INTERNATIONAL DESIGN CONFERENCE - DESIGN 2014
Dubrovnik - Croatia, May 19 - 22, 2014.

DESIGN INNOVATIONS AND IMPLEMENTATION CHALLENGES – A CASE OF SMART TEXTILES IN FUTURE HOSPITAL INTERIORS

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Keywords: design innovation, design thinking, textiles, hospital design

1. Introduction

New products, new materials, new services and solutions are developed and introduced as new design innovations every day. Some of these innovations change the way we experience the world, and the way we plan and engage in daily activities. However, it is not all innovations that are successfully implemented, and despite they might share a great potential, they will not necessarily match contextual human values or ideals, and due to various challenges and barriers they will fail the implementation process. These challenges of innovation implementation will be the overall focus in this paper. By introducing the case of implementing smart textiles in hospital interiors, the paper relates to this design innovation and through the scope of a developed strategic framework, the implementation challenges will be discussed from an integrative design perspective. With this explorative initiative, our aim is to present specific approaches for further research to progress the design innovation and the context for implementation.

The case we will relate to in this paper is concerned with the construction of new Danish hospitals, and focuses especially on the implementation of smart textiles as new functional and hygiene improving materials, innovated on the basis of new emerging technologies.

The architecture of most current hospitals in Denmark, and the Western world, has through the last decade been widely criticised by architects and design researchers as being too clinical and institutional to fit their intended purpose of providing accommodating surroundings for modern hospital care [Wagenaar 2006], [Ulrich et al. 2008]. The architectural response to this critique, and a general societal progression towards future patient care [Gerteis et al. 1993], has led to the introduction of the design concept healing architecture, promoting a vision of improved patient recovery, supported by stimulating architecture and design [Ulrich et al. 2008], [Frandsen et al. 2009]. However, when exploring the design of the new hospitals being planned, the use of materials in the interior design of the hospital environment, seems limited to the traditional materials of vinyl, plastic and plasterboards that are also used in the current hospitals today, imparting the institutional atmosphere. From an architectural perspective, this confined material use, are considered in risk of discarding the potential of healing architecture, as it contradicts with our knowledge of the materials' general influence on the architectural experience and perception [Pallasmaa 2005], [Zumthor 2006], [Bille and Flohr Sørensen 2012].

At the same time, traditional interior textiles are being phased out in the hospital context, and are replaced by plastic or laminated textiles, with limited tactile or architecturally aesthetic qualities. These decisions, restricting the field of available materials for hospital design even further, are most often made on the basis of functional considerations and rational concerns, regarding the costs of efficient cleaning and hygiene procedures.

However, as architects and designers, we see this development, and the use of these institutional materials, as conflicting in regards to the overall vision of healing architecture, seeking to stimulate the patients' healing process through accommodating and inspiring architecture.
From this perspective, we have initiated the project "Smart Textiles in Future Hospitals", exploring how textiles in hospital interiors may have an immediate architectural potential in regards to the vision of healing architecture; and by relating to the emerging field of smart textiles, we focus on the potential balance of functional, as well as aesthetic, concerns in modern healthcare architecture.
Smart textiles are generally defined as textiles with functional properties [Tao 2001], and for hospital interiors, smart textiles are designed to provide new hygienic functionalities with antibacterial or biostatic properties [Gao and Cranston 2008]. As design innovations, these products have already been introduced to the international market [Simoncic and Tomsic 2010], and have found successful implementation in many European countries [Gao and Cranston 2008].
However, despite the potential and international success, they have not yet been implemented in a Danish context, and the benefits of the design innovations thus remain unexploited.
With this paper, we will relate to this specific issue, and from the holistic perspective of a designerly approach, we will present a strategic framework for exploring this specific implementation challenge, and provide suggestions for new approaches to the development of the design innovation of smart textiles for hospital interiors.

2. Design innovations

In order to explore the challenge of innovation implementations, and to define specific approaches to the progression of the field of smart textiles for hospital interiors, design thinking will be introduced as a holistic approach and a new design perspective to this specific area of concern.
The concept of design thinking is related to complex design problems, and defined by Tim Brown [2008] as:
"[A] discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity" [Brown 2008, p. 2].
From this definition, Brown [2008] is emphasising that design thinking is first of all covering a *designerly* approach to the perception of the situation, and furthermore the transformation of the designer's methods in developing products, services, processes and even strategies. In this definition of design thinking, the fields of business, technology and human values are united, and thus establish an integrative discipline with potentially successful design innovations as the derived outcome. Relating this to the case of smart textiles in hospital interiors, this innovation may be considered as an example of successful design thinking when cogitating Western Europe as the overall context. As there through many years has been an increase of multi-resistant bacteria in European countries, the desire and motivation for finding alternatives to maintain high hygienic standards has been extensive [Møller 2011]. The development of new textiles as technological hygiene solutions has therefore been a major concern, also defining a substantial business potential, where the total production of functional textiles with antibacterial properties was estimated to 30.000 tons in Western Europe in 2000, with a predicted increase by more than 15% a year in the following years [Gao and Cranston 2008]. Thus, in a European context, the desirability and human values of the actors in modern hospitals searching for hygiene improvement; the technology feasibility; and the viable business potential, are together defining the foundation for a successful design innovation. In this case, the three fields of design thinking thus gives the possibility to unite the interdisciplinary design factors in an integrative solution, and turn technological innovation into human welfare.
However, although successful in a European perspective, the innovation of smart textiles are not yet implemented in the Danish hospital context, despite the fact that new hospitals are constructed these years, and the Danish textile industry are concerning the hospital context as an area of significant growth. As we thus consider the business potential for smart textiles stronger than ever, this paper will have concentrated focus on the link between technologies and human values. Supported by literature findings and empirical data, we will discuss how the main challenge towards implementation may be a discrepancy between the current fields of technology and human values. In the following section we

will start by introducing our overall strategic framework for this explorative analysis, eventually seeking to define new approaches to progress the innovation of smart textiles for future possible implementation success.

3. Implementation challenges

Before describing the two fields of technology and human values that in our case are considered in conflicting disharmony, we will propose a strategic framework for exploring the challenge of implementing this design innovation.

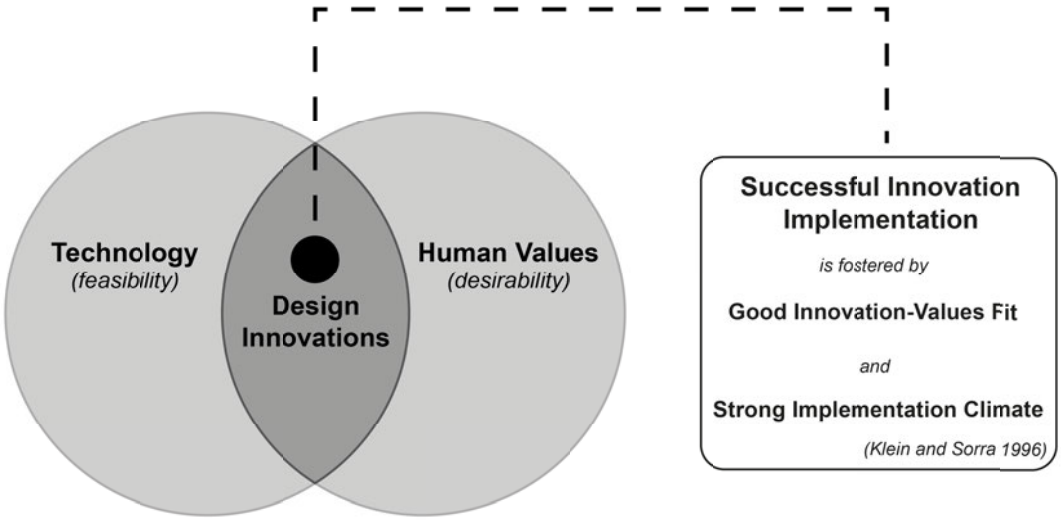

Figure 1. Model of our strategic framework for analysing design innovation implementation

As the model above illustrates, our developed strategic framework for analysing the challenge of innovation implementation, derives from the perspective of a holistic design approach. Inspired by design thinking, the fields of technology and human values are united to render a potential design innovation, and in this harmonious cross-field, Klein and Sorra's [1996] approach to successful innovation implementation is positioned; hereby proposing that the *successful innovation* implementation is a function of *a) an organisation's climate for implementation* and *b) the targeted organisational member's perception of the innovation's fit to their values* [Klein and Sorra 1996].

In our case, the technology field includes the different strategies of developing functional textiles for the hospital context, while the field of human values relates to the relevant actors defining and regulating the use of materials in hospital interiors.

According to Klein and Sorra [1996], the lack of innovation success is caused by a combination of a weak *implementation climate* and *poor innovation-values fit*, and an organisation's failure to achieve the intended benefits of an innovation, is thus reflecting either a failure of the implementation, or a failure of the innovation itself [Klein and Sorra 1996]. In the case of applying smart textiles in future Danish hospitals, we see this as an example of a design innovation with lack of implementation success. In this regard, we will explore how the fields of technology and human values may be progressed to improve the implementation climate and the innovation values-fit. The organisation may, in this case, be defined as the Danish Hospitals, where a vertical hierarchy of groups including national counsellors and regional, local hospitals are situated. In all groups *"the innovation-values fit describes the extent to which targeted users perceive that use of the innovation will foster (or, conversely, inhibit) the fulfilment of their values."* [Klein and Sorra 1996, p. 1063].

The climate for implementation are relating to the implementation policies and practices that the organisation defines for the innovation, where

"A strong implementation climate fosters innovation use by a) ensuring employee skill in innovation use, b) providing incentives for innovation use and disincentives for innovation avoidance, and c) removing obstacles to innovation use." [Klein and Sorra 1996, p. 1060]
Evidently both the innovation-values fit, and the implementation climate are essential to consider when proposing innovations for any large organisation, and initiatives regarding these concerns, will potentially bring the fields of technologies and the human values closer together. Having presented this overall strategic framework for exploring the implementation challenges, we will in the next two sections give an overview of the two fields of technology and human values, before discussing the challenges of implementation from the specific case perspective.

4. Smart textiles – technologies

In this first of two overview sections, we will introduce the technology of smart textiles with a short review of the different technologies and strategies currently available in the European market. Today the risks of hospital-acquired infections (HAI) in Danish hospitals are high, and studies have shown that app. 10% of all patients are infected during hospitalisation [Leth and Møller 2006], [Jensen 2007]. Traditional textiles have in that regard long been known as potential bacteria reservoirs [Gao and Cranston 2008], and bacterial survival on textile surfaces has been measured to several weeks in a range of studies [Noskin et al. 2000], [Neely and Maley 2000], [Lankford et al. 2006], [Huang et al. 2006]. However, by introducing smart textiles in hospital interiors, new technologies can provide the textiles with specially designed functional properties improving the general hygiene level and the possibilities of using textiles. The technological treatments of textiles may coarsely be divided in two categories; the *active* and the *passive* technologies [Mucha et al. 2002], [Höfer 2006], where the active technologies, traditionally, has been the primary solution in a European context. In order to analyse the link between technologies and human values, we will in this chapter give a short overview of the different strategies and technologies to obtain an antibacterial or biostatic textile.

4.1 Active technologies

The *active technologies* are based on *synthetic organic compounds*, *metallic compounds,* or *natural organic compounds*, consisting of antimicrobial substances or metallic ions that affects the cell membrane, the metabolism, or the core substance of the microorganism. This prevents cell division, and the bacteria will be decomposed. The effectiveness of textiles with active antibacterial properties is depending on the diffusion of the bioactive substance or the metal ions to the textile surface [Mucha et al. 2002], [Höfer 2006], [Gao and Cranston 2008].

4.1.1 Synthetic organic compounds

Based on *synthetic organic compounds* the antibacterial agent Triclosan has been used since the 1960s as a broad-spectrum and effective substance also applied and used in several textile finishing [Gao and Cranston 2008]. As Triclosan later has been found to promote bacteria resistance [Yazdankhah et al. 2006], its "unnecessary use" is today cautioned against in most European countries [Gao and Cranston 2008]. In the same category of synthetic organic compound, another alternative of using QAC (Quaternary Ammonium Compounds) is available as a widespread antibacterial agent for textile finishing. Through covalent bonds to the textile material the product adherence is good and allows for several wash cycles. Resistance is widely observed and related to some types of QAC, although little information, on the single type that are most applied in textile finishing today, are available [Gao and Cranston 2008], [Simoncic and Tomsic 2010]. Besides Triclosan and QAC, other synthetic organic compounds may be used for textile finishing, as for instance PHMB and N-Halamine [Gao and Cranston 2008].

4.1.2 Metallic compounds

In the field of strategies based on *metallic compounds* it is products with *silver* that have had the strongest growth rate in a European context. The silver may be applied as a finishing or be incorporated in the polymer fibres for increased durability. In both cases the silver diffuses and forms

the antibacterial Ag^+ ions in contact with moisture, which are particularly efficient to most microorganisms. However, silver are found being in high risk of increasing bacteria resistance, and its environmental impact are furthermore of certain ecotoxicity risks [Gao and Cranston 2008], [Wijnhoven et al. 2009], [Marambio-Jones and Hoek 2010], [Hansen and Baun 2012]. Other metals may also be used for antibacterial impacts, including cobber and zinc compounds, among others [Dastjerdi and Montazer 2010].

4.1.3 Natural organic compounds

Finally the *natural organic compounds,* as for instance *chitosan,* are to be mentioned within the group of active technologies. Extracted from crustacean's outer shell, it has a natural antibacterial effect, and is even completely biodegradable and biocompatible. Despite great potentials, disadvantages of the handle of the fabric, among other factors, has caused that chitosan until know only have found limited application in textile finishing [Lim and Hudson 2003], [Gao and Cranston 2008], [Simoncic and Tomsic 2010].

4.2 Passive technologies

The other category of textile finishing that we will include in this overview, is defined as *passive technologies*. Based on biostatic compounds they provide easy-to-clean surfaces, and with no bioactive effects the bacteria cells are not directly affected. Instead the structure of the fibre and the surface of the textile are manipulated in order to prevent the bacteria from adhering to the fibre surface, thus hampering the bacteria growth conditions [Mucha et al. 2002], [Höfer 2006].

4.2.1 Nano structured surfaces

The category of passive technologies includes products with *nano-structured surfaces* exploiting for instance the lotus effect, where the rough and super-hydrophobic surface of the textile inhibits bacteria adherence and makes the surface easy to clean. This effect may be achieved with a physical nano-structured surface combined with various compounds [Solga et al. 2007]. Textiles based on this technology are recently introduced to the market, where its potential has received great interest and attention [Sawhney et al. 2008].

4.2.2 Textile finishing

Alternatively, passive textile finishing as for instance fluorocarbon compounds can be applied as an efficient water repellent product. Nevertheless, the use of PFOA, and earlier PFOS, in the manufacturing of fluoropolymers as for instance Teflon, has raised a range of environmental issues with some of these products. New standards have however these years been adopted by manufacturers, enabling the use of alike products in the future [Jensen et al. 2008].

A final strategy in the category of passive technologies to be mentioned in this paper is the use of *silicon dioxide*. Based on the principles of the wet-chemical sol-gel process, SiO_2 molecules are bonded to the textile surface, providing an ultra-thin transparent layer without changing the textile handle. The technology provides easy-to-clean surfaces, and being biocompatible their environmental potential seems remarkable, although only few studies on ecotoxicity exists [Jindasuwan et al. 2009], [Connor 2010], [Mikkelsen et al. 2011], [Latthe et al. 2012].

Smart Textile Technologies for Hospital Environments

Active Technologies	Passive Technologies
▪ Synthetic Organic Compounds *Triclosan, QAC, PHMB, N-Halamine, etc.* ▪ Metallic Compounds *Silver, Cobber, Zinc, etc.* ▪ Natural Organic Compcunds *Chitosan, Milk fibres, etc.*	▪ Nano Structured Surfaces *Physically re-structured surfaces, Lotus effects, etc.* ▪ Textile Finishing *Fluorocarbon compounds, Teflon, Silicon dioxide, etc.*
▪ *Actively kills the bacteria on contact with the active surface.* ▪ *Main issues with risk of increased bacteria resistance.*	▪ *Biostatic, easy-to-clean, surface inhibiting bacteria growth.* ▪ *Issues of bacteria resistance are generally avoided.*

Figure 2. Overview of the technologies for smart textiles in hospital interior environments

4.3 Strategies - technologies for the hospital context

With this overview of the different available technologies, it has been our intention to present the two overall strategies of *active* or *passive* technologies within the field of smart textiles that are immediate applicable for the hospital context. Today, the passive technologies are rarely used, while the active is used more widely in European countries. Nevertheless, the active technologies, having issues regarding bacteria resistance, are in some countries attracting a considerable concern, which results in barriers towards direct implementation. In the following section, this concern will be unfolded within a Danish context, relating to the human values of the organisation of Danish hospitals as users of the design innovation.

5. Smart textiles – human values

As defined earlier, the human values of the organisation should be linked to the technology to ensure the foundation for successful implementation. In this section will relate to the Danish hospitals as the overall organisation, and elaborate on how this organisation relate to the proposed innovations of smart textiles for hospital interiors. The hospital organisation as a whole is evidently broad and covering a complex field of disciplines. However, concerning the decision on the use of materials in hospital interiors, it is first and foremost related to the hospital infection control to recommend the use of smart textiles as new innovations.

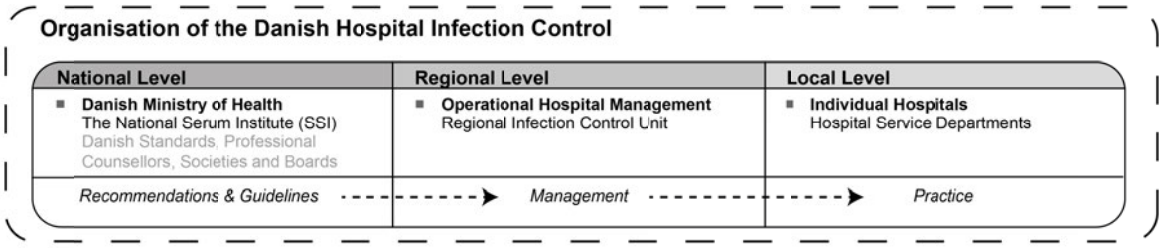

Figure 3. Simplified diagram of the Danish organisation of hospital infection control. Based on work by Riisberg [2011a]

5.1 Organisation of hospital infection control

The national organisation of hospital infection control are organised in a consulting hierarchy, where the *national* counsellors under the Danish Health and Medicines Authority are ranked highest in the organisation proposing *guidelines and recommendations* to the *regional* hygiene teams and the service departments at the *local* hospitals. While introducing these three levels of the national, regional and local organisation, we will elaborate on their ideals and standards towards the use of smart textiles in hospital interiors. This description is based on explorative empirical data collected through meetings with actors in the field of Danish hospitals and the textile industry, and matched with literature and findings by Vibeke Riisberg [2011b] in the Danish project "Textiles in Future Hospitals - User-driven innovation and communication of textiles qualities".

Regarding the application of smart textiles for hospital interiors, it is above all the Danish Ministry of Health and the Danish Health and Medicines Authority that on the *national level* are the supreme authorities on the national health issues. Under the Ministry of Health, The National Serum Institute (Statens Serum Institut - SSI) is organized as a public enterprise, with the main task of securing preparedness towards infectious disease. Being the national laboratory of microbiology, they together with other national organisations, support the development of national guidelines and instructions on hospital hygiene and infection control, as well as recommend strategies and products for disinfection in the health care sector [SSI 2013]. They are accordingly considered the main leading actor on the national level, and their recommendations are the foundation for infection control of regional and local hospitals in Denmark. The approach and authorisation of SSI is not to legislate or regulate against the use of certain materials, and their concern is instead formulated as recommendations and guidelines. Nevertheless these recommendations are followed accordingly, and in the quarterly newsletter from the Central Unit on Infection Control (Central Enhed for Infektionshygiejne – CEI), SSI respond to a

range of enquiries on the use of silver based products, including textiles, in the Danish health care sector. The immediate conclusion is clear, and due to the risk of resistance and uncertain effect on the human normal flora, the use of silver based products cannot be recommended [Jensen 2007]. There are naturally other groups relating to the national level of infection control, including Danish Standards, who develops and provides standards on hospital cleaning, as well as a range of counselling organisations, societies and boards, however usually sharing the immediate outline presented by SSI (for further information and a more thorough description see [Riisberg 2011a]).
In Denmark the operational management of the hospitals are situated at *regional level.* Here, the regional infection control unit are organised with a hospital team, where hygiene nurses supervise across local hospitals and takes precautionary measures against hospital-acquired infections [Riisberg 2011a]. On the *local level,* it is most often the service departments at the individual hospitals who are maintaining the physical environment of the hospital by undertaking the daily cleaning as well as purchasing of new interior objects. As a defined standard, the actors on the *local level* consult with the *regional* infection control team, and the regional purchasing department, regarding the choice of new textile based interior objects, like furniture, curtains, etc. Together, they base their guidance on the recommendations of SSI at *national level* [Riisberg 2011a], generally emphasising that before using antibacterial products in Danish hospitals there should be evidence that they are working - without any unnecessary risk.
However, as this position towards active technologies only is formulated as a recommendation, products based on these technologies, are still being attempted introduced on local levels by companies within the textile or building industry. However, as the general position by SSI is observed on regional and local level, the human values of the organisation of infection control are considered shared. From this perspective the statement is clear, and as the use of smart textiles with active technologies concerns a risk of increased resistance, these products are currently not recommended in Danish hospitals, and their potential use are thus strictly limited. However, the passive technologies, exploiting the biostatic properties of easy-to-clean textile surfaces, are fundamentally relating on another strategy, which may be more in line with the human values and principles of the key actors in the organisation.

6. Discussion – new approaches to the implementation challenges

Having presented this short overview of the fields of technologies and human values, we will argue that the unsuccessful national implementation is related to an inadequate link of these fields; with a poor innovation-values fit and a weak implementation climate as direct consequences. According to Klein and Sorra [1996], this combination of innovation-values fit and implementation climate is resulting in *"essentially no innovation use"* [Klein and Sorra 1996, p. 1066] and browsing through the context of Danish hospitals this is illustrated as the general case. As the architectural potential of textiles in hospital interiors, relating to the vision of healing architecture, still is unexploited in a Danish context, new approaches are considered needed to facilitate the implementation of smart textiles as new design innovations. Relating to the concept of design thinking, and our strategic framework, these new approaches should support the connection of the fields of technology and human values. This we suggest could be achieved through progressions related to the framework and the model by Klein and Sorra [1996]. This first of all calls for improvement of the innovation-values fit, and an increased focus on the technology, or innovation, itself. Currently, the focus on active technologies will potentially increase the risk of resistance, which is in strong discrepancy to the values and ideals of the Danish organisational actors. Although the current active technologies certainly have their potential and relevance in many contexts, we, from a national perspective, sees an immediate stronger potential in increasing the focus on developing the passive technologies. This would also relate to the current practice and system of hygiene control and cleaning at Danish hospitals, and is thus more likely to improve the potential implementation success.
Concerning the implementation climate, Klein and Sorra [1996] are regarding three aspects that foster a strong innovation climate, including a) ensuring skills in innovation use; b) providing incentives for innovation use, and c) removing obstacles for innovation use [Klein and Sorra 1996]. While this naturally calls for internally organisational changes, we from an external perspective, sees a strong

need for disseminating new research based knowledge to the users in the hospital organisation, regarding the specific smart textile products and their architectural potential in hospital interiors.
With these specific initiatives, searching to overlap the fields of technology and human values, our paper defines a call for further research improving the innovation-values fit by *progressing the innovation, or technology, itself*, and to improve the implementation climate by *providing the users' with knowledge on the architectural potential and qualities of textiles in hospital interiors*. With these new case specific suggestions, regarding changes in the fields of both technology and human values, we hope to support the progression of the design innovations for a future successful implementation.

7. Conclusion

Having presented the case of smart textiles for hospital interiors as a promising innovation, however unsuccessful in a Danish context, we have explored how a strategic framework departing from the holistic concept of design thinking, could act as a model for analysing these challenges of innovation implementations. The link between technologies and human values was defined as a main concern in our case, and through an explorative analysis a discrepancy in the primary active technologies and the human values of the Danish infection control organisation was defined. In this paper, the business field was not included in the analysis, although equally important in regards to the holistic approach in strategic design thinking. This study, of viable and commercial business aspects, thus remains as an interesting field for further research, linking the physical environment and the patient experience to economic potentials of possible shorter hospital stays. Nevertheless, with our focus on the technology and the human values, we have contributed with the development of an overall strategic framework that has acted as a functional tool and model to analyse the challenges of innovation implementation. Furthermore, based on this framework, we have defined a strong need for new initiatives to progress the innovation, or the technology, itself and to increase the knowledge on smart textiles and their architectural qualities and potentials.
Design thinking has gained ground in the design field as a holistic and integrative approach to developing successful design innovations. In this paper, we have build on this integrative concept of understanding design innovations, and have found it useful as foundation for a strategic framework for exploring the challenges of implementation. Although developed with this particular case in mind, the framework is also considered applicable in other areas, where a similar designerly and integrated holistic perspective, could promote other research or industrial R&D projects, where the innovation implementation may be a challenge.
Concerning our case, the hospital organisation shares a strong focus on the rational and functional concerns regarding the materials in the hospital environment. However, the easy hygienic solution providing future hospitals with smooth and hard surfaces of plastic and vinyl, are considerably in high risk of providing even more clinical and institutional hospitals as experienced and criticised today. Thus the potential of implementing smart textiles in future hospitals are believed to be widely comprehensive, in terms of both functional and aesthetic aspects, but as illustrated through our explorative analysis, the potential will remain unexploited if not a more holistic and progressive approach to the design innovation is established. Through this paper, we have suggested the following new approaches regarding the fields of technologies and human values respectively: 1) Increase the focus on passive, or alternative active, technologies to meet the stated values of the hospital organisation. 2) Increase the knowledge on the architectural qualities of textiles, and their influence on the atmosphere of the hospital environment. Having suggested these specific implications, from the basis of this paper, we will continue our work to define the architectural demand for these new materials, and thus hope to strengthen the incentive and climate for future implementation. As the research on new strategies and technologies are constantly on going, and some passive technologies are already available, we as architects and designers will direct the users in the hospital context. Hence, concerned with the patients' experience of the physical hospital environment, this work will be continued in our project "Smart Textiles in Future Hospitals", and will be conducted on the basis of a range of design experiments, planned to be carried out at Danish hospitals in the following phase of the project.

Acknowledgement

We are very grateful to associate professor Vibeke Riisberg, Kolding School of Design, for her sharing of valuable knowledge and insights about the use of textiles in hospital interiors, relating to the project "Textiles in Future Hospitals - User-driven Innovation and communication of textiles qualities", run from 2008-2011 at the Kolding School of Design and the Technical University of Denmark (DTU), together with two textile manufacturers Kvadrat and Trevira-Neckelmann. We would also like to thank professor Ulrik Jørgensen, Aalborg University (former DTU) and associate professor Hanne Lindegaard, Aalborg University (former DTU), who have provided valuable knowledge about this former project as foundation for this paper. Finally we would like to express our appreciation to the textile companies and the hospital staff, who have participated in explorative interviews and meetings in regards to the PhD project "Smart Textiles in Future Hospitals" at Aalborg University and Via University College.

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