A UNIVERSALIST STRATEGY FOR THE DESIGN OF ASSISTIVE TECHNOLOGY

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ABSTRACT

Assistive Technologies are specialized products aiming to partly compensate for the loss of autonomy experienced by disabled people. Because they address special needs in a highly-segmented market, they are often considered as niche products. To improve their design and make them tend to Universality, we propose the EMFASIS framework (Extended Modularity, Functional Accessibility, and Social Integration Strategy). We first elaborate on how this strategy conciliates niche and Universalist views, which may appear conflicting at first sight. We then present three examples illustrating its application for designing Assistive Technologies: the design of an overbed table, an upper-limb powered orthose and a powered wheelchair. We conclude on the expected outcomes of our strategy for the social integration and participation of disabled people.

Keywords: Universal Design, Assistive Technologies, Niche marketing.

1. INTRODUCTION

More than 500 million people around the world are considered as disabled because of a mental, a physical or a sensory deficiency. Many historical (e.g. Second World War disabled persons) and sociodemographic factors (e.g. ageing population, medical development) change the look we take at disabled people. Beyond cultural differences between countries, care policies in Europe or in the United States convey a real concern for improving life conditions of people with disability and aim to favor their social participation: for example right for the compensation of disability, integration into education and work, accessible environment, products and services (Coleman *et al.*, 2003; Borg *et al.*, 2009). To achieve an accessible society, disabilities must be taken into account as soon as in the planning and design of equipments or the organization of activities: this is the principle of Universalist philosophies like Universal Design. In parallel to such movements, the technologies for health and autonomy have developed and aim to meet the same needs.

Ergonomists have their say in disability management and Assistive Technology design. From the incorporation of Ergonomics in rehabilitation projects (Kumar, 1992), the ergonomic approach has been used for example in job analysis (Chi, 1999), identification of appropriate employment for disabled people (Shrey & Breslin, 1992; Chen & Ko, 1994), and adaption of users' home and workplace (Eriksson & Johansson, 1996). Ergonomics also participates in the design and prescription of Assistive Technologies, mainly by providing anthropometric data accounting for specific body structure of the disabled (Nowak, 1996; Sims *et al.*, 2012), kinematic or kinesiologic analyses of activities (Ait El Menceur *et al.*, 2008; Sangelkar *et al.*, 2012), capabilities databases (Porter *et al.*, 2004; Tenneti *et al.*, 2012), collection of functional needs (Cowan & Khan, 2005) or deficiency simulation (Rousek & Hallbeck, 2011). Ergonomics also provides evaluation tools for products and environments developed within the framework of Universal Design (Beecher & Paquet, 2005; Afacan & Erbug, 2009; Gray *et al.*, 2012) as well as design guidelines (Nisbet, 1996; Abascal & Nicolle, 2005).

The multiple benefits of combining technological (e.g. market, product, process) and ergonomic requirements in a concurrent design approach was repeatedly shown in the literature (Mital, 1995; Lee *et al.*, 2001; Kim *et al.*, 2008; Battini *et al.*, 2011), despite some designers' resistance who consider that Ergonomics should be cared of at use site rather than in the design process (Kim *et al.*, 2008). For this reason, we propose in this paper a wider approach of ergonomic intervention for the design of Assistive Technologies, including functional needs, accessibility, social acceptability, but also cost-effectiveness and marketing concerns.

2. ASSISTIVE TECHNOLOGIES

Assistive Technologies include a large number of products, systems and services which aim to compensate for a loss of autonomy, in the medical and social domains (Newell, 2003). Assistive Technologies aim to provide a support to disabled people in their everyday life and for their social participation. However, some critical aspects of Assistive Technology industry in Europe were emphasized (Vernardakis *et al.*, 1995), in particular with regard to innovation. The following limitations were notably identified: the characteristics of companies (e.g. size, know-how, techno-centered approach); the oriented competition (e.g. segmentation in accordance with disabilities) or quasi-monopolistic competition; the influence of the third party supporting parts of the costs of Assistive Technologies (e.g. health insurance, power of associations); the lack of knowledge of end-users' needs (needs related to using and purchasing Assistive Technologies). Specialized or medicalized products also bear the risk of stigmatizing their users (Coleman *et al.*, 2003) because they tend to emphasize the disability in the person's social identity. Finally, although the global volume of the market may seem important, particularly if elderly people are included, it appears to be divided into numerous niches, segmenting the market as a function of users' disabilities (motor, sensory or cognitive disabilities) or functional impairments.

Because it is impossible to imagine a single product suitable for everybody, there will always be a market for specialized products adapted to individuals with special needs. However, in a Universalist approach, one could imagine that Assistive Technologies could broaden their target population to people without known impairment (Newell, 2003). This change in market position would prompt the designers to address the current limitations of specialized products (Vernardakis *et al.*, 1995; Deloitte & Touche, 2003): the lack of adequacy between demand and supply (e.g. user dissatisfaction, reliability problems, stigmatizing products), a specialized distribution network (in particular in France and some European countries) which involves multiple profit margins impacting the price of the product and the difficulty to maintain product service, and difficulties (length and cost) for the user to purchase the product.

The remote control remains one of the most cited examples of a technological innovation coming from the field of disability, but Universalist movements have provided many other examples of products, equipments and pieces of architecture that facilitate and improve everybody's life (Keates & Clarkson, 2004): domestic appliances designed for people with strength or dexterity impairments (e.g. Oxo products, Panasonic's accessible washing machine), urban architecture (e.g. curb cuts, inclined planes) improving accessibility for people using a wheelchair, but also for parents using a baby stroller or travelers pulling a suitcase, and public transportation (e.g. Amtrak Acela Express, with all interior spaces accessible, improved signaling means, and accessible platforms).

These examples may suggest that Universalist design principles are easy to apply. Yet examples of unsuccessful universal products also exist and show that usability is sometimes insufficient to convince the mass market: for example the Toyota Raum car with improved accessibility, which was designed and marketed for elderly people, was perceived as stigmatizing and did not find its market (Macdonald, 2006). Conversely, some products initially designed specifically for disabled people were transferred to mass market, for example the Big Button phone which was intended for elderly people but actually enables everybody to dial quicker (Clarkson *et al.*, 2003). A product should not be defined only for use and production, but care should also be taken to its semiotic and perceived functions. Beyond usability, social acceptability or societal value are key features for market success.

System acceptability relies on two criteria (Nielsen, 1993): functional acceptability (e.g. usability, usefulness) and social acceptability which refers to the image of the product, its esteem value. Universalist movements usually add the accessibility criterion to functional acceptability (Clarkson *et al.*, 2003). Indeed, usability being defined for a specified user sample and a specified context of use, accounting for accessibility may enable designers to extend the functional acceptability to a maximum of persons.

Should all kinds of products be designed with a Universalist approach? Domestic appliances, urban architecture and public transportation are good candidates because their use potentially concerns *everybody*. This statement does not apply to other kinds of products, for example professional devices (e.g. a machine tool), whose use would be restricted to a certain kind of operators, with corresponding skills and training. Such tools should be accessible to a disabled employee, but for example it is not necessary to address children's needs in their design since these are not supposed to be a working population. Likewise for the design of driving controls in a car, it is not necessary to integrate children's and blind people's needs since today these populations are not allowed to drive. Therefore the application area of Universal design may be related to the volume of population potentially concerned by using the product. In this respect, to what extent are Assistive Technologies eligible to Universal design? In the remainder of the paper, we will focus on three examples of Assistive Technologies: an overbed table, which is an adjustable device enabling users to have meal or to work in a bed, in a wheelchair or in an armchair; an upper-limb powered orthose meant to assist everyday movements for people suffering from shoulder or elbow impairments but with residual muscular capacities in the hand; and a powered wheelchair. Is Universal design relevant for these three products? Or do they definitely belong to the category of niche products? In the following section, we will first characterize niche marketing and niche products, before formalizing Universal design (section 4), and present our own approach (section 5) to be applied to our three example products (section 6).

3. Niche marketing

Industrial competition and market diversity have resulted in the emergence of new marketing approaches such as niche marketing. To cope with this evolution, companies must be more and more reactive and find new markets with the following characteristics (Dalgic & Leeuw, 1994):

- A sufficient size to be cost-effective,
- No real competitors,
- A growing potential,
- Customers with sufficient income,
- Customers that need a special consideration,
- The possibility to develop customer loyalty,
- The possibility for a company to easily enter the market with its expertise.

Such characteristics can be considered as inherent to niches, since a niche market can be defined as a narrow segment corresponding to a precise target population with special needs, poorly exploited and associated to a specialized service or product (Kotler, 2003; Parrish, 2003; Dalgic, 2006). Niche market is also defined by a low number of niches (Kotler, 1991; Dalgic & Leeuw, 1994) and bears a strong potential since most of mass markets come from niches markets (McKenna, 1988; Dalgic & Leeuw, 1994; Parrish, 2003). In this respect, there seems to be two main marketing strategies (Chalasani & Shani, 1992; Dalgic & Leeuw, 1994; Parrish, 2003): A top-down approach in which segmentation leads to the division of a broad market in smaller segments; A bottom-up approach which starts from the needs of a small group of customers with the aim to be extended to a larger population in a long term (Fig. 1). An example of the top-down approach can be found in Coca-Cola, which was long available in only one flavor and one type of bottle, and recently launched new products like Coca-Cola

Zero or Cherry Coke. The bottom-up strategy corresponds to a pull-approach (pulled up by customers needs; Shani & Chalasani, 1992): its main advantage is a better knowledge of the customer, due in particular to the small segment size. The customer is expected to be more satisfied and therefore more loyal (Stanton *et al.*, 1991; Shani & Chalasani, 1992; Parrish, 2003; Dalgic, 2006). For example this is Apple's main strategy to provide the mass market with niche services and technologies (e.g. customized applications available on the web or voice recognition).

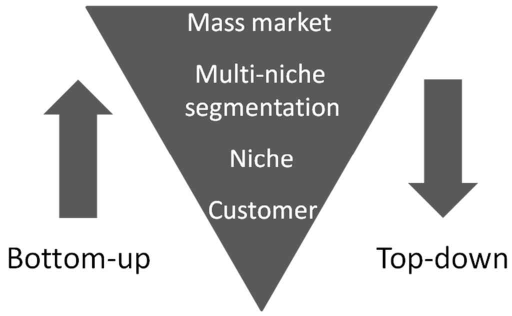

Fig. 1. Bottom-up and top-down approaches in niche marketing.

According to Kotler (1991), the key notion in niche marketing is *specialization*: special localization, special needs, special products, special value for money, special service, special distribution channel, etc. To enter a niche market, a company should be capable of meeting special requirements. Niche marketing enables companies to differentiate along five main criteria: product, customer service, distribution network, communication, or price. However, creating a business on a single source of differentiation is economically insufficient, while a differentiation on the five criteria is quite impossible. Each company has to find the successful combination in accordance with its target niche (Linneman & Stanton, 1991).

Are Assistive Technologies a niche market? This is a highly segmented market actually, where competition is quasi-monopolistic. However, even if disabled people have special needs, it should be noted that their needs remain poorly known and poorly satisfied, and that Assistive Technologies are expensive although disabled people are low-income customers. Customer loyalty in the field of Assistive Technologies results from a tradeoff between cost and service with the idea that *a dissatisfying product is still better than a lack of autonomy* -- indeed many assistive devices are used despite multiple usability problems (Bühler, 1996; Hamill, 1996). Therefore, this market partially meets the criteria of a niche market and does not benefit from all the advantages of this kind of business. In particular, the *growing potential* of Assistive Technology market is not self-evident to industrial stakeholders despite the aforementioned favorable political and socio-economical context.

4. UNIVERSAL DESIGN

The concept of "Universal Design" originates in the movement for the rights of disabled people in the 90's in the USA, for example the American with Disabilities Act which set the first principles of accessibility and adaptability (Keates *et al.*, 2000; Conte, 2004; Plos & Buisine, 2006). Afterwards, spurred on by activists and architects (e.g. Ron Mace in the USA, Selwyn Goldsmith in the UK), the "Barrier-Free Environment" movement appeared and emphasized the importance of centering the design process on users' needs (Keates *et al.*, 2000). There were many consequences on town planning and built environment like curb cuts on sidewalks, tactile paving or textured ground, automatic revolving doors, etc. (Clarkson *et al.*, 2003). In Mace's definition, Universal Design seeks to encourage products and environments that are more usable by everyone with no adaptation required. It is intended for people of all ages, sizes and capacities in order to simplify use with no extra cost or at low cost (Vanderheiden, 1997; Laroche, 2004). Universal Design or "Design For All" aims to conciliate two approaches that seem conflicting (Brangier & Barcenilla, 2003; Conte, 2004): designing products for mass market, intended for average, ordinary, healthy users; and designing specialized or dedicated products (like Assistive Technologies) intended for people with disabilities. Seven principles mainly based on the notion of usability were defined for Universal Design. They are used to evaluate existing products and environments, guide the design process and train designers and users (Preiser & Ostroff, 2001). Below we report the principles and examples from the Center for Universal Design of North Carolina State University:

1. Equitable Use: The design is useful and marketable to people with diverse abilities (for example power doors make visiting public spaces easier for all users; e-mail makes communication easier for everyone, including people who have trouble communicating via phone).
2. Flexibility in Use: The design accommodates a wide range of individual preferences and abilities (for example large grip scissors accommodates use with either hand and allows alternation between the two in repetitive tasks).
3. Simple and Intuitive Use: Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or education level (for example public emergency stations utilize recognized emergency colors and a simple design to quickly convey function to passers-by; intuitive ATM interfaces allow use without instruction or training).
4. Perceptible Information: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities (for example small bumps on a cell phone keypad tell the user where important keys are without requiring the user to look at the keys).
5. Tolerance for Error: The design minimizes hazards and the adverse consequences of accidental or unintended actions (for example the "sequential trip" mechanism on a nail gun prevents accidental firing when the tool is not pressed against an object).
6. Low Physical Effort: The design can be used efficiently and comfortably and with a minimum of fatigue (for example door lever does not require grip strength to operate, and can even be operated by a closed fist or elbow).
7. Size and Space for Approach and Use: Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility (for example wide gates at subway stations accommodate wheelchair users as well as commuters with packages or luggage).

There are many Universal movements around the world (e.g. in the USA, Japan, Europe). "Design For All" is the European version of Universal Design with a focus on Information Technology. It is supported by the European Design for All e-Accessibility Network (EDeAN) whose goal is to set some European design guidelines (Clarkson *et al.*, 2003; Laroche, 2004). "Inclusive Design" arose in the UK from collaboration between companies, designers, researchers and teachers. The aim is to identify best practices enabling designers to meet special needs from disabled people while developing products for the mass market. Inclusive design requires taking minorities into account in the design of products intended for everyone (Keates & Clarkson, 2004). The goal is to include a maximum of users without compromising user satisfaction and company profits. Inclusive design does not focus on a specific target (e.g. elderly or disabled people) but tries to determine the number of persons excluded on a social basis. The process consists in evaluating the capacities required for using a given product or service, and redesigning it (Clarkson *et al.*, 2003; Keates & Clarkson, 2004). Finally "Transgenerational Design", developed by James Pirkl's team, emphasizes a Universalist approach on a market rather than a functional standpoint, with no direct relation to the analysis of elderly people's capacities (Pirkl & Babic, 1995; Clarkson *et al.*, 2003).

Studies from the Cambridge Engineering Design Center (Goodman *et al.*, 2006) and Trace R&D Center of University of Wisconsin (Trace R&D Center, 2000; Vanderheiden & Tobias, 2000), show that to most of companies, Universalist movements are perceived as interesting on a social viewpoint, but difficult to apply because of an increase in development time, a delay in product launch and related extra costs. Some companies find it too complicated to include disabled people and health institutions in the design process with regard to the industrial constraints they have to face. Finally, the lack of aesthetics in products and the detrimental effects of a "product-for-disabled" label were also mentioned, although conflicting with the first principle of Universal Design (which requires avoiding stigmatization and adopting an appealing design). The possibility to sell products and services to disabled people is not a sufficient motivation, in particular for big companies, which prefer to leave this niche to small and medium sized enterprises. However, the potential of Universalist movements to help improve products' ease-of-use for everyone appears more attractive to them, even if they ask for tangible signs of success to be convinced. Indeed some industry stakeholders may suspect that Universal Design impoverishes product functions (Chan *et al.*, 2009) or proves unprofitable from a socioeconomic point of view (although the opposite was shown in the field of transportation, Odeck *et al.*, 2010; Fearnley *et al.*, 2011). Laws are recognized by companies as an effective factor to favor the integration of special needs in product design, provided that they are formalized as target results rather than process constraints (which are considered as inhibiting for innovation). Companies also need easy and well-targeted methods for their domain to help them apply a Universalist approach. The training of designers is viewed as necessary, and should ideally be integrated to university programs or be as short and economical as possible for professional designers.

5. The "EMFASIS" framework

The state of the art of Universalist movements shows that there are two main approaches to design products adapted to everyone (Fig. 2): An adaptive or top-down approach which consists in designing specialized products and extending them afterwards to other kinds of users; and a proactive or bottom-up approach to design products intended for the maximum of users (like Inclusive design). Note that top-down or adaptive Universalist approach corresponds to the bottom-up approach in niche marketing: it consists in designing specific products that can be extended to a broader population (i.e. market extension in niche marketing). To achieve a successful niche strategy, the Universalist adaptive design process should therefore address the special needs of a given segment of disabled people with a differentiation plan for subsequent market extension.

Fig. 2. Top-down and bottom-up approaches in Universal design.

A *front-end strategy for market extension* therefore seems central to break down the existing barriers in Assistive Technology design and achieve innovation: by removing the issue of the small market size, it may enable companies to improve their product's quality (e.g. adequacy, reliability) while reducing its price. Furthermore, designing the product straightaway for the mass market, anticipating its future extended form, should help designers produce an aesthetic, socially-acceptable design, subsequently removing the stigmatization issue. Finally if these conditions are met (functional acceptability, acceptable price and design), the product may be able to enter mass distribution networks.

Our approach is called EMFASIS (Extended Modularity, Functional Accessibility and Social Integration Strategy), and can be summarized with the following design principles:

Extended market: This is the first step and the cornerstone of our strategy. Anticipating market extension for a specialized product enables the team to prepare the ground for the "growing potential" necessary for a successful niche. It is also in line with the adaptive approach of Universal Design which results in the first principle ("equitable use"). Of course it is not straightforward, particularly for Assistive Technologies, to find usefulness for people who do not belong to the initial target (e.g. can an upper-limb powered orthose be useful to able-bodied?). It requires a shift in how designers view their own product; this is why it is **one of the most creative steps of the EMFASIS framework**. This step is also likely to orient the search for business partners (e.g. providers, sub-contractors, distribution network). In this respect, for reaching Universal Design, it may be recommended to favor partners that are used to address the general market rather than disabled users. Such a choice may help designers radically change their approach to Assistive Technology.

Modular design: Universal Design does not imply to achieve a Universal Product. It is much more technically feasible to design a range of products instead of a single one aiming to meet all (sometimes conflicting) requirements. This range of products should be associated to **a single aesthetic identity** (therefore avoiding stigmatizing products for disabled people) but nonetheless **satisfy a variety of needs**. Imagine for example a set of saucepans and frying pans of different diameters, depths and coatings: they meet different needs and there is no stigmatizing model that could be labeled as a "product for disabled people". This is the kind of design solutions we wish to achieve. Ranges can also be designed with more complex types of products, for example cars. The same car can be available in a family model, in a coupé model, in a convertible model, with different optional extras, etc. For such variety to be economically viable, manufacturers use modular design (Gu & Sosale, 1999; Marshall & Botterell, 1999): this method consists in defining a product architecture composed of interchangeable subsystems in order to increase the number of models and the number of functions (Starr, 1965; Holmqvist & Persson, 2003). Some components are common to all the models, others are specific. This method offers more flexibility to meet new needs or to integrate new technologies, by creating new products with new combinations of components. It is also cost-effective and time-saving (Salhied & Kamrani, 2008).

Functional acceptability: To reach this criterion, the product must be usable and useful, which requires a thorough needs analysis. However, this is not always easy since some users, particularly disabled people, tend to censor their own needs, being usually content with what they have. Hence we recommend using **several repeated methods to survey users' needs**. One can meet, observe and interview disabled people; one can also involve specialists of disability (e.g. occupational therapists, physiatrists) in the design process. Contacting associations is also helpful to find users and specialists, and organize the meetings.

Accessibility: This criterion corresponds to the extension of the abovementioned functional acceptability to several populations. In our process it is anticipated from the first step ("extended market") and further investigated through needs analysis targeted to different kinds of populations. Of course it also has to be checked all along the process, together with functional acceptability.

Social Integration: The image of the product, its aesthetic features and social values, its integration to the social and societal environment, is addressed through several methods. It is first anticipated during the "extended market" phase which is supposed to define the product's dominant category (e.g. leisure, transportation, professional, domestic) and the related stylistic codes. Then, modular design imposes to keep the global style constant on all product models and versions, with marginal personalization (e.g. color, motif). All these requirements must be implemented by a stylistic designer, who is a key actor of our strategy. The lack of stylistic designer has been the cause for many stigmatizing designs in the field of Assistive Technology and their detrimental consequences (e.g. rejection of products, feeling of exclusion associated to the use of some products).

These design principles should not be viewed as a process, with a specified sequence, since they should ideally be addressed concurrently. For example Accessibility is interdependent with Extended market and Functional acceptability; Modularity implements a technical solution to the specifications collected through Extended market, Functional and Social acceptability, and Accessibility. In the following section we will present three design projects we have applied the aforementioned EMFASIS framework to: the design of an overbed table, an upper-limb powered orthose and a powered wheelchair.

6. Application projects

In this section we describe three projects along the EMFASIS framework and show how each step was addressed.

6.1. The Adap'Table project

The goal of this project was to design an overbed table that would be usable at home without stigmatizing its users. Indeed existing models all look cold and evoke the hospital, hence users are reluctant to buy them although they would need such a device for their everyday life at home, to work or to have meal in their bed, armchair, wheelchair, etc.

Extended market: For this product, market extension was not an issue since it is easy to find mass market for an adjustable multifunction table: in particular for a small space like a student room where the same piece of furniture can be used for working, eating, as a coffee table, an ironing board or a bedside table. Regarding business partnership, the process was conducted with no specific partner but the final design was proposed for industrialization to Ropox, a Danish manufacturer accustomed to Universal Design.

Modular design: Based on the orientation chosen for market extension, on the needs analyses for functional features and style (developed below), we designed an architecture composed of (1) the base of the table with a manual and an automatic version to comply with the variability of capacities, (2) storage components adapted to different lifestyles (with e.g. an optional component to accommodate a computer) and (3) customizable boards enabling users to personalize the style and functions of their table (presence of a surround, integration of a screen or tactile screen, possibility to pivot or rotate the board…).

Functional acceptability: Our key target group remains that of disabled people living at home and of their professional or family helpers. Therefore needs analysis was surveyed with 14 disabled users (people with muscular dystrophy, elderly people, patients in functional rehabilitation, and children in pediatrics), 20 helpers and 8 potential users from the mass market (students). We used a questionnaire addressing their habits regarding the use, cleaning, tidying of tables, the problems encountered with existing products, etc. This analysis was completed with field observations and interviews in a hospital. The results mainly emphasized the lack of aesthetics and lack of storage means in existing products.

Accessibility: Accessibility was addressed by the involvement of different kinds of populations in the design process and the collection of their specific requirements on both functional and social criteria. We involved people using a wheelchair (with specific requirements for access and adjustment of the table), people with temporary and permanent functional impairments, able-bodied people, and users of different ages (children, students, elderly people).

Social Integration: The project was leaded by an industrial designer with a multidisciplinary team (mainly composed of engineers, ergonomists and designers). We analyzed the perception of existing products and the definition of an ideal aesthetic profile for the future table by means of a semantic and emotional analysis (Mondragon *et al.*, 2005; Bouchard *et al.*, 2009). Following the example of the aforementioned needs analysis, we surveyed disabled users, helpers and students for this stage. A second iterative cycle was conducted to analyze several shapes, designs and ambiences for the future product. It resulted in the selection of a concept built around a slender vertical board, to be joined up to the base and to receive the storage components and the horizontal board(s) (see Fig. 3). This general shape was evaluated as dynamic and as marking a break with the look of medical overbed tables. Moreover, this vertical area provides additional room for personalization by receiving a printed film between two transparent plates.

Fig. 3. An existing overbed table (left) and our design (right, exploded view).

6.2. THE TEASE PROJECT

This project is called TEASE for "Transparent, Easy, Adaptable and Soft Exoskeleton". It was aimed to design an upper-limb powered orthose to assist everyday movements for people with shoulder or elbow impairments but with residual muscular capacities in the hand. Existing orthoses are imposing, heavy, unintuitive to control and do not cover users' needs.

Extended market: Market extension for this product was not so easy since it is a highly specialized device. However, with technological monitoring and a bit of creativity we found out several fields that could be interested in a technological transfer: military equipments (enhancing infantryman's capacities), handling of heavy material in many domains (dock work, furniture removal, goods packing…), virtual reality (haptic systems, force feedback systems), teleoperation, physiotherapy, body building, etc. We subsequently could gather a consortium composed of a partner in the defense area (Thales Group), a partner in the field of virtual reality (CEA LIST), an academic partner specialized in robotics (LISV-University of Versailles) and a manufacturer of assistive technologies (TechInnovation) to design the TEASE system. Students in industrial art (ENSAAMA) were also involved in stylistic design of the system.

Modular design: We designed a customizable system allowing the activation of degrees of freedom and the specification of movement amplitude in accordance with each user's needs and capacities. For example wrist pronosupination, which is involved in eating operations, was developed as an optional component specific to disabled people but unnecessary for other users of the TEASE system who do not use it for eating. Movement amplitude also had to be restricted for disabled users because of articular shrinkage associated to neuromuscular diseases. Finally several control interfaces were designed for meeting the requirements of each user population.

Functional acceptability: We collected the needs and requirements of disabled people while our partners were in charge of analyzing needs for their own application field. We interviewed 12 persons with muscular dystrophy and other motor impairments, 2 helpers and 5 occupational therapists; we also conducted field observations and kinesiologic analyses of movements like eating, brushing one's teeth, blowing one's nose, going to the toilet, opening a door, catching something, using a cash dispenser, etc. Kinesiologic analyses of gestures enabled us to accurately specify the degrees of freedom required for each joint of the system. This phase also enabled us to realize that none of the existing systems was capable of restoring wrist pronosupination, although necessary to lift a spoon to one's lips. We also surveyed residual motor capacities in order to specify the human-system interface for controlling the orthose.

Accessibility: As previously mentioned, three distinct user populations were considered in the design process: potential users in the defense area, in the field of virtual reality, and disabled people. Cohesion between these populations was addressed by gathering their requirements within a single specification file. Subsequently we defined the mandatory or optional nature of each specification, and accordingly distributed the functions onto common and specific components of the TEASE modular architecture.

Social Integration: Needs analysis from disabled people emphasized the noise and the look of existing products as major rejection criteria, before the weight, reliability problems or efficiency problems. Social acceptability therefore became a major design challenge for our project. To find relevant solutions we conducted a creativity session with disabled people, an occupational therapist, 2 technicians, an electronics engineer, a roboticist and an industrial designer. This session resulted in the selection of a design and a concept of seamless interface adjusting to user's arm like a glove (see Fig. 4) and using residual hand capacities to control the orthose. In the near future the TEASE project will end up with final evaluation and product certification.

Fig. 4. An existing powered orthose (left), our design (center, here mounted on a wheelchair) and the "glove" control interface (right).

6.3. THE WHING PROJECT

WHING stands for "WHeelchair Initiative New Generation" and consisted in designing a more effective, adaptive and inexpensive electrical wheelchair. The target price was 15 000 € for the same level of functionality as wheelchairs currently available for 25 000 €.

Extended market: From the very beginning of the project we considered our product as "a vehicle for personal mobility" instead of a wheelchair. Therefore we set up a partnership with a manufacturer from the transport sector (Matra Automobile Engineering, now Segula Technologies) and a generalist research consultancy (Bertin Technologies). This successful collaboration resulted in creating a company (DRK Mobility) for manufacturing and distributing the WHING 30% cheaper than existing products.

Modular design: The WHING general architecture includes all basic functions like standing up to a vertical position, lifting the seat to reach high up objects, adjusting all angles of the seat, clearing a 10-cm curb, and 30-km range. Home automation controls were also integrated into the armrests (e.g. infrared controls for turning on a light or a TV, opening a door or a shutter). Additional components include an "outdoor+" package with extra range, storage components, accessories, 18-cm obstacle clearing, and adaptation to driving controls of a car.

Functional acceptability: WHING's target population includes children, adults and elderly people with varying impairments. Users are functional tetraplegics (i.e. from minor to severe motor impairment affecting the 4 limbs) sometimes with progressive diseases (like muscular dystrophy or multiple sclerosis). Extension to elderly people without known motor disease was also considered since they already represent 33% of electrical wheelchair users in France. Needs analysis was stimulated by a creativity session gathering users and experts from many fields (assistive technologies, robotics, functional impairments, transport, and computer science) and formalized through a specification file. This first analysis was completed with a survey on 89 users and families throughout France. The results emphasized the need for a comfortable vehicle as effective indoor and outdoor. Indoor effectiveness corresponds to compactness and easiness to handle, while outdoor effectiveness mainly corresponds to obstacle clearing and battery's range. One of the main technical innovations we achieved in this project was to allow a 10-cm curb clearing, which is not possible with existing products. We also designed a unique modular basis (that we called "flower petals") for the chair to adapt to all kinds of morphologies and increase both static and dynamic comfort for users.

Accessibility: In the early stages of the projects (in particular for market extension and social integration) we imagined a small indoor-outdoor vehicle accessible to anyone (able-bodied, elderly, disabled people) but in later stages (from detailed design) we had to focus more closely on disabled users. Therefore, accessibility was primarily validated for the varying categories of the latter, and WHING was awarded an "accessibility and urban health" prize from the Advancity cluster, a major socio-economic institution in France.

Social Integration: The first step of social integration was addressed by collecting sources of inspiration from the general category of small vehicles (small cars, scooter, baby strollers, segways, bikes…). We subsequently generated avant-gardist designs in order to mark a break with regard to existing wheelchairs (see Fig. 5). The attractiveness of our concepts for the mass market were validated through a semantic and emotional analysis with 15 disabled and 15 able-bodied subjects, aged 20 to 61 years. However, as previously mentioned, the WHING project later focused primarily on disabled people and adopted a less challenging design. A minimal customization of the wheelchair was preserved (choice of colors, see Fig. 5, right), which is still better than existing products that are not customizable at all.

Fig. 5. An existing electrical wheelchair (left), one of our concepts (center) and the final WHING (right, here a blue model).

7. Discussion and Conclusion

In this paper we presented the EMFASIS approach, which is an integrated strategy for removing stigmatization issues from Assistive Technology. Among the projects we presented, the most complete application of EMFASIS may be the Adap'Table project, which achieved a breaking design, a customizable solution to better meet users' needs, as well as a real potential for entering mass market. This success may be related to the nature of the product (technically less complex and less specialized than the other examples we took) but remains representative of a large category of products that could easily become acceptable and useful to anyone. In pedagogical projects we addressed the cases of a reader that automatically turns the pages a book, and of a walking frame. Engineering students were highly motivated by these exercises and they successfully found out many ways for these devices to become useful to anyone. Our pedagogical goal was met since they easily perceived the potential of EMFASIS to improve social integration of disabled people.

The TEASE project constitutes an intermediary example of a product that proved to be useful in very different domains (defense and virtual reality) but did not really become “transparent” as we expected in the beginning of the project. Indeed the technology remains imposing, cannot be fully hidden (e.g. under users’ clothes) and does not resemble any “usual” technological device. Maybe in the future we will see people wearing robotic technology in the street and will not be able anymore to decide whether it is a sport device, a personal mobility device, or an Assistive Technology? Full social integration will be possible only at that time. This is why this project focused more on technological transfer than on extension to mass market.

Finally the WHING project was carried through to industrialization, which may partly explain why we could not bring the application of EMFASIS to its maximum. Indeed we were mostly involved in the early stages of the project and leaded to our industrial partners the steps of detailed design, production and industrialization. However we believe that EMFASIS contributed to some decisive orientations like the choice of the automotive partner and the collection of users’ requirements which resulted in technical and economical innovations.

The EMFASIS approach, which attempts to conciliate Universalist principles with niche marketing, goes far beyond traditional ergonomic approach: it is grounded on a front-end strategy for market extension, which, in our view, can be achieved only through technical solutions like modular design and a close attention to aesthetics and social acceptability. Many actors of the design process consider aesthetics as non-essential for Assistive Technology. However, today about 1/3 of Assistive Technologies are abandoned, some after 3 months, some after 5 years of use (Scherer, 2002), which shows that their acceptability should be questioned. We got to know disabled users and learnt how complex their relation to Assistive Technology could be. Assistive Technologies are desired because they help going on living, they restore functions, they also restore a relation to the environment, social participation and therefore self-esteem. However, they are also rejected at the same time because they underline the disability, they are associated to dependence and they degrade the image of the user himself. Using a stigmatizing product can be lived as a kind of exclusion and some persons will prefer staying isolated at home rather than going out with a stigmatizing device. It is now urgent to become aware of the powerful lever for integration offered by industrial design, so long as needs are met and technological reliability is ensured.

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9. REFERENCES

Abascal, J., & Nicolle, C. (2005). Moving towards inclusive design guidelines for socially and ethically aware HCI. *Interacting with Computers*, 17, pp. 484-505.

Afacan, Y., & Erbug, C. (2009). An interdisciplinary heuristic evaluation method for universal building design. *Applied Ergonomics*, 40, pp. 731-744.

Ait El Menceur, M.O., Pudlo, P., Gorce, P., Thévenon, A., & Lepoutre, F.X. (2008). Alternative movement identification in the automobile ingress and egress for young and elderly population with or without prostheses. *International Journal of Industrial Ergonomics*, 38, pp. 1078-1087.

Battini, D., Faccio, M., Persona, A., & Sgarbossa, F. (2011). New methodological framework to improve productivity and ergonomics in assembly system design. *International Journal of Industrial Ergonomics*, 41, pp. 30-42.

Beecher, V., & Paquet, V. (2005). Survey instrument for the universal design of consumer products. *Applied Ergonomics*, 36, pp. 363-372.

Borg, J., Lindström, A., & Larsson, S. (2009). Assistive technology in developing countries: National and international responsibilities to implement the Convention on the Rights of Persons with Disabilities. *Lancet*, 374, pp. 1863-1865.

Bouchard, C., Mantelet, F., Aoussat, A., Solves, C., Gonzales, J.C., Coleman, S., & Pearce, K. (2009). A European emotional investigation in the field of shoes design. *International Journal of Product Development*, 7, pp. 3-27.

Brangier, E., & Barcenilla, J. (2003). *Concevoir un produit facile à utiliser: adapter les technologies à l'homme* (d'Organisation ed.).

Bühler, C. (1996). Approach to the analysis of user requirements in assistive technology. *International Journal of Industrial Ergonomics*, 17, pp. 187-192.

Chalasani, S., & Shani, D. (1992). Exploiting Niches using relationship marketing. *The Journal of Consumer Marketing*, 9(3), pp. 33-42.

Chan, C.C.H., Wong, A.W.K., Lee, T.M.C., & Chi, I. (2009). Modified automatic teller machine prototype for older adults: A case study of participative approach to inclusive design. *Applied Ergonomics*, 40, pp. 151-160.

Chen, J.J.G., & Ko, M.D. (1994). The Disability Index analysis system via an ergonomics, expert systems, and multiple attribute decision-making process. *International Journal of Industrial Ergonomics*, 13, pp. 317-335.

Chi, C.F. (1999). A study on job placement for handicapped workers using job analysis data. *International Journal of Industrial Ergonomics*, 24, pp. 337-351.

Clarkson, J., Coleman, R., Keates, S., & Lebbon, C. (2003). *Inclusive Design: design for the whole population* (Springer ed.).

Coleman, R., Lebbon, C., Clarkson, J., & Keates, S. (2003). Introduction: from margins to mainstream. In *Inclusive Design: design for the whole population*, pp. 1-25: Springer.

Conte, M. (2004). La conception pour tous: une approche encore écartée en France. Proceedings of 17èmes Entretiens de l'Institut Garches, pp. 23-28,

Cowan, D.M., & Khan, Y. (2005). Assistive technology for children with complex disabilities. *Current Paediatrics*, 15, pp. 207-212.

Dalgic, T. (2006). *Handbook of niche marketing: principles and practice* (Routledge ed.).

Dalgic, T., & Leeuw, M. (1994). Niche Marketing Revisited: concept, applications, and some european cases. *European Journal of Marketing*, 28(4), pp. 39-55.

Deloitte, & Touche. (2003). *Access to assistive technology in the European Union* (Bruxelles: European Commission ed.). Bruxelles.

Eriksson, J., & Johansson, G. (1996). Adaptation of workplaces and homes for disabled people using computer-aided design. *International Journal of Industrial Ergonomics*, 17, pp. 153-162.

Fearnley, N., Flügel, S., & Ramjerdi, F. (2011). Passengers' valuations of universal design measures in public transport. *Research in Transportation Business & Management*, 2, pp. 83-91.

Goodman, J., Dong, H., Langdon, P., & Clarkson, J. (2006). Factors involved in Industry's: response to Inclusive Design. Proceedings of 3rd Cambridge Workshop on Universal Acess and Assitive Technology (CWUATT), pp. 31-39,

Gray, J.A., Zimmerman, J.L., & Rimmer, J.H. (2012). Built environment instruments for walkability, bikeability and recreation: Disability and universal design relevant? *Disability and Health Journal*, 5, pp. 87-101.

Gu, P., & Sosale, S. (1999). Product modularization for life cycle engineering. *Robotics and Computer-Integrated Manufacturing*, 15(5), pp. 387-401.

Hamill, C.T. (1996). The growing role of home medical equipment and rehabilitation/assistive technology. *The Case Manager*, 7, pp. 77-86.

Holmqvist, T.K.P., & Persson, M.L. (2003). Analysis and improvement of product modularization methods: their ability to deal with complex products. *Systems Engineering*, 6(3), pp. 195-209.

Keates, S., & Clarkson, J. (2004). *Countering design exclusion: an introduction to inclusive design* (Springer ed.).

Keates, S., Clarkson, J., Harrison, L.A., & Robinson, P. (2000). Towards a practical inclusive design approach. Proceedings on the 2000 conference on Universal Usability, pp. 45-52, ACM, NY, USA.

Kim, S., Seaol, H., Ikuma, L.H., & Nussbaum, M.A. (2008). Knowledge and opinions of designers of industrialized wall panels regarding incorporating ergonomics in design. *International Journal of Industrial Ergonomics*, 38, pp. 150-157.

Kotler, P. (1991). From mass marketing to mass customization. *Planning Review*, pp. 11-47.

Kotler, P. (2003). *Marketing Management* (Upper Saddle River ed.): Prentice Hall.
Kumar, S. (1992). Rehabilitation: an ergonomic dimension. *International Journal of Industrial Ergonomics*, 9, pp. 97-108.
Laroche, B. (2004). *Design pour tous: Etat des lieux*. Saint-Etienne: Saint-Etienne Métropole.
Lee, M.W., Yun, M.H., & Han, S.H. (2001). High Touch - An innovative scheme for new product development: Case studies 1994-1998. *International Journal of Industrial Ergonomics*, 27, pp. 271-283.
Linneman, R.E., & Stanton, J.L. (1991). *Making Niche Marketing Work: how to grow bigger by acting smaller*. New York: McGraw-Hill.
Macdonald, A.S. (2006). Universal Design in japanese technological industries. Proceedings of 3rd Cambridge Workshop on Universal Acess and Assitive Technology (CWUATT), pp. 13-19,
Marshall, R., & Botterell, P.G. (1999). Modular Design. *Manufacturing Engineer*, 78(3), pp. 113-116.
McKenna, R. (1988). Marketing in an age of diversity. *Planning Review*, pp. 88-95.
Mital, A. (1995). The role of ergonomics in designing for manufacturability and humans in general in advanced manufacturing technology: Preparing the American workforce for global competition beyond the year 2000. *International Journal of Industrial Ergonomics*, 15, pp. 129-135.
Mondragon, S., Company, P., & Vergara, M. (2005). Semantic differential applied to the evaluation of machine tool design. *International Journal of Industrial Ergonomics*, 35, pp. 1021-1029.
Newell, A. (2003). Inclusive design or assistive technology. In J. Clarkson, R. Coleman, S. Keates & C. Lebbon (Eds.), *Inclusive Design: design for the whole population*, pp. 172-181: Springer.
Nielsen, J. (1993). *Usability engineering*: Morgan Kaufmann.
Nisbet, P. (1996). Integrating assistive technologies: Current practices and future possibilities. *Medical Engineering & Physics*, 18, pp. 193-202.
Nowak, E. (1996). The role of anthropometry in design of work and life environments of the disabled population. *International Journal of Industrial Ergonomics*, 17, pp. 113-121.
Odeck, J., Hagen, T., & Fearnley, N. (2010). Economic appraisal of universal design in transport: Experiences from Norway. *Research in Transportation Economics*, 29, pp. 304-311.
Parrish, E.D. (2003). *Niche Market opportunities in the global marketplace.* North Carolina State University, Raleigh.
Pirkl, J.J., & Babic, A.L. (1995). *Guidelines and strategies for designing transgenerational products: a resource manual for industrial design professionals*: Copley Publishing Group.
Plos, O., & Buisine, S. (2006, April 22-27). Universal Design for mobile phones: a case study. Procceedings of CHI 2006,
Porter, J.M., Case, K., Marshall, R., Gyi, D., & Oliver, R.S. (2004). 'Beyond Jack and Jill': Designing for individuals using HADRIAN. *International Journal of Industrial Ergonomics*, 33, pp. 249-264.
Preiser, W.F.E., & Ostroff, E. (2001). *Universal Design handbook* (McGraw-Hill Professionel ed.).
Rousek, J.B., & Hallbeck, M.S. (2011). The use of simulated visual impairment to identify hospital design elements that contribute to wayfinding difficulties. *International Journal of Industrial Ergonomics*, 41, pp. 447-458.
Salhied, S.E.M., & Kamrani, A.K. (2008). Chapter 10 - Modular Design. In A.K. Kamrani & E.S. Abouel Nasr (Eds.), *Collaborative Engineering: Theory and Practice*, pp. 207-226: Springer.
Sangelkar, S., Cowen, N., & McAdams, D. (2012). User activity - product function association based design rules for universal products. *Design Studies*, 33, pp. 85-110.
Scherer, M.J. (2002, 15-20 July 2002). The study of Assistive Technology outcomes in the United States. Proceedings of 8th International Conference on Computers for Handicapped Persons (ICCHP), pp. 764-771,
Shani, D., & Chalasani, S. (1992). Exploiting niches using relationship marketing. *The Journal of Services Marketing*, 6(4), pp. 43-52.
Shrey, D.E., & Breslin, R.E. (1992). Disability management in industry: A multidisciplinary model for the accommodation of workers with disabilities. *International Journal of Industrial Ergonomics*, 9, pp. 183-190.
Sims, R.E., Marshall, R., Gyi, D.E., Summerskill, S.J., & Case, K. (2012). Collection of anthropometry from older and physically impaired persons: Traditional methods versus TC² 3-D body scanner. *International Journal of Industrial Ergonomics*, 42, pp. 65-72.
Stanton, W.E.J., Etzel, M.J., & Walker, B.J. (1991). *Fundamentals of Marketing*. New York: McGraw-Hill.
Starr, M.K. (1965). Modular Production, a New Concept. *Harvard Business Review*, 43, pp. 131-142.

Tenneti, R., Johnson, D., Goldenberg, L., Parker, R.A., & Huppert, F.A. (2012). Towards a capabilities database to inform inclusive design: Experimental investigation of effective survey-based predictors on human-product interaction. *Applied Ergonomics*, 43, pp. 713-726.

Trace R&D Center. (2000). *Universal Design research project final report: understanding and increasing the adoption of Universal Design in product design.*: University of Wisconsin-Madison: Trace R&D Center.

Vanderheiden, G.C. (1997). Design for people with functional limitations resulting from disability, aging and circumstance. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics*, pp. 2010-2052. New York: Wiley.

Vanderheiden, G.C., & Tobias, J. (2000, Jul 29- Aug 4). Universal Design of consumer products: current industry practice and perceptions. Proceedings of the XIVth Triennal Congress of the International Ergonomics Association and 44th Annual Meeting of the Uman Factors and Ergonomics Association, "Ergonomics for the New Millennium", pp. 19-22,

Vernardakis, N., Stephanidis, C., & Akoumianakis, D. (1995). On the impediments to innovation in the European assistive technology industry. *International Journal of Rehabilitation Research*, 18(3), pp. 225-243.