with two collaborators who had practiced two different professions. The goal was to make them talk about their daily work and to obtain a feedback on potential ideas. We tried to obtain the same information than with questionnaire but with interviews because it is less time-consuming. We started by making them introduce themselves, describe their functions and difficulties, and narrate a "typical day" at work. We also asked questions about the security standards on construction sites, the equipment and vehicles used. We tried during the non-directive phases of the interviews to debate on our first design ideas and see if it would be adaptable to their work. We concluded afterwards that it was hard to obtain precise information on their "typical day" during an interview because the collaborators simply had trouble remembering work practices immediately. In order to make it easier for them, questionnaires were also sent to them after the interviews. They said it was easier to describe something precisely in writing than orally and that it helped to have more time. The feedbacks on potential ideas were however very relevant because they could put themselves in a position of actually using them.

3.2.1.4 Inquiry about Paraplegics' needs

This inquiry was not led by the author of this paper and is the subject of another article. It was led by Elsa Zapata who we collaborated with during this study.

3.2.2 Data Interpretation

3.2.2.1 Scenarios and *Sequence model*

The data collected allowed us to create prospective scenarios of use, as if Handroïde already existed and was used for 4 different professions on site. We displayed these scenarios in form of sequence models to show the succession of tasks the collaborators performs on site, and also to visualize numeric values of distance, slope, speed, etc... (See Figure 9). The blue rectangles show the different locations on the construction site, the arrows show the order in which the locations are reached. In green are sometimes described specific tasks associated with a location. These models therefore provide us with a thorough description of the context of use including work practices. The underlined text is the mode Handroïde is expected to be used (during tasks in green or as a vehicle associated with an arrow). We can also see parameters like the time spent, the distance covered, the estimated slope coefficients and the speed. It was extremely helpful because it provided us with entry parameters to calculate the energy consumption we could expect for our product. It was a relevant estimation because we referred to scenarios based on real experience shared by collaborators. Estimating the initial consumption of Handroïde was the first step before designing innovative solutions that would minimize it, and including users in the process to understand the context of use made that possible.

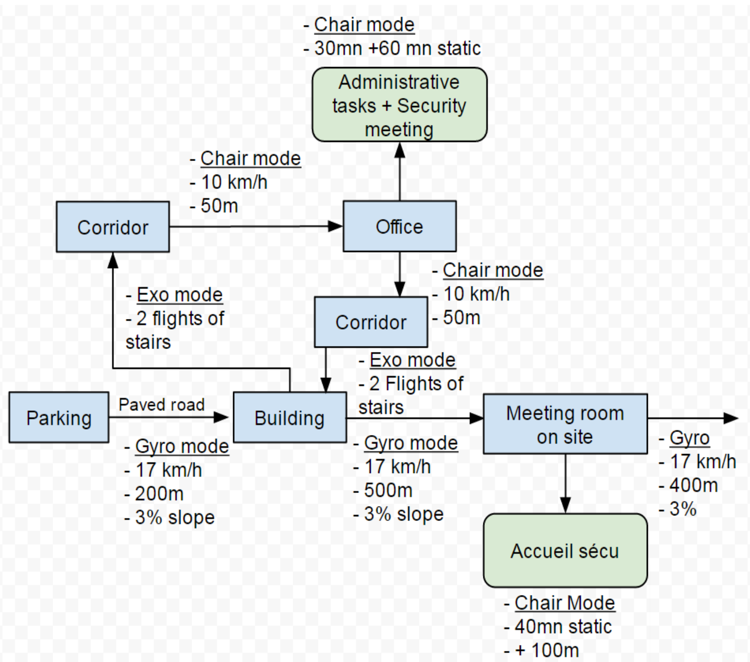

Figure 9: Extract of the Sequence Model for a Health Security Environment manager

It also helped us imagine which mode was most appropriate for each task. The results drawn from this interpretation phase is synthesized on the following chart (See Figure 10):

Profession	Site	Distance covered (m)	Energy consumption (Wh)	Chair Mode	Gyro Mode	Exo Mode	
Site supervisor	ITER site	9600	986	64,34%	3,59%	32,08%	% Time
				15,92%	67,12%	16,96%	% Distance
Health Security Environment Manager	Pharmaceutical production site	8550	939	43,79%	4,07%	52,14%	% Time
				6,08%	70,18%	23,74%	% Distance
Logistic Project Manager	Port of export	4600	818	39,24%	1,67%	59,09%	% Time
				6,74%	67,39%	25,87%	% Distance
Site supervisor	Solar plant construction site	4620	747	97,13%	1,47%	1,39%	% Time
				43,29%	52,94%	3,49%	% Distance

Figure 10: Estimated energy consumption of Handroïde based on end-user defined

3.2.2.2 Mindmapping

Collaborators also helped us list the different sources of energy available on site. We collected information during the contextual inquiry and created the following Mindmap which was used during the creativity sessions.

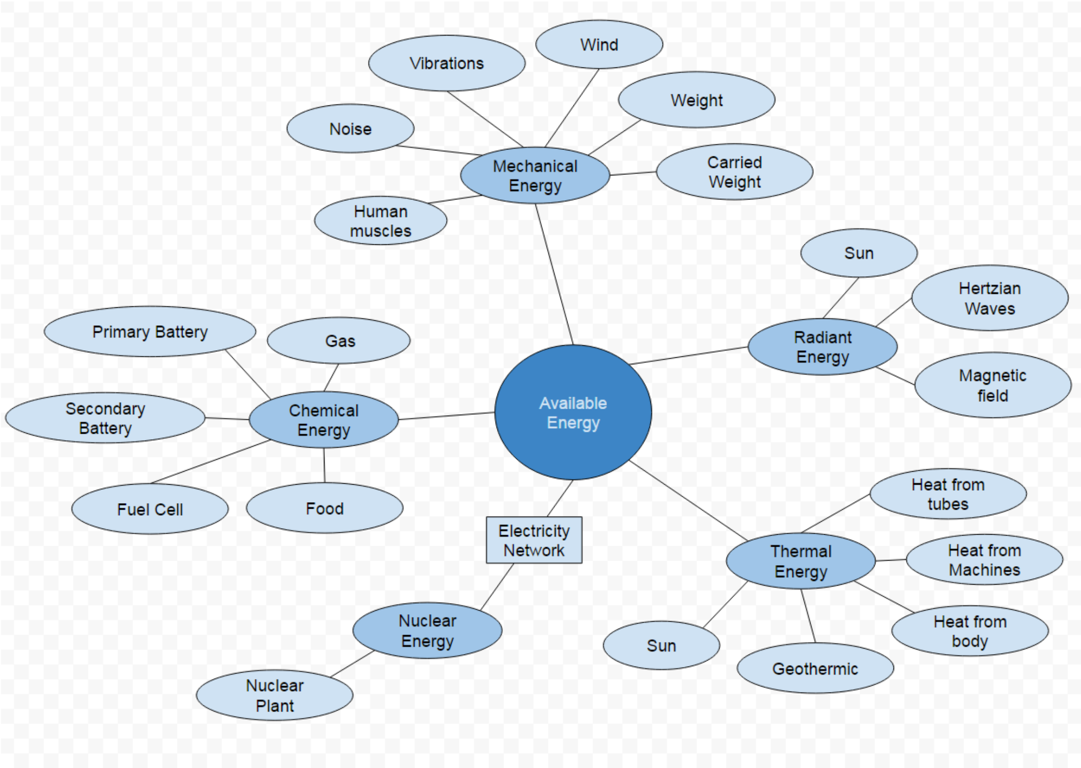

Figure 11: Mindmapping of the available sources of energy on site

3.2.3 Creativity phase

Once the data was interpreted, we had a more thorough idea of the needs our solutions had to meet. We organized a first creative workshop to start generating concepts. One paraplegic (Thierry) and the design team participated to this workshop.

We started with a brainstorming, used the mind map described earlier, and finished by generating idea cards based on scenarios from the interpretation phase. We managed to produce 35 idea cards. Thierry helped us during the post-evaluation phase at the end of the workshop. He could imagine actually using the generated concepts and give instant feedback. Evaluation criteria that seemed important to him were noted and taken into account in the evaluation phase.

3.2.4 Evaluation phase

We first defined more precisely the goals of the products with the project managers in order to choose appropriate evaluation criteria and weighting coefficients. Each of us 3 then evaluated the 35 ideas produced. We set a threshold at 36.5 points and 7 ideas made the cut. 4 of them do not need a more thorough description but need a typical feasibility survey because they were mainly technical ideas with very limited interactions with the user. We will thus forget about those four ideas at this stage of the study. However, the remaining 3 were very dependent on the environment of use and of the behavior of the user so we organized a 2nd creative workshop in order to imagine how they could be used on site. 3 site collaborators participated in this workshop. During a brainstorming, we managed to list every imaginable problem that could occur if each concept existed on site and we then tried to solve them. It was very productive because it was both a creative and an evaluative session.

The collaborators could give us feedback about the three concepts. In the end, one clearly stood out whereas the two others weren't well received.

Involving site collaborators on this 2nd evaluative workshop was a very good way to make sure the chosen concept was adaptable to its future usage environment.

3.2.5 Expected results

This paper was written during the creation of a thorough description of how our concept could be used based on the 2nd workshop. We thus expect that the chosen concept will be described precisely enough to be evaluated correctly by a sample of our target population. We also recently included in the design team two construction site collaborators so we expect them to give us almost instant feedback to avoid time-consuming iterations with external informants. Once the concept is validated, other existing tools are expected to be used for the technical design such as functional analysis and TRIZ.

4 CONCLUSION AND FUTURE WORK

The purpose of this research was to adapt existing methods and tools to our specific case of study to develop a design procedure that could be used on other products. Our procedure aims at permitting both end-user representative groups to be included throughout the front-end of the innovation process. This procedure is intended to help designers come up with innovative and acceptable solutions to maximize the technical performances of the product. In fact, the energetic design is inevitably linked to the way the product will be used and the environment in which it will evolve.

This research also consisted in the testing of this procedure with a case study. The first results showed that the procedure indeed helped the design team understand the usage environment of the product and the point of view of paraplegics. The involvement of the target population and the collection of data on their work practices and needs provided us with guidelines for a relevant reflection. Their external point of view was very appreciated during evaluation phases. Furthermore, collaborators who we actually included on the design team were also very helpful because they could give us instant feedback on ideas.

We are currently testing the evaluation procedure. Future work will consist in describing more thoroughly the chosen concepts in order to create scenarios of use sufficiently specified to be communicated to end-user representatives for evaluation. The first steps of the proposed evaluation procedure were very well received by the design team because it resolved the issue of a lack of rigorous methodology, and helped us make informed decisions about our concepts. In fact, we gained time by putting aside concepts found not to be relevant by end-user representatives, and managed to keep in mind what was relevant in these concepts to improve chosen concepts.

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Main Contact information:
COLLANGE Alexandre
3 rue du Sergent Blandan, 92130, Issy-les-Moulineaux, France
alex.collange@gmail.com
0627993343