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ACCESSIBILITY EVALUATION: ASSISTIVE TOOLS FOR DESIGN ACTIVITY IN PRODUCT DEVELOPMENT.

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Abstract. *The application of inclusive design theory, principles and methods to the design process is a strategy used to enhance accessibility for a wider range of people, including the disabled and the elderly. A growing number of companies, design consultancies and retailers are aware of the demographic changes in the population, and the need for designing for inclusivity. However, for many design teams, time and budget constraints present challenges in the application of the principles of inclusive design when developing new products.*

This paper examines a variety of design evaluation tools and discusses the approach they provide to apply accessibility principles to new product development. These tools are thus classified into three groups: 1) user-centred techniques, 2) design trials techniques and 3) virtual techniques. This is followed by a cross-comparison of the methods and characteristics of each presented tool to the needs and preferences of the designer teams in the industrial context.

The adoption of accessibility evaluation tools may depend on the impact caused by their implementation into the design process and the design activity. The paper assesses some of the challenges imposed by the industry followed by a presentation of future possibilities to cope with them.

1. INTRODUCTION

The industry and designers have an important role to play in preparing products and improving everyday lives by facilitating the use of new technologies and integrating them to a wider range of people, independently of their physical, sensorial and cognitive condition [1, 2, 3].

According to various authors [4, 5, 6, 7, 8, 9] the adoption of inclusive design supporting tool depends on the impact caused by its implementation to the design process, which highlights the importance of understanding new product development.

Although many representations of the design process are a sequence of stages or phases [10, 11, 12] and do not include the back-tracking to previous phases, or the non-linearity of the process [7], the representations are useful to describe important and similar characteristics of such stages throughout different companies. This supports the engineering management to set appropriate evaluations according to distinct phase to assess whether the product is meeting its specified requirements [13].

In the case of accessibility and usability, the requirements are those regarding the future users, which mean those considering their physical, sensorial and cognitive limits. The earlier a product meets the user's requirements, the lesser the changes impact the design process, which includes the effect in the project budget, the project plan and the design activity [14]. In this case, the most recommended stage to adopt an accessibility evaluation tool is the one where the design team create and select the new design that will be detailed and developed for manufacturing in the next phases [15]. This would cause a minimum impact on the process.

An extensive range of tools has been developed to enable product designers to understand the end user requirements. These tools vary in format and scope, including, among others, guidelines, user trials and physical or digital simulation tools. This paper presents some of accessibility evaluation tools that are commonly adopted by industry as well as those that are not. They are divided into three groups: firstly, user centred techniques; secondly, designer trials techniques and; thirdly, virtual techniques. Each of them are separately analysed on next session, followed by a cross-comparison on session 3 to enable a better understanding of the techniques characteristics and their impact on the process and the interests of design teams in industry.

2. DESIGN EVALUATION TOOLS FOR PRODUCT DEVELOPMENT

As a way to assess product's accessibility issues, checklists and guidelines have been suggested by many experts as well presented by Nicolle and Abascal [16]. Some guidelines are presented as lists of the general user requirements that the designers should cover in their new concept, whether others are more specific in providing information about dimensions of the product or the product features.

The weaknesses of guidelines are that they do not cover all product possibilities or the entire range of features, as a result of which they cannot tackle the entire accessibility problem that the designers face during product development [17]. Moreover, the deficiencies in the guidelines' theoretical basis hinder their connection and relation. Furthermore, their data are presented in descriptive texts and tables, which is not an effective way to display data for the designers, as pointed out in some studies [18, 19, 20]. This drives designers to seek other sources of accessibility support in their activity that complement the guidelines and can cover the new concept features more precisely. One of these supportive techniques is a reasonable way to understand the users need by letting them to interact with a given product in order to get their feedback. This logic is exactly the one used by user-centred techniques.

2.1. User-centred techniques

Direct users participation in the design process is a well known way to enable designers to understand user's needs and develop empathy to them [9, 21, 22]. This helps designers to fulfil the needs of a broader range of the population, including elderly and disabled people. The user-centred techniques can be applied in different phases of the design process: they can be used before the generation of the conceptual design, by letting the users interact with products similar to the one to be developed; or later in the concept phase, when ideas have been already created and the users are involved in the trials of rapid prototypes. The core of the technique is to enable the users to interact with a given product to explore its accessibility and usability issues [23].

The value of user centred techniques is proved to be high as their outcomes elucidate designers to address product problems with an inclusive approach, taking into account the capability losses of a diversity range of users [24, 25]. An advantage of the user trials and user observations is that they can now be implemented during the development of a new design product rather than *ad hoc* evaluations. This is possible by using rapid prototyping technologies to supply design teams with real physical models that provide realistic interaction with users.

Nevertheless, independently of the phase in the design process or the user centred method adopted, there are two research conditions that enhance the assessment, the sample selection and the data collection process. Firstly, the diversity of participants in a representative range of age and capabilities enhances the resulting accessibility and usability data. A method proposed by Keates and Clarkson [26] is the adoption of 'edge-case' users, which is defined as the population that would use a product but do not use it, or limited use it, due to the high level of capability (physical, sensorial or cognitive) required to exploit its features. Secondly, the data collection process influences the impact that the data has in the design team. Successful applications of the data from user centred techniques are more likely to happen when the designers take part in the data collection or can see the problems the users face. This means that the designers better understand the real implications of the results from user's trials if they feel involved in its process [22, 27], rather then hire an external consultancy.

The value of user-centred techniques is often undermined by the techniques constraints. The time related to organise the user trials or user observation sessions, as well as the time to recruit and select a representative sample, added to the time for data collection, negatively affect the design process. As already mentioned, the more the time the technique consumes, the less probable is its adoption by the industry. In addition, while the involvement of the design team with the elderly and the disabled users is beneficial, it also brings concerns about ethical issues related to this approach. The effect of these restrictions is highlighted in collaborative design projects. Dong and colleagues [5] described that future implementations of their attempt in engaging users with disabilities into the design process were unlikely to happen due to *"lack of budget and time and complexity associated with recruiting critical users."*

2.2. Designer trials techniques

Due to the challenges mentioned to employ user participation, many designers opt to assess the accessibility of a new product by their own [28]. The techniques suitable in this case vary from self- observation to more complex assessments with simulation apparatus.

The self observation is often the most used method applied in the design process. Generally, by trying products or by testing mock-ups of their concepts, the designers check its accessibility, usability and other aspects related to the product interaction [21]. Self observation of products similar to the one to be developed generally happens before the conceptual design phase. At this point the self-observation has an inspiring role in the design process as the designers can find problems that will bear in their minds when generating a new concept.

The disadvantages of using Self observation are more evident when the product under analysis is the product being developed by the designers whom are doing the evaluation. In this case, the designers know too much about the product, the familiarization plays a crucial role that negatively affects their judgement about the problems that users can have when using the product. The team “can no longer put themselves into the role of the viewer” after being involved in the project for a long time [21 pp. 155]. Another disadvantage is that design teams are generally composed by healthy and young adults, able to access most of the features that they create, which means that self observation is not an accurate accessibility evaluation tool. Furthermore, they cannot feel the capability demand that an impaired person would feel and consequently, cannot find a wide range of accessibility problems. These limitations of self-observations explain the use of accessories to simulate physical and sensorial restrictions imposed by capability loss. This kind of simulation started approximately three decades ago and since then has been used in lectures, workshops and training sessions to help the young able-bodied to understand the limitations of physical impairments [29, 30]. Most recent versions of these apparatus are: Third-Age Suit, Age Explorer and Simulation Toolkit.

The Third-Age Suit and Age Explorer were developed by different companies and universities, though their concepts are very similar. Both have braces, pads and other physical restrainers sewn into the suit, fogged or yellow spectacles to limit the vision and earmuffs to decrease the wearer’s hearing capability. These suits have been used by designers to enable them to experience physical limits that they are unfamiliar with. Consequently, there is a significant value in raising the designer’s awareness of capability loss problems, which overcome one of the limitations of the self observation.

More complex simulation apparatus have been developed to supply the design team with precise and adjustable restrainers that emulate the difficulties of different and gradual levels of motor and sensory capability losses [31]. For instance, the Simulation Toolkit is one that goes beyond the idea of experiencing physical limitations [32].

The limitations of the suits and also of the Simulation Toolkit is that wearing the apparatus is a time consuming task that can hinder the designers of using the apparatus frequently. According to Cardoso [33], who carried out trials with the simulation toolkit, the designers wore the ‘least severe impairment simulator’ for all simulations (visual, dexterity, reach and locomotion restrainers), all were set only once for the studies carried out. An undesirable extra work and amount of time would have been consumed if the calibration features was completely used during his tests. Another limit of these tools is related to the problem prioritisation among the issues found during the assessments. The problems are prioritised based on designer’s assumptions, which can drive to erroneous assessments, instead of supporting inclusive design evaluation.

2.3. Virtual techniques

Duffy [34] presented a variety of Digital Human Modelling (DHM) applications developed until the present moment, some of which simulate human interactions with new product concepts to support design teams to explore the product's accessibility.

RAMSIS is used by more than 75% of car manufactures around the world [35] and, with JACK they are the most disseminated accessibility design software, specifically in automotive industry. Both these software packages were developed to address ergonomic issues in product development and assembly lines [20]. Their major differences are the anthropometric data and the ergonomic methods used in their applications. Although drawing from different databases, each of these software has anthropometric data set that is based on measurements taken from the healthy and the able-bodied groups [36, 37].

Among the methods used in JACK for ergonomic evaluations are: 3DSSPP (tri-dimensional static strength prediction program); reach assessment; hand access; and, vision simulation. These methods characterise JACK as an application to be used mainly for assembly lines rather than product development. Differently, RAMSIS is primarily used to product development. Its methods include body evaluations, such as body measurements correlations, postural forecast, comfort zone and also vision simulation [38]. Both software packages have features able to quantify the exclusion caused based on their anthropometric data.

Despite the advantages of the integrated ergonomic evaluation tools of JACK and RAMSIS, there is a very peculiar and misleading feature in both these DHM: the results of any assessment are built by relating the task and product to the anthropometric database, which is a range of able-bodied humans and not a wide range of people that includes the disabled and the elderly [39]. Consequently, the resulting exclusion rate is rather lesser than the real exclusion caused in real interaction and task performance. Another limit of these DHM is that the simulation is performed according to the designer assumptions, which is defined by their knowledge of the product, the task, the users and the interaction [40]. Coping strategies, for instance, can occur when the product demand exceeds the individual's capability, and thus, unexpected actions are taken to cope with the task requirements [41, 31]. Even experienced professionals cannot fully predict the range of diverse strategies that people use to interact with a product or to perform a task.

Differently of JACK and RAMSIS, a Digital Human Modelling named HADRIAN was developed to consider the limits of a wider range of people, including the elderly and the disabled people as part of the user's population. The software package has a database drawing from an anthropometric survey with 100 individuals with a broad range of abilities [42]. The software is also equipped with videos that show a sort of tasks being performed by a diverse range of people. The video database was built concerning activities of daily living in which the participants were asked to not exceed the comfortable boundary. The data was based on a series of movements and forces that are not the maximum, but, instead the comfortable range for each specific task under analysis. The package is prepared to import and work with CAD models from different sources [43].

Although the software package seems complete, the fact that the tool was developed to cover a range of tasks and has a sample of 100 individuals, restrict what HADRIAN is able to analyse and quantify respectively.

Similarly to HADRIAN, recent European Union co-funded project named VERITAS, has focused on accessibility and usability issues related to a wide range of people, including disabled and elderly people when interacting with products. VERITAS project aims to improve manufactured product process by developing Digital Human Models that have disability data setup that guides their tasks performance. The project under development combines a task model, its primitive tasks, the user disabilities related to those primitive tasks and finally, the avatar. In this way, VERITAS intends to cope with physical and cognitive disabilities, as well as psychological and behavioural characteristics [44, 45].

With a different approach, the Exclusion Calculator, software tools developed within the Inclusive Design Toolkit [46], explore the capability loss related to some impairments and their severity. The Exclusion Calculator can provide the proportion of people (in UK, 1997) excluded by the visual, hearing, thinking, reach, dexterity and locomotion capability demands. The capability demands are based on data from scales of the Disability Follow up Survey. The outcome is an estimate of the overall exclusion or the exclusion based on each capability demand. The Exclusion Calculator can effectively raise the designers understanding about the way different disabilities affect the user perception and thus, their interaction with a product. The disadvantage is that the exclusion calculation is based on designers' selections of specific tasks. The designers assumptions have a risk of not being accurate, which can drive to incorrect assessments.

3. DISCUSSION

The previous session described the evaluation tool techniques that in different ways can be applied to the product development to draw the designer's attention to the accessibility problems. However, as it is indicated in many researches, in the industrial context, the adoption of such tools only happen when the impact caused on the design process is minimum, considering at least the two mandatory aspects of time and budget [14, 9, 6, 7, 8]. In addition, the implementation of a tool into the process unlikely occurs if the benefits for the final design are not clear. Therefore, the reasons that drive to the acceptance by the industrial designers vary from the tools efficiency, the interface and the outcomes of the assessment. Table1 present the tools mentioned in this paper and their relation to the design process, the interface and the result characteristics; three aspects relevant to industrial design teams when deciding how to assess accessibility.

Many studies show that user trials and user observations are very fruitful methods of accessibility evaluation as they highlight problems that the designer would not realise by their own assessment [5, 24, 25]. Certainly, the direct user participation can be inspiring [4]. However, the challenges imposed by these techniques hinder their adoption in industrial context. As previously mentioned, the sample selection and the involvement of the designers in the process enhance the technique; meanwhile time is consumed in every instance that the recruitment of users is required. An important aspect of user-centred techniques is that, if they are used as accessibility evaluation tools, a recruitment request should occur every time the product changes. In other words, if the idea selected is rapid prototyped and tried by a sample of users, the changes pointed out in the trial should back track the designers to the generation of other ideas or modifications that should also be tested by the users again, and so on, until the design better satisfy the users. This would ensure that the final product is the one assessed by the users. However, the integration of the technique to the design activity is not straightforward as it impacts on the project budget, time and ethical requirements.

Similarly, the design trials techniques should occur with the same frequency described above, every time that the product is modified. However, this does not change the fact that these techniques are not precise and can drive the designers to wrong assumptions.

	Process integration	Interface	Results
User trials / User observation	Early in the conceptual phase, through similar products, or later through rapid prototypes.	Observation of real users and/or get their feedback after the trial.	Inspiring. Exclusion is not quantifiable. Re-assessing the product is an issue due the sample selection.
Self observation		Observation of themselves.	Inspiration is limited as the design teams do not represent a wide range of people.
Third-Age Suit / Age Explorer		Designers observe themselves with physical restrictions.	Inspiring. Exclusion is not quantifiable. Re-assessing the product means to wear the suit again.
Simulation Toolkit		Observation of themselves with different levels of restrictions.	
JACK /RAMSIS	Later in the conceptual phase through CAD models.	Virtual interaction with user avatars.	Dependent on the knowledge of the designer. Exclusion is limitedly quantifiable due to the anthropometric database.
HADRIAN			Exclusion is limitedly quantifiable due the range of tasks and the users' database.
Exclusion Calculator	Early in the conceptual phase, through similar task analyses.	Virtual interaction with a range of applicable tasks.	Dependent on the knowledge of the designer.

Table1. User-centred, designer trials and virtual techniques in relation to relevant aspects for industrial design teams to evaluate accessibility of new concepts

From the virtual techniques mentioned, two DHMs (JACK and RAMSIS) were pointed out as well disseminated and well accepted by the designers into the industry. These mean that there must be advantages that justify this acceptance. Past research point out aspects considered by designers that match with some characteristics of these tools, three of which are the following:

1. The visual interface of the application. The entire simulation is built on visual information. According to some authors the use of images (or animation) is described as the best way to communicate with designers [47, 20].
2. The results are quantifiable according to the anthropometric data set. This means that in accessibility analysis, such as reach and hand access or any other evaluation, like strength prediction or comfort evaluation, the results are quantified through the number of people able to perform the task, and; consequently, the percentile of the population excluded from the interaction is given [48].
3. The integration with CAD models is a popular feature well accepted in many design teams [49]. Both these DHMs can be used as mannequin in specific CAD software (CATIA for instance), or as a software package that can import a wide range of CAD models.

It is important to bear in mind that despite both DHMs (JACK and RAMSIS) have a good interface to the design activity and show quantifiable results, they do not underpin a wide range of the population with their variety of capabilities, which affects the results and drives the designers to wrong accessibility evaluation.

On the other hand, although the HADRIAN software shares similar interface characteristics, it is not largely adopted by the industrial design teams. The reason may lie in the exclusion calculation and in the range of tasks covered in the software database. The sample of 100 individuals is not statistically representative and the range of tasks restricts what the software is able to analyse. However, differently of JACK and RAMSIS, HADRIAN's approach of accessibility evaluation takes into account a wide range of capabilities, including those of the elderly and the disabled people, which would contribute to fair design of new products.

The limits of the tools described above may justify the interests of the VERITAS project in creating a DHM that broadly consider the elderly and the disabled capability loss with statistical data to measure the exclusion that certain product designs can cause. The VERITAS project is still under development, a fact that limits the comments in this paper, though the project structure adopts an inclusive design approach, at the same time it seems feasible to the design process in industrial context.

Concerning the design process, an important characteristic of the DHMs mentioned in this paper is the integration to the process through CAD models. Therefore, neither the predominant use of CAD software, nor the benefits that are brought by integrating CAD with accessibility tools can be ignored. According to Macdonald and others [50] the integration facilitates a quick feedback and stimulate analyses follow-up during the design process. However, it is important to emphasize that despite the impact on the design process can be minimum when using CAD models, in many cases, the stage where it is adopted is later in the ‘conceptual phase', which can drive to limitations in the design implementation based on the results of the accessibility evaluation. Consequently, it is still necessary to investigate if decisions made by analysing CAD data overcome the accessibility problems or if there are restrictions related to the stage of the process that hinder fully implementation. Furthermore, the features that designers would analyse by using CAD models should be also explored in order to implement accessibility evaluations. Another significant aspect of the virtual techniques approached in this paper is the dependency of the knowledge of the designers and their assumptions when performing the simulation. This aspect drives our attention to the extent that guides the need of performing a task to find out the exclusion that a product design can cause. In other words, there may be cases where buttons demand high force to press, pull or turn; or connectors are too small and have no guidance to facilitate the insertion to the connection’s hole; or foreground and background colours are difficulty to visualise; cases in which the task would not need to be performed because the capability the feature demands from the users already causes exclusion of a portion of the user’s population. Therefore, further investigation of the possibilities inherent to CAD software would help to identify ways where an accessibility evaluation tool could be integrated to product modelling. This could propose another approach for certain accessibility problems and could also be incorporate to the design activity.

4. CONCLUSION

The industrial adoption of accessibility evaluation tools is strongly connected to its impact on the design process and the design activity. This means that such tools should be easily integrated to the time and budget allocated to the project, as well as the benefits of using them should be clear to the design team. The benefits include the efficiency of the tool, the interface and the outcomes of the assessment. These aspects were confirmed by analysing the industrial acceptance of accessibility tools, though the tools well disseminated in the industry do not include a broad range of the real users. Consequently, there have been efforts to overcome the exclusion caused by products, some of which are seen in the tolls like HADRIAN and Exclusion Calculator. Both of them approach, by different ways, the capability losses that the disabled and the elderly people suffer. Additionally, the ambitious VERITAS project intends to aggregate physical, sensorial and cognitive capability losses in a DHM, which seems a well disseminated way to address accessibility problems. However, the paper identified three aspects in which further research should be done. Firstly, the limits of virtual analysis by using CAD data as they may be advanced in the design process; secondly, a better understanding of the design activity to clarify the features in CAD that would be assessed by accessibility tools, and; thirdly, the possibilities implicit to CAD models that could be used to evaluate certain design features.

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