1
Intelligent textiles and clothing – a part of our intelligent ambience

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1.1 Introduction

Although intelligent textiles and smart clothing have only recently been added to the textile vocabulary, we must admit that the industry has already for several years focused on enhancing the functional properties of textiles. New chemical fibres have been invented. By attaching membranes on textile substrates, fabrics were made breathable and yet waterproof. Three-dimensional weaving technology paved the way for new exciting technical textile developments. These are some examples of a textile-based approach for improving the properties and functionality. Wearable technology, the electronics-based approach, started to add totally new features to clothing by attaching various kinds of electronic devices to garments. The results, however, were often bulky, not very user friendly and often very impractical. The garment was truly wired with cables criss-crossing all over, batteries in pockets and hard electronic devices sticking out from the surface. The piece of clothing had become a platform for supporting electronics and was hardly wearable in a clothing comfort sense. The current objective in intelligent textile development is to embed electronics directly into textile substrates. A piece of clothing remains visibly unchanged and at the end of the day the consumer can still wash it in the washing machine without first removing all the electronics. This of course is very challenging.

1.2 Intelligent systems

Intelligent systems are normally understood to consist of three parts: a sensor, a processor and an actuator. For example, body temperature monitored by the sensor is transferred to the processor, which on the basis of the received information computes a solution and sends a command to the actuator for temperature regulation. To achieve such interactive reactions three separate parts may actually be needed. The sensor may be embroidered on the surface of the T-shirt by using conductive yarns. Signals are transmitted wirelessly between the processor, sensor and the actuators, which could be microscopic flaps that open in order to increase ventilation and temperature transfer. Or the system may work on the basis of physics like phase change materials.

Phase change materials (PCM), shape memory materials (SMM), chromic materials (colour change), conductive materials are examples of intelligent textiles that are already commercially available. This is also reflected in the contents of this book. Part I deals with phase change materials. Part II introduces shape memory materials. Chromic and conductive materials are presented in the next part. The final part deals with applications.

There are numerous research projects on the way around sensors and actuators as can be seen from EU's research records Cordis.[1] Conductive fibres and yarns are equally important. Power supply, perhaps the toughest challenge for intelligent textiles, should also be an integral part of textiles. Flexible solar cells, micro fuel cells and the possibility of transforming body motion into electric power are interesting topics. Infineon Technologies AG has developed a textile embedded power supply based on the temperature difference between the outer and inner surfaces of a garment. Photonics, including textile-based display units, are being developed by many research institutes and companies. Interactive Photonic Textiles, an invention published by Philips in September 2005, contain flexible arrays of inorganic light-emitting diodes, which have been seamlessly integrated into textile structures. The invention turns fabric into intelligent displays to be used for ambient lighting, communication and personal health-care. The textile surface can also be made interactive and Philips has managed to embed orientation and pressure sensors as well as communications devices (Bluetooth, GSM) into the fabric. The jacket display making a man invisible developed at the University of Tokyo is one of most exciting latest inventions.

1.3 Applications

'Where are the commercial applications?' is a frequently asked question. Despite nearly ten years of research and development we have seen only a few smart textile and apparel products on the market. The computerized jogging shoe No. 1 by Adidas is one of them. Interactive Photonic Textiles by Philips may bring a few more around. But countless hours of research and development work is presently allocated to this area by universities, research institutes and companies in different parts of the world. Scientific conferences and commercial events are organized around this theme. One of them was Ambience 05, a scientific conference organized at Tampere, Finland in September 2005. More than 200 participants from 24 different countries

1. Community research & development information service (www.cordis.lu)

participated and 42 papers focusing on intelligent textiles, smart garments, intelligent ambience and well-being were presented. In the interactive concluding session regarding future trends in smart textile research the participants were able to express their opinion on key questions through a remote-control on-line voting system. The results of the survey are presented in Table 1.1. It was felt by 79% of the participants that commercially successful

Table 1.1 Future trends in smart textile research according to the participants at scientific conference Ambience 05

Commercially successful smart textile/garment applications will be available in	0–1 years	14.8%
	1–5 years	50.8%
	5–10 years	28.9%
	> than 10 years	3.9%
	Never	1.6%
In which sector do you expect commercially viable smart innovations first to become reality?	Sports and extreme	40.2%
	Occupational clothing	24.8%
	Transportation	6.0%
	Technical textiles	21.4%
	None of these	7.7%
It is possible to miniaturize electronic devices enough to insert them into fibres in	0–1 years	1.5%
	1–5 years	26.7%
	5–10 years	45.0%
	> than 10 years	23.7%
	Never	3.1%
Energy sources can be fully integrated into textile structures in the near future	Agree totally	22.5%
	Agree slightly	43.4%
	Disagree slightly	24.0%
	Disagree totally	10.1%
Phase change materials with real warming/cooling impact will be available in	0–1 years	13.6%
	1–5 years	50.8%
	5–10 years	19.7%
	> than 10 years	8.3%
	Never	7.6%
Shape memory and colour change textiles will generate breakthrough smart garment applications in the near future	Agree totally	18.5%
	Agree slightly	43.1%
	Disagree slightly	28.5%
	Disagree totally	10.0%
Textile embedded sensors and tele-monitoring of patients will be applied in hospitals despite high costs	Agree totally	40.3%
	Agree slightly	38.7%
	Disagree slightly	19.4%
	Disagree totally	1.6%
Breakthrough nano-technology applications in textiles, beside finishing, will be available in	0–1 years	6.4%
	1–5 years	37.6%
	5–10 years	36.7%
	> than 10 years	18.3%
	Never	0.9%

Source: Ambience 05 on-line poll at the interactive concluding session with more than 200 scientific participants.

smart textile and garment applications will be available in the market between five and ten years, most likely in sports and extreme wear, in occupational and professional clothing and in technical textiles. Nano-technology applications and adequate miniaturization of electronic devices for inserting them into fibres were still expected to take a considerable amount of time, while the majority felt that energy sources can be fully integrated into textile structures in the near future. More efficient phase change materials were expected to be available within the next five years, but the majority did not quite believe in breakthrough results with shape memory or colour change materials. Most of the participants expected textile embedded sensors and tele-monitoring of patients to become reality in hospitals despite the high costs.

Intelligent textile and garment research is very cross-scientific. Beside textile knowhow many other skills, such as electronics, telecommunications, biotechnology, medicine, etc., must be brought into the projects. One research institute cannot carry out such projects alone. Networking as well as considerable amounts of financing are required. There are high hopes in the scientific community toward the EU's seventh framework programme for financing and for further networking within the sector. The complexity and broadness of knowledge required for intelligent textile research is also highlighted by this book.

2
Methods and models for intelligent garment design

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2.1 Introduction

In recent years, interdisciplinary studies have been the mainstream in research discourses and practices. At the same time, the number of projects with shared expertise has increased enormously. As Klein (1990, 13) states in her book on interdisciplinarity, 'As a result the discourse on interdisciplinarity is widely diffused' and 'the majority of people engaged in interdisciplinary work lack a common identity'. Interdisciplinarity is thus an ambiguous term, applying 'to both the idea of grand unity and a more limited integration of existing disciplinary concepts and theories' (ibid., 27).

Especially in research areas where the research object or the phenomenon explored could be characterised as a complex and hybrid field, the means used in interdisciplinary and multimethodological approaches have been seen as reasonable and useful. According to Klein (1990, 11), educators, researchers, and practitioners have turned to interdisciplinary work, for example, in order to answer complex questions, to address broad issues, to explore disciplinary and professional relations, to solve problems that are beyond the scope of any one discipline, and to achieve unity of knowledge.

When discussing hybrid products, we normally refer to the object in terms of both material and immaterial properties. We speak about intelligent products such as smart houses, vacuum-cleaners, cars, and clothing. Such products could be studied in relation to different contexts, e.g., work, sport and leisure, entertainment, well-being and health, and with regard to fashion design practice (Ullsperger, 2002), to name just some approaches.

Human beings are always in a dynamic state, which can be described as non-linearity, broken symmetry, dissipation of free energy, complexity, orderly disorder and dynamic stability. Even identical twins are phenotypically different. (Yates, 1993) The regulatory functions of homeodynamic responses are pulsatile. From birth to death we are thus in a state of oscillating non-equilibrium. Our reactions are stimulus dependent on and modulated by the central state defined as the total reactive condition, and this state fluctuates.

(Vincent, 1993). Stimuli are collected from the outside world and from within the body. They affect information processing in the brain as well as our behaviour. In cold climates, foresight is evidenced by, among other things, clothing, the construction of shelters, and the discovery and use of fire for heating (Denton, 1993). We can use technology to increase the sensitivity of our sensory systems. Technology can be integrated into garments. Using computing systems, for example, it is possible to develop warning systems that help workers avoid danger. Our sensory and brain mechanisms, as well as motor and vegetative functions, show decline with age. This can be partially compensated for by intelligent garments and integrated computing systems, which can provide warnings or summon expert help if accidents or diseases so require. These computing systems can be in homes, working places, or in fact any location if the information is transmitted in digital form, trends are calculated and smart warning limits have been established. These systems and products are objects of research that clearly go beyond the scope of any single discipline.

2.2 Background context

The aim of the article is to describe the underpinnings of the interdisciplinarity elaborated in the research and design project Methods and Models for Intelligent Garment Design (MeMoGa), funded by the Academy of Finland's Proactive computing program and conducted jointly by University of Lapland, Tampere University of Technology, and University of Kuopio in Finland during the years 2003–2005. The purpose of the project was to analyse the conceptual framework offered by the theoretical bases of the research on clothing and dress and ascertain their applicability to the study of ubiquitous computing and the services, activities and social situations to be found in intelligent environments.

2.2.1 Intelligent garments in the light of clothing theories

An examination of the research on clothing and fashion reveals that in many respects the concept of an intelligent garment has yet to be analysed. The phenomenon whereby the traditional characteristics of a garment are augmented with sophisticated functional features is referred to using terms such as 'wearable computer' (see Suomela *et al.*, 2001) or 'interactive materials' (Nousiainen *et al.*, 2001). The discussion in the field in recent years has revolved around the technological research and knowhow involved, and few if any references can be found in the literature to the conceptual points of departure used in the research on clothing and dress and in fashion design. For example, there has been no research done in the area of clothing theory to clarify how an intelligent garment acquires meanings in social interaction and communication, although new forms and means of communication are more often than not the focus of interest when intelligent garments are mentioned.

Clothing, jewellery and watches have long been part of the everyday life of people in the West. Accordingly, it can be assumed that the theoretical bases and methods developed to study such objects can be profitably applied in solutions for intelligent products and in anticipating the usability and acceptability of such products in everyday life. Research in clothing theory helps us to understand conceptually the social processes which render the wearing of various artefacts natural and familiar. In this way, the approaches and analogies found in research on clothing and dress will prove significant when we proceed from user-centred information technology to proactive applications, i.e., from interaction between people and technology to interaction between people and the environment. Interestingly, an examination of the theoretical approaches of the research on clothing and dress reveals precisely such a transition: whereas in 1930 J.C. Flugel defined the *needs* for clothing and dress in terms of people's desire for protection, modesty and self-decoration (Flugel, 1930), in the 1980s Alison Lurie described clothing as a system akin to *language* (Lurie, 1992). In 1990, Susan B. Kaiser submitted that the meanings of clothing and dressing should be interpreted in *context* (Kaiser, 1990). The underpinnings of the contextual approach lie in symbolic interactionism, which concerns itself with the *communication* between a person's self and the community. Lamb and Kallal (1992) have proposed a Consumer Needs Model that assesses user needs by incorporating the functional, expressive, and aesthetic dimensions of clothing.

One particular focus of the MeMoGa project was to determine how the approaches identified might be used in elaborating models and strategies for research on the usability and acceptability of wearable intelligence and in developing design methods. An additional aim was to develop frameworks that might help initiate R & D projects on new-generation garments and environments for ubiquitous computing in the next few years. The research and design group also created a garment concept in the field of wearable intelligence that can be easily adapted for different users and is acceptable and accessible to as many users as possible.

The researchers in the MeMoGa project focused on the garment needs of workers in heavy industry and supported the concept design of an intelligent garment for them by drawing on Lamb and Kallal's Consumer Needs Model. In Lamb and Kallal's, view functionality (F) encompasses the fit of a garment and the mobility, comfort, protection, and ease of donning and doffing it offers. A garment's aesthetic properties (A) embrace the design principles and artistic elements involved, such as line, pattern, colour and texture. Expressiveness (E) in turn is associated with the communicative and symbolic characteristics of the garment or outfit.

2.2.2 Research and design procedure

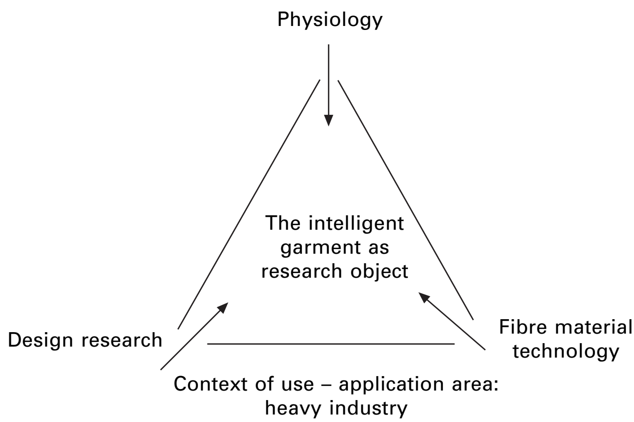
The MeMoGa project started with empirical analyses to inform intelligent garment design in which the researchers identified the needs of the selected focus groups, i.e., workers in heavy industry. The data on the target group were collected using semi-structured interviews and a tentative analysis was carried out. The results of the interviews were operationalised into *design criteria* that then guided the concept design process. Here, the term 'concept' refers to the vision stage of the product design process. The purpose of the concept design process was not to produce a detailed description of the product but to facilitate creation of the innovations and visions for forthcoming product design processes (Keinonen and Jääskö, 2004, 21).

In order to test the usability and accessibility of the garment concept, which involved protective clothing for workers in heavy industry, the research team created a multimedia presentation showing the concept in a setting in which the clothing would actually be worn. According to Wright and McCarthy (2005, 19), the use of scenarios and other narrative techniques are different ways 'in which designers can engage with user experience.' The creation of a virtual prototype and 3D modelling has been estimated to bring efficiency to the area of wearable intelligence. Animations in particular have been seen as meriting further research (Uotila *et al.*, 2002). Generally speaking, the research team were much more interested in developing methods that could assist in the early stage of design and could support open communication between users and designers through the concept design and interactive virtual prototypes than they were in producing prototypes or final products (Bannon, 2005, 37). The present findings also indicate that virtual prototypes make it possible to provide initial information about concepts, products and the use of products in different socio-cultural contexts and communities.

The co-operation between the professionals from different fields of research and between the professionals and the end users of the products took place using the virtual working environment Optima. With the partners in the project located at opposite ends of and all over the country, this environment created a good foundation for not only the research and design work but also project management. It provided an appropriate environment for communication by the multidisciplinary research and design team, 'bringing together people with different skills and expertise to discuss together user data, mock-ups, video prototypes, etc.' (Bannon, 2005, 37). Although the environment facilitated real-time communication between the partners, it did not replace face-to-face meetings.

There is no need here to go through the project in depth and present the detailed empirical findings of the research. A number of articles are forthcoming on the topic by the researchers and PhD candidates working in the project

(Mäyrä *et al.*, 2005; Matala *et al.*, 2005; Pursiainen *et al.*, 2005). Instead, we attempt to give a framework for discussion of the concept of interdisciplinarity as regards the research areas mentioned above. The focus of the MeMoGa project is depicted in Fig. 2.1, providing the context for the discussion on interdisciplinarity to follow.



2.1 The intelligent garment as an object of interdisciplinary research from the perspective of three research disciplines: design research, fibre material technology, and physiology.

2.3 The underpinnings of interdisciplinarity

The research on ubiquitous computing and ambient intelligence is very labour intensive and cannot be carried out by just one or two researchers. To gain an orientation to interdisciplinarity it is important to review how researchers view intelligent garments as research objects, and how different disciplines define intelligent products and services integrated into products on the basis of different research paradigms. To this end, this section formulates the concept of the intelligent garment as an object of interdisciplinary research from the perspective of three individual research disciplines: design research, fibre material technology, and physiology. Where scientific models are concerned, the section discusses the scientific practices and models in the various disciplines and the benefits that can be derived from them for smart products, in particular intelligent garments.

2.3.1 Mature sciences vs. pre-sciences

In his publication *The Structure of Scientific Revolutions*, Thomas S. Kuhn (1970) distinguishes mature, normal science from immature, pre-sciences. In any mature science, every scientist will accept the same paradigm, most of the time (Laudan, 1977, 73). In a similar vein, Chalmers (1999, 108) has pointed out, 'A mature science is governed by a single paradigm'. In contrast, in immature sciences there is no consensus on theories, methods, and research objects as there is in more established research areas. Bringing this into the context of the present study, it could be said that where design research is still going through its immature research stage, physiology and fibre material technology are normal sciences in the Kuhnian sense in that they have already reached maturity and are in the process of redefining their concepts and methods.

Then again, it could be said there are no mature sciences. In chemistry and physics one can work with molecules such as DNA and their constituents and calculate their behaviour *in vitro* under experimental conditions. Unfortunately, all life phenomena are non-linear even at the cellular level, and one cannot, for example, extrapolate from DNA what behavioural responses will occur in humans in real life, although most of our genes are similar to those in mice and even closer to those of the primates. Genes are, in a way, prisoners of the successful physiology that carries them, but also of the successful ecological niche in which they find themselves. Integrative physiology is an old and a new science at the same time (Noble and Boyd, 1993).

Another difference is that where the natural sciences are closely connected to empirical research practices and empiricism, design research draws its orientations from design-driven practices, humanism and, quite often, hermeneutics. The natural sciences are usually understood to include physics, chemistry, biology, and their border areas (Hempel, 1966, 1), with the humanities including disciplines such as philosophy, history, and the arts. Although the methods of the natural sciences and the rationale of scientific inquiry have quite often been considered to be more scientific, the questions of knowledge construction, truth and reliability are also essential for human studies. One may ask what the meaning of the hermeneutic dimension is for all knowledge construction, and for modern natural sciences (Gadamer, 2004, 130).

This discussion is significant from the point of view of design research. The positivist doctrine and technical-rational underpinnings of design research have been challenged by reflective practices of design – 'design as discipline, but not design as a science' (Cross, 2001, 54), and with 'its own intellectual culture, acceptable and defensible in the world on its own terms' (ibid., 55). Nowadays design is a broad field of making and planning disciplines (Friedman, 2000, 6). In this vein, Diaz-Kommonen (2002, 27) has asserted, 'There is no single, solid, discursive foundation underlying design, but rather the landscape is one of fluctuating positions, representing discursive formations, in the process of negotiation'. But could there not be some unity of design discipline that sifts multiplicity from the atomistic? (Klein, 1990, 22).

As in any research area, in design research it is possible to distinguish the questions typical of basic research, applied research and development work. Basic research in design includes the underlying theoretical assumptions, i.e., the ontological, epistemological, and methodological underpinnings of the studies. The ontological assumptions about human reality and human values in the foundations of design research also belong on this level. Case studies, which may be understood as design particulars, represent the level of applied design research and development work.

2.3.2 The intelligent garment as an object of interdisciplinary research and design in terms of the Popperian worldview

On the level of basic research it is reasonable to ask, 'What is the object of research?' In his theory of three worlds, Karl Popper distinguishes natural objects as part of world 1, subjective awareness as an aspect of world 2, and cultural products, events and social situations as manifestations of world 3. Crucial to Popper's theory are what he refers to as the emergent features of organisms, that is, the features that produce innovation but which cannot be predicted on the basis of lower-level features or laws. 'Life, or living matter, somehow emerged from nonliving matter; and it does not seem completely impossible that we shall one day know how this happened' (Popper 1987, 150).

Popper's theory of three worlds can also be applied to explain the relationships between designers, artefact (interface) users and the contextual environment of their interactions (Popovic, 2002). The contextual environment of an artefact (interfaces) includes *the artefact's physical environment* (world 1), *social environment* (world 2) and *knowledge environment* (world 3). According to Popovic, *the knowledge environment,* which is analogous to Popper's world 3, consists of a user's and designer's knowledge. In that world, the designer attempts to present her or his knowledge of world 2 (*the social environment*) and world 1 (*the artefact's physical environment*) (ibid. 368).

In general, research in fibre material technology, done by technologists, defines intelligent textiles as interactive material, i.e., material that performs an expected function in response to changes in the environment. Intelligent systems are normally composed of a sensor, a processing unit and an actuator. In intelligent textiles and garments the three may be combined, with the function activated by the physical environment. Phase change materials are one example. Capsules containing paraffin wax are inserted into fibres and when the wax changes its phase from solid to liquid or liquid to solid, heat is either released or absorbed, with the user feeling a warming or cooling effect. In the area of clothing physiology, intelligent garments can help in detecting vital physiological signals in a socially acceptable way, signals which previously could only be recorded with great technical difficulty.

The point of departure in the MeMoGa project was to use Popper's theory of three worlds as the analytical tool for defining the intelligent garment as an object of research. The idea was to view wearable intelligence or intelligent garments more as a social situation and cultural events than as individual objects. Ultimately, the contexts of the user and the identity of the user shape the meanings, uses and impacts of technology.

The research thus adopted a broad conceptual framework by keeping together user-centred and technology-centred approaches. It sought to benefit from the strengths of both approaches while overcoming their limitations by identifying how each provides a crucial part of the context for the other and by recognising the common processes of social change that affect both users and what is known as the smart environment. Accordingly, the notion of intelligent environment and context of use was stressed throughout the R & D project, precisely to avoid the problems of technological determinism that often confront research on technology and new technological innovations.

2.4 Scientific practices and research strategies for intelligent garments

The MeMoGa project provides a framework for discussing not only interdisciplinarity but also collaboration with professionals from different fields of study. Collaboration may be fruitful, but it is always challenging, for each discipline has its own specialists and specialised research procedures and practices.

2.4.1 Crossing scholarly borders

One starting point in defining research through design is to draw a distinction between the semantic, syntactic, and pragmatic dimensions of research. The semantic dimension focuses on the context of end-user, the syntactic dimension on the design process, and the pragmatic dimension on the use of products. The specific methods used in design research for analysing the context of the end user are surveying and interviewing individuals who represent the different target groups. Sometimes studies of the design process can concentrate on the final products to be produced; at other times, they focus on the concept design process, where the aim is to produce visions or ideas of products that have yet to be made rather than to present tangible, final products.

In the field of material technology, the focus is on research methods for testing the properties of different combinations of materials. Testing functional, interactive materials in order to verify their functions and suitability for intelligent garments is particularly important; the test methods have to be specified with particular regard for functionality and safety. In designing future consumer products, aspects of comfort, simplicity, miniaturisation and aftercare should also be taken into consideration.

In the area of ergonomics and clothing physiology, specifying the context (e.g. tasks, repetition, loads, and dynamic-static efforts), environment (e.g. cold or hot), organisation (e.g. individual-group, monotonous-rich work designs) and physiological properties (e.g. gender, age and strength), as well as psychological and social characteristics (e.g. intro- and extroversion, vigour), are essential. Human measures must be the starting point of garment design, especially for female workers (Asikainen and Hänninen, 2001). Assessing the usability of intelligent garments and their prototypes by measuring and analysing their functional efficiency, ease of use, comfort in use, health and safety and their contribution to working life belongs to the area of physiology. The colours and designs of clothing help colleagues recognise each other and thereby increase safety.

Drawing these observations together, it could be said that design research, fibre material technology and physiology have different kinds of relationships to theory and practice. In Kuhnian terms, the testing typical of technology and physiology should be connected to the theory, and this theory must be precise (Kuhn, 1970, 23–24; see also Diaz-Kommonen, 2002, 42). Hence, the testing relies on empirical findings produced by objective research methods. Inductive methods from practice to theory are more typical of design research. Subjective methods are also essential and are used both when design solutions are produced and when the usability of intelligent garments and their prototypes are assessed. In all cases, the current debate in the field suggests that the research questions should be posed by the designer (Diaz-Kommonen, 2002, 43). In this sense, there is justification for design to be understood as a discipline and intelligent garments as research objects of design research, physiology, and fibre material technology.

2.4.2 Dialogue in participatory design

Collaborative frameworks and participatory practice do not apply only to the co-operation between professionals and experts, however. Participatory practice can also be made a part of collaborative design practices and user-centred design. The participatory dimension in design emphasises the proactive role of the end users in the design process and the assessment of product usability. Sanders (2002) has addressed this issue by stating that in participatory experiences the roles of the designer and the researcher become blurred and the user becomes a critical component of the process. Siu (2003, 71) shares this view, stating that ‘participation allows users to engage in the design decision making process’. In the area of interaction design, Wright and McCarthy (2005, 20) stress that each user is ‘their own expert’ in the activity and continue that although the designers may not be their own experts in the user domain, they are 'their own experts' in designing and creating 'possible applications of technology'.

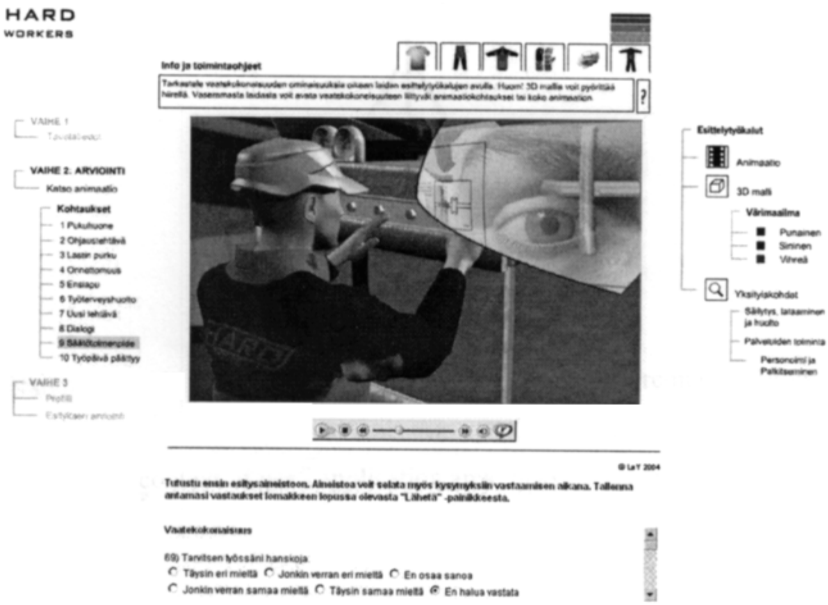
Participatory design provides a number of advantages. Only the end users know all the details of their work and can predict the problems they will face if the protective garments and/or work organisation are changed. Such changes may also change the work of others. For instance, redesigning wheelchair-using clients' standard outerwear decreased the physical work load and strain of their personal helpers. This resulted in savings of effort and energy and increased the service capacity of nurses, with diminished stress levels in the disabled persons as well as the nurses caring for them. (Nevala-Puranen *et al.*, 2003).

In the MeMoGa project, user participation was taken into account by integrating users from heavy industry into the research and design process in the following ways. Firstly, the researchers interviewed the users and gathered information about their clothing needs in the working context. Secondly, the users were allowed to give their comments and opinions during the concept design process. The concept and product design that was carried out in the project had its foundations in the philosophy known as 'design for all', whose point of departure is what people want from technology and what they can or have an opportunity to do with it (Coleman, 1999). The terms 'design for all' or 'universal design' are used to describe design approaches that have the explicit aim of designing products and services which meet the needs and circumstances of the widest possible range of users, including disabled and elderly people. The aim was to design a garment concept in the field of wearable intelligence that can be easily adapted for different users and is accessible to as many users as possible.

Physiological measurements of the old work organisation, the garment designs and the prototypes in collaboration with the workers provided objective data to guide further design work. Wearable sensors and telemetric recordings permitted normal efforts at work without disruption. Textile sensors can even be built into underwear.

Thirdly, the concept designed was evaluated by the users by using a multimedia presentation (Pursiainen *et al.*, 2005) that showed the garment concept in the actual settings of use. The users were able to assess the concept by filling in a questionnaire on the computer that was included as part of multimedia presentation. A screenshot of the multimedia presentation used in the concept assessment is presented in Fig. 2.2. This example of participatory research practice in design may give some ideas on what the basic research activity could be in design-driven research areas that focus on the user experience and phenomenological features.

One should remember, however, that in all working places there are people who have temporary or permanent disabilities. The number of workers near



2.2 Screenshot from the multimedia presentation produced by the research and design team (Pursiainen *et al.* 2005).

– or even past – retirement age will also increase and intelligent garments may in principle help them continue to contribute. These workers and their limitations must be taken into account in planning. Wearable sensors and computer programs are at present reasonably easy to learn to use. The collection of subjective information using visual analogue scales on computers, for example, is also straightforward and such scales are recommended to designers, as they yield numerical information which the designers can then rely upon in their work. A short basic course in clothing physiology adapted to the needs of designers would nevertheless be very helpful. Participatory design programmes would be worthwhile in ergonomics courses.

2.5 Conclusions

At the time of writing, the MeMoGa project is almost completed and knowledge building has started. As the research consortium will not produce any concrete prototypes, it will not be possible to return to the situations in which the products are used and to the everyday world of the user, i.e., working life and work-related situations. Hence, the concrete situations in which the products are used and the different dimensions of usability and the acceptability of the products in industry could not be specified.

What then are the contributions of the MeMoGa project to research in applied technology and intelligent garments? In general, the challenges will be to pursue coherent research thinking, methods, and theory in design research. Where knowledge building is concerned, the challenging question to be answered now and in the future is how technological innovations will become culturally accepted final products, artefacts and natural parts of our everyday life. The second question that could be posed, on a more theoretical level, is how the natural sciences and researchers in those disciplines will meet the humanities and share their knowledge, concepts and working methods in these complex research areas. Accordingly, in further studies a third focus of interest would be to analyse the dialogue between the designer and the user, and study it with reference to the idea of shared expertise through complex products and through interdisciplinary research and design processes.

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