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A PROPOSAL OF AN EVALUATION MODEL UNDER THE PRINCIPLES OF UNIVERSAL DESIGN

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1. Introduction

The aim of this work is to try to set out how the Universal Design (UD) paradigm can influence the process of product design and how the models of evaluation should work for products designed for all users. Firstly, we will give a short introduction of some of the basic models that try to explain the product design and development process emphasizing, especially, the role given to evaluation of the design stage. Secondly, what we would like to do is explain, on one hand, the paradigms of Human Centred Product Planning and Design and, on the other hand, UD/Inclusive Design (ID)/ Design for All (DfA) in order to clarify the bonds and relationships which are established between these in the field of Ergonomics and Human Factors. In this context, we explain how these philosophies have an effect and an influence in the process of design, especially in the interstages of evaluation. Finally, we present a model that proposes the integration of UD principles into the process of design applying it to the case of a wheelchair.

2. The modelling of the product design and development process from different points of view

The product design and development process calls for a framework that serves the practical goals of the numerous disciplines affected by it. This systematization has been carried out in the theoretical-scientific tradition, in the fields of Engineering and Economics, creating a theoretical framework that includes different integrating models in which several actors and activities are normally considered.
Several perspectives aim to offer some proposals about the modelling of the product design and development process.
Generally, the product design and development process can be described by means of four fundamental sequential stages, similar to those of the innovation process: the study stage; the development stage; the prototype and production stage; and the market stage.
From the same perspective of development of new products, Juratovac's proposal is integrated in the tradition of Engineering and includes the intermediate and checking stages: Planning and strategy of the product; Definition of requirements of the product; Design and development; Manufacture; Quality checking; Launch to market [Juratovac 2004].
In contrast, Zeisel's model draws the vectors among three actors of the communication process that is necessary for good practice and the effectiveness of the final result: the successful launch of a product in the market. The special characteristic of this model is that it distinguishes between the user and the paying client. This model reveals important gaps in the communication among actors, particularly, with the elements relating to the final user, who is apparently not taken properly into account by the paying client and the designer [Lawson 1997].

However, from a closer perspective strictly based on the conception and product design stage, some authors, such as Stanton, summarize this model in three fundamental stages: analysis, creation and evaluation [Stanton 2005].
Markus and Maver specify these stages in greater depth by describing three levels: the first one corresponding to external proposals; the second one corresponding to the schematic design and the third and last one, corresponding to the detailed design. In all the levels the same stages are included: analysis of the problem, synthesis, evaluation and, finally, decision making, in order to pass from one level to other until the definitive design is attained. The special characteristic of this model is the inclusion of some evaluation stages between levels [Dong et al. 2003 b].
As can be seen, there are different points of view in connection with the study of the process of design. However, we would like to emphasize the fundamental importance of evaluation between the stages during the product design and development process.

3. Human-centred product planning and design

After the discussion of the models of the product development process, we feel it is necessary to talk about some strategic perspectives that encourage human involvement in product design: human-centred design.
The field of knowledge of Human Factors Engineering (HFE) deals with the question of the characteristics and human factors that are important and significant in product design. At the same time, and according to Hoffman, the discipline of Ergonomics can be considered in essence homonymous to the Human Factors [Hoffman 2005].
Despite the terminological confusion, the concept of usability is latent in these philosophies of design as well as in other terminological designations. According to the ISO 13407 standards in Human Centred Design (HCD), usability is defined "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". However, the objectives of usability are centred on ten factors: Effectiveness, Efficiency, Satisfaction, Learnability, Intuitiveness, Helpfulness, Controllability, Avoiding excessive mental load, Avoiding excessive physical load and Safety.
In contrast, some authors, such as Rouse, assume and propose a more specific designation of the matter, known as Human-Centred Product Planning and Design. Rouse's contribution focuses on the association of different stages of the design process with some appropriate techniques. This author proposes different techniques and methods which enable the flow of information and knowledge necessary to obtain the usability objectives required of the product. These techniques are varied and may be of a quantitative or qualitative nature, for example, questionnaires, individual interviews, opinion polls or rapid prototyping. Using these techniques, in their respective stages of the process, assured the success of the product in terms of acceptability [Rouse 2001].
On the other hand, it is worth mentioning that there are some proposals of integration of the Human Factors in product design that have their origins in the Social Sciences, specifically in the Cultural Studies of Anthropology. The knowledge acquired in Ethnography opens a wide range of possibilities for application, beginning with the transfer of its techniques to the world of product design. This knowledge has not gone unnoticed in the field of Engineering, and in Human Factors, some of these techniques are applied in the innovation and development of products: "Ethnography research, based on Cultural Anthropology, focuses on observing what people do, in their 'natural habitats' and, applying that knowledge to improve existing products, to add useful attributes and features to products, or even to uncover unmet needs that require totally new products" [Juratovac 2004].
Visual research methods and expert observation are some of the methods used by ethnographers in order to expand their knowledge bases that can be useful for the purpose of designing new products or for redesigning existing ones. The field of product design and development tries to achieve a specific end, which is, precisely, the implementation of products in the market, starting from the knowledge of people who are going to interact with the product, in harmony with the model of Zeisel [Lawson 1997]. As Hoffman explains:

"Who are the users to consider when designing a product? Anyone who interacts with the product or system. This may be operators, maintainers, or even persons on whom the product is being used (for example the patient)." [Hoffman 2005]. These users are referred to here as indirect (secondary) users.
In this sense, and for the development of this work, we must distinguish between direct and indirect users. The last ones sporadically interact with the product, although their activity with it is essential.

4. The concept of UD in the context of Human Factors and Ergonomics

UD is a philosophy with a novel and specific conception within the field of Human Factors. As Dong quotes: "Universal Design is closely linked to Human Factors and Ergonomics" [Dong 2007]. This philosophy of design starts from the premise that:
"Each person is unique in age, size, abilities, talents and preferences. Human abilities can be grouped into the following categories: cognition, vision, hearing and speech, body function, and mobility." [Mueller and Follette 2002].
In this situation, in terms of usability, attending to all human needs in the design of products seems quite difficult due to the great diversity of users. Therefore, it is necessary to create some criteria and principles to deal with the specific problems of how to create products under usability parameters and, at the same time, adapting to people's physical and cognitive diversities. In any case, it is also necessary to pay attention to universal solutions. The process of universalization of products should not enter into conflict with the possibility of customization. By means of the customization of products, emotional links with the user are created which are important in order to ensure successful use.
In the origins of this philosophy, Muller and Follette explain some experiences which brought about a change in management strategy at the moment of implementing the concept of usability in products in order to extend their market prospects. They conclude that:
"They began to realize that, rather than creating special products for unique user groups, they could integrate the accommodations into their regular product lines and improve usability for everyone." [Mueller and Follette 2002].
In this way, what the UD paradigm fosters or, rather, what it does not renounce is that usability unites all the users, starting from all the critical groups in terms of specific requirements. These groups are clustered under the clinical classification of physical, cognitive and mental disabilities. Moreover, all those people who may be temporarily affected in their abilities and daily tasks, such as pregnant women, are also part of them. In any case, the UD philosophy does not aspire to a special treatment towards these groups, but rather it seeks to integrate them in a group with everyone else, understanding that limitations or abilities affect all of us, in one way or another.
The basic principles of UD were established in 1997 by the Center for Universal Design (CUD) and they are focused on certain aspects with the main aim of creating equality among people and improving the usability of products. These principles, basically, are summarized in the following seven guidelines applicable to products, services and processes:

1. Universal and equitable use.
2. Flexible use.
3. Simple and intuitive use.
4. Easily perceptible information.
5. Design with tolerance for error, that is to say, the design must stand, among other factors, mistaken uses without affecting safety.
6. Design with requirements of low physical effort.
7. Design with enough space for access, accessibility, approach, maintenance and use.

It is appropriate to clarify that, around the same time as the creation of UD other synonymous terms such as Accessible Design, Design for All (DfA) and Inclusive Design (ID) also came into use. As The European Institute for Design and Disability says: "Design for All has roots both in Scandinavian functionalism in the 1950s and in ergonomic design from the 1960s. (…) Comparable concepts have developed in parallel in other parts of the world. The Americans with the Disabilities Act contributed to the evolution of UD, while Inclusive Design has gained ground in the UK. (…) Design for All is design for human diversity, social inclusion and equality. This holistic and innovative approach

constitutes a creative and ethical challenge for all planners, designers, entrepreneurs, administrators and political leaders."

5. Implementation of UD in the product design and development process

We have introduced two areas within the Human Factors and Ergonomics: firstly, the modelling of the process of design and product development and, secondly, the philosophy of UD. Thus, now it is appropriate to consider the influences that these latest philosophies have in the specific design process.
According to the abovementioned models, the design process can be divided into some logical stages corresponding to different activity levels. So taking as a base, on one hand, the traditional model that is based on a time sequence of the design and product development stages proposed by Jurotavac [Juratovac 2004] and, on the other hand, the seven principles of UD, proposed by the CUD, the influence of these principles in the process could be their application in the stages which are characterized by conceptualizing, analysing, evaluating, checking and validating the product. It is important to add that although in the early stages these principles are integrated with special attention, in the subsequent stages, logically, the possibilities of negative validations and/or evaluations will be reduced.
In a general way, and according to our proposal, the initial stages, such as the strategic planning and specifications of the product needs, are the most important for properly developing the overall process of UD. So these stages should include these principles in the requirements, which, later on should serve as guidelines for the designers. At the same time, designers should have enough know-how to understand the aim as well as to use the principles specified in the requirements in order to contribute their knowledge to this work. This is in harmony with the holistic models that foster the communication and participation of all affected agents in the development of products.
However, from a process perspective centred in the design activities, strictly speaking, the conceptualization process, creation, or resolution of the design of the product, beginning with the points of departure, which are proposed in the needs, should anticipate and integrate the analysis stages and evaluation in the way that Lawson proposes. In this case, the points of view of analysis and evaluation should take into account the fulfilment of the specific needs mentioned in the principles of UD [Lawson 1997].
Furthermore, the detail design stage should include an analysis and evaluation of whether all the principles are fulfilled, that is to say, if the needs that contain these principles proposed in the initial stages, are covered, and if so to pass to the next stage of manufacture, checking of quality and launching in the market.
In parallel with the stage of design and development, the instruction manual and product packaging should take into account the same types of needs as the product itself, in terms of usability adapted to all the users.
In this sense, Dong, from the British ID perspective, proposes a model which integrates the checking and evaluation stages as interstages, which guarantees that the parameters of inclusion are taken into account. The model is based on the users' needs, just as it is fostered from Human Factors, to identify what would be the ideal design before developing the requirements. Once the requirements have been developed, they should be analysed and evaluated again, and if the requirements are satisfied, then the design and development of the product would be the next steps. Subsequently, the developed product should enter into a third stage of evaluation until, finally, it is considered an acceptable product from the perspective of ID [Dong 2003 b]. Obviously, there are also other state of the art systems of evaluation of products which are for example, centred on the mechanics of the product, such as the one created by Gooch et al. for the design of a manual wheelchair based on quantitative methods and kinetic and kinematic models. This point of view is especially useful for calculating wheelchair propulsion parameters [Gooch et al. 2008], although these sorts of systems of evaluation do not integrate, specifically, the use by indirect users as a basic principle to be included in the conceptual design stage.
The reason that the model by Dong is quite clear and appropriate as a synthetic model is that it summarizes the implementation of the principles of the UD in the design process. It is obvious that the stages of evaluation integrated in the overall model guarantee that the implementation of the

philosophy of UD is being satisfied or otherwise the product will not be accepted as a valid one. Therefore it is a useful guideline for designers.

5.1 Proposal of evaluation model of products under the perspective of the UD principles

According to Dong's proposal, an evaluation model of products from the perspective of the UD paradigm can be stated. Essentially, it consists of a model that integrates the seven principles of UD as questions in order to filter out possible unsuitable results during the analysis of the product.
In summary, the model starts from a first analysis stage and a second evaluation stage with the object of creating the definitive product: that is to say, an acceptable object from the UD perspective [Figure. 1].

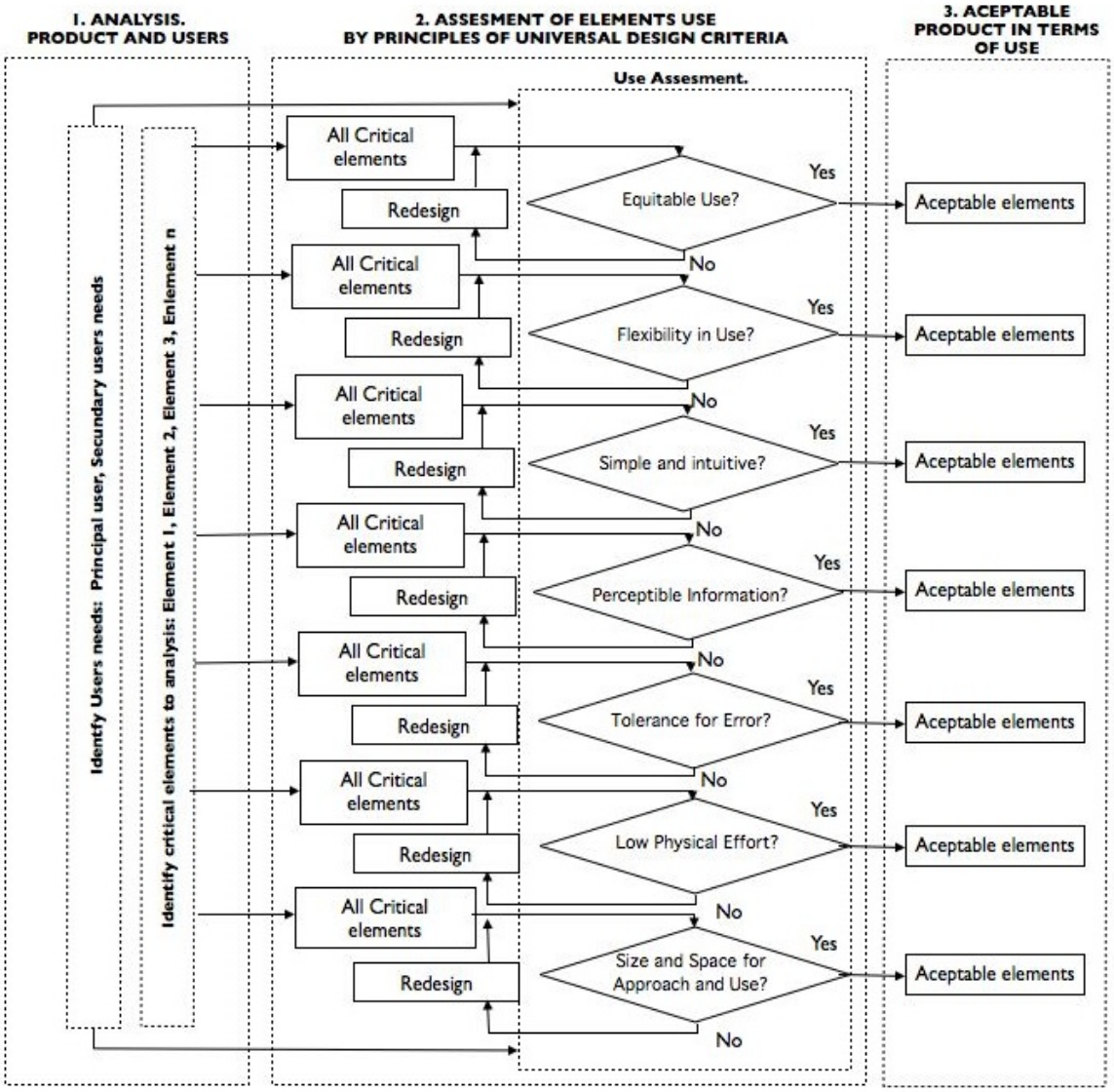

Figure 1. Scheme of analysis model of products under the discipline of UD (own elaboration)

In the first stage, the users must be identified as well as the critical elements of product use. In this identification of the users, we have to pay special attention, according to Hoffman's recommendations [Hoffman 2005], to the indirect users of the product, that is to say, those who interact with it although they do not have a continuing experience with the device. Moreover, in this initial stage, the object must be analysed, systematically, in order to break it down into functional units or critical parts from the perspective of use. These parts will serve, later on, as critical elements for the evaluation.

In the second stage, the evaluation of the critical elements in the first stage is carried out. This evaluation consists, firstly, of a filter of seven questions regarding the use. These questions correspond to the seven principles of UD. All the critical elements must also be understood contextualized in the overall view of the product and not in isolated units: each part affects the whole. If the critical element overcomes the seven questions, the product will be considered acceptable from the point of view of the use. If the critical element does not overcome some of the questions, it will have to be redesigned until it fulfils the requirements which are posed in the question. When all the elements have passed the evaluation stage, the product is considered as an acceptable one from the point of view of UD since all the parts related to the use fulfil the requirements of the seven principles of UD. However, it is also necessary to evaluate the economic and sustainability impact of the design before its total acceptance for its launch in the market.

The recommended methodology, in the evaluation stage, should combine quantitative methods together with qualitative ones, in harmony with Juratovac's recommendations [Juratovac 2004] regarding the use of ethnographic methods, such as participatory observation for the innovation of products. Some items of the seven principles of UD can be measured, such as the items which make reference to the perceptible information, tolerance for error, low physical effort and adequate size and space for approach and use. In this case for example, a time to task or questionnaire designed to produce the results in quantitative terms allows us to achieve a reliable result but with a rigorous application of qualitative methods it is possible to achieve correct results as well.

In spite of the above, some of the principles of UD cannot be measured through quantitative methods. In this case, a group of experts, taking into account direct and indirect users, must use anthropological methods, such as direct and participatory observation. Using qualitative methods it is possible to know if the critical elements of the product are acceptable for an equitable, flexible, simple and intuitive use.

5.2 Example of an application of a model of evaluation under the perspective of UD. Real case

A brief example allows us to recognize the possibilities of this model of evaluation in which the methodology of participatory observation is essential:

5.2.1 Description of the product analysed

The object analysed is a wheelchair to be used at home [Figure 2]. Its weight is 21 kg, width 53 cm, length 106 cm and height 96 cm. It has four wheels of 125 mm in diameter, which cannot be propelled by the user who needs the assistance of a secondary (indirect) user [Hoffman 2005]. The armrest and footplates are removable. The chair has a brake system integrated in the back wheels, which can only be used by the assistant or secondary user. A manual system to push the wheelchair is located on the back of the chair. The position and angle of the backrest and the seat are not adjustable.

The wheelchair is broken down into the following critical elements: a steel structure composed of a padded seat and detachable back, and system of movement and propulsion for the assistant; brake system integrated in the back wheels; removable armrest system and removable footplate system.

Figure 2. Wheelchair with armrest and footplates

5.2.2 Description of the users

The principal user is an elderly person, 80 years of age, afflicted with arthritis, especially intense in the knees, who has a significant medical history [figure 3]. The user is not able to walk normally because of the arthritis, thus he needs assistive devices in order to recover his mobility and independence. He is 180 cm tall and weighs 81 kg. The user is not strong enough to propel the chair on his own. The tasks to be conducted on the wheelchair are varied; among the most critical ones are the transfer to the bed and water closet, which he needs assistance with. Other users of the wheelchair are the persons assisting the main user: his wife, family and, at times, a physical therapist or other clinical assistants, such as ambulance drivers, nurses, etc. These users are named secondary users, although their relation with the product is essential [Hoffman 2005].

Figure 3. Sequence of moving the user to the couch with the assistance of an indirect user to immobilize the wheelchair

5.2.3 Analysis and evaluation of the elements of the wheelchair under the principles of UD

Only the most relevant details are going to be analysed in this evaluation. That is to say, the ones that, after the evaluation, will need to be redesigned in accordance with the general functionality of the wheelchair. The users' opinions and the participatory observation of the users' relationships with the product have been taken into account in the analysis.

1. The question relative to the first UD principle, that is, whether its use is universal, can be affirmatively answered because any user can use it, but not any user can propel it and carry out the assistance. This last requires a certain level of physical condition. In any case, the assistance is to be performed by indirect users, although it is an important task.
2. In the second question, relative to the flexibility of use, it is possible to say that the wheelchair presents certain flexibility due to the removable elements such as the footplates and armrest. In general the wheelchair has also been used in different contexts such as home, urban areas, watching TV and, also, to travel to the bed, sofa or bathroom. Although the wheelchair is not adjustable, as will be seen in the seventh question.
3. In the third question, it is possible to affirm, from the participatory observation, that the wheelchair is intuitive and simple to use.
4. In the fourth question, relative to the perception of the information, the wheelchair does not present information. Therefore, in this case, we do not proceed with the question. From of the point of view of the semantics of the object, the functions associated with the different components are clearly perceived. The removable elements are used in an intuitive way.
5. In the fifth question, relative to error tolerance and safety, the wheelchair presents certain problems. It may be impossible for some users to use the brake system properly, which could result in errors and consequently safety problems related to the stability. Only the back wheels are fitted with brake system. All four wheels revolve and, although the brake system is

activated, there is always a certain movement which makes it difficult for the assistant to transfer the user and drive the chair.

6. In the sixth question, relative to physical effort, the brake system is the element that merits the most criticism. The direct observation evidence is that some secondary users are not able to activate the brake system because they need to use their feet to activate it and a certain ability and strength is needed to do it. Some secondary users need to get into a difficult position in order to use their hands, instead of their feet, to activate the brake system [figure 4].
7. In the seventh and last question, relative to size and dimensions for reach and use, the chair allows only one position. Although the anthropometric dimensions are the ones recommended for these cases, the steel structure with padded seat and backrest does not allow adjustment. The backrest does not have lumbar support and it is not adjustable either. The principal user does not wish to stay in the chair for long periods of time, for example, while watching TV, because the chair is not comfortable. Moreover, getting the user up out of the chair with assistance when carrying out rehabilitation exercises is difficult due to a steel bar located under the front part of the chair. The steel bar prevents the user's feet from moving backwards but without this movement, it is more difficult to stand the user up. That is to say, there is no free space under the seat. The dimensions are correct for moving around and for transfer although the size of the wheels is not suitable for overcoming small obstacles in the home, such as rugs.

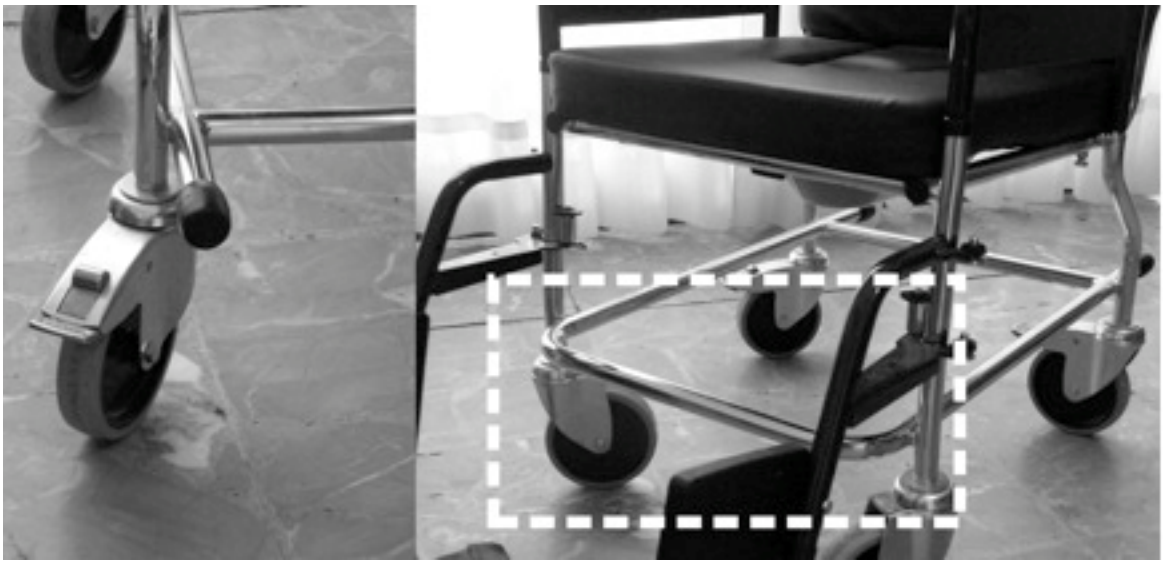

Figure 4. Brake system of the wheelchair and steel bar under the seat

5.2.4 Proposals for improvement. Elements to be redesigned

As has been seen in the previous phase of analysis some of the critical elements are not acceptable from the perspective of the UD principles. These elements are the brake system and the steel structure of the chair. The first does not fulfil principles five and six, and the second is not acceptable according to the seventh principle.

A brake system that could be activated by the users' hands without as much physical effort as the current one, which is activated by the feet, would be sufficient in order to avoid the problem related to the brake system. It would be necessary to fit the four wheels with the brake system in order to improve the stability of the chair. There is no need for four rotary wheels. The back wheels could be fixed. This would be an improvement in connection with the safety and comfort of the driving.

On the other hand, the steel structure is not adjustable. It would be necessary to make it adjustable in order to adapt it to different sized users. This would improve its comfort especially when it is used for extended periods. In addition, the steel bar located under the seat blocks the seating of the user and

makes his or her rehabilitation exercises more difficult. The bar could be moved back in order leave some free space under the seat and to allow the user to stand up with some assistance.

6. Conclusion and Further Work

The application of practical models of evaluation, such as the one proposed, allows us to make Dong's general model [Dong 2003b] more specific. This model particularly emphasizes the phases of analysis and evaluation.

Also it is interesting to indicate the possibilities opened up by using systems of evaluation based, overall on qualitative methods such as observation and UD's philosophy.

As we have seen in the results, this proposed model is useful in identifying unacceptable elements in the experience of all the users who interact with the product, following Hoffman's recommendations [Hoffman 2005]. The model enables us to detect incorrect applications of the principles of UD in order to re-design objects or to analyse the validity of the parts of a product from the point of view of its use. But the model has not been designed to create new solutions to improve the critical elements that are not acceptable under the principles of UD. It only identifies these elements.

The application of the model shows how the principles of UD can affect the process of product design in the case of a wheelchair. These principles can be useful for evaluating the product and redesigning the parts that have been created without taking into account the UD philosophy.

As we have seen the UD paradigm can be integrated into the process of product design, specifically, in the stage of conceptual design, as a means of evaluation.

In future studies it would be desirable to analyse more types of products orientated to people with disabilities in order to detect gaps and to improve the consistency of the proposed model including, for example, other quantitative methodologies as well as to study the cohesion between functional critical elements of the object. Therefore, this proposed model should be tested in other products in order to validate the model. At the same time, it would be useful to try to integrate creative techniques in order to help propose solutions for unacceptable parts.

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