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The Design and Evaluation of Assistive Technology Products and Devices Part 1: Design

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This article is the first of three parts and discusses the design of assistive products. Part 2 considers evaluation and Part 3 the outcomes of assistive product use.

Introduction: What are Assistive Products?

Assistive products can be considered to be a particular category of assistive technology or AT. Although the term assistive technology is frequently used and the abbreviation AT is becoming current, a generally accepted definition has not yet been obtained. There are a number of different definitions and a brief survey of some of them is given by the author in (Hersh and Johnson, 2008a). Examination of some of the definitions (AAATE; AC 2004; ACT; Digiovine et al 2007; EC 2003; FAST1; ISO 1999; Pasha and Pasha 2006; Technology&Disability) shows that assistive technology is a generic or umbrella term which covers technologies, products, services and systems used by disabled or elderly people to increase their independence and participation in society and/or enable them to carry out activities that would be difficult, dangerous, or impossible otherwise. Drawing on the definitions in the Chambers and Oxford Concise English dictionaries, the term 'assistive product' will be understood here as an assistive technology article produced by manufacturing or other processes, possibly, but not necessarily for sale. It should also be noted that definitions of assistive technology are generally based on either the social (UPIAS, 1976; Barnes, 1994; Johnstone, 2001) or medical (WHO, 1980, 2001) models of disability. This leads to definitions based on overcoming barriers, or overcoming the user's 'deficits' and extending their funcational capacities respectively.

The definition of assistive product used here is based on the definition of assistive technology in (Hersh and Johnson 2008a):

> "Assistive technology is a generic or umbrella term that covers technologies, equipment, devices, apparatus, services, systems, processes and environmental modifications used by disabled and/or elderly people to overcome the social, infrastructural and other barriers to independence, full participation in society and carrying out activities safely and easily."

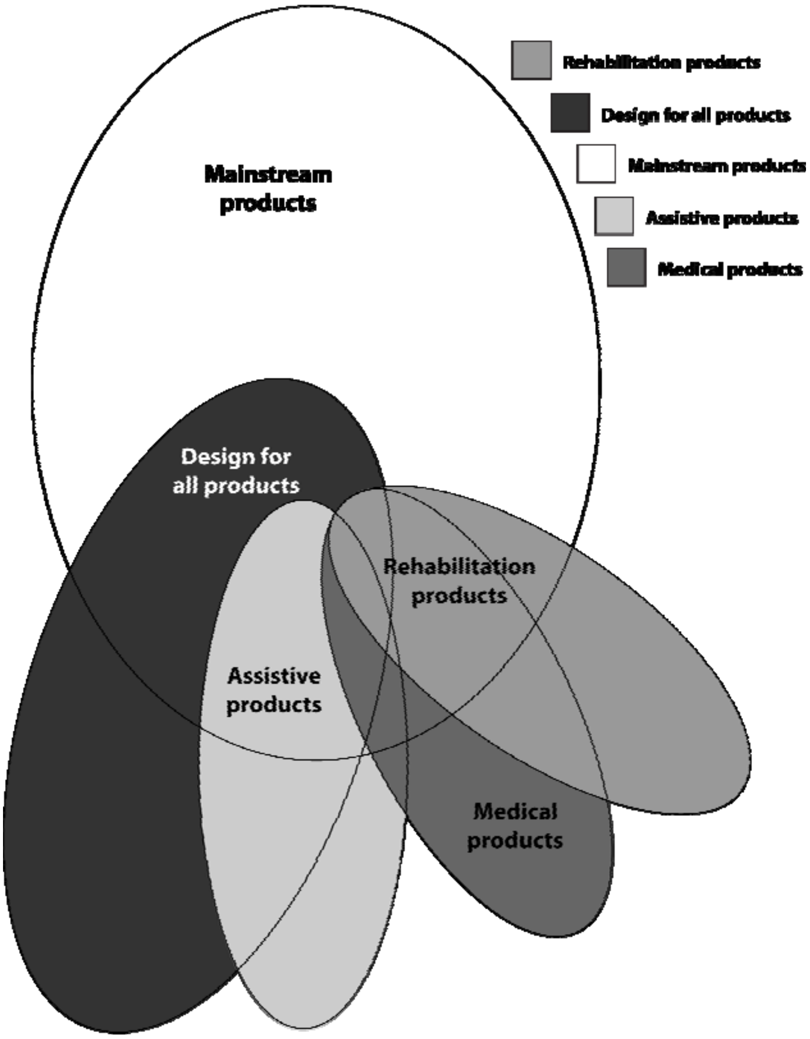
It should also be noted that products, devices and services can be categorised as follows, with some overlap between the categories and fuzzy rather than clearly defined boundaries:

- Mainstream products: products designed for the 'general population' and which can be obtained from standard retail and other outlets. Unfortunately, they are frequently designed without consideration of the needs of disabled and many other groups of people.

- Design for all (European) or universal design (American) products: an approach to design which aims to make products accessible and useable by as wide as possible a range of users, regardless of factors such as disability, age, size, culture, ethnic background or class. Ideally all mainstream products would use a design-for-all approach.
- Assistive products, which are designed to remove barriers for disabled and elderly people.
- Rehabilitation products, which are designed to restore the functioning of disabled or elderly people or people experiencing ill-health.
- Medical products, which are designed to support a range of health care practices and promote healing in people experiencing illness or other forms of ill-health and who may be categorised as patients.

Thus, although assistive and rehabilitation products are both used by disabled and elderly people, assistive products modify the interaction between a disabled or elderly person and their environment in order to remove barriers, whereas rehabilitation products act (directly) on the person to overcome their ‘limitations’ (Hersh and Johnson, 2008a). This difference parallels that between the social and medical models of disability. The relationships between the different categories are illustrated in Figure 1.

Figure 1: The relationships between mainstream, design for all, medical and assistive products



Assistive products can be divided into those used to make existing mainstream products accessible and those required to overcome the barriers due to partially or totally inaccessible infrastructures and environments. While there will probably always be a need for some assistive devices, the application of design for all principles to the design of mainstream products will remove the need for some of them. For instance, screen readers are required to make computer operating systems accessible to blind people. However, many of these operating systems now incorporate screen readers and improvements in the functionality and performance of these incorporated screenreaders will probably eventually remove the need for additional screen readers as assistive devices. However, for the foreseeable future there is likely to be a need for assistive devices in the form of Braille displays and keyboards and eye control input devices, since including them in standard computer setups would increase price and complexity. The mobility of physically disabled people generally requires a combination of accessible infrastructures and environments and a mobility or support device. The accessibility of infrastructures and environments is improving with the removal of barriers and the addition of ramps and lifts. However, for the foreseeable future the use of personal mobility or support devices such as wheelchairs and walkers is likely to be the best solution in terms of the use of resources and the state of technology.

This article is the first of three parts and discusses the design of assistive products. Part 2 considers evaluation and Part 3 the outcomes of assistive product use. This article is organised as follows. Section 2 discusses the factors which are common to good practice design of assistive and other products, as well as those which are specific to assistive products, the stages in the design process and sustainable design. Section 3 considers a number of important aspects of assistive product design, including product appearance, usability and accessibility, interface design and standards. End-user involvement, including the categorisation of different types of end-user involvement, communication issues, methods for end-user participation and structuring end-user information, is considered in Section 4. Section 5 considers ethical and safety issues and Section 6 presents very brief conclusions.

Design of Assistive Products

Design of Assistive the Consumer Products: Common Factors and Differences

Many features of the design and development of assistive technology products and devices are similar to those of other (consumer) products. In particular, they should follow good practice in product design, including the following:

- User-centred design, with end-users involved throughout the design and development process from the very start (Dvir et al. 2003).
- Iterative, multi-criteria approaches, which consider function, form, attractiveness to all the senses, pleasure in use, usability, accessibility, performance, reliability, safety and environmental factors. There are a number of different frameworks for taking into account the various factors which should be included in design. These include the Promise Project's six As: awareness, accessibility, availability, appropriateness (usefulness), affordability and acceptability (CEN 2003).
- Appropriate trade-offs between (i) the provision of different modes of use and/or inputs and outputs and information in different formats, with a degree of redundancy, and (ii) simplicity and cost. Factor (i) will generally improve accessibility and usability for disabled and elderly people, as long as the product does not become (over)-complicated as a result. Excessive cost will act as a barrier, whether users purchase the device directly or with financial support from a third party.
- Ease of upgrading, repair and maintenance, as well as robust design to reduce the likelihood of faults occurring. This has benefits to both end-users and the environment. Minimisation of negative environmental impacts over the whole life cycle will make it easier to meet legislative requirements and could make the product more attractive to some users and, in some cases, will reduce costs.
- Ease and intuitiveness of use, with a minimum of documentation and training, as well as consideration of the subsequent provision of information, support and repair facilities to end-users.
- A modular software architecture, to reduce the impact of any problems that occur in any one component on the rest of the design and to facilitate the later addition of further modules.
- Compliance with any relevant national and international standards or other regulation. Good design practice generally goes beyond minimal compliance and can lead to commercial advantage if the standards or regulations become stricter due to the greater ease and reduced costs of proactive rather than reactive compliance.

However, there are the following differences between the design of assistive and other (consumer) products:

- Many, though not all, assistive devices are developed for relatively small numbers of users and sometimes even a single person. There are examples of assistive products for which there is widespread demand, such as hearing aids and wheeled mobility frames for elderly people. However, an assistive project is more likely to develop a large market sector if it has additional applications for non-disabled people.
- The small numbers of potential users of many assistive devices has resulted in a number of ‘non-standard’ routes to the conception, design, further development and distribution of assistive products.
- Since, assistive products are often supplied to users by health or social services or non-governmental organisations, the immediate purchaser is often not the end-user. Therefore, the design may need to satisfy both the end-user and the funder or purchasing organisation.
- Many standard user interfaces in consumer products are inaccessible or difficult to use by particular groups of disabled and/or older people.

Thus, the design of assistive products should meet the following conditions:

- Standard good design practice (see list above).
- Interfaces which are accessible to disabled and elderly people or at least disabled and elderly people who meet a number of pre-specified conditions.

In addition, they are frequently influenced by one or both of the following factors:

- Small market size.
- The need for the design to satisfy both end-users and the funder or purchasing organisation.

This is illustrated in Figure 2.

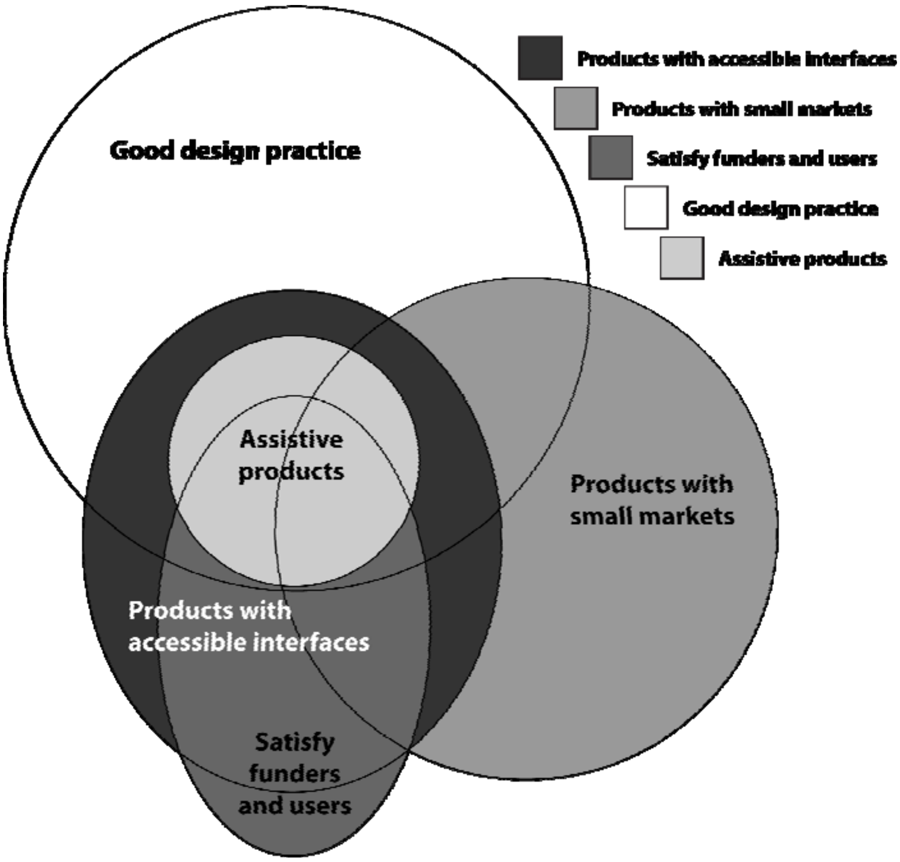
The Different ‘Routes’ to the Design and Development of Assistive Products

There are a number of different ‘routes’ to the design and development of assistive products including the following:

- Industry, generally small or medium-sized firms (SMEs).
- Developments by charitable organisations or other NGOs of devices in conjunction with industry or researchers. Examples include the global positioning systems (GPS) ViaVoice by the Cavazza Institute for Blind People in Italy and Kapten by the Spanish Organisation for Blind People ONCE.
- Student or academic projects.
- Collaboration between government departments and universities or research centres (Lane 1997).
- Collaboration between industry and universities or research centres (Lane 1997).
- One-off developments for a particular end-user by non-governmental organisations, frequently with charitable status, such as the UK organisation REMAP (REMAP).

- One-off developments for a particular end-user by assistive technology researchers, such as the multi-functional domestic alert system developed at the University of Southampton for a specific deafblind user and built and installed in his house (Damper, 1993; Damper and Evans, 1995).

Figure 2: Assistive technology design requirements and constraints



Since the details of the further development and distribution of assistive products are beyond the subject of this paper, other than as they affect their design, this topic will only be considered briefly here. It will therefore be noted that the relative importance of the difference 'routes' listed above depends on a number of factors and that the small size of the market for many assistive products means that one-off developments and projects are more important in this area than for other types of products. In some cases there would be value in the further development of one-off products for a particular end-user, but there seems to be little record of this happening. The lack of availability of funding and other resources has meant that many potentially valuable devices originating in student or academic projects have not been developed beyond the prototype stage. There are also examples of products, such as the communication system for deafblind people based on the CyberGlove sensory glove and GesturePlus fingerspelling software (Kramer, 1991; Kramer and Leifer, 1988), which were initially developed as student projects and then commercialised by the developer setting up their own company.

While there is a need for increased funding to enable the further development of assistive products originating in student and academic projects, these developments have educational benefits and potential benefits to end-users even if they do not lead to useable products. In particular, student involvement can lead to increasing awareness of the needs of disabled and older people and the issues associated with designing assistive technology. This can lead to improvements in design for both disabled and non-disabled people.

Before deciding to design an assistive product, it is important to be aware of what other similar products are available or under development, to determine whether there is likely to be a demand for the new product and whether and, if so, how its performance and other features can be improved relative to existing products. Sources of information include:

- Databases, such as the EASTIN database (EASTIN) in Europe; the ABLEDATA (ABLEDATA) and Assistivetech.net (assistivetech.net) databases in the USA and the FAST database of assistive technology projects (FAST2) in the UK.
- Trade fairs, such as the Rehacare, RehMedika and Health and Rehab Assistive Technology and Rehabilitation Trade Fairs and the Medica International Trade Fair and Congress for Medical Technology.
- Catalogues of vendors of assistive technology, rehabilitation and medical products.
- The European Commisssion IST Conference and exhibition.
- Consultation with and/or surveys of end-users.
- Searches of the literature on the design, development and use of assistive technology and the experiences of disabled people.

Stages of the Design Process

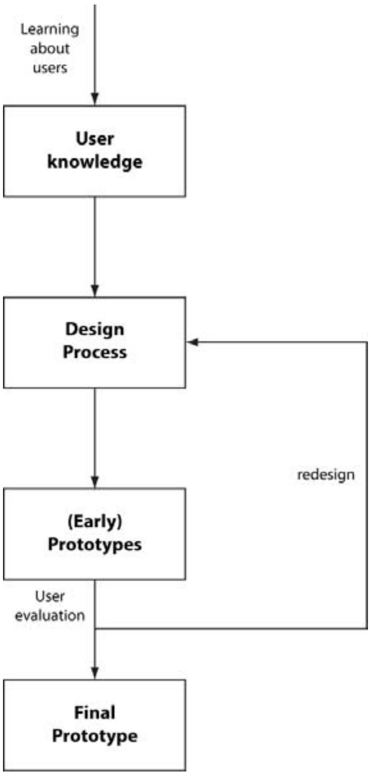
Design involves a multi-stage iterative process, with frequent backtracking, as well as overlap between the different stages. User-centred design is considered to be best practice, particularly in systems that involve human-computer interaction or software. It has been shown to lead to more usable systems and to save time in large projects (Bradley and Dunlop, 2008). It is particularly important in the case of assistive products, since their end-users may have very precise requirements and the fact that designers of assistive products are generally not themselves disabled or elderly and are therefore unlikely to be aware of these requirements without the involvement of end-users.

There are a number of different approaches to user-centred design, but they are all based on the following four main steps (den Buurman 1997; Gould and Lewis 1985), which could be considered a model of user-centred design. This is illustrated in Figure 3

1. Learning about the users and the tasks they want to carry out very early on.
2. Using the current knowledge of the users to inform the design.
3. Presenting the users repeatedly with early prototypes for evaluation.
4. Iterative (re)-design to fix problems and take account of issues identified in end-user testing, giving an iterative cycle of design, test and measure and redesign, repeated as often as required.

A number of other decompositions of the design process have been used, either in general or for specific problems, for instance (Roozenbrook and Ekels 1995; Gemperie et al. 2003; Keates et al. 2000), but will not be presented here, due to the advantages of user-centred design (Bradley and Dunlop, 2008) discussed above. The initial awareness of the issue which leads to the design may come about through contact from end-users, sometimes from an individual, in which case it may lead to a one-off solution; actively looking for problems to solve; looking for market opportunities; cross-fertilisation between different areas of knowledge or literature studies. Although formal market surveys and evaluations do take place, this is less common than for other types of products. Approaches to learning about users and end-user testing are discussed in section 3. The information on users and tasks, as well as technical and other design requirements can be formulated as design specifications, which may be updated as the design progresses. There are a number of different checklists of factors to facilitate developing a complete design specification (Pahl et al. 1996; Pugh 1990).

Figure 3: Iterative four-stage approach to the design process



The process of obtaining prototypes frequently involves a number of different stages. It is usually based on a design concept, which should be presented to end-users for comments before further development. In the case of assistive products, it is generally not necessary or appropriate to use methods which generate very large numbers of design concepts. Suggestions from end-users should be sought, though they may find it difficult to generate suggestions or comment on design concepts for products that are unfamiliar to them. Methods such as brainstorming, a brainwriting pool and check lists can be useful for generating initial ideas (Roozenburg and Eekels 1995). If more than one design concept is produced, a decision between them will need to be made at some stage and end-user feedback should play an important part in this decision. At what point in the design process this decision is taken will involve trade-offs between the additional resources required in further development of several concepts and the risk of choosing an unsatisfactory design and having to backtrack.

Time, financial and technical constraints will generally prevent a fully functioning prototype being used in all discussions with end-users. Therefore, there may be a need for other types of representations than prototypes, which are still able to give end-users sufficient information to make decisions on the aspects of the product being considered. This information needs to be available in an accessible format to all end-users. Many design simulations involve sketches or other visual representations, which will be suitable for some, but not all groups of disabled people and, in particular, not for many blind and visually impaired people (the term ‘blind’ covers people who are legally blind, as well as those who have no vision at all or only light perception.). Consultation with organisations of disabled people or small numbers of end-users may be required to determine whether a particular type of representation is appropriate and present the features of interest in a way that is easy to understand and that allows discrimination between different designs. In some cases computer representations or virtual prototypes will be appropriate. However, this will depend on the end-user group and, in particular, their familiarity with computer technology, and whether the use of haptics would provide sufficient and appropriate information in the case of blind end-users. Towards the end of the design process fully functional prototypes will be required for end-user testing, evaluation and modification.

Discussion of the design process in the literature seems to assume that it will be successful. However, it can happen that the design chosen proves unsuccessful. In the case of assistive products, sufficient resources are generally not available to develop several designs concurrently until it is clear that one of them will be successful in both technical and end-user terms. Therefore, mechanisms are required to identify design dead-ends and strategies for moving on from them, whether involving a significant modification of the design or the choice of a totally different design approach. Product evaluation, including decisions on whether to proceed with product design and development, is considered in Part 2 of the paper.

The number of cycles of re-design, user testing and further modification will depend on the available resources and problem complexity, amongst other factors. Designers in consultation with end-users will need to make decisions as to when a sufficiently good design has been obtained and it is not worth investing additional resources in making further small improvements. Inspired by the free or open source software community, open design projects use the web to collectively design products. (Bonanni et al. 2008). While this has generally been less successful than free software design, successful open design sites include one which involves the community of prosthetics users (Open Prosthetics Project) and uses both open source and ‘do it yourself’ (DIY).

Sustainable Design

At the minimum designers need to be aware of and implement relevant environmental legislation and regulations, such the European Union directives on the Reduction of Harmful Substantives (ROHS 2003) and Waste Electrical and Electronic Equipment (WEEE 2003). Design processes which minimise the materials and energy used and waste generated as well as using recycled materials wherever possible can reduce costs, leading to commercial advantage. Users may also prefer products that are designed to have low energy consumption and an extended life span and to be robust in use and easy to maintain and repair. Meeting international environmental standards, such as the ISO 1400 series (Sarkis et al. 1996), may also lead to cost reductions and/or improved marketability. Product designers and developers should also note that the trend, which is likely to continue, is for environmental regulations to become more stringent over time. It is generally advantageous, including in economic terms to be proactive rather than reactive with regards to such legislation. In particular, late implementation of legislation may incur additional costs, even if there are no direct penalties for late compliance. A number of systems based approaches to good practice in integrating sustainability issues into design and reducing the negative environmental impacts over the whole life span have been discussed by the author (Hersh 1998).

Features of Assistive Product Design

A number of studies have shown significant under-use and abandonment of assistive devices (Blackstone 1992; Garber and Gergorio 1990; Ko et al. 1998; Murphy 1997; Phillips and Zhau 1993; Shepherd and Ruzicka 1991) and it has been suggested that this is due to their lack of compatibility with the user's needs, roles, values and context (Smith, 1995). Devices and products are more likely to be used if they enable users to complete important tasks and facilitate social and psychological freedom rather than just physical functioning (Phillips and Zhao 1993).

Appearance

Appearance is an important factor in determining the acceptability of assistive products to end-users. A recent survey of end-user attitudes to a proposed robotic guide (Hersh and Johnson 2010) found that potential end-users were particularly concerned about it being discreet and inconspicuous and not drawing attention to them or resembling medical equipment. They also required it to be attractive and elegant and possibly to resemble an item in common use. Similarly, an evaluation of commodes found that users were very concerned about the commode's appearance and that it was important to them that its function was not obvious (Ballinger et al. 1995). Assistive products should also be compatible with the lifestyle, culture, tastes and aspirations of end-users (Barber 1996). This may require variations in design of the basic product to take account of factors such as age or cultural group without significantly increasing overall cost. There may also be differences based on culture or other factors which affect the tradeoffs users make between attractiveness and performance or other factors. However, in some cases, an attractive and attention catching design will be successful. For instance, user trials found that children liked the appearance of a brightly coloured prehensor (hook) artificial hand (Plettenburg 2006).

Usability and Accessibility

The development of products for disabled people has generally paid more attention to accessibility than usability. However, there are a number of general formal definitions in the literature of usability, as well as several usability standards. In the case of accessibility, the main focus has been website accessibility and there are guidelines rather than standards for the accessibility of website content and authoring. Accessibility definitions are frequently given with respect to a particular type of accessibility rather than for accessibility in general.

However, both usability and accessibility should be considered as part of good design practice and included from the earliest stages of system specification and design. Both concepts are relevant to all users, but particular consideration is required to ensure that products are accessible and usable by disabled people. Accessibility is about the environmental characteristics of the system input and output which either enable or prevent particular groups of users from using the system, whereas usability is the ability of the system to carry out the intended function(s) when used by particular groups of users (Federici et al. 2005). Despite the focus on accessibility, there seem to be few definitions and most of them are concerned with only a specific type of accessibility, such as web accessibility or building accessibility or stated in terms of compliance with guidelines, as in the Americans with Disabilities Act Accessibility Guidelines. The definition used in the World Wide Web Consortium (W3C) Web Accessibility Initiative (W3C [updated 2005]) directly involves disabled people, namely 'Web accessibility means that people with disabilities can perceive, understand, navigate, and interact with the Web, and that they can contribute to the Web.' A related, but more general definition (Jarmin) is 'A website or electronic document is accessible when anyone can access the information contained in it, regardless of physical, economic or technological circumstances.'.

Dictionary definitions of accessibility include 'able to be accessed, approachable, easily understood or appreciated' (Oxford), 'able to be reached easily, easy to understand and enjoy or get some benefit from' (Chambers). In environment and planning architecture accessibility is related to the ease with which activities in the society can be reached (Planning) or 'the ability to reach desired goods, services, activities and destinations' (Adhikari et al., 2010). Accessibility is often considered to be an umbrella term for the parameters that affect human functioning in an environment. It is sometimes defined either directly or implicitly in legislation. For instance the Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities considers that accessibility 'Describes a site, building, facility, or portion thereof that complies with these guidelines' (ADA [updated 2002]) and Section 508 of the 1998 US Rehabilitation Act (Section 508) that it describes 'the process of designing and developing Web sites and other technology that can be navigated and understood by all people, including those with visual, hearing, motor, or cognitive impairments.'

Designing application software for accessibility involves designing for the following three functions (Vanderheiden, 1994):

- Direct accessibility so that the software can be used by as many people as possible without requiring adaptive software.
- Compatibility with access features in the operating system or third party access features, software and assistive devices.
- Accessibility of documentation, training and support systems.

The International Organization for Standardization standard ISO 92 4-11 considers usability to be 'the extent to which a product can be used by specified users to achieve specified goals in a specified context of use with effectiveness, efficiency and satisfaction'. In ISO 9126-1 the term 'quality in use' is used instead of usability and includes the additional component safety. Other definitions (McLaughlin and Skinner 2000; Quesenbery et al 2001; Nielsen 1993) characterise it in terms of some combination of the following components:

- Checkability, low error rates or error tolerance: design to prevent errors caused by interaction with the user and help the user recover from errors, including by checks to ensure that the correct information is entering and leaving the system,
- Confidence: users are confident in both the system and their ability to use it.
- Control: users have control over system operations, including input and output information.
- Ease of use: the system is easy (and intuitive) to use.
- Speed or efficiency: the system responds and carries out functions quickly.
- Understanding and ease of learning: users are able to understand the system and its outputs and learn to use it easily.
- Engaging: the product is pleasant and satisfying to use.
- Easy to remember procedures.
- Effectiveness or high productivity: the completeness and accuracy with which users achieve specified goals.

Of the various methods to test and evaluate usability, Nielson's (1993, 1994) usability heuristics are probably the best known. These include: presenting information in a natural and logical order and avoiding technical terms, keeping users informed with appropriate feedback, eliminating error-prone conditions, the ability to exit easily from an unwanted state, consistency, provision of information rather than expecting recall.

There are a number of different standards related to different aspects of usability (Bevan 2001a; Earthy 2001), which can be divided into four main categories (Bevan 2001ab)

- Quality in use, including effectiveness, efficiency and satisfaction in a particular context of use.
- The user interface and interaction.
- The processes involved in product development.
- Organisational capability to apply user-centred design.

Some examples of usability standards are given in Section 3.5 on standards.

USERfit (USERfit) provides a methodology for the generation of usability specifications for assistive technology and a design environment, comprising nine 'summarising tools'. Each tool includes several forms covering user analysis, activity analysis, and product analysis, context and product environment amongst other factors. These tools provide a structured approach using paper based forms to the collection, evaluation and development of information, including on all the stakeholder groups identified in the user data mapping exercise. This structured approach also supports the development of usage scenarios for each stakeholder group and the production of product specifications and encourages designers to look at the issues required to produce a usable product. Other components include requirements and design summaries. The final stage is usability evaluation. While a very useful tool, USERfit is somewhat time consuming to use. The USERfit tool was developed to facilitate the use of the USERfit methodology and the sharing of design information between different designers (Abascal et al, 2003).

Design for All

Design for all or universal design involves the extension of usability considerations to the wider population, including disabled people. The following seven principles have been proposed by a working group of architects, product designers, engineers and environmental design researchers at the Center for Universal Design (Connell et al. 1997; CEN 2003). They are equally relevant to the design of assistive and other (consumer) products.

1. Equitable use: The same or equivalent means of use for all users.
2. Flexibility in use: The design accommodates a wide range of user preferences and characteristics.
3. Simple and intuitive use: The design is easy to understand, regardless of the user's experience, knowledge, language skills or current level of contentration.
4. Perceptible information: Relevant information is communicated effectively, regardless of ambient conditions, the senses used to access information or other factors.
5. Tolerance of error: Minimising any negative consequences or hazards of user errors, accidental or unintended actions, including through warnings and fail safe features.
6. Low physical effort: Efficient and comfortable use with a minimum of effort and fatigue.

7. Size and space for approach and use: Appropriate size and space to approach, reach, manipulate and use, regardless of body size, posture or mobility.

Interface Design

The device interface is the means by which end-users interact with a product. For simple low technology devices the interface may just be a handle, whereas it will generally have both input and output components for more complicated and higher technology products, such as a computer. Good interface design is particularly important for assistive devices. A clear separation of the application and interface can facilitate the design of accessible interfaces (Abascal 2002). In the case of some low technology devices, the provision of a longer handle and/or a firmer grip is all that distinguishes the 'assistive' from the general version. However, the good performance due to the improved handle makes the 'assistive' product attractive to the general population and turns it into a universal design product.

In deciding on an appropriate interface, the sensory modalities used by the target user group and the parts of the body they can most easily control, as well as the types of movements they can make, should be taken into account. This will avoid information being provided in an inaccessible or difficult to access format, such as small print text, to blind and visually impaired people, or users required to undertake operations which are not feasible or which would require the agility of a contortionist with the parts of the body they can use easily. Many end-users require or prefer to have clearly perceptible feedback when they carry out an operation. It is therefore useful to provide a combination of visual, audio and tactile feedback. However, some end-users with autistic spectrum conditions will be disturbed or otherwise stressed by visual indicator lights and/or audible clicks and possibly also by tactile feedback. There should therefore also be an easy and intuitive means of switching off this feedback, as well as remembering users' preferences. Easily customisable interfaces can have benefits for all users, whether or not they are disabled or elderly.

Interface enhancements to improve accessibility and which enable the same product to be used by both disabled and non-disabled people and, which are compatible with most electronic products have been developed by EZ Access [updated 2007]. These enhancements are also useful in noisy environments, in poor lighting or very bright sunlight and when users have their hands occupied or are tired. They include speech output and button navigation to give full access to all onscreen controls and content, reading aloud or describing aloud on-screen text and graphics, a visual presentation of text or sounds that are not already displayed visually, context sensitive information about using the device, instant identification of any button on the device and layers of help. The different features can be accessed by a five button EZ keypad, with some versions having three additional buttons. The buttons have different colours and shapes to enable them to be easily identified both tactilely and visually. However, the different colours may be distracting or disturbing to some people with autistic spectrum conditions. The provision of 3.5 mm stereo and 2.5 mm headset jacks allows users to use their own ear piece or headset. EZ Access comprises a set of interface techniques that can be built into product software rather than as an add-on and therefore should be considered from the start of the design process. While modifying existing systems for compatibility with EZ Access is often possible, this will frequently lead to additional costs.

Standards

Technical standards provide specifications with regards to performance, quality, safety and reliability. They may also provide specifications to allow intercompatibility of products or components from different manufacturers. Safety is always an important component of technical standards, particularly in the case of systems and devices which are in close contact with users. The availability of new information and technological advances means that both the safety and technical performance specifications in standards may be frequently revised upwards.

There are national, European and international standards. The main international standards are maintained by the International Electrotechnical Commission and the International Organisation for Standardisation and indicated by the letters IEC and ISO respectively. European standards are set by the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardisation (CENELEC) and have the designation letters EN. National bodies that are members of CEN or CENELEC participate through technical committees The American National Standards Institute maintains US standards with the designation letters ANSI.

Assistive products are covered by a number of different standards, with both standards covering specific products and a general assistive technology standard. For instance the IEC 60118 series specifies performance and safety standards for hearing aids. The ISO standard ISO 13570-1:2005 is aimed at wheelchair users rather than designers and manufacturers and aims to explain how to use the International Standards on Wheelchairs to select their next wheelchair. General consumer production legislation will also be relevant to assistive products.

The two identical documents, ISO/IEC (2001) Guide 71 and CEN/CENLEC Guide 6 (CEN/CENELEC, 2002) are addressed to the developers of standards and are guidelines rather than standards. However, they provide some useful information, which is relevant to the developers of both assistive and design for all products. The standard ISO 9999:20007 gives a classification of assistive products.

There are a number of different usability standards (Bevan 2001ab; Earthy, 2001), some of which are listed below:

- ISO 9241 series, which has had the most impact and includes ISO 9241:11 Guidance on Usability, which provides a definition of usability.
- ISO/IEC 9126 Software engineering – product quality, which defines usability in terms of understandability, learnability, operability and attractiveness.
- ISO 20282 Ease of Operation of Everyday Products, which specifies the usability of the user interface of everyday products.
- ISO 9241 Ergonomic requirements for office work with visual display terminals
- ISO 14915: Software ergonomics for multimedia user interfaces
- IEC TR 61997: Guidelines for the user interfaces in multimedia equipment for general purpose use.
- ISO CD 9241-151 Software ergonomics for World Wide Web user interfaces
- ISO 13406: Ergonomic requirements for work with visual displays based on flat panels
- ISO 13407 specifies the activities required and internationally accepted good practice in user centred design.
- ISO 16982 outlines the types of methods that can be used in user centred design
- ISO WD 20282, a multi-part standard which is being developed to specify the usability information required about a consumer product to enable purchasers to

In addition to the requirements of standards, some assistive products are also classified as medical devices and are therefore liable to the approval processes required of medical devices. Despite some attempts at standardisation by the World Health Organisation (WHO 2003), there are still significant differences in the approval processes, for instance in the European Union and the USA (Chai, 2000). In the USA being able to show that the product is 'substantially equivalent' to an existing product which has been approved, either directly or through 'substantial equivalence' to another product significantly facilitates the process (WHO, 2003). However, other than noting that good design practice should be followed and designers and developers should be aware whether their product is likely to require approval, space limitations prevent further discussion of this topic.

End-User Involvement

Categorisation of Different Types of End-User Involvement

Successful design requires an understanding of the target user groups and their goals, requirements, preferences (Scherer 2002), language, cultural and other contexts, which may be different from those of the dominant culture of the country or region they are in (Parette et al. 2004). This requires end-user involvement from the start, as decisions on functionality and how the product will be used are generally made early on and changes at a later date are likely to both be less effective and more expensive. In addition, if rather than obtaining end-user information at the start of the process, designers wait until they already have a design, they will be tempted to try to obtain information which supports the existing design (Den Buurman 1997). Only (potential) end-users fully understand their own requirements, can test what does and does not work in practice and determine whether a product is acceptable to them. Technical performance is often not the most important factor to end-users. The fact that many design professionals are not disabled and frequently also not elderly, increases the importance, but sometimes also the difficulties, of involving end-users in the design of assistive products.

The primary end-users of assistive technology are disabled and/or elderly people and their requirements should be given prime consideration in design. However, there are a number of other groups of people who can be considered secondary end-users. A classification of the different categories of users of medical devices has been carried out based on a study of the literature (Shah and Robinson, 2008), but there does not seem to be an analogous classification of the users of assistive technology. These groups depend to some extent on the particular assistive product, but may include family members and/or friends, personal assistants, teachers, social workers, occupational therapists and medical personnel. While they should also have some involvement in the design process, the views of the primary end-users i.e. the disabled or elderly users of the assistive product should be given the greatest consideration. Another important stakeholder is (potential) funding organisations, that can include state healthcare and social services departments and a range of non-governmental organisations. To maintain independence and the highest standards of design, potential funders should not be involved in the design process. However, it is prudent for assistive product designers to take account of the fact that many assistive products are either supplied by, for instance, social or health services or purchased with full or partial financial support rather than paid for directly by the end-user.

End-user involvement in the (assistive) product research, design and development process can be divided into the three main categories listed below. Design and development of a particular product could involve end-users in more than one of these roles.

- Participation in which end-users (generally representing particular organisations) are involved in the decision making processes and are considered part of (one of) the research team(s).
- Consultation in which advice is sought from end-users at different stages, including testing prototypes and finished devices.
- Involvement as research 'subjects'.

Specific approaches include the following:

- Living Labs.
- The FORTUNE Project approach.
- Other participatory approaches, including participatory design and participatory research.
- USERfit methodology.

The FORTUNE Project (Bühler 2000) and other participatory approaches involve end-use participation, whereas the USERfit methodology (USERfit) treats end-users as research subjects. Living Labs (Living Lab [updated 2010]; Living Labs Global) involves a different type of paradigm, which could be considered a combination of consultation and participation, with researchers becoming involved in the end-users' context to carry out product design and development. While the relative advantages and disadvantages of the participation, consultation and research subject approaches are well-known, there has not to date been a comparative evaluation of the specific methodologies listed above.

The different definitions of Living Labs all have the following common factors:

- A human-centric approach to end-user involvement.
- A multidisciplinary research approach.
- User community driven innovation based on real life experiments.

There is a European Network of Living Labs (ENoLL), launched by the European Commission coordination action project CoreLabs, with129 member Living Labs at the time of writing.

The FORTUNE project developed seven principles of user participation, including:

- Partnership as a basis with users as members and/or representatives of organisations.
- Users to be paid and to have access to relevant materials and premises.
- All partners guarantee confidentiality, respect and expertise
- Partnership from the start of the project with a detailed project plan for user participation.

The USERfit methodology (USERfit), which is discussed in section 3.2, could be used to structure obtaining end-user information and discussion with end-users.

There are a number of different approaches to participatory design and action based research (Whyte, 1989). In participatory research some of the subjects are invited to play a more active role. Some of the key informants may become collaborators in the research, as is the case with the FORTUNE Project. Thus, participatory design involves key informants in the design process.

Participatory action research is most frequently used in the social sciences. It aims to directly implement change, generally in the organisation being studied, as a result of the research. It involves a spiral of cycles of research and action with the four main components of planning, acting, observation and reflection (Swan, 2002). In the case of assistive product design, there is rarely an organisation being studied which can be directly changed as a result of the research and any resulting (societal) change is achieved indirectly through the implementation and use of the product, rather than directly as a result of the design process and/or the associated research. In this sense, participatory design is a more appropriate methodology than participatory action research. However, there are exciting possibilities related to the use of participatory action research to determine how the design, implementation and use of assistive technology can contribute to changing attitudes to disabled people and be used to leverage the removal of infrastructural and other barriers. Unfortunately, this wider research agenda, though it may (eventually) lead to better assistive products is generally beyond the resources of the assistive technology industry, which mainly comprises SMEs. It may be more appropriate in a university context and would require highly interdisciplinary research teams with cross faculty collaboration.

The extent of end-user involvement will generally depend on both the complexity of the project and the available resources and be a compromise between what would be desirable and what is feasible. Where possible, disabled and elderly end-users from ethnic, linguistic and other minority groups should be involved. This will require awareness of cultural differences in interactions and what people are willing to discuss and that there may be different attitudes within a given family to assistive technology use (Parette et al. 2004).

Communication Issues

Successful involvement of end-users requires effective communication. In the case of disabled and elderly end-users this gives rise to the following two issues:

- The use of jargon, scientific and engineering terms, which are likely to be unfamiliar to lay people.
- Different ways or styles of communicating or the use of different languages.

The first issue is relevant to the co-operation of all mixed groups, involving engineering and scientific ‘experts’ and the lay population, whether or not they include disabled and elderly people. However, elderly people are less likely to be familiar with technical terms that are coming into general usage than younger people. Engineering, design and other professionals should take responsibility for avoiding communication problems of this type, since they generally have access to more resources than end-users and understand technical terms. In addition, failure to do this is likely to have negative consequences for the product or device. In particular, end-users who feel that they are being talked down to or that incomprehensible technical jargon is being used, may lose interest or feel inadequate and are unlikely to ask for explanations, particularly if this is a regular occurrence. This may lead to them leaving the project or not participating in a meaningful way if they remain. The resulting assistive product is likely to be of poorer quality than if end-users had been actively involved and may not meet users' needs and/or have low take-up.

Therefore, wherever possible technical terms and jargon should be avoided. In addition, a glossary of any essential terms, which explains them in clear non-technical language, should be provided in appropriate formats, including large print, Braille, sign language and electronic format, as well as new terms being explained when they are introduced. Engineers, designers and other professionals will also need to learn to communicate in appropriate ways with people without a technical education and may require training in order to do this.

The second issue is specific to the participation of disabled and elderly people, as well as people from ethnic and other minority groups, who may have language and cultural differences from the designers, engineers and other professionals. The accessibility of documents, design representations, experiments, equipment, one-to-one communication, group discussion and presentations all need to be considered. It is useful to check the accessibility requirements of end-users in advance, so that appropriate arrangements can be made, while avoiding unnecessary expenditure on accessibility measures that are not required. It can also be useful to contact organisations of disabled people to obtain information and possibly also training on accessibility. While it is can be useful to talk to the families of disabled and elderly people, this should be additional to rather than instead of talking to disabled or elderly people themselves.

Document accessibility will require the provision of documents in a number of different formats, which could include electronic versions which are compatible with screen readers and screen magnifiers, low-text high graphics and large print versions, Braille versions, audio versions on CD and sign language videos or DVDS. Representations of product designs will need to effectively simulate the product or design features being investigated in a way that is accessible to all the target groups of end-users. All experiments and equipment should also be designed to be fully accessible (Hersh et al. 2004).

The accessibility of one-to-one or group communication or presentations may require the provision of interpreters, assistive listening systems, notetakers and/or a speech-text conversion system. Adequate and appropriately positioned lighting will be required for lipreading and viewing interpreters, screens and documents. There should be an allowance for breaks for interpreters and the translation of technical or special terms by interpreters or into Braille should be discussed in advance to prevent misunderstandings. It should also be recognised that some disabled people interpret everything very literally and/or may have difficulty understanding metaphors, allusions or some types of humour. All premises should be fully accessible, with regards to sufficient entrance width, the provision of ramps, lifts within buildings, accessible toilets and signposting (Miesenberger et al. 2009).

In the case of end-users with general learning difficulties, particular attention will be required to make communication clear and simple, while avoiding being patronising or speaking down. In the case of people with dementia, considerable ingenuity may be required to develop appropriate strategies and repeated approaches may be required both to develop rapport and find a time when the person is at their most lucid. It may also be easier to involve people in the early stages of dementia, though it is possible their attitudes and preferences may change as the condition progresses, when it will be more difficult to consult them.

Designers should also be careful to learn the terminology that is considered respectful by organisations of disabled people for referring to particular groups of disabled people in the country they are working in. For instance, in the UK the general term is ‘disabled people’. Expressions such as ‘handicapped’, ‘invalid’ and ‘retarded’, as well as ‘afflicted with’ and ‘suffering from’ should be avoided. ‘Wheelchair users’ are not ‘wheelchair bound’ and ‘blind people’ or ‘disabled people’ are preferred by organisations of disabled people to ‘the blind’ or ‘the disabled’. It is generally perfectly acceptable to say ‘see you soon’ to a blind person or ‘did you hear about’ to a deaf person, but not to use blindness and deafness in negative metaphorical ways, such as ‘blind to reason’.

Methods for End-User Participation

A range of different methods have been developed for consulting and involving stakeholders in decision making, for instance (Bryman 2008; Roozenbrook and Ekels 1995). In principle, most of these methods are equally applicable to disabled and elderly people if account is taken of the communication issues discussed in Section 4.2. Some of the methods can be used for generating ideas with end-users and/or designers and others for obtaining information and feedback from end-users.

Brainstorming is a technique for generating ideas or solutions. Participants call out their suggestions, which are written down for future discussion. There is no criticism or discussion of the ideas during the brainstorming process. A brainwriting pool is a variant in which ideas are written down and put in a ‘pool’. Participants draw a sheet of ideas from the pool and try to add suggestions to it. Wizard of Oz uses metaphors or simulation tools to identify the type of solution at an early stage when nothing comparable exists.

Direct Observation involves studying end-users using a particular device, in their own environment, without the observers interacting with the users. User and Field Trials involve testing a product or system respectively in a controlled context, such as a laboratory, or a normal environment, such as home or work. In the laboratory, video recordings or recordings of body and eye movements may be used to study performance in more detail. In both cases direct observation or user commentaries, for instance in the form of activity diaries, could be used and users will generally require sufficient familiarisation time before observations start. Usability Testing involves field or user trials which concentrate on the issues of effectiveness, efficiency, safety and comfort.

Survey methods in the form of questionnaires and interviews can be used to obtain both quantitative and qualitative data from end-users. Email and internet (web) based surveys have the advantages of speed, low cost and accessibility if the forms are properly designed. In addition they provide information in electronic format and it may be possible to use software to summarise the data for analysis. However, they are only suitable if a high proportion of the end-user group of interest has internet access. Personal or telephone interviews allow follow-up questions, as well as unstructured and semi-structured approaches and are useful if respondents require additional explanations or assistance in writing the answers. However, they are time-intensive and costly to carry out.

Organising End-User Information

There are a number of different approaches to organising end-user, context and other information. These include assistive technology models, such as the Human Assistive Technology (HAAT) model (Cook and Miller Polgar 2008), the Matching Person to

Technology (MPT) model (Fuhrer et al. 2003) and the Comprehensive Assistive Technology (CAT) Model (Hersh and Johnson 2008ab), as well the Needs Analysis and Requirements (NARA) framework (Smith-Jackson et al. 2003) and the USERfit methodology (USERfit).

The NARA procedure is carried out in several cycles of four steps: obtaining information from users, for instance through focus groups or interviews; using the information to obtain requirements; producing a paper based mock-up or low fidelity prototype which implements the requirements; and evaluating the guidelines for accurate implementation, usability and relevance, through development of a new group of assessment activities rolled over from the initial procedure and applied to a new sample of end-users.

The HAAT and CAT models have a hierarchical structure with the four components of person, activity, technology and context at the top level. They could be used for information gathering in the format of questionnaires or interviews. The context, activity and person descriptions are better developed in the CAT model and it is not implicitly restricted to the countries with a well-developed infrastructure. The MPT and USERfit processes have a well developed questionnaire structure for obtaining end-user data.

Space limitations prevent a detailed discussion of the applications of these models to organise end-user data and, where the model or methodology supports this, to structure the development of design specifications. Therefore, readers are referred to the references for details. However, as an illustration the person and assistive technology components of the CAT model will be presented in Figures 4a and 4b respectively. These components of the model have been chosen as the person component is used to organise end-user information and the assistive technology component has the main role in deriving design specifications.

Figure 4a: Person component of the CAT model

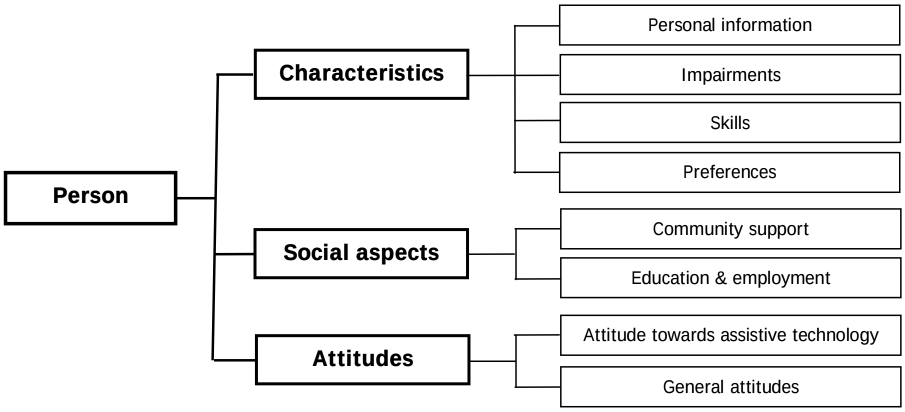
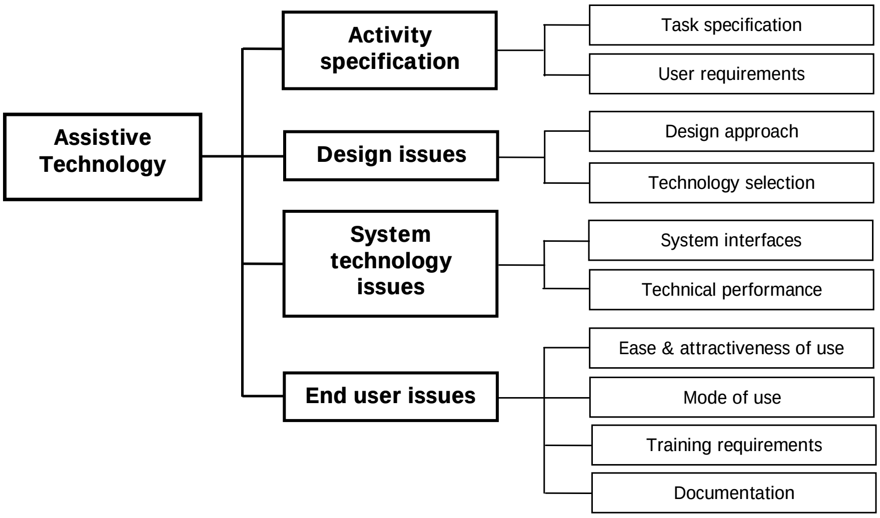


Figure 4b: Assistive technology component of the CAT model



Ethical and Safety Issues

Product designers need to be aware of and comply with the ethical research policies of their organisations as well as national and international legislation, regulations and standards. There are also codes of practice for ethical practice with regards to the involvement of human subjects produced by organisations such as the British Psychological Society. While being familiar with and following regulations, standards and codes of practice, product designers should also recognise that ethical practice frequently goes beyond simply complying with policies and regulations. Many assistive products do not raise ethical issues in themselves, though there may be potential applications of the product or parts of it which are ethically controversial. However, some assistive products can raise privacy issues or reduce the user's freedom. For instance remote monitoring systems can reduce risks for people with long term health conditions living at home, but are intrusive and provide information about the user's activities and location to a hospital (Abascal 2002). Some systems to support independent living by people with dementia may stop them leaving the house at certain times or inform other people if they have left appliances on. This is a restriction of their freedom of movement and/or an infringement on their privacy, but could increase their safety or that of other people in their vicinity. In deciding whether or not to develop products of this type it is important to consult with (potential) end-users and not just their family and personal assistants.

Other issues include honest communication, the use of data and safety and risk. Honest communication involves the provision of information on the main aims of the activity; the desired involvement and associated time commitment; whether expenses or payment will be available; any training that is provided; the benefits to the specific person, as well as more generally, and the time span these benefits will occur over. In the case of trials of a particular product or device, participants should be informed whether they will be able to continue to use it after the end of the study period. Information should not be withheld or participants misled and participants should have the right to withdraw at any time, including when payment is made. Disabled and elderly people will require information and consent forms to be presented in appropriate and accessible formats and language, as discussed in Section 4.2. The provision of information using pictures and photographs (High 1992) or vignettes and storybooks (March 1992) may be particularly appropriate for some groups of disabled people including Deaf signers and people with learning difficulties or cognitive impairments.

Particular care is required when providing information to and obtaining consent from people with dementia or other cognitive impairments. On the one hand they should not be prevented from participating in research, as this removes their right to volunteer (Milliken, 1993) and the possibility of obtaining satisfaction from this contribution or the associated social interaction. In addition, the lack of involvement of people with cognitive impairments could lead to the development of products which are unsuitable for them. On the other hand, it is important that they are not exposed to unethical practices and that they fully understand what is involved in the research and any risks (Arscott et al., 1998). In the case of the development of assistive products for children, consent should be obtained, if at all possible, from the child, as well as their parents or guardians (Ethical Principles 2009).

Issues relating to the use of data include how raw data is stored and who can access it, the option of data being stored anonymously, and issues associated with publication, such as whether or not respondents want to be named or remain anonymous and what measures will be taken to protect their identity and that of their organisations. Many countries have legislation on data protection, the provisions of which should be studied and implemented.

Safety is both a practical and an ethical issue. All possible measures should be taken to minimise risk and cost saving, for instance by using cheaper materials or techniques, should not be considered a valid reason for exposing people to risks. Payment should never be used to induce people to be involved in possibly risky product trials. In general, the aim should be to reduce any risks to a few events with minimal consequences and very low probabilities. Any risks to a research subject should be proportionate to the benefits to both that person and society as a whole (Emanuel et al., 2000) and should not be greater or additional to those encountered in their normal life unless full information has been provided and informed consent obtained, as well as disinterested approval from independent advisers (Ethical Principles [updated 2009]).

All laboratory and equipment users should learn the appropriate safety rules and precautions and should also attend any necessary training courses. While all measures should be taken to avoid accidents, it is essential to know safety procedures in the case of accidents, as well as the location of fire exits, fire extinguishers and how to use them, and the location of first aid equipment.

Working with disabled people may raise particular safety issues, which should be discussed with them. For instance when a group of blind people tests the performance of a new mobility device, safety precautions will be required to ensure that their reliance on the new device does not lead to accidents. Both designers and disabled or elderly people should be aware of the procedures for, for instance, evacuating blind people and people in wheelchairs in the case of fire. Deaf and hearing impaired people should be provided with vibro-tactile pagers to alert them to fire or other incidents.

Conclusions

This article has provided an overview of some of the main issues in the design of assistive products. In doing this it has highlighted the importance of end-user involvement from the start and throughout the design process and provided a brief overview of some of the methods of doing this, as well as the need to take account of good practice in the design of (consumer) products. This includes using iterative, multi-criteria approaches, appropriate trade-offs between different design criteria, ease and intuitive use, compliance with and, where possible, significantly exceeding relevant national and international standards, legislation and regulations, as well as sustainable design. It has also overviewed both the similarities and differences in designing assistive and other (consumer) products and the increased importance of accessibility, as well as an appropriate and well-designed end-user interface. It should be noted that design is a complex subject and readers are referred to books on the subject, such as (Green et al. 1999; Hypponen 1999; Pahl et al. 1996; Roozenberg and Ekels 1995; Ulrich and Eppinger 2008) for further information.

(Consumer) product design is a fairly mature field in which a number of methodologies have been developed, though there is always a role for further developments. The fact that there are frequently even greater differences between the end-users and designers of assistive than other (consumer) products makes the use of user-centred design particularly appropriate for assistive products. Existing design approaches can be used for assistive product design, including the design of one-off products. However further work will be required on the development of methodologies for accessible and usable design, though this should become good practice for all (consumer) products, not just assistive ones. Further work is also required in the area of end-user involvement, with a particular focus on methods which are suitable for disabled and elderly end-users.

As indicated in the introduction this article is the first of three parts. Part 2 will discuss the evaluation of assistive products and Part 3 the outcomes of assistive product use.

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