COMMUNICATION OF SMART MATERIALS: BRIDGING THE GAP BETWEEN MATERIAL INNOVATION AND PRODUCT DESIGN

THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

TUĞÇE AKIN

IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
INDUSTRIAL DESIGN

SEPTEMBER 2009

Approval of the thesis:

COMMUNICATION OF SMART MATERIALS: BRIDGING THE GAP BETWEEN MATERIAL INNOVATION AND PRODUCT DESIGN

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ABSTRACT

COMMUNICATION OF SMART MATERIALS:
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September 2009, 155 pages

This thesis is intended to help eliminate misconceptions and missing information over the realm of smart materials, by offering a newly structured 'Information Hierarchy for Smart Materials Communication for Industrial / Product Design'. Industrial and product designers are invited to use the findings of the thesis to assist in developing a common smart materials language and culture, enriched by details, technicalities, opportunities, and creative and innovative material attributes.

The study commences with the creation of a concise and compact reservoir of technical knowledge on smart materials and critically contrasts two established systems of classification for smart materials. Then, the subject of materials information appropriate to industrial design is discussed, highlighting channels through which smart materials information may be communicated at an optimum level so as to be amenable to exploitation by industrial designers. A sectoral analysis of smart materials use follows, including the presentation of factors that may hinder their more extensive exploitation in major industrial sectors.

The thesis concludes that smart materials have potential to initiate a breakthrough in the materials universe, and that industrial designers have a role in promoting smart materials knowledge, the capabilities of smart materials, and their innovation possibilities. It is recomended that since smart materials are a new generation of materials quite different from the conventional, they be promoted carefully through the proposed Information Hierarchy.

Keywords: Smart materials, material properties, industrial design, product design, information hierarchy, communication.

ÖZ

AKILLI MALZEMELER BAĞLAMINDA İLETİŞİM: MALZEME İNOVASYONU VE ÜRÜN TASARIMI ARASINDAKİ BOŞLUĞU GİDERMEK

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Eylül 2009, 155 sayfa

Bu tezin amacı, akıllı malzemeler alanındaki yanlış algılamaları ve eksik bilgiyi gidermeye yardımcı olmak için özgün bir şekilde yapılandırılmış ‘akıllı malzemeler bağlamında, iletişim gereksinimini karşılamaya dönük, endüstriyel tasarım ve ürün tasarımı ile ilgili bildirişim hiyerarşisi’ni sunmaktır. Akıllı malzeme evrenini tanımlayan ortak bir dil ve kültürü geliştirmeye yardımcı olacak detaylar, teknik özellikler, fırsatlar ve malzemelerden kaynaklı yaratıcılık ve buluşçuluk, malzemelerin öznitelikleri ile zenginleştirilerek endüstri ürünleri tasarımcılarının değerlendirmesine sunulmuştur.

Bu çalışma, ilk aşamada, akıllı malzemeler üzerine yoğunlaştırılmıştır ve özlü, teknik bir bilgi rezervuarı oluşturur; akıllı malzemelerin sınıflandırılmasına dönük kabul görmüş iki mevcut sistemi eleştirel olarak inceler. Bir sonraki aşamada, endüstri ürünleri tasarımı için uygun malzeme bildirişimini sağlayarak, endüstri ürünleri tasarımcıları tarafından kullanılabilecek akıllı mazlemelere ilişkin bilginin optimum ölçütlerde iletilebileceği kanalları önemle vurgular ve irdeler. Bunu, temel endüstriyel sektörlerde akıllı malzemelerin daha yaygın olarak kullanılmasını engelleyebilecek etmenlerin sunumu da dahil olmak üzere, akıllı malzemelerin sektörlere göre analizi takip eder.

Tez, akıllı malzemelerin, malzeme evreninde teknolojik bir atılımı tetikleme potansiyeline sahip olduğunu ve endüstri ürünleri tasarımcılarının, akıllı malzeme alanındaki bilgi birikimini, akıllı malzemelerin kabiliyetlerini ve buluşçuluğu artırma olasılıklarını geliştirme noktasında önemli rolleri olabileceği sonucuna varır. Akıllı malzemelerin, konvansiyonel malzemelerden oldukça farklı yeni kuşak malzemeler olması nedeniyle, bu tezde önerilen 'Bildirişim Hiyerarşisi' yolunun titizlikle takip edilerek kullanılmalarının teşvik edilmesi önerilmektedir.

Anahtar Kelimeler: Akıllı malzemeler, malzeme özellikleri, endüstriyel tasarım, ürün tasarımı, bildirişim hiyerarşisi, iletişim.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude for those who have put effort into the realisation of this thesis at least as much as I have done. My thanks go to my supervisor Assist. Prof. Dr. Owain Pedgley, for his serious, academic, efficient and humane stand in providing me with invaluable feedback and emotional support to guide me through the labyrinthine smart material universe.

I am also thankful to the distinguished academic staff of the Department of Industrial Design, especially to Assoc. Prof. Dr. Gülay Hasdoğan, Head of the Department, who initiated the writing of this thesis with her academic determination and humane encouragement. My special thanks also go to Assist. Prof. Dr. Naz Börekçi, my former supervisor, who provided great effort for me prior to her maternity leave. With them, my appreciation for Assist. Prof. Dr. Fatma Korkut, Inst. Figen Işık Tüneri and Inst. Refik Toksöz for the long hours they have spent in the reading of this dissertation. In addition, I would like to say a few words in appreciation of the academic principles with which I have been imparted during my Bachelors degree in the Department of Metallurgical and Materials Engineering, METU, and to the most distinguished scholars Prof. Dr. Abdullah Öztürk and Prof. Dr. Muharrem Timuçin, who still sustain their innermost efforts of support for my advanced studies.

I also thank my family for having given to me the capability to perceive life from a wide scope, and not to be stereotyped, ever. Their contribution to my being an interdisciplinary person has been great. Without them and their continuous support and love which they never ceased to give, this thesis could not have been so much enjoying to me.

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INTRODUCTION

1.1. Background: Problem Statement and Significance of the Study

1.1.1 Problem Statement

Scientists and engineers have been developing new smart materials besides existing technology. In the past twenty years, more materials have evolved than previously in the whole of human history. According to Blownell (2006, 7), material innovation sustains its “accelarated pace”, which he attributes to (i) advances in military and NASA research in the 1980s that are now in our daily lives, (ii) consciousness related to the world’s raw material sources, (iii) biomimicry, or (iv) just for desire to achieve aesthetic and psychological effects in products without a particular utilitarian aim.

There are many “new materials and technologies” waiting for “potential application” (Addington and Schodek 2005,viii). Industrial designers have a particular effect on their application. They work on possible application areas, as long as many new materials are developed. A material finds its value in the product to which it is applied. A material can be in its best with its most appropriate application given the creative input of industrial designers.

Therefore, it is essential to distinguish the so-called new materials from those that are known as traditional materials. Such distinction will eventually lead industrial designers to encounter a new realm of the material universe, in which they will find possibilities for novel design solutions. Blownell (2006) depicts such a distinction in clarifying the classification of improved materials (created in response to some design need, solution for a problem or instigation by developing technology) into seven categories:

> 1) *Ultraperforming materials:* Material has the capability of being lighter, stronger, etc. The improvements encourage dematerialization, such as increased porosity, greater transparency and so on.
> 2) *Multidimensional materials:* Materials with a ‘z axis’; more structurally stable, with enhanced texture and visual interest. Encouraging miniaturization, systems integration, and prefabrication.
> 3) *Repurposed materials:* Materials that are less precious, non-toxic also repurposed in functionality. Encouraging adaptability and conservation of limited sources.
> 4) *Recombinant materials:* Materials that are recombined to give superior properties, such as composites; they are stiffer, stronger, harder, etc.
> 5) *Intelligent materials:* Materials that are designed to improve environments, and may be termed ‘smart by design’. They have benefits such as pollution reduction and water purification.
> 6) *Transformational materials:* Materials that undergo a physical metamorphosis in reaction to an environmental stimulus. Transformational products are important because they offer multiple functions where one would be expected, they provide benefits that few might have imagined, and they simply make us view the world differently.
> 7) *Interfacial materials:* Materials that are tools between physical and virtual worlds.

A criticism of the classification of new materials by Blownell (2006) is that it is not very detailed. A more thorough and integrated picture of the world of smart materials, which fall into fifth and sixth groups in the list above, is needed.

After focusing on where smart materials lie on the universal plane of materials, *it has now become a major question as to how knowledge of smart materials can be provided to industrial designers in a way that is compatible with their primary motivation to envisage new products and the practical necessity they face to materialize product ideas.* There must be a coordination and collaboration established between “owners of relevant knowledge” (material engineers and scientists) and “inventors of potential applications” (industrial designers) (Addington and Schodek 2005, viii and Utterback et al. 2007). However, it is not easy to converge these professions unless knowledge and applications are made interconnected and thus bridge the gap in materials expertise that traditionally exists between professions. Relevant “information technology” must be established according to Fulton (1992, 75) so that the “high cost of misdirected investment”, spanning time, labour and capital, can be eliminated.

Within this challenging process of becoming familiar with new and smart materials, the mentality of exploring materials for their obvious and already known characteristics has to be cast aside. In the early days of smart material adoption into product design, the technological attributes of those materials were mostly ignored. When, for instance, a capability to change color (a characteristic of some types of smart material) was exploited as a popular practice and application in coffee mugs, other possible fields of smart materials applications and their technicalities remained obscure and undiscovered. This was due to the fact that, as also Addington and Schodek (2005) suggest, a smart material characteristic would simply dominate over any designer’s creative capability, because, the material characteristic itself alone was appealing and attractive enough to motivate people to buy a product. Because of this, smart materials remained locked into limited applications and were not able to receive recognition for wider applications. To some extent, smart materials also remained as enigmas for engineers and scientists to experiment on and explore. Therefore, historically, there has been a distance between smart materials development by materials engineers and smart materials exploitation by product and industrial designers.

Besides ignorance concerning the technicalities of smart materials, and the need for an authority to discover their properties, designers have also been overwhelmed and preoccupied with the changing nature of materials and the variety of newly developed materials waiting to be exploited. For that matter, the more a material exhibits appealing intrinsic properties, the less design input is necessary for creating an appealing product. In other words, the designer's mission became recessive as the material with its properties came to the foreground of attention and became dominant (Addington and Schodek 2005). When the designer regarded the material as a means to create new impressions, the material began to express itself with some capabilities in its own potential. The designer did not need to generate a specific impression, because within the smart material itself was already characteristics that matched with the designer's desired impression. Offering such wonderful possibilities of expression, smart materials inevitably took their place in the field of product design. As Addington and Schodek (2005, 7) say, when history is judged, it will be observed that "smart materials' entry into [the] design area was idiosyncratic … although there had already been rapid expansion in these technologies in the science and engineering fields".

Even if designers had up until now known and exploited technical characteristics of smart materials, their knowledge alone would not have been enough for a complete appreciation of the potential of this new material class. In order to contemplate a material for use in a design, according to Ashby and Johnson (2002), two things are of utmost significance: (i) information transcending just technical properties, and (ii) a meaningful language to be established concerning new materials. It is not enough to have some information about the technical properties of the material with which a design will be made. Some materials are not either recognised or known for their properties; for that matter, the areas of their application remain either limited, or unknown to the general population (Addington and Schodek 2005). As the properties of some materials are unique to themselves, their application areas are to be developed accordingly. Moreover, a language, specific to new or smart materials, alongside related jargon, must be formed in a meaningful way so that it can effectively exchange knowledge and information between the stakeholders involved in developing and exploiting those materials.

Material improvements have an impact on product design. Since it has become surprisingly common that new materials keep on appearing and existing materials are enhanced, most products available today are likely to be touched by advances in materials in the near future. In an era of evolutionary material changes, it is not easy to keep pace of the changes. Furthermore, while materials can be seen as a driver for new product designs, the reverse is also sometimes true: new designs can be a driver for the development of materials. Designers interact directly with the evolutionary process that combines materials and product ideas. In so doing, they require up-to-date and reliable information about new materials and associated technical and aesthetic qualities. However, although there have been some efforts in establishing a bridge between materials and designers, such efforts are not yet constructive enough to deliver a satisfactory level of interaction.

1.1.2. Significance of the Study

As new materials emerge and existing ones are enhanced, they become new sources for design. However, providing knowledge of new materials to industrial designers remains as a problem since technical information, datasheets, books and alike, are not yet improved enough and effective to bear information related to new materials.

One prominent new material group is smart materials. These have properties that distinguish them from other materials, and the properties are even harder to describe than for conventional materials. Also, in the literature, there are some methods such as developing datasheets, performing workshops and alike to describe a newly emerging smart material, but, still, studies are on-going as current information exchange is not sufficient for designers to act upon or integrate smart materials into their decision-making processes.

The study reported through this thesis was devised to collate the related knowledge, information and languages on smart materials with a view to overcoming existing communication barriers. A wide range of materials information sources are explored and design methodology with smart materials is examined across industry sectors, so that a pool of knowledge can be generated for designers to make use of in future designs.

Thus, the significance of the study is in its collation of information on smart materials, their new exploitation possibilities and their behavioural patterns and functionalities, so as to create an integrated work whose main aim is to bring together the work of industrial designers and engineers. To that end, it was considered essential that a new awareness, as opposed to conventional awareness, on smart materials be established.

The thesis introduces various “demonstration products” (Ashby 2002, 157) already on display as case studies, from which new exploitations of materials can be inspired and enlightened in industrial designers. It is an intention of the thesis to enable designers to ‘reach out’ for smart materials. There are special usages of newly emerging materials. They may either be used on their own or in combination with well established materials. Novel combinations of materials can contribute to novel solutions to conventional problems, as suggested by Fischmeister (1989). Besides this, the presentation of their characteristics in an unconventional way, makes them to be used in “new and unexpected ways” (Bell and Rand 2006, 11). As new materials are developed and introduced to the market, they are firstly encountered with suspicion and used in “demonstration products”. However, demonstration products are important as they are means by which markets can be reached. As is generally known, markets develop by introducing new product ideas, innovations and design advantages. Of course, within this new materials have contributory advantages and disadvantages. If a material is new to a particular product sector, there can be some “risks” (Ashby and Johnson 2002, 157) in selling products manufactured with that material. However, if newly introduced materials are used to the point and efficiently, they can provide many advantages. Sports, display technologies, medical products and alike have become more advanced due to material improvements. New production techniques have increased the efficiency of material use and enabled the creation of product forms with fast, clean joints. Therefore, this thesis represents an effort to eliminate misconceptions about newly emerging smart materials and to establish a faith in them as materials of the future.

The bridge between materials and designers is, then, to be established for innovative design possibilities. The more new materials and their properties are discovered by designers, the more innovations in design will begin to emerge. Fischmeister (1989, 309) states that materials can inspire designers in making innovations, in a process he calls "materials-inspired innovation", which supplies "important driving forces for technological progress." According to the Fischmeister, a designer must be set free of conventional steps of evaluating and processing materials to exploit new materials for more efficiency and better performance, clearing the way so that "genuine breakthroughs may come about". Consequently, materials-inspired innovations are found to be an approach to design that cannot be ignored and can lead to strong product proposals. The same attitude is shared by Beylerian et al. (2007,19):

> We often seem attracted to those who can create new ideas, new applications, new installations, new fashion or new buildings. Yet, in the context of material innovation, the term 'new' is most obviously applicable to those who can think laterally and apply their imagination to develoing new vistas where materials, blended with creativity can produce new 'products'. It can also be extended to creating new solutions to an existing model, or a completely new invention, that is even better.

As put forward earlier, there are two hinderences to the consideration of materials in design processes. One is the traditional mentality to exploit materials idiosyncratically, disregarding their properties in covertly offering newer possibilities for design. The other is the potential of materials, which must be provoked and activated. For the first hinderence, a solution is to create an awareness that each material is not limited only to current applications or exploitations. It should be understood that the "working memory" of the designer must be activated with "experiential knowledge" more than knowledge of material specifications (Fishmeister 1989, 311). Therefore, it is desirable to increase the experiential knowledge imparted to designers so that, in turn, they may break away from traditions. Besides this, Fishmeister finds that, although many technical potentials of materials are considered to be obvious by designers, in fact, most of them are "latent technical potentials [that] are activated through a sudden demand pull ... or some spark of an idea ... of a potential technical answer" (1989, 315).

When ignorance on smart materials is considered, it is vital for industry to have accurate and well-presented, reliable information source to decide on whether to use smart materials or not, making reference to their advantages and disadvantages. The information is required to yield where and when to use smart materials, along with factual property information.

To increase the use of smart materials, and widen their associated knowledge base, first the designer's general interest and awareness in the behaviour of smart materials should be raised. By doing so, it has been suggested that a broader range of smart materials will be introduced to industrial design (Addington and Schodek 2005). Thus, it has to be accepted as one of the primary missions of materials developers to create and promote interest and awareness in the area. Following on from this, certain phenomena and physical properties must be fully understood in order to design a behavioural pattern. As the knowledge about smart materials is potentially so vast, the derivation of behaviours most relevant to the product or industrial design professions has to be formed (Addington and Schodek 2005). This might be contemplated through use of established channels of information, such as articles, panel discussions, and poster presentations. However, none of these channels seems to have proved itself to be functional enough to communicate smart materials knowledge. Therefore, new channels should be investigated or invented and put into application.

Thirdly, Deng and Edwards (2005) state that materials-related design activities can be identified in terms of design problems arising from activities that require materials with specific functionalities. Also, activities utilising material phenomena and principles is a second problem. A third problem is where a materials solution is more important than a structural solution. Finally, the problem emerges in design activities where both the structure and its constituent materials achieve some functions.

As smart materials have begun to define the future world, they bring along with them many career opportunities from transportation and civil engineering to even medical science. Paul Butler, who is, for the time being, academic visitor to the Department of Materials at the University of Oxford, points out that materials science and materials engineering as well as nanotechnology will contribute to the development of smart materials (Azo Materials 2002). Since these are the most essential foundations for smart materials, a wide scope of disciplines can benefit from career opportunities based on smart materials development, such as materials science, chemistry, surface engineering, design and mechanical engineering. These opportunities vary from academic careers to smart packaging to be used in the packaging industry. Such applications will not only bring smart materials closer to the public eye but increase reliability of products. Smart materials have a wide range of applicability across industrial sectors, for example in architecture, automotive, aerospace, industrial design, civil engineering, fashion, electronic equipments, and medical equipments (Schwartz 2002).

1.2 Aim and Scope of the Study

1.2.1. Aim of the Study

The primary aim of the work reported in this thesis is to provide information on the definition, characteristics, and exploitation possibilities of smart materials in a general sense and to explore those sectors of application that do, or have potential to have, crossovers with product or industrial design ('industrial design' will be used here after to suggest product/industrial design). Supporting this primary aim is a secondary aim to research and argue ways in which the exploitation and uptake of smart materials by industrial designers can be improved, made more prominent and widespread, and be accepted as more important than is currently the case. Thus, a key focus in the work has been a study of channels of smart materials information, transaction and exchange between material developers, engineers and industrial designers.

1.2.2. Objectives of the Study

1. To systematically define, characterise and categorise smart materials.
2. To review current and preferred means (channels) of materials information presentation and exchange for industrial design.
3. To identify the range of industrial sectors in which smart materials are making an impact.
4. To propose an ideal information hierarchy for smart materials communication between material developers, engineers and industrial designers, in order to raise smart materials awareness and selection in design disciplines .
5. To depict limitations to be confronted during the preparation of the dissertation and to offer solutions and recommendations to encourage future research on smart material universe.
6. To answer research questions stated below.

1.2.3. Research Questions

In pursuing the research aim and objectives, the following six research questions were posed.

1. What kinds of capabilities do smart materials provide?

2. How can smart materials knowledge be provided to industrial designers in a way that facilitates the development of innovative new products?

3. Through what sort of a process do new materials reach a level of utilization and how do they meet consumers' needs?

4. What role do (or can) industrial designers have in encouraging the uptake of smart materials in products?"

5. What influencing factors can be identified that urge, necessitate or broaden the usage of smart materials?

6. What are the major barriers that may hinder the growth of smart materials use in products?

1.2.4 Definition of Terms

As with any study, it is a priority to collate relevant terminology and define them as necessary so that they lead to a shared and better understanding. This is especially the case in a predominantly technical subject such as materials selection and development. The thesis makes regular reference to 'smart materials', 'intelligent materials', 'transformational materials', 'very smart materials' and 'technology', each of which will now be defined.

Smart materials. Smart materials are a group of materials that have special dynamic characteristics that distinguish them from 'traditional' materials. Addington and Schodek (2005, 10) define these characteristics as any one or more of: transiency, selectivity, immediacy, self-actuation and directness. Moreover, they can have capabilities of property changing, energy exchange, discrete size and location, and reversibility. Besides such characteristics, smart materials can be defined as those materials that "can sense and respond to the environment around ... in a predictable and useful manner" (Parliamentary office of science and technology 2008, 1-4). They have capability to develop current technology. They offer a wide range of application possibilities.

Intelligent materials. Many smart materials also fall into the more specific sub-grouping of intelligent materials. Blownell (2006, 9) describes intelligent materials as those "designed to improve their environment (like pollution reduction, water purification, solar radiation control, natural ventilation) and that often are inspired from biological systems, acting actively or passively." Blownell distinguishes intelligent materials as being "smart by design"; in other words, the intelligence within these materials has been purposefully conceived and realized through materials engineering.

Transformational materials. This group of materials is significant because many smart materials transform from one state to another and, therefore, also fall into the category of transformational materials. Transformational materials are those that undergo a physical change based on environmental stimuli (Blownell 2006). This change may occur automatically on the basis of the properties of the material, or it may be user-driven. Transformational materials are remarkable in that they offer multiple and often bipolar functions where traditionally only function one would be expected.

Very smart materials. Very smart materials have a capability to learn in response to the environmental stimuli with which they modify their “property coefficients” (Newnham and Ruschau 1991, 1).

1.3. Methodology and Structure of Thesis

This chapter, Chapter 1, is concerned with constructing and elaborating the thesis problem statement, which is identified as shortcomings in the communication of smart materials properties and applications to an industrial design audience, alongside the importance of studying such an issue, which is likely to have augmented significance in the near future. The chapter puts forward the aim, objectives and research questions for the study. A brief list of terminology is defined and a summary of the thesis structure and associated research methodology is presented.

Chapter 2 comprises a review of mostly technical literature spanning the spectrum of different smart material types. Highlighted are the characteristics of smart materials, their categorization, solutions, usages and behavioral patterns. The chapter also informs that smart materials are mainly different types of sensors, actuators and transducers.

Chapter 3 explores through literature how knowledge and information related to smart materials is, or ought to be, communicated. To this end, the chapter begins by concentrating on the communication of information, which is essential for instilling knowledge to end recipients, in this case industrial designers. To initiate solutions for communication, the chapter offers more thorough research on, and development of, information profiles for new materials. Another attribute of the chapter is to offer a critical path to the contribution of guiding design research on smart materials in academia and application process in professional design practice. Smart materials are not only given as materials that are inspired by designers, but also as materials that inspire designers themselves with the possibilities they offer. This two-way interaction between the inspired and the inspiration is further discussed as a solution for todays' growing needs based on intellectual expectation, emotional satisfaction and cultural transformation . The various channels by which traditional materials information is conveyed to industrial designers are raised and their appropriateness to smart materials is contemplated. It is noted that such means of communication can instigate inspiration, which can be channelled towards creative product ideas based on the use of smart materials.

The fourth chapter is a compendium of case studies from the literature, across industrial sectors, revealing the level of smart materials use in everyday and specialist products. It discusses those sectors that are most important in spreading the adoption of smart materials.

The final chapter, Chapter 5, comprises a discussion on the interconnected topics raised in the thesis and, more specifically, the extent to which the research aims and objectives have been met. The chapter synthesizes that it is best to categorise smart materials according to the opportunities they offer since their innovation potential is the source for opportunities which conventional materials do not yield. Also, in the chapter, a table outlining a proposed 'Information Hierarchy for Smart Materials Communication for Industrial Design' is developed. Furthermore, direct answers to the research questions are given towards the end of the chapter, and used to construct suggestions for further research in the area. Limitations of the study as conducted are also identified.

CHAPTER 2

TECHNICAL REVIEW: SMART MATERIAL TYPES AND PROPERTIES

Though seemingly easy to define, the term ‘material’ may create some problems of comprehension on behalf of the actors that use it. To this end, it is a priority to attain a solid definition of what material is. The term is referred to in the Oxford English Dictionary cited by Schwartz (2002, v) as “matter from which a thing is made.” The correlation between the ‘thing’ and ‘matter’ is formed in this definition with the term ‘made’ which signifies the *way* in which matter is transformed into the thing. The *way* is understood to be the series of manufacturing processes that are creatively applied to transform matter into a thing for a specific use. Therefore, inspiration is required in the process of materialisation of product ideas. This is where designers give substantial input into product development.

On the other hand, besides inspiration, there is a need to know the specific features or characteristics of materials, without which design problems cannot be solved comprehensively. The realm of smart materials is a comparatively virgin or unexplored field of study, so it is a fact that the features or characteristics of smart materials are yet to be explored. Smart materials are depicted as a “logical extension of the trajectory in materials development toward more selective and specialized performance” (Addington and Schodek 2005, 3). To facilitate design innovation and open up new product opportunities, designers must be able to comprehend the essential characterisitcs or features of smart materials.

With regard to features, characteristics and properties of smart materials, a broad depiction can be made with reference to certain common denominators. These are, as Newnham and Ruschau point out (1991, 463), that smart materials can act like human organs in that they are “analogous to biological systems”. This means that not only do they appeal to human senses as they have sensorial properties, but they also have a capability to “sense” and “remember”. They also respond to environmental stimuli, have stimulus capabilities in themselves, and finally are sometimes regarded as intelligent systems.

According to Baurley (2005, 275), who believes that contemporary life is deprived of every emotional or intuitive need, and has become purely ‘material’, “elements that stimulate human senses (sight, touch, sound, taste and smell)” are at the focal point of perception. Similarly, products that appeal to five senses can be especially captivating. However, form Baurley’s perspective; this is a superficial way of getting in touch with life, and one that is encouraged by material pop culture. Smart materials, with their unique features that are often multisensory in nature, are likely to contribute much to people’s emotional and creative needs and moods.

Of course, by acting as if they are organic beings revealing biological responses to their environment, smart materials have parallels with human responses. For instance, as Newnham and Ruschau (1991) depict, smart materials can act like “ears by which fish senses vibrations” (as in the case of piezoelectric hydrophones); or, they can yield performance like a “human nose” (as in the case of chemical sensors). However, perhaps the most striking property that smart materials possess is memory, which is the capability to ‘remember’. A well-known example is shape memory materials: these can deform considerably under an external load, but when unloaded they revert back to their original shape (Newnham and Ruschau 1991, 463). This characteristic is beyond just the provision of sensorial information: it is time-based, and repetitive. Therefore, smart materials offer more than conventional materials do by collaborating with the human faculty of creativity, beyond the realm of “scientific knowledge”(Olson 2000, 998). Design, which by definition is driven by a fusion of human creativity and scientific knowledge, opens up and offers new material-based solutions and more ‘control’ over the material world.

The use of smart materials is likely to be a solution to transcend limitations within the present-day conventional material world and its material culture. Furthermore, the adoption of smart materials gives hope for a future world in which creative thinking, intellectual formation, human emotion and sentiments will dominate (Ashby and Johnson 2002, 169). Smart materials offer updated solutions to many necessities that everday use requires. Ever increasing numbers of smart materials are finding their way into everyday applications. According to Addington and Schodek (2005), piezoelectric and electrostrictive ceramics, piezoelectric polymers, fiber-optic sensor systems, micromachined electromechanical systems (MEMS), magnetostrictive materials, shape memory alloys and polymers, conductive polymers, chromogenic materials and systems, electro- and magneto-rheological fluids, biomimetic polymers and gels are some of the smart materials likely to contribute to the building of a future world.

In order to realize such a future world, it is essential, therefore, that smart materials and their features be studied thoroughly. According to Baurley (2005), in reference to Philips electronics, Netherlands, “our environment of the future will consist of invisible interactive systems that will be embedded in our living spaces and clothing, creating an ambient intelligence that could form a natural part of our life’’.“Smart functionality”, as Baurley calls it, is one of the most outstanding characteristics of smart materials that is applicable to many aspects of daily life, thus evolving material culture and establishing a culture of “more intensive experiences and higher order meanings” (2005). Among such experiences are “cognitive, aesthetic, self-actualisation and self-transcendence” needs (Baurley 2004, 275). Baurley understands that smart materials themselves will become important in humanity's future, so it is vital that their features, characteristics and properties be urgently specified and studied:

> Hence, the transition from making and marketing a product to developing non-tangible concepts that satisfy the demand of higher order needs, such as ideas, sensory and emotional fulfilment, cultural experiences and entertainment which stimulate the intellect, is underway and gaining momentum. Intelligent materials will improve our control over our material environment and facilitate our creative interaction with it as we seek to be co-creators, tailoring experiences to correspond to our various moods (Baurley 2004, 275).

Like Baurley, Ferrieri (1991, 14) also believes that new materials urge the designer to establish new transactions with the user. Such transactions are communicated through "psychological and symbolical [relationships] ... and such they provoke emotional, as well as rational reactions".

Smart materials do not only replace conventional materials but also they can act as a 'technology' (Addington and Schodek 2005, 29). By this, what is meant is that smart materials possess parametric components that constitute a specific technology with their characteristics. It is to be understood that smart materials technology offers ways to update conventional or traditional technologies and to realize new generations of practical applications.

The need for new technologies can be met in part by the characteristics of smart materials. As a class of material, they make it possible to reinvent the already existing (or newly invented) physical or chemical characteristics of materials so that thay become multifaceted. They can initiate and urge the establishment of new correlations and possibilities, or can contribute to the evolution of an existing technology. Any new material is to be exploited by means of new exploitation techniques that serve and satisfy design purposes. Therefore, smart materials contribute to more developed forms, better material performance, system performance, design inspiration, etc.

Unfortunately, literature spanning smart material properties and applications benefiting from smart materials seems insufficient or, at least, it has yet to champion the potentially great contribution that smart materials can have for human progress. The areas of smart materials application are currently limited or secretive, and details of their material characteristics or properties are presently difficult to source.This can be a source of frustration for designers, who need quick and convenient access to materials information to incorporate into their design decision-making.

> As a result,today's... [design professionals] often think of materials as part of a design palette from which materials can be chosen and applied as compositional and visual surfaces (Addington and Schodek 2005, 3).

Put simply, if smart materials are to be contemplated or utilised in new product designs, their characteristics have to be known to designers. Such knowledge leads the designer to an accurate selection of a smart material that would serve identified design objectives. This fact is highlighted by Harold van Doren in *Industrial Design* (1954, 84), who foresees the significance of materials in design:

> Before you begin actual designing, it is important also to know not only the facilities your client has available, but also a good deal about the appropriateness of various materials for the particular job.

As Doren puts forth, 'the appropriateness of various materials' is a key consideration for design and production, and it is through material characteristics and properties that a level of appropriateness for a given design can be determined. A reliable information source is that which provides information on characteristics of smart materials, for appropriate usage. Among such usages, smart materials can act as "sensors, transducers or actuators" (2005, 110).These three basic roles are further defined.

> - A detector [or *sensor*] refers to an assembly consisting of a sensor and the needed electronics that convert the basic signal from the sensor into a usable or understandable form.
> - A *transducer* is normally a device that converts energy from one form to another, used for the purpose of transmitting, monitoring or controlling energy.
> - An *actuator* is a device that converts input energy in the form of a signal into a mechanical or chemical action (2005, 114).

Alongside the new possibilities of application that smart materials offer to industrial designers are similar possibilities for engineers, where the significant role of smart materials to function as converters can be harnessed.

2.1. Characteristics and Capabilities of Smart Materials

Addington and Schodek (2005, 21) define smart materials as those having conceptual characteristics that distinguish them from traditional materials. These characteristics are "transiency, selectivity, immediacy, self-actuation and directness". Transiency, in this respect, is the capability of a smart material to "respond" to external stimuli that appear "in more than one environmental state", while selectivity is the "response" of a smart material which is "discrete and predictable". Immediacy is a term that refers to "response in real time". Self-actuation means "intelligence is internal to, rather than external to, the 'material" and directness means "the response is local to the 'activating' event" (2005,10).

Addington and Schodek also refer to smart materials as having 'capabilities' besides their characteristics. They discuss that smart materials can have a capability of property changing, capability for energy exchange, discrete size/location and reversibility/directionality (2005,79). Each of these is now examined in more detail.

Smart materials possessing a *property changing capability* change their properties through a transformation in, for example, color, toughness, or resistance, in reaction to a chemical, thermal, mechanical, magnetic, optical or electrical stimulus. The stimulus causes a direct effect in the material as in figure 2.1, which may be detected through a change in one or more property such as change in color due to thermal stimulus (Addington and Schodek 2005).

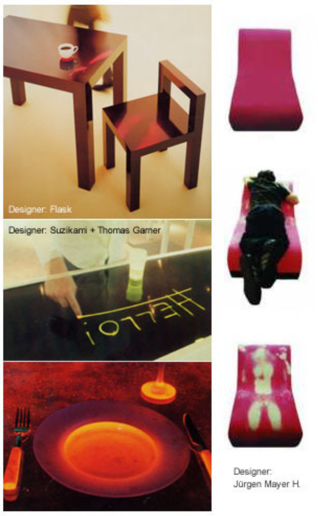

Figure 2.1. Examples of property change (color) due to thermal stimuli (http://beverlytang.com/materials)

Smart materials are 'first law materials', which means they adhere to the principle of conservation of energy, that is, they can "change an input energy into another form to produce an output energy in accordance with the first law of thermodynamics" (Addington and Schodek 2005, 80). Such smart materials are described as *energy-exchanging*. Smart materials can be applied as excellent environmental sensors, and output energy can be used as an actuator. Piezoelectrics, pyroelectrics, photovoltaics, electrostrictives, chemoluminescents and conducting polymers are all examples of smart materials within this category. Smart materials with energy exchange capability reveal energy conversion efficiency that is much lower than that of conventional technologies, but they offer much greater utility of potential energy as in figure 2.2 with piezoceramic material.

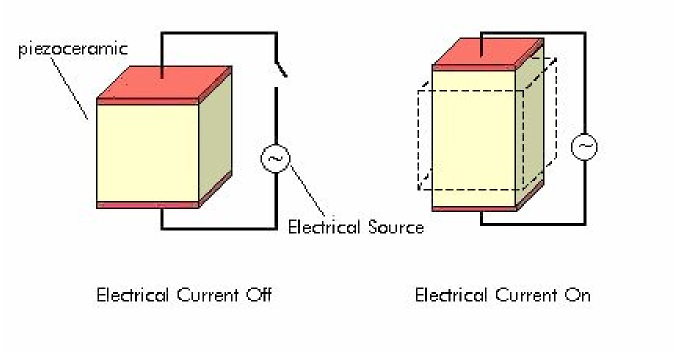

Figure 2.2. Energy exchange between mechanical energy and electrical energy in a piezoceramic (http://www.piezomaterials.com/piezoeffect.jpg)

Smart materials having a capability of *discrete size/location* offer economy in material usage, size and components. Similarly, if a component or element of smart material is used for the reason of reducing the quantity and number of materials, they would yield designs much smaller in size and with fewer elements, thus becoming more compact, light and handy in the location that they would be used (Addington and Schodek 2005).

Finally, property-change and energy-exchange capability of many smart materials manifests in either *reversible* or *bi-directional* outputs, which makes them suitable for accomplishing many tasks in a novel way such as phase-changing pellets in figure 2.3. to control and regulate temperature by energy storage (Addington and Schodek 2005).

Figure 2.3. Example of reversibility: phase-changing pellets to control and regulate temperature by energy storage. They have the capability to absorb energy from environment when the environment is hot; or, release it when the environment is cold (Addington and Schodek 2005, 162).

2.2. Approaches to the Categorization of Smart Materials

The great variety of smart materials and their various applications in industry make it inevitable for a categorization system to be developed to assist in material selection based on material properties. According to John Fulton, in his book, *Materials in Design and Technology* (1992, 55), "it may be more convenient to group them [materials] according to their most obviously useful characteristics, in order to look at how materials generate and embody ideas." In line with this proposition, grouping smart materials as of categories calls for an emphasis on main co-authors, 'Michelle Addington and Daniel Schodek' and author 'Axel Ritter' to be referred to extensively, being the current authorities on smart materials classification. Addington and Schodek (2005) offer a categorization of smart materials by starting with two main groups: 'property-changing smart materials' and 'energy-exchanging smart materials'. This categorization can be traced through the logic below.

> If the mechanism affects the internal energy of the material by altering either the material's molecular structure or microstructure then the

> input results in a property change of the material. If the mechanism changes the energy state of the material composition, but does not alter the material, then the input results in an exchange of energy from one form to another (79-80).

On the other hand, Ritter (2007) categorizes smart materials into three groups, comprising ‘matter exchanging’(see 2.2.3), ‘property changing’(see 2.2.1), and ‘energy exchanging’(see 2.2.2). He subdivides property changing smart materials into ‘shape changing’, ‘colour and optically changing’ and ‘adhesion changing’. He subdivides energy exchanging smart materials into three subgroups; the first two of which are ‘light emitting’ and ‘electricity generating’, while the third sub-group is named as ‘energy exchanging’ reminding and repeating the main group name. Finally, he subdivides matter exchanging smart materials into ‘gas/water storing’ and ‘particle storing’, which may be defined as either absorbents (which absorb liquids), adsorbents (which hold gases) or super absorbents. Each of these categories is unique to smart materials, and within them holds the potential for design inspiration, improved material performance and better products.

Table 2.1 presents an overlay of the differences between the smart materials categorizations of Addington and Schodek, and Ritter, as the primary authors in classifying smart materials.

Table 2.1. Categorization of Smart Materials: An Overlay of Differences bapproaches used by Addington and Schodek, and Ritter

Property-Changing Smart Materials		
Addington and Schodek	**Ritter**	
Color-Changing Phase-Changing Conducting Polymers and Other Smart Conductors Rheological Property-Changing Liquid Crystal Technologies Suspended Particle Displays	Shape-Changing	Photostrictive
		Thermostrictive • Thermal expansion • Thermobimetals • Shape memory alloys
		Electroactive • Electroactive polymers
		Magnetostrictive
		Chemostrictive
		Piezoelectric
	Colour and Optically-Changing	Photochromic
		Thermochromic/tropic
		Mechanochromic
		Electrochromic
		Chemochromic
	Adhesion-Changing	General • Physical • Chemical • Mechanical
		Stimulus-Oriented • Photoadhesive • Thermoadhesive • Electroadhesive • Hydroadhesive • Bioadhesive
Energy-Exchanging Smart Materials		
Addington and Schodek	**Ritter**	
Light-Emitting Basic Semiconductors Photovoltaics, LEDs, Transistors, Thermoelectrics Piezoelectric Effects Shape Memory Alloys and Polymers	Light-Emitting	Photoluminescent
		Electroluminescent
		Bioluminescent
		Chemoluminescent
		Crystalloluminescent
		Radioluminescent
		Radiophotoluminescent
		Triboluminescent
	Electricity-Generating	Photoelectric
		Thermoelectric
		Piezoelectric
		Chemoelectric
	Energy-Exchanging	Light-Storing
		Heat-Storing
		Electricity-Storing
		Hydrogen-Storing
Matter-Exchanging Smart Materials		
Addington and Schodek	**Ritter**	
	Gas/Water-Storing	Particle-Storing

2.3. Property-Changing Smart Materials (Addington and Schodek's Approach)

Property-changing smart materials are sub grouped into "colour-changing materials, phase-changing materials, conducting polymers and other smart conductors, rheological property changing materials, liquid crystal technologies and suspended particle displays" (2005, 83-95).

2.3.1. Colour-Changing

The first sub-group called colour-changing materials or 'chromics' change their colour upon impact by an energy input instigating property change in the optical properties of a material which are its absorbance, reflectance, or scattering. They take their specific names according to the energy source by which they are affected, such as electro-, photo-, chemo-, mechano- and thermo-chromic, as described in more detail in Table 2.2.

Table 2.2. Colour-Changing Materials (Addington and Schodek 2005, 83)

Photochromics	"Materials that change colour when exposed to light"
Thermochromics	"Materials that change colour due to temperature changes"
Mechanochromics	"Materials that change colour due to imposed stresses and/or deformations"
Chemochromics	"Materials that change colour when exposed to specific chemical environments"
Electrochromics	"Materials that change colour when a voltage is applied ... [and] that change colour or transparencies when electrically activated"

2.3.2 Phase-Changing

The second subgroup called phase-changing materials "involve the absorbing, storing or releasing of large amounts of energy in the form of latent heat"; furthermore, "a phase change from solid to liquid, or liquid to gas, and vice versa, occurs at precise temperatures" (Addington and Schodek 2005, 88). Examples include inorganic hydrated salts, salt hydrates, paraffins and fatty acids, which can help to stabilize the thermal environment in buildings, and limit temperature fluctuations in a range of products from outdoor clothing (figure 2.4, Schoeller-PCM designed jacket), lamps and furniture.

Figure 2.4. Schoeller-PCM designed jacket keeps internal temperature stable (http://www.wbikes.com/home/News/How_to_win_the_cold_war)

2.3.3. Conducting Polymers and Other Smart Conductors

The third subgroup called conducting polymers and other smart conductors are materials with intrinsic electrical conductivity. "Electroactive polymers change their electrical conductivity in response to a change in the strength of an electrical field applied to the material" (Addington and Schodek 2005, 90). Examples are polyaniline and polypyrrole, used to create artificial muscles.

Semiconduction and light emission are behavioural patterns that can be obtained from certain polymers. To illustrate, "electrochemical polymers exhibit a change in response to the strength of the chemical environment”; “photoconductors and photoresistors...exhibit changes in their electrical conductivity when exposed to a light source”; “motion sensors already employ various kinds of photoconductors or photoresistors”; “pyroconductors are materials whose conductivities are temperature-dependent”; and “magnetoconductors have conductivities, responsive to the strength of an applied magnetic field”(Addington and Schodek 2005, 91).

2.3.4. Rheological Property-Changing

The fourth subgroup is called rheological property-changing materials. Many of these materials are termed “field-dependent”, “structured fluids with colloidal dispersions that change phase when subjected to an electric or magnetic field” (Addington and Schodek 2005, 92). The authors continue: "electrorheological (ER) fluids, for example, can cause the stiffness of the [car] tire to change upon demand, thus making it possible to ‘tune’ tires for better cornering or more comfortable straight riding”. Further, “devices that require mechanical interfaces, e.g. clutches which might conceivably use smart rheological fluids as replacements for mechanical parts” might in the future be “embedded in seats and arms so that the relative hardness or softness of the seat could be electrically adjusted”.

2.3.5. Liquid Crystal Technologies

The fifth subgroup is called liquid crystal technologies. One example is liquid crystal displays (LCDs). These use “two sheets of polarizing materials with a liquid crystal solution between them” (Addington and Schodek 2005, 92). A liquid crystals an intermediate material phase between an isotropic liquid and a crystalline solid.

2.3.6. Suspended Particle Displays

The sixth subgroup is suspended particle displays. It is used for display systems and for more general uses. These materials are used to create displays that are “electrically activated and can switch from an opaque to a clear colour instantly and vice-versa" (Addington and Schodek 2005, 94). Importantly, a constant voltage is not required to maintain the state of the material.

2.4. Property-Changing Smart Materials (Ritter's Approach)

Ritter uses three main subcategories for property-changing smart materials: shape-changing, colour and optically-changing, and adhesion-changing.

2.4.1. Shape-Changing

The first group of property changing smart materials are defined as shape-changing. According to Ritter (2007), shape-changing materials are those that can retain their original shape and/or dimension after an external source causing an observable change from the original shape and/or dimension. In this case, external stimuli may be from amongst light, pressure, temperature, magnetic field or even a chemical stimulus.

The stimulus can result in a shape change (but no dimension change), a dimension change (but no shape change), or a change in both shape and dimension simultaneously. Ritter (2007) subdivides shape-changing materials according to the stimuli that cause the changes, as outlined in Table 2.3.

Table 2.3. Ritter's Categorisation of Shape-Changing Materials

Smart material	Stimulus
Photostrictive	Light / electromagnetic energy
Thermostrictive	Temperature / thermal energy
Electroactive	Electric field / electrical energy
Magnetostrictive	Magnetic field / magnetic energy
Chemostrictive	Chemical environment / chemical energy
Piezoelectric	Pressure / Tension / mechanical energy

As highlighted in Table 2.3, Ritter considers smart materials that change shape as dependent variables that are changed by independent variables such as light, temperature, an electric field, a magnetic field, a chemical environment, or pressure/tension.

2.4.1.1. Photostrictive Materials

Photostrictive smart materials produce "strain by irradiation of light with ... photovoltaic and piezoelectric effects" (Montana State University). Photostriction is the fusion of two types of effects: one being a photovoltaic effect in which light turns into electricity, and the other being a piezoelectric effect in which mechanical motion is obtained from electricity (see Figure 2.5).

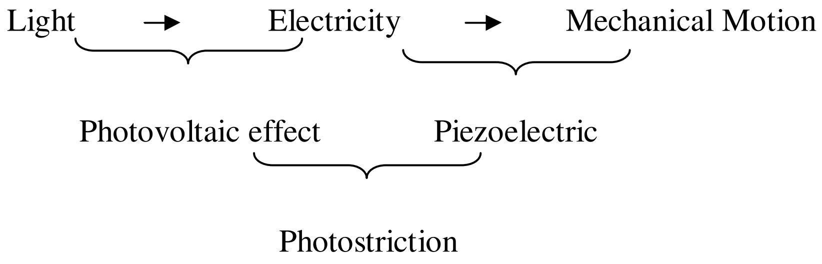

Figure 2.5. Mechanism of photostriction

2.4.1.2. Thermostrictive Materials

Thermostrictive smart materials change their shape and/or dimensions due to temperature change. The heating may be in any way such as radiation, conduction or direct heating. Ritter (2007, 47) divides thermostrictive materials into three strands, as shown in Table 2.4

Table 2.4. Ritter’s Division of Thermostrictive Materials

Thermal Expansion Materials (TEM)/ Expansion Materials (EM),			Thermobimetals (TB)	Shape Memory Alloys (SMA)
Thermo-bicomposite materials	Shape Memory Polymers (SMP),	Shape Memory Foams,	Shape Memory Ceramics	Biological Systems with Shape Memory Effect

Ritter’s evaluation of *thermal expansion materials* (TEM) reveals that they have either a considerable positive or negative coefficient of thermal expansion or a value close to zero. Table 2.5 identifies key attributes and applications of thermal expansion materials.

Table 2.5. Thermal Expansion/Expansion Materials

Properties	Continuous or discontinuous change in volume in response to continuous temperature expansion.
Examples	Alkanes (expansion wax), alcohols, N-alkanes C10 to C 18, paraffin oil, paraffin wax.
Advantages	Yield longer travel paths.
Disadvantages	Can be damaged with a constraint in thermal expansion.
Current usages	Piston controlled working elements, thermometers, valves, automobile construction industry, heating thermostats, greenhouse systems, ventilation systems.
Function	Pressure controlling, altering elements of variable heat requiring systems.

Ritter defines *thermobimetals* as laminated composite materials composed of two different components with different coefficients of thermal expansion. He highlights that the two components are bonded permanently so as not to become separated in use. Table 2.6 identifies key attributes and applications of thermobimetals.

Table 2.6. Thermobimetals

Properties	Composition of two components with different coefficient of thermal expansion.
Examples	TBs comprising alloys may include passive components in iron-nickel (Invar), nickel-cobalt-iron (Superinvar) and active components in iron-nickel-manganese, manganese-nickel-copper, iron-nickel-manganese and copper. TB bands are simple strips, but TBs are available in u-profile curved strips, reverse strips, spirals, helices, creep action discs, snap action discs and stamped parts.
Advantages	Can be synthesized to create continuous and linear movement, which is actualised by two-dimensional shapes. When three-dimensional shapes are required, strips can be folded. They can also be installed as clamped at one end.
Disadvantages	They have slow reaction times.
Current usages	"Measurement and control systems as in thermostats and electric control as components in mechatronic systems" (Ritter 2007). Also used in automatic opening and closing of ventilation flaps, and less expensive fire protection doors.
Function	"Depending on the way the temperature changes over time, the components used and their geometries, the composite takes up a curved shape and can be used for various applications and purposes." (Ritter 2007)

Ritter's definition of *shape memory alloys* (SMAs), also known as shape memory metals or memory metals, is derived from the fact that they have the capability to retain their original shape despite being subjected to thermomechanical treatment. Table 2.7 identifies key attributes and applications of shape memory alloys.

Table 2.7. Shape Memory Alloys

Properties	Such alloys consist of at least two different metallic elements and exhibit a capability to retain their original forms through a repeatable change between two crystal structures.
Examples	Basic alloys nickel-titanium (NiTi, e.g. Nitinol), copper-zinc-aluminium (CuZnAl), iron-platinum (FePt), and gold-cadmium (AuCd). SMAs are available in standard stocks of full section wires and rods, hollow wires and rods (tubes), springs, bands and strips and sheets. SMAs are also used in products including clamps and stents, and variable connection devices being hook and loop fasteners.
Advantages	Nickel-titanium wire and copper-zinc-aluminium wire can be weaved mechanically or manually and can be clamped at one or both ends. Advantages of SMAs are that they can be actuators or positioners as drives and they can provide continuous, almost linear or discontinuous sudden movements. They can generate rotational movements, as they are elastic. They are also structural components with relatively long actuator paths. In short, they reveal such properties as bending tension, compression, torsion and shape changing while also being silent.
Disadvantages	Relatively slow reaction times.
Current usages	Architectural structural materials, aeronautic experimentation bound to solar radiation, cardiovascular technology, microsystem technology, measurement and control technology, electrical and automobile engineering, flexible spectacle/glasses frames, textiles, household electronic appliances.
Function	Behavioural patterns through light stimulation ,mechanical simulation or change in temperature

SMAs are one of the most popular and currently exploited groups of thermostrictive smart materials, and show good promise for future applications. For instance “light stimulated shape memory plastics (memory polymers)” are likely to guide future research especially in the field of medicine. Apart from a few exceptions, SMAs have not yet been introduced in mass-marketed consumer goods; rather, they have mostly been a subject matter for scientific research and specialist end applications. Industries that have benefited from SMAs include (Guidot 2006, 214-215): aeronautics (solar panels and satellites), biomedical (orthodontic arc wires, bone staples and strengthening bone implants, self-expanding coronary stents that expand with body heat, surgical instruments especially for endoscopy, clothing (underwires for bras that do not bend in the washing machine), food (thermomarqueur), frames (NiTi alloy-superelasticity), and seismology. Figures 2.6.a and 2.6.b illustrate the use of SMA in the textile industry: the SMAs shorten when the temperature rises.

Figure 2.6.a. SMA integrated into textiles (http://www.gzespace.com/gzenew/index.php?pg=oricalco&lang=en)

Figure 2.6.b. Shape memory interior textiles using SMA threads. (Ritter 2007)

2.4.1.3.Electroactive Materials

Electroactive smart materials change their shape in the presence of an electric field. Table 2.8 identifies key attributes and applications of electroactive polymers, as a particular type of electroactive material.

Table 2.8 Electroactive Polymers (EAP)

Properties	Large deformations and small actuation forces.
Examples	Electronic EAP components are dielectric EAPs and ferroelectric EAPs. Ionic EAP components are electrically conductive polymers (conductive polymers, CPS) and ionic polymer gels. Other EAPs are acryl-based components with graphite and polypyrrol-based conductive composite polymer. They are available as fibres, yarns, strips, films and coils.
Advantages/ Disadvantages	Their properties of large deformations and small actuation forces may be regarded as advantageous or disadvantageous depending on context.
Current usages	Technology demonstrators.
Function	EAP products are under development. EAPs were mainly developed for trials and demonstrations.

Ritter explains that "future applications of EAPs are likely to include adaptive wing sections and elastic tubes that are able to change their local diameters" (2007, 67). Continuing, "in the short term, electrically deformable, large surface-forming components could be made from EAP films to produce various textures in wall coverings or wallpaper" (2007, 69).

2.4.1.4. Magnetostrictive Materials

"Magnetostrictive materials undergo a change of physical dimensions when subjected to a magnetic field; they can either be used as actuators or sensors" (Guidot 2006, 214).

2.4.1.5. Chemostrictive Materials

The shape of chemostrictive materials changes when “excited by the effect of a chemical environment (chemical energy)” (Ritter 2007, 46).

2.4.1.6. Piezoelectric Materials

Piezoelectric materials change their shape when they are “excited by the effect of pressure or tension (mechanical energy)” (Ritter 2007, 46). Furthermore, “piezoelectric materials generate an electric voltage when they are stressed, and vice versa. The best known piezoelectric material is the quartz crystal used in clockmaking” (Guidot 2006, 214). Other examples, identified by Schwartz (2002) include microphones and speakers, charcoal grill fire starters, vibration reducing skis, and doorbell pushers. It is interesting to examine the mechanism of piezoelectric materials. Schwartz (2002, v) explains that “an applied mechanical force produces deformation that in turn produces an electric voltage, or, conversely, an applied voltage that causes a mechanical deformation in the material that can be used to produce a force”. Such properties are well matched to the creation of a very wide range of position sensors and small actuators. Schwartz (2002, v) continues: “piezoelectric transducers are widely used in automotive, aerospace, and other industries to measure vibration and shock, including monitoring of machinery such as pumps and turbo machinery, and noise and vibration control”. Technical Insights Inc., (2000) gives further explanation of piezoelectrics and their application.

> These ceramics or polymers are characterized by a swift, linear shape change in response to an electric field. The electricity makes the material expand or contract almost instantly. The materials have potential uses in actuators that control chatter in precision machine tools, improved robotic parts that move faster and with greater accuracy, smaller microelectronic circuits in machines ranging from computers to photolithography printers, and health-monitoring fibers for bridges, buildings, and wood utility poles.

2.4.2 Color and Optically-Changing Smart Materials

The second group of property-changing smart materials is defined as color and optically-changing. Ritter (2007) subdivides colour and optically-changing materials according to the stimuli that cause the changes, as outlined in Table 2.9.

Table 2.9 Ritter's Categorisation of Color and Optically-Changing Materials

Smart Material	Stimulus
Photochromic	Light
Thermochromic/tropic	Temperature
Mechanochromic	Mechanical energy
Electrochromic	Electric
Chemochromic	Chemical

Photochromic, thermochromic, thermotropic, electrochromic and electrooptic smart materials have a range of applications in architecture due to their availability and long-term stability. As Ritter explains (2007, 71),"assuming further development and market placement, piezochromic, gaschromic and halochromic smart materials could gain in importance in the near future".

2.4.2.1. Photochromic materials (PC)

"Photochromic materials (PC), photochromics and UV-sensitive materials are able to reversibly change their colour in response to light"(Ritter 2007, 73).Table 2.10 identifies key attributes and applications of photochromic materials.

Table 2.10. Photochromic Materials

Properties	Colour-changing in response to light.
Examples	Organic compounds (naphthopyranes, spiropyranes, spirooxazines), spirodihydroindolizines, chromenes, diarylethenes, fulgides, azo compounds, bakteriorhodopsin (BR)) and inorganic compounds.
Advantages	Long term stability, availability in markets, aesthetics.
Disadvantages	No known large-scale uses of these systems.
Current usages	Self-colouring sunglasses, which have been on the market for over twenty years, products for children, and dental sealant materials (fissure sealants). Aqueous solutions or as dyes on, for example, films for the display, storage or processing of optical information. Some examples are dyes made from photochromic organic compounds, dyes made from reversacol (technology by James Robinson), paints incorporating photochromic organic compounds and glass incorporating electrochromic inorganic compounds.
Function	Indication of energy state or time, or of changes in surface temperatures.

2.4.2.2. Thermochromic/tropic materials (TC, TT)

Ritter (2007) defines thermochromic materials and thermotropic materials as smart materials which respond to light and temperature:

> Thermochromic materials (TC) and thermochromics are materials or components that are able to reversibly change their colour in response to light. In contrast, thermotropic materials (TT) and thermotropics are materials or components that are able to reversibly change their optical characteristics (e.g. transparency) in response to temperature (Ritter 2007, 80).

Table 2.11 identifies key attributes and applications of thermochromic materials.

Table 2.11. Thermochromic Materials

Properties	They react to a continuous temperature rise by changing colour.
Examples	Organic compounds such as cholesteric liquid crystal, leuco dyes and inorganic compounds such as metal oxides, zinc oxide, bismuth oxide, copper oxide and metal iodides. Thermochromic materials or components also include minerals being rutil and thermochromic gemstones.
Advantages	Thermochromic materials have market presence, they can be made in large quantities, can be used in low to medium temperatures (< –20°C to > +100°C), provide a reasonable number of cycles of possible changes of colour, are suitable for precise applications and are non-toxic.
Disadvantages	They require special manufacturing technology. They have relatively low colour intensity. A black background is required to maximise the colour effect, and they are relatively expensive.
Current usages	Leuco dyes incorporating TCs, paints incorporating TCs as part of a paint system (Eclipse, technology by Alsa Corporation), dyes (e.g. inks, printing inks) incorporating TCs (e.g.naphthopyranes, spironaphthoxazines; DynaColor, technology by Chromatic Technologies Inc.), microencapsulated TCs (compounds), threads incorporating TCs, hydrogels incorporating TCs, papers incorporating TCs, films incorporating TCs, textiles incorporating TCs (e.g. thermochromic yarns), glass systems incorporating TTs.
Function	Indication of energy state or time, or of changes in surface temperatures.

2.4.2.3. Mechanochromic

The color of mechanochromic materials transforms into an alternative color spectrum when they are exposed to an externalstimulus such as “compression, tension orfriction (mechanical energy)”(Ritter 2007, 72).

2.4.2.4. Electrochromic

“These materials change their colour and/or optical properties when excited by the effect ofelectrical fields, electrons or ions (electrical energy)” (Ritter 2007, 72). Technical Insights Inc., (2000) provide further description.

> Electrochromism is defined as the ability of a material to change its optical properties when a voltage is applied across it. These materials

are used as antistatic layers, electrochrome layers in LCDs (liquid crystal displays), and cathodes in lithium batteries.

2.4.2.5. Chemochromic

According to Ritter (2007) chemochromic smart materials are sensitive to any stimulus from chemical environment, with which they yield change in color together with optical properties. This change is due to a release of chemical energy yielded by such examples as hydrogen, oxygen, salt content (pH value), a solution or water.

2.4.3.Adhesion-Changing Smart Materials

The third group of property-changing smart materials is defined as adhesion-changing. Ritter (2007) provides two broad categorisations of adhesion-changing materials (general, stimulus-oriented) and subdivides these categories according to the stimuli that cause the changes, as outlined in Table 2.12.

Table 2.12. Ritter's Categorisation of Adhesion-Changing Materials

General (Ritter 2007, 97-98)	
Physical	"The main attraction forces are due to adsorption, secondary bonding, van-der-Waals forces, electrostatic bonding, dipolar bonding and secondary valency bonding between different components."
Chemical	"Chemical bonding provides the main attraction forces between different components."
Mechanical	"These attraction forces arise mainly from interlocking, anchoring or intermeshing between different components."
Stimulus-Oriented (Ritter 2007, 97-98)	
These materials "change the attraction forces of adsorption or absorption of atoms or molecules of solid, liquid or gaseous components."	
Photoadhesive	Light
Thermoadhesive	Temperature
Electroadhesive	Electrical field
Hydroadhesive	Liquid components
Bioadhesive	Biological components

2.5. Energy-Exchanging Smart Materials (Addington and Schodek's Approach)

Energy-exchaning smart materials are subgrouped into those that are: light-emitting; basic semiconductors; photovoltaics, LEDs, transistors, thermoelectrics; piezoelectric effects; and shape memory alloys and polymers.

2.5.1. Light-Emitting Materials

The subgroup includes luminescent, fluorescent, phosphorescent and electroluminescent materials.

2.5.2. Basic Semiconductors

"Basic semiconductor materials, such as silicon, are neither good conductors nor good insulators, but, with the addition of small impurities called dopants, they can be made to possess many fascinating electrical properties" (Addington and Schodek 2005, 100).

2.5.3. Photovoltaics, LEDs, Transistors, Thermoelectrics

"A second and more complex behaviour occurs in semiconductors because of general movement of electrons and holes" (Addington and Schodek 2005, 102). Lasers, LEDs (light-emitting diodes), light strips, panels, and bright backlights in inexpensive watches are created using this technology. The common LED functions as the converse of a photovoltaic cell.

2.5.4. Piezoelectric Effects

Previously covered in section 2.4.1.

2.5.5. Shape Memory Alloys and Shape Memory Polymers

Previously covered in section 2.4.1.

2.6. Energy-Exchanging Smart Materials (Ritter's Approach)

Energy-exchanging smart materials are sub grouped into those that are: light-emitting; electricity-generating; and energy-exchanging. These are further subdivided into categories according to the stimuli that cause the changes.

2.6.1.Light-Emitting

Table 2.13 provides details of Ritter's categorisation of light-emitting materials.

Table 2.13. Ritter's Categorisation of Light-Emitting Materials (Ritter 2007,107-108)

Smart material	An optical phenomenon in which...
Photoluminescence	"a molecule is excited and emits light due to the effect of light." (Classed as *fluorescent* or *phosphorescent* depending on the properties of their luminous behaviour with respect to time)
Bioluminescence	"a chemical reaction occurs to excite a molecule in a living organism to emit light."
Chemoluminescence	"a chemical reaction occurs to excite a molecule to emit light."
Crystalloluminescence	"a molecule is excited due to crystallisation and emits light."
Radioluminescence	"a molecule is excited by the effect of radioactive radiation and emits light."
Radiophotoluminescence (Thermoluminescence)	"a molecule is excited by the effect of radioactive radiationfollowed by thermal radiation to emit cold light."
Triboluminescence	"a molecule is excited by a mechanical effect to emit light."

2.6.2. Electricity-Generating

Materials falling into this category require certain stimuli to produce electric current. Table 2.14 provides details of Ritter's categorisation of light-emitting materials.

Table 2.14. Ritter's Categorisation of Electricity-Generating Materials

Smart material	Electricity generated when excited by...
Photoelectric	Light (electromagnetic energy)
Thermoelectric (Pyroelectric)	Temperature (thermal energy)
Piezoelectric	Compression or tension (mechanical energy)
Chemoelectric	Chemical environment (chemical energy)

2.6.3. Energy-Exchanging

Energy-exchanging smart materials are grouped under one property, 'energy storage'. Table 2.15 provides details of Ritter's categorisation of energy-exchanging materials.

Table 2.15. Ritter's Categorisation of Energy-Exchanging Materials

Smart material	Energy storage in the form of...
Light-Storing	Light
Heat-Storing	Heat and cold (negative heat)
Electricity-Storing	Electricity
Hydrogen-Storing	Hydrogen

2.7. Matter-Exchanging Smart Materials (Ritter's Approach)

Of the two smart materials classifications developed by Addington and Schodek (2005) and Ritter (2007), only Ritter includes a category of 'matter-exchanging' materials, which he defines as "materials and products that are able to reversibly take up and/or in, to bind and release matter either in the form of molecules, as gaseous, liquid or solid components by various physical and/or chemical processes" (Ritter 2007, 170). Table 2.16 provides details of Ritter's categorisation of matter-exchanging materials.

Table 2.16. Ritter’s Categorisation of Matter-Exchanging Materials (2007, 170)

Gas/water-storing	“They are excited by gas and/or water to adsorb or absorb them. Through contact withanother medium such as air, and in certain situations through other influences(e.g. increased temperatures), they can become excited and desorb the stored matter”.
Particle-storing	“They are excited for example by ionised, electrical or electromagnetic fields to absorb particles. When the field is removed, they are excited and desorb the stored matter”.

2.8. Confusions about Smart Materials

Smart materials establish a realm of materials with a variety of intriguing and unusual characteristics. Naturally, when such variety is considered, it can be concluded that this new realm demands precise definitions and descriptions so that confusion in the minds of industrial designers and engineers can be eliminated. Similarly, it is equally important to create a heightened general awareness as to what smart materials are.

Smart materials are distinguished from other materials through their changeable properties and energy transfer functions. In order to make effective communications about smart materials, information providers should make careful study of literature so that reliable information is offered to industrial designers and engineers. To the uninitiated, it can be difficult to decipher whether a new material is indeed ‘smart’. As an example, according to Ritter, “surfaces that change colour depending on the angle of view are not smart materials” (2007, 31). Addington and Schodek (2005, 14) provide another effort in distinguishing smart materials from non-smart new materials.

> Many of these interesting materials, such as composites based on carbon fibres or some of the new radiant mirror films, change neither

> their properties nor provide energy transfer functions; and hence are not smart materials. Rather, they are what might best be described as 'high-performance' materials. They often have what might be called 'selected and designed properties' (e.g., extremely high strength or stiffness, or particular reflective properties). These particular properties have been optimised via use of particular internal material structures or compositions. These optimized properties, however, are static.

A second confusion arises over the difficulty in making a distinction between 'smart' and 'semi-smart'. According to Ritter, "semi-smart materials are notable for their ability, for example, to change their shape in response to an influence once or a few times …. With smart materials these changes are repeatable and changeable." (2007, 8)

A third confusion arises in judging what is 'smart' and what is 'intelligent'. Addington and Schodek (2005, 19) put forward the argument that "the term 'intelligent' itself is as problematic as the term 'smart', yet it surely suggests something of a higher level than does 'smart' …. We do expect more out of 'intelligent systems' than we do from 'smart materials'." Ritter (2007, 8) brings further explanation.

> Smart materials are often described as adaptive or intelligent materials. Whilst most of the smart materials known today may also be described as adaptive materials because of their property to adjust themselves, the description 'intelligent materials' is to be considered as colloquial. This description is incorrect as intelligence also has associations with computer science, and the materials and products known to date are not generally suitable or until now have not been used in such a context.

Ritter's argumentation exposes certain problems in even the definition of smart materials, which can make the communication of smart materials information problematic. He not only highlights that the term 'intelligent' refers to associations with computer science, but that it may be misinterpreted as a synonym for 'smart'.

Ritter recommends that such colloquialisms be eliminated from the literature so that a common set of terms and reference can be established for better communication between industrial designers and engineers.

To conclude, this chapter has been dedicated to the clarification of what smart materials are their various categories, distinctive properties and their positioning within the development of new materials technology. With this effort, the main objective of the chapter has been to offer a concise, compact and easy to access reference point for people, especially designers, who wish to enter into the realm of smart materials. It is proposed that only through such a concise compilation of interrelated terminology can an effective language of smart materials and basic comprehension be established. Of course, as with any language, a smart materials language must be updated through continuous effort to ensure relevance to those who use it and refer to it.

CHAPTER 3

COMMUNICATION OF INFORMATION ON SMART MATERIALS

3.1. Materials Information Needs of Product Designers

The ways in which new information is communicated are via various channels of information such as advertising, press releases, profiles and datasheets. These are transmitted through some text whose main mission is concerned with reflecting the given information to target audiences without any distortion of facts, in a clear and direct manner and with straightforward guidance. The target audience as receptor of information requires some preliminary education about the new language or the jargon that is used to transmit the new discourse in a new field of study. John Fulton (1992, 54) explains this need as, “each discipline acquires a vocabulary, and sets up categories according to its methods and practice”. Roozenburg and Eekels (1995, 30-31) also highlight the need for building up a new language, which is also required as a step of design methodology that requires “conceptual tools for designers”. The authors state that concepts and terminology initiate thinking and design processes and that they establish “communication between the different experts contributing to product development”. Smart materials establish a new discipline to be communicated with a new lexicon, through which its methods of design, application and practice are to be transmitted.

Smart materials, as a new field of study, require a certain language with new jargon that is to be clearly understood by the receptor target audience. The audience within this realm is industrial designers and engineers, who are expected to change through the transmission of “simulacra ... and strategies” and through representations and text that are themselves a “simulated medium in which an idea is embodied out of a paradigm that emerges ‘as a system’” (Akın 2007, 6). Since smart materials are a new paradigm, the audience must be made familiar with the ideas that they offer for new possibilities of application. The familiarity of the audience can only be developed through a common effort to establish a language with which industrial designers and engineers can exchange logical and meaningful significations. In order to establish such significations, a semiotic and semantic agreement has to be determined. As semiotics (communication science) emphasizes, signs must be meaningful and agreed upon. Therefore, each sign (smart material or product made out of smart material) needs to construct meaning via “connotation” and be understood as “denoted meanings” (Bürdek 2005, 290). An adequate means of communication in this context must yield denoted meanings that are equally agreed by parties without any ambiguity. Besides denoted meanings, each sign embodies a connoted meaning for those who exploit the material for a specific purpose. The difference in deciphering connoted meanings opens up new routes of signification leading to different possibilities of exploitation of the material. From this point of view, a language of signs is expected to yield both direct and indirect signals of meaning. As for direct meanings, technical qualities of new materials are communicated to the audience who are to be exposed to the smart material for the first time and who look for much simpler and more direct material attributes. This is the phase of a popular confrontation between the audience (designer) and the new product made out of a new material, namely the smart material. Indirect meanings, on the other hand, are required to promote and encourage inspiration concerning usage of smart materials.

To promote widespread use of smart materials, it is essential that communication be established between designers from various backgrounds. This will lead to the usage of smart materials in the formation of new design ideas. Such communication is required to yield, prior to technical qualities that call for a more advanced level of understanding, basic communicative components. Being a new paradigm, smart materials must be reconciled with designers. Industrial designers, and indeed designers from various backgrounds who may use smart materials in proposing new design ideas, look for easy-to-understand information with clear and concise language, further clarified by pictures, diagrams and similar visual means of communicating information. In addition, information is best presented in a way so as to provoke an idea in the mind of the designer.

Information on a new material is expected to include such attributes as the names, mechanical and sensorial functions as well as non-technical parameters such as colour and texture. The information to be communicated has to embody some general knowledge with which the new material can be set in contrast and comparison with 'conventional' materials, knowledge of which is already familiar to designers. Only after such a popular outlook is established can a smart material be communicated successfully by its developer, whose primary mission is to express the technical attributes of their material in a meaningful language. Technical attributes are for establishing an "ideal mindset", whereas expansion beyond technical attributes to include other mentioned attributes could be considered to lead to an "optimum mindset" (Mann 2009). Achieving the optimum mindset, therefore, is the target of developers of smart materials. Before introducing smart materials to clients, designers or engineers, the developer has to work on the above stated necessities, which Ashby (2002, 162) also confirms.

> The information includes that required for product design: 1) much more than just technical attributes 2) the language in which it is expressed has meaning both for the supplier and the designer, requiring a vocabulary to express design requirements and material behaviour that both parties can understand. The need, then, is one of communication.

Ashby proceeds by suggesting that information sources may be used by the sender of the information either in the form of misinformation or disinformation. In the former, some information is deliberately omitted or left out so as to report only what is good or to conceal what is bad. In the latter, information is deliberately deviated or distorted. Therefore, any developer is required to follow the ethics of providing true information by concentrating on the necessary language through which they express the technical attributes of the material, as well as the visual and tactile attributes. Similarly, since the primary matter is to become acquainted with smart materials as new materials, it is first required to design and establish appropriate information channels, which may be exhibitions, books and all possible providers of information.

In summary, it can be said that there is a need for developing a new language and a new literature for the communication of information on smart materials. Furthermore, the new language and the literature should bring together many proponents that need to cooperate and interact with each other during the process of design and production. As opposed to the ancient or old way of utilising a material with one craftsman who is responsible for production, today there is a need for a multidisciplinary approach that can be traced back to the 1950s.

> A closely knit team consisting of the designer, the specialist in form, the engineer, the specialist in techniques; and the manufacturer and merchandiser, the experts in production and distribution. Each, with a growing understanding of the others’ problems, contributes his share to the end in view. (Van Doren 1954, 8)

So that different members of a design team can understand each other’s problems, there is a need to communicate information, which can be understood and shared equally by all members. Since knowledge of smart materials is rarely found in the profile of current industrial designers, there is a need to provide, assemble and communicate information to paint a fuller picture of the emerging character of smart materials. Manzini (cited in Ashby 2002, 163) cites the example of wood as a traditional material with which designers are familiar: “it has been touched, smelt, bent, broken, cut, strained, stressed, dried, wetted, burned and maybe even tasted by most humans; we know what wood is and what it does". In contrast, smart materials are not materials with which designers have usually had some earlier cognisance. The newness, therefore, is a barrier for cognition and transmission of information, both of which have to be overcome.

When the available sources of information on smart materials are looked into, language and vocabulary, though they contribute to communicate potential capabilities, are barriers between the developer and the designer, too. Like Manzini, the designer Richard Seymour (cited in Ashby 2002) expresses that materials manufacturers can propagate their ideas to the people; in this case, leading people to make use of the unique properties of smart materials by conceiving innovative new ideas and application areas. In other words, Seymour believes that as in every new field of innovation, there is a need to establish a system with which the new technology and its application can be reconciled.

Ashby's answer to the reconciliation issue is related to the transmission of knowledge via a new language, and identifying and bringing together components of the new paradigm. His first explication is concerned with developing the language to express the profiles of new materials in their completeness, which must encompass both technical and aesthetic attributes. His second explication is an effort to bring together those people who produce and characterise materials with those who design with them, through a series of workshops. Workshops, as Ashby notes, are very practical and functioning for getting used to a new language and finding out about material capabilities, processing possibilities, practical limits, character and behaviour qualities, competing materials, prior applications, potential applications, and so forth. Such were the issues and questions raised at a workshop on aluminium foams, a relatively new type of material, attended by three material scientists and four designers. To answer the questions, the workshop urged the participants to establish amongst them a common language with a new jargon so that the answers may be discussed and communicated in a free flowing manner.

On a similar topic to the above, van Kesteren (2006) points at the necessity of transmission of information in her work on product designers' information needs in materials selection and new design ideas. According to van Kesteren, "for an efficient materials-selecting process, the content and presentation of information about materials should be accustomed to product designers' approaches and needs" (2006, 133). Her approach in considering smart materials as a new field of study highlights the necessity that information with a thorough content has to be reliably presented to product designers, who can then make use of smart materials and other materials in new product ideas. Van Kesteren develops her discussion on information specification in line with exploring the needs and ways in which industrial designers may choose materials. To meet that end, she conducted a series of interviews with designers. Her interviews revealed four basic areas of need: "the need for comparable information, information related to product issues, information on multiple detail levels, and information on material samples" (2006, 133).

When the needs for materials selection are examined there appears to be one common denominator, which is 'information'. Therefore, it is also in her findings that information, its related terminology and language, as well as optimum channels of transmission are to be considered a priority for companies in the business of making and selling materials. Van Kesteren continues, saying "problem solving demands a large and constant flow of information" for selecting from existing materials (2006, 133). The information, therefore, has to be developed based on material properties and performances, prices, benefits to product design, and technical and aesthetic attributes.

The fact is materials (and most recently smart materials) offer to product designers a great variety of characteristics and possibilities. Therefore, the new field opened up by smart materials has seemingly unknown frontiers, which may be regarded as their basic advantage if the right information with specific parameters is provided. On the other hand, the amplitude of the new field may become a problematic nightmare for product designers if the related information is not transmitted to them in a way that they can readily make use of. Therefore, a new era of information presentation has started according to van Kesteren (2006), exploring and answering the needs and demands of product designers in a comprehensive way. In her research, van Kesteren begins with the information sources that are currently in use. Then she explores the formulation of the material needs of product designers, which she finds spans the four points stated previously. Moreover, van Kesteren examined the extent to which available information sources satisfy those needs.

The needs of people, satisfied through products, are preferably determined with simplicity, so as to attain a precise description on which to base design decisions. Mayall (1967, 123) depicts simplicity as a minimal approach to the understanding of the need for a new material as a “problem”, requiring clear and comprehensive specification. The problem is then expected to be analysed to establish correlations with possible material choices.

To encourage a new generation of products created with smart materials, designers first of all have to become accustomed with knowledge of the properties of these materials. Designers would naturally seek general information concerning the application potential of smart materials to the needs they seek to satisfy through product design. However, in order not to overload the designer with a large variety of probabilities, there is a new branch of science, “probabilistic material science” (Olson 2000, 8), which is now being developed so that property distributions of smart materials can be scientifically mapped to help guide designers. The correct guidance leads to the solution for a need, and, finally the solution leads the designer to a final synthesis of a product proposal destined for manufacture.

According to van Kesteren (2006), who has made a thorough literature search on materials selection, a variety of approaches may be taken. For instance Dobrzanski, she puts, suggests that requirements for a new product are compared with a broad materials database, out of which the required characteristics are finally inspected in a particular material choice. Van Kesteren finds that there are four methods for selecting materials, as put forward by Ashby and Johnson (2002), namely: by analysis, by synthesis, by similarity and by inspiration. Analysis involves the translation of product requirements into material objectives and constraints, by the end of which a database of materials is screened. In synthesis, product requirements are translated into desired features, and the process ends in exploration of a database of materials. Similarity, on the other hand, is a method dedicated to the process of finding close relations with desired materials already in use in existing products. The fourth method, inspiration, is based on the generation of new product ideas from random exposure to materials databases.

Material selection, therefore, can be made from various perspectives, spanning technical functions through to aesthetic characteristics; the latter being termed ‘product personality’ by Ashby and Johnson (2002). Van Kesteren also adds more considerations to material selection such as product personality, use, function, shape and manufacturing. When there are too many variables, materials selection is difficult, as is the corresponding process of information provision and use of information.

With regard to non-technical properties with which materials can also be selected, Karana (2006) offers ‘sensorial properties and perceived values’, which are tied to cultural aspects, trends, associations and emotions. Sensorial properties such as levels of transparency, gloss, tactile qualities, and alike physical attributes must be included in materials information that is to be regarded as comprehensive.

To summarise materials selection, it can be put forward that product designers make use of different selection methods and that the choice varies according to projects and phases of design. Another reality is that product designers are on a quest to satisfy a wide variety of product issues when they select materials. Also, the role of a material in a product changes as its functionality and the product personality that it creates changes. Therefore, to provide information that is pertinent for use in materials selection is not a trivial matter because requirements may vary, expectations may be many, and the combinations of materials and products tends towards infinity. For such reasons, a systematic information database – let alone targeted just at smart materials – is a highly ambitious goal.

Van Kesteren (2006) scans through currently used information sources such as general material applications, independent sources and materials on supply. Experience, testing and example products are the types of sources for materials selection under the category of 'general material applications'. While product designers exploit all available experience in selecting a material, they are found to take aid from institutions where tests and experiments have already been made with many materials. Also, product designers may demand information from example products, which can be skimmed at competitions, trade shows, and even through magazines while shopping.

With regard to independent sources, van Kesteren (2006) identifies databases and search engines, sample collections, books, and exhibitions. The first refers to company databases, commercial databases, search engines and trade guides. The second includes samples from former projects and commercial sample collections. Another source of information, materials on supply, can be a person who is an advisor from a material supplier or manufacturer. It can be also the internet, yielding a variety of information on suppliers, databases and datasheets. It may also be samples and brochures either delivered on request or in the form of advertisement, and finally trade shows and magazines, all of which are currently-available source information for which product designers have a long history of use.

However, because smart materials occupy a considerable part of the materials universe, the above-mentioned and currently available information sources are in need of improvement for smart materials to be appreciated by industrial designers. One study on how information sources can be improved, also carried out by van Kesteren (2006), compared the use of two materials databases. The study was run with six participants and involved material selection for the housing of an electric kettle. The test proved that the participants needed more training about the use of database programmes, and that they needed time to become accustomed. The participants were confused while beginning to use databases. They were also found to be in demand of more images than were provided in the databases, as a substitute for information expressed through words. The participants liked the information directed to idea and concept phases in one of the databases, while in the other information targeted at embodiment and detailed design phases was viewed positively.

Out of this experimentation, van Kesteren found that a good materials information source must have an easy-to-understand language, take little time in getting adapted to, convey strong visual representations, place little need for training on the user (user friendly), and offer information relevant for idea, concept, embodiment and detailed design phases. To this end, another study, included within van Kesteren's research, was dedicated to "presenting information about materials on multiple detail levels" (2006, 144).

The principle behind van Kesteren's follow-up study was that there is a need for product designers to have access to material information of an ever-increasing technical detail as their design process progresses. According to van Kesteren's research, it was found that out of the wide range of possible material properties, both expert and student designers sought mechanical, general (density, price) and sensorial information as a priority. As for ways of obtaining data and methods for data comparison, there were no common points between experts' and students' expectations. But it can be inferred from van Kesteren's research that experts and students both prefer to have access to material properties explained in numbers and text, or more ideally as a visual representation, and neither demanded a chemical formula of the material. Another finding in van Kesteren's work (2006) was that expert and student designers had common needs for materials comparison tables and graphics. To satisfy these needs, there must be a search engine in which the name of the material can be entered and the second step could be a search function from which mechanical and sensorial characteristics of materials appear. The third step should be the presentation of tables and graphics, which would enable designers to make comparisons. Comparisons can become more comprehensive if materials are accompanied by textual and visual information, in addition to numerical.

Another study by van Kesteren (2006) was dedicated to unpredictable aspects of materials embedded in a product, which may arise during the entire lifecycle of the product. Since finished products manufactured from different materials are subjected to phases of manufacturing, transportation, storing, sales, utilization, disposal and recycling, it is expected that selected materials for a product will respond well to each of these phases. To this end, thirteen product designers were asked about the kinds of information they sought from a physical material sample. The following findings were made, from highest frequency of response to lowest (2006, 141):

> ... colour, texture, thickness, production technique, scratch resistance, supplier portfolio, [if it] can be used for customer presentations, [if the product] can be held, touched and looked at from all sides [and if it is] easy for storage in boxes.

From this finding, it is estimated that non-technical parameters of materials such as colour and texture are the most in demand by product designers, who use mostly samples that represent product-related issues.

Van Kesteren (2006) carried out an additional study into the identification of information sources usually used by product designers to obtain material samples. One collection, known as Tech Box, is a vast source of material samples and technologies. In this collection, about 360 sample materials are named, stored, given serial numbers and supplier identifications. Besides such organized sample collections, designers can be inspired simply from the physical objects encountered during their daily shopping experiences. In van Kesteren's study, when designers were asked to respond to what they look for in hunting for materials to be used in design, it was found that attractiveness, their essential necessity for the application, and their usability "do not differ much"(van Kesteren 2006, 143), thus they are preferences of almost equal degree. A similar approach to the understanding of what good design is, and what the material needs of designers are, is put forward by Fulton (1992, 69).

> As a criterion of good design, 'truth to material' held that a well designed object should be conceived and formed so as to reflect the more satisfying qualities of the material used.

Designers particularly look for interaction qualities of a material, which appeals to tactile and visual sentiments. Also, functionality is another characteristic of concern to designers. Functionality, interaction, and usability as characteristics are all integrated in the material memories of designers, in order to recall what is available in the market. An information database aimed at supplying designers with the four main materials information themes (technical properties, sensorial properties, process properties, geometry properties, as well as general information, supplier information and images) would probably provide enough inspiration to assist designers in their brainstorming activities.

The studies by van Kesteren made it clear that the four main materials information themes are commonly blended into a consolidated package; that is, the information may be based on yielding any two, three or four properties for a wider scope of inspiration. In other words, related aspects of materials are brought together at various level of detail so as to assist decision-making in design.

When literature related to information needs is synthesized, a general outlook for information needs can be suggested as an information database for product designers. This is presented in Table 3.1.

Table 3.1. Proposition for a Database Suitable for Conveying Information on Smart Materials

PRODUCT DESIGNERS’ MATERIALS INFORMATION NEEDS: Information Database		
Easy language	Simple and direct expression	
	Easy jargon	
User compatibility	User friendly	
	Easy adaptation by the user	
Visual representation	Diagrams	
	Images	
Compactness of information	Idea / concept	
	Embodiment	
	Detail design	
Attributes to be included	Names	
	Functions	Mechanical
		Sensorial
	Tables	
	Comparisons	
	General information	
	Non-technical parameters	Colour
		Texture

A database as outlined in Table 3.1, if it is to be effective, should possess an easy-to-understand language, require little time in getting adapted to, yield visual representations, give some easy training to the user (user friendly) and combine idea, concept, embodiment and detailed design phases all together. Moreover, it should hold the names of materials, which would ease the process of searching for their functions, both technical and sensorial. It would be worthwhile to present all materials information in the form of tables and graphics to ease the job of making comparisons. Furthermore, textual information and images/diagrams must accompany general information such as supplier contact details. An effective materials information source for product design must contain non-technical parameters of materials such as colour and texture, which are frequently in demand but mostly evaluated through physical material samples.

To conclude, there are serious technological and linguistic barriers to the compilation of informational data on materials to be used by product designers. These barriers multiply in number tremendously when a new realm of materials, in this case smart materials, is considered. Since current databases containing materials information are inadequate and are not routinely developed and updated for designers through a systemic approach, it can be predicted that the preparation of a universal 'super database' for smart materials is unlikely to be achieved in a short time.

3.2. Ways of Eliminating Communication Barriers for Materials Information

As with the establishment of any communication system, the presentation of information on smart materials is challenged by several barriers. Three in particular can be identified. The first is the lack of familiarity with the new material class; the second is that application areas of smart materials are not yet very well known; and the third is that the design opportunity that smart materials can offer is currently ambiguous and multifaceted. In order to overcome such barriers to the exploitation of smart materials, a well chosen or developed communication means for conveying smart materials information is needed.

Such barriers to communication are studied by Mann (2009) and McCann et al. (2005). According to Mann, it is essential that information about smart materials must not only establish familiarity with the material but also expose entirely every phase related with its application to the manufacturing of products. Only through such communication can the application of a smart material to industrial sectors be grasped by designers or engineers. Moreover, designers must be protected under patent rights so that they can reap benefits from their inventive or innovative efforts. Concomitantly, intellectual property owned by smart material developers must be conveyed unambiguously.

McCann et al. (2005) put forward the perspective that information tied to a 'critical path' must be communicated. This is to give guidance for design research and development processes, in the event that smart technologies are applied from initial sourcing to the selection of appropriate materials, alongside consideration of their usages, application areas and methods for development.

3.3 Possible Channels for Communicating Smart Materials Information

Ambiguities establish barriers to access in the usage of smart materials. In order to eliminate such problems, communication between material developers/providers and designers/engineers must be established via appropriate channels. However, for smart materials, it is not clear which channels are the most effective. Possibilities include databases and networks, sample packs, conferences, workshops, SMEs, reports, consulting, books, research centres, companies and universities. Each of these channels is now examined for their potential to effectively communicate smart materials information.

3.3.1. Databases and Networks

Databases and networks establish an important part of information supply and reservoir. This reservoir embodies factual and reliable information from primary sources, with updated versions and is enriched via graphical presentation, as Voight (1996, 180) concludes for databases:

1. Collection of data expressed as facts.
2. Include detailed graphs and image based information
3. Hold large volumes of data
4. Most data require frequent updates to reflect factual change
5. Database revisions and updates can be done rather easily
6. Primary data sources include textbooks, atlases, dictionaries, user manuals, and checklists
7. Driven by pregenerated dataprogressing programmes

However, Voight's approach to the understanding of databases remain limited when compared with van Kesteren (2006) who regards databases as established to give guidance rather than just data to designers. The guidance that they provide is presented from the perspective that material utility is a priority, echoing the principle that form should follow function, or as Jim Lesko (1999, 3) states, referring to the Bauhaus movement, where "function leads and form follows." According to this understanding, Lesko adds, information has to be accessible according to two major groupings, namely, "performance specification demands, including all user-friendly aspects, and cost and manufacturability" (1999, 3).

One example of databases is 'Matweb', which is a Web source for materials information. The Web offers an easy access for users, who may submit quantitative property queries such as physical properties, alloy compositions and advanced research regarding material properties. It also offers categorised searches based on type of material, name of manufacturer, trade name and metal UNS (Unified Numbering System). Database searches for text can be initiated by entering a keyword or phrase regarding many materials, including thermoplastic and thermoset polymers (e.g. ABS, nylon, polycarbonate, polyester, polyethylene, polypropylene), metals (e.g. aluminium, cobalt, copper, lead, magnesium, nickel, steel, superalloys, titanium and zinc alloys), ceramics, semiconductors, fibers, and other engineering materials (http://www.matweb.com/).

How to Find Property Data in MatWeb

Quantitative Searches:

- Physical Properties
- Alloy Composition
- Advanced Search (Registration Required)

Categorized Searches:

- Material Type
- Manufacturer Name
- Trade Name
- Metal UNS Number

Text Search:

- Enter a key word or phrase in the box below (this search is also available at the top of every page).

Figure 3.1. Matweb main page (http://www.matweb.com/)

Alongside Matweb is SMART.mat (Smart Materials and Systems 2008), a United Kingdom based knowledge transfer network established with the aim of transferring materials knowledge in the form of a database amongst a network of subscribed users. Especially taking the business community as its target user, the network offers information concerning materials and their benefits. The ultimate end is to encourage and ease the development of new products and their applications. SMART.mat has also been designed as a ‘business support network’ and its aim is to bring industry and academia (i.e. the originating science base) closer to foster joint projects and collaborations that bring about mutual benefits. The network is directed by David Arthur (2006) as the Project Director, whose intention is to expertly offer information for those who are in need of technical assistance. Since smart technology requires considerable knowledge and awareness, Arthur (2006) initiated SMART.mat as a network that could bring together a partner organization, a customer or a designer.

SMART.mat carries out many activities to establish communication: it organises conferences, seminars and other networking events, raises funds for smart ideas for problem solving and technology demonstrations, and produces a smart materials design guide with information on properties, availability and suppliers. Taken together, SMART.mat delivers a wide range of technical information to non-specialists.

3.3.2. Sample packs

Among the efforts dedicated to spreading awareness and knowledge of smart materials, sample packs fulfil a significant role. A creative effort through sample packs has been initiated by Chris Rice, Director of Education at a United Kingdom school. This effort was exhibited at the *DATA Millennium Conference* under the initiative of the TEP (Technology Enhancement Program 2006). The initiative undertaken aimed to transfer to students aged between 11 and 16 an awareness and ability to identify a product in need of some improvement and then to take that product and use it for a specific design purpose. To this end, students were given some preliminary information about characteristics and applications of various materials, some of which were also smart materials. One of the smart materials, thermochromic film, was offered to them as a physical sample and they were requested to determine a need for such a material so that they can use it in a design process. To integrate the material into their designing, the students were expected to develop their knowledge of the properties of thermochromic film, evaluate it as a smart material, and find out where it could be used. In this way, familiarity between the material and the student was established.

Sample packs have proved to be effective as material study packs for students. A similar effort to that of Chris Rice's has been carried out by Eddie Norman (2008), a Senior Lecturer in the Department of Design and Technology at Loughborough University, United Kingdom. He assigned his students a product design project to be realized using smart materials for the purpose of assisting product disassembly and, by implication, the opportunities for reuse, recycling and reduced environmental impact. In simpler words, the sample pack was designed to encourage students to make use of smart materials from an environmentally friendly philosophy. The project was founded on the idea that worn-out or used electrical and electronic products are to be eventually recollected so that they can be disassembled for recycling or reuse purposes. The old methods of sorting out components of used materials by automatic means or manually would either harm the components or it would be too costly. To eliminate the damage and the high cost in dissembling the components, smart materials could be of some radical help as they could expand, contract, melt and change colour. These properties could be used during the process of assembly and disassembly. So, at the final stage of disassembly, only the structural characteristics of the binding smart materials are reversed so that all components may be disassembled in a very practical and cheap way. “Smart materials to help disassembly” (Norman 2008) is the sample pack that provides details for types of smart materials and their use in disassembly. Norman added to the pack certain parameters of limitation on the project, regarding the life span of the product, the safety principle in the use of smart materials, and the final value to be more than the cost value of the smart material.

3.3.3. Conferences

Conferences are an integral part of any research and it is through them that data and findings are exchanged, both to avoid repeated and overlapping research, and to share knowledge and open-up new routes for further research studies.

In the field of smart materials, a variety of conferences have been held among scholars, researchers, scientists and companies concerned with extending and expanding knowledge and exploitation of smart materials.

Some of the recent conferences on smart materials have initiated a wide exchange of related knowledge. For instance, on its website, Newsweaver announces the conference, ‘Smart Materials Design Guide’, held on 22 October 2007, dedicated to the usages of smart materials in product design. The conference meeting demonstrated the new SMART.mat design guide and the ways in which it could be used for product design. The speakers in the conference were Dr Fiona Lowrie, QinetiQ and Dr Paul Legood, Corus. A succession of conferences organised by METU (2003) was dedicated to ‘Nanotechnologies, Smart Materials and New Production Procedures’. Some of the topics discussed included ‘Research on the Nanocrystal-Nanoalloy, Metallic Glass Production and Their Physical Qualities for the Applications of Advanced Technological Practices’ (Akdeniz and Elerman); ‘MEMS ve Microsensors’(Akın); ‘The design and synthesis of new nanomaterials’ (Akkaya); and ‘Production of Bio-origined Strategical Materials from Mussel Shells’ (Ögel) (M.E.T.U Research Coordination Office 2003).

3.3.4. Workshops

On its website, the Smart Textiles Network (2006) based at Central Saint Martins College of Art and Design, London, and SMART.mat Materials Knowledge Transfer Network (KTN) state that they organized five workshops on smart materials. The first centred on textile sensors and actuators; the second on light-emitting textiles for fashion and health; the third on smart materials and design education; the fourth as a design and smart materials bazaar; and the fifth on fashion for smart materials.

As revealed on the Smart Textiles Network website, the aim of the workshops was to enable dialogue and to establish partnerships between designers and developers or producers of smart materials so that the future use of smart materials could be enlivened or envisaged. The ultimate purpose was to introduce smart materials to the appreciation of the public.

Within this perception and understanding, the series of workshops were dedicated to the creation of a futuristic view of how smart materials can be used especially in the fields of innovation, textiles, technology, fashion, design and enterprise. Under the subtitle of '*A View of the Future'*, the designer needs of the future were explored and the findings presented for public appreciation in an activity named *Smart Materials Bazaar*. The bazaar was arranged so that materials, gadgets and products made of smart materials were exposed to the public in an engaging way. The purpose behind this was to reconcile the public with smart materials so that a popular public taste is established. Besides popular playthings, design visualization tools were created so as to let the participants in the workshop produce product concepts and projects for future designs made in smart materials.

In order to further the workshop so that it would appeal to the public interest, it focused on the stylish and fashionable expectations of a security-driven society. The main objective was to combine the technology offered by smart materials to support popular fashion. Similarly, the link between clothing, textiles and smart materials was emphasized in relation to health monitoring, security, entertainment, products of culture, communication and expression, so that a futuristic exploitation of smart materials in the textile industry may meet and satisfy the emotional, sensory and experiential needs of society. Moreover, the workshop suggested that design becomes a keyword for the future production of smart materials. In simpler terms, future applications of smart materials should be designer-driven and based on people's enjoyment and appreciation of innovation, technology and design.

Another workshop, dedicated to future possibilities of usage, was held as the Second National Workshop on 'Smart Materials for the Design of Intelligent Systems and Industrial Application' by the Department of Mechanical Engineering, Indian Institute of Technology (2007). The workshop concentrated on the design of intelligent systems and industrial applications, and brought together industrial experts, academics, and research and development personnel in industry. The workshop involved a process of brainstorming to generate ideas concerning useful applications of smart materials in industry.

Gregory B. Olson in *Materials by Design: Efficient Innovation* (2000) states that one workshop, entitled ‘Materials Design Science and Engineering’, which was sponsored by the NSF (National Science Foundation), had a focus on ‘computational materials design’, reflecting a future contribution to US competitiveness. Computational materials design is based on complex adaptive microstructures capable of supporting biomimetic materials, which “emulate or adapt biology's unmatched brilliance in materials innovation” (Olson 2000, 5). Shape memory alloy, which exploits structural transformations in materials enabling them to change shape in a controlled manner, is one of the applications in the field.

The application of smart materials to design is found through the workshop to eventually result in reduction of costs of discovery and development of new smart materials. Not only reduction in costs, but also in various industrial fields of application, smart materials are predicted to contribute to new generations of products whilst decreasing the time of production and development.

3.3.5. Companies and SMEs

According to the Flemish Company Centexbel (2008) in *Product innovation by means of smart materials*, “the 21st century will be marked by the development of products with an increasing number of additional functionalities”. Within this context is predicted to be the addition of smart materials to a variety of products, with the chances that will lead to new innovations to satisfy the demands of distinctive companies and SMEs (small and medium sized enterprises). Continuing from the Centexbel web page, “countless companies look for specialised niche products with a very important contribution of expertise”. Smart materials offer a variety of specialised applications, so they have potential to become indispensible for SMEs.

Echoing the concern of this chapter to discover ways to provide information for industrial designers about smart materials, the Research Centre of the Belgian

Technological Industry started an action plan that encourages companies to acquaint themselves with the application possibilities and product innovations associated with smart materials. The action plan also aims to unite different sectors at interdisciplinary intersection points to find out about innovations. Many industrial sectors cooperate to improve product development in the Flemish industry. Furthermore, many people are employed in companies participating in this action plan. Centexbel (2008) in *Product Development*, to encourage TIS (product innovation and development utilising smart materials) for Flemish industrial companies in a more systematic and efficient way, focuses on SMEs and an action plan was conceived to contribute to a broad cluster of TIS projects in:

- wood and furniture sector (Febelhout/Optimo);
- technological industry (Agoria/WTCM);
- textile industry (Fedusria /Centexbel /Textivision);
- synthetic industry (Fechiplast/Agoria);
- steel industry (Staalinfocentrum);
- graphic industry (Vlaams innovatiecentrum voor grafische communicatie);
- Flemish industry generally (a cluster project) (http://www.centexbel.be/product-development)

Coordination of actions within the industrial sectors and on a trans-sectoral level is a requirement for the listed projects, as an incentive to encourage more individual projects to join the cluster. Moreover, the process of clustering the projects is intended to lead companies within a particular sector to establish better means of cooperation and transfer of knowledge, hopefully leading to synergies and a higher efficiency level.

Companies have begun to contribute to the development of literature related to smart materials. Their contribution in doing so is gradually building up in a network of collaboration with particular designers and manufacturing companies that collectively intend to make more extensive use of smart materials. The contribution of companies to the communication of smart materials information may not be directly in the form of a report or press release but rather through a physical product that demonstrates new possibilities.

A recent example is Sergem Engineering BV of Leidschendam, The Netherlands, which has specialized in innovative materials production technology and the design of lightweight constructions. The company has supplied technological backup to support a project with the aim of exploring a group of smart materials differentiated by their properties, structure or functions. The project has concentrated on those smart materials having capability to respond to environmental stimuli. The project ends in the exploitation of one smart material, a shape memory alloy (SMA), in the development of smart ventilation systems. The smart materials supported by Sergem Engineering span many application areas, which could be increased in number if small alterations are made in their working principles designing in line with market demands.

3.3.6. Reports and Research

Reports consist of invaluable information based on thorough research, so as a rule they are strong contributors to the appreciation of new materials in that they yield sophisticated information for designers and engineers. Reports on smart materials, therefore, appear to be the most reliable sources for the appreciation of smart materials. The 21st century will be dominated by a wide range of smart materials: “smart materials are the next frontier in engineering and manufacturing”, as stated in the report on smart materials that was published in 2000/01 by Technical Insights, a unit of the academic publishers John Wiley & Sons. The report points out, “understanding and using these advanced materials in new product development efforts may make the difference between success and failure in today's intensely competitive markets.” Therefore, smart materials have already become determinants of new market and economic dynamics that shape the current and future formation of global markets.

It is required that designers and engineers make a thorough research on the most suitable and promising material to serve their purpose. Similarly, another obligation is the establishment of updated laboratories where these materials can be developed into products, which companies can in turn supply to markets. When considered from these points of view, the economic feasibility of using smart materials has to be calculated by researchers and engineers, which is not an easy process despite the fact that there are many labs that belong to the private sector for performing such research on a global scale. However, so that they may become beneficial for use, smart materials are required to be evaluated from all of the above-mentioned points of view.

Reports on the feasibility and economic benefits offered by smart materials will become greater in number in the near future, and these issues have already started to appear in the smart materials agenda. The Technical Insights report is one such example.

> Based on Technical Insights' close monitoring of the intensive worldwide development of smart materials, and drawing on extensive interviews and research, [the report entitled] *Smart Materials: Emerging Markets for Intelligent Gels, Ceramics, Alloys, and Polymers,* brings you a comprehensive overview of the technology and its current and potential markets (Technical Insights Inc., 2000).

This source serves corporations worldwide with its printed and electronic intelligence services and reports. Executives and managers have relied on Technical Insights to identify emerging technologies and analyze their commercial impact. The report contains a list of 80 researchers and developers active in the smart materials sector. It gives opportunity to these personnel to connect with equipment, facilities, consultations, licenses, and partnership opportunities. Moreover, it also gives an overlay of profiles, names, addresses, phone numbers, e-mail addresses, as well as details for organizations that seek licensing or partnership opportunities. The Technical Insights report also highlights possible markets for smart materials.

As in the Technical Insights report, other reports on smart materials make it easy for the leading players in the field to advertise and appear in lists and permit them also to have a comprehensive outlook on tracing new opportunities for licensing, partnering, or co-developing.

Another report, prepared by the Frost & Sullivan Growth Partnership Services (2004) and entitled *Global Advances in Smart Material Technology*, highlights the significance and indispensability of nanotechnology, which backs-up the quality, performance and application areas of smart materials. The report concentrates on the recent developments in smart material technologies and presents the latest global trends on the issue. Moreover, it gives an extensive list of developments initiated and executed at universities, R&D centres at leading companies, and many research institutions in the United States, Europe, and Asia Pacific. While highlighting opportunities and limitations in the global market of smart materials, the report opens up a way for its readers to identify and reach those with whom they could collaborate, take a lead in the smart materials market and follow critical developments with updated information.

3.3.7. Consulting

The yet uncovered and unexplored domain of smart materials is under continuous attempts to be exposed to designers and engineers. These attempts have given rise to many consultancy companies, whose main mission is to provide specific research and development services but at the same time also offer general consultancy concerning smart materials. A good example is Midé Technology Corporation, an R&D company that develops, produces, and markets high performance engineered components. The company functions in such industries as aerospace, automotive and manufacturing and also produces high performance products from smart materials such as piezoelectric transducers and actuators.

Midé Technology Corporation shares its experience in engineering but it also serves as a consultant for smart materials. While it answers the specific needs of its clients with a crew of innovative researchers, it solves problems with high performance and intelligent systems by conceptualising, designing and delivering proposals to meet demands from clients. In this process of satisfying the demands, the corporation has an extensive supply of smart materials consulting covering shape memory alloys and piezoelectric materials. The smart materials consulting section of Midé covers the transfer of know-how for adapting smart material technologies to engineering needs, as well as specific material-based consultations. Within the realm of Midé's consulting services, the following smart materials are supplied with information demanded by customers:

- Shape memory alloy. Production of Nitinol-based products and designs, and manufacture of shape memory actuators. Midé has reportedly developed the fastest actuators in the market, which are designed as custom made components to meet customers' needs. During the process of production, Nitinol is treated to become a superelastic wire or sheet for energy absorption applications.

- Piezoelectric materials. Developed in the form of packaged piezoactuators to be used in the household. Whilst Midé is an expert on systems that use piezoelectric actuators in a wide variety of shapes and such sizes as wafer, stack and ring, it has also been producing piezoelectric amplifiers and provides complete system solutions.

- Magnetostrictive Materials. These materials, which change length under the impact of an electromagnetic field, also have the capability of generating electromagnetic fields when deformed by an external force. For this reason they are used for sensing and actuation. Terfenol-D with ‘giant’ magnetostriction at room temperatures is used as an actuator and vibration isolator, with the apparatus being designed by Midé.

- Electroactive Polymers. One example, polyvinilidene fluoride (PVDF), is used for making strain and vibration sensors, or when shaped, functions as a filter. They have characteristics suitable for operation in air, vacuum or water in a wide range of temperature.

Midé has assumed a leading expertise role in giving consultancy and system engineering solutions by designing, testing and supplying actuators, sensors, control systems, and power electronics utilizing smart materials.

3.3.8. Books

Books remain a popular means of communication that yield serious and often scientifically valid knowledge. Although books focusing on smart materials are currently few, it is very likely that they will become more widespread in parallel with the increased scientific research and growing number of end applications for smart materials.

One textbook, published under the title of *GCE Design and Technology: Product Design* (Halliwell and Lambert 2004, 112-120), which is intended as a course book for 16-18 year old students, combines graphics with materials technology. The context of the book embodies related patterns of “aesthetics, balance, colour, decoration, design, form, function, line, scale, shape, styling, surface pattern, texture", along with design and culture, and various design movements such as Arts and Crafts, Art Nouveau, Art Deco, Bauhaus, and Memphis. Besides serving as an artistic and functional guide to design solutions, the textbook offers information on new materials processes and technology, including smart materials as the most modern solutions in the field. Under the heading 'Unit 3: Further Study of Product Design', the usage of modern and smart materials in industry is referred to through the description of LCD displays, which have well-known widespread use in the computer and electronics industry.

Another textbook to be used as a rich sourcebook for smart materials is published under the title *A Fascinating Look at Smart Materials* (Technology Enhancement Program 2006). While the textbook accounts for the impact of smart materials on our daily lives, it also gives their application to household appliances such as colour changing kettles when the water within boils and condition-reporting garments that are displayed in MP3 players and batteries. The textbook also offers an interesting insight into the work of new designers from a wide range of disciplines from fine arts and jewellery to product design and engineering. The book is the outcome of the Technology Enhancement Program (TEP), and its publication is stated as forming a contribution to the creative exploitation of smart materials through information, support and inspiration.

As a general observation, the currently available books on smart materials concentrate more on fashionable and popular usages of smart materials, intended for a general audience and popularized for cultural consumption, rather than suited to the information, guidance and inspiration needs of product designers.

3.3.9. Research Centres

Offering many different characteristic capabilities, smart materials are most likely to become a point of major effort in the field of research. Many more research centres will become established to explore ways in which smart materials can be used to their fullest.

One of the examples of research centres established and functioning in Turkey is TEMAGEM (Technological Materials Research and Application Centre) based at Süleyman Demirel University, Isparta where work focuses on research, application and training in the field of materials. Example research topics include sensors and application technologies, high frequency technologies, surface-processing technologies, heat insulation, solar energy, composite production technology, technical ceramics production, as well as smart material application technologies.

3.3.10. Academia

It is evident that the extensive possibilities offered by smart materials can be best and most reliably computed, evaluated, assessed and synthesized at universities with a scientifically reliable, theoretical and practical (i.e laboratory-based) modelling of the ways in which smart materials can be deciphered and introduced to the market. To this end, there is a need to establish "more collaboration both between academic disciplines and between academia and industry" (Parliamentary Office of Science and Technology 2008, 3) so that smart materials can be fully exploited for utmost benefit, as of fields of application, their exploitation potential and innovation possibilities.

One example is from Purdue University, where experimentation on the application of smart materials to car tires is being pursued at the Purdue Research Foundation Office of Technology Commercialization. This research was announced via a newsletter article published on December 18, 2007. Supervised by Professor Gary Krutz and carried out by graduates and research assistants of the Electro Hydraulic Centre, the experimentation concentrates on a flat tire that has lost its tread, being replaced by a smart material so that a safer car is provided for the occupants. Also in this experimentation is the development of quality control systems based on smart materials to detect tire defects during manufacture.

Another example of smart materials researched and experimented at a university is that at the Harvard University Graduate School of Design. The university supports the application of smart materials and advanced technology to architecture, through a succession of workshops. The indulgence of the Design School in smart materials marks a dramatic shift of interest from conventional materials to smart materials. The philosophy of the school is for students to explore architectural materials not in a classical way, which may involve initially constructing a visually attractive solution, but in a new sense that demands consideration of interactive or multisensory possibilities of smart materials, drawing heavily on designers' imaginations. The school embraces smart materials as a fresh beginning in observing, analyzing and adapting physical and chemical material characteristics to surrounding environments. In other words, the school does not introduce smart materials as a new visual paradigm but instead offers smart materials as a source of encouragement for new inspirations and designs in a far wider sense.

Universities also support innovative projects dedicated to the exploitation of smart materials. For example, at Temple University (2007) a project was run by four students in the College of Engineering, who developed 'smart wings' for airplanes. The smart wing eliminates a conventional mechanical problem of heavy and noisy hydraulic driven flaps. The smart material they used is activated by electrical current and is classed as a shape memory alloy, which is activated so as to generate control and positioning of the airplane wing flaps. Their system coordinates electric current to generate heat, which in turn is used as an instigator to lead the shape memory alloy into action. The project won the Ridenour Prize for best mechanical engineering senior project; it not only eliminates hydraulic and motor systems in an aircraft wing, signifying a significant cost reduction and greater reliability owing to fewer moving parts, but also supplies improved fuel efficiency and lower maintenance costs with its lightweight design. Temple University maintains financial and systematic support of the project and its variety of applications in other fields of use, such as navigational and steering systems used throughout aircraft.

Examples of university-supported research and findings on smart materials are also to be found in Turkish universities. One example is the Department of Chemistry at Middle East Technical University, where research has been carried out on the manufacture of mobile telephone and television screens from new smart plastics and glasses (Kasap 2007). Electrochromic materials, as they are inorganic, do not have variable colours and cannot accomplish colour transformation. However, 'polymeric electrochromics' do have the capability of colour transformation. In addition, polymeric materials can be obtained for much less cost when compared with inorganic alternatives. So far, this project has tried to overcome the impediment of the colour green in displays. The research was completed in 2007 and is now at a point of development for patent protection.

CHAPTER 4

PRACTICAL APPLICATIONS AND GROWTH OF SMART MATERIALS ACROSS INDUSTRIAL SECTORS

4.1. The Significance of New Materials

Since there is a direct correlation between scientific or technological innovations and national economies, it can be put forward that any investment into technology is expected to improve life standards, thus offering economic welfare to countries. New materials are one of the components that urge new technologies or which contribute to the evolution of new technologies. Although in the past, traditional materials (such as iron, steel and coal) and their properties have contributed to technological innovations and breakthroughs, it is more likely that they will be replaced (as they already have been since the 1990s) by new materials that directly contribute to sophisticated and high-technological evolution. However, if this direct contribution is expected to employ radical changes in life and economy, the contribution must be owed to a technological breakthrough, as of high research and development-dense technologies backed up by new materials. The breakthrough will be referred to as “technological explosion”, here after (Güleç 1989).

The technological explosion in the 1980s was incomparably revolutionary against the industrial revolution of the 19th century. This was due to three basic reasons according to Güleç (1989), who explains the first point as the fact that computers are the technological breakthrough of many innovations. Güleç puts forward the second point as information technologies such as telecommunication, electronics and informatics, all of which have a total added value to wealth and welfare. Since the technological breakthrough is required for an improvement in wealth and welfare, it is inevitable that research and development technologies be developed and invested in; a fact that has led especially developed countries to spend large sums of money on such projects. Finally, as the third point, Güleç highlights the privatization of state enterprises by governments, the encouragement of entrepreneurships, the increase of cooperation activities and the initiation and development of new businesses (Güleç 1989).

When it comes to the 1990s, a technological explosion is observed to have produced a need for new materials so that technological evolution can be sustained. As new technologies are defined and grouped, new materials to be researched, developed, invested in and used have inevitably come to the foreground of needs. Such needs or demands vary according to the expectations of the actors that actively participate in industries. According to one research, Baxter (1995, 1-3), "in terms of selling products, companies must continually introduce new products to prevent their more innovative competitors eating away their market share", suggeting in five points what the actors in industry are in demand for new products to be developed:

- Customers want improved product performance and better value.
- Marketers want a competitive edge and product differentiation.
- Production engineers want simple production and easy assembly.
- Technologists want to try new materials, designs and processes.
- Accountants demand costs and margins for minimum investment.

Research and development efforts, most invested in, were according to Güleç (1989), new technologies, which were grouped under two main topics. First of such areas is that which requires high research and development-dense technologies, with a sub-topic called ‘new materials’. The second is that which requires ‘Research and Development Technologies’. These two topics are likely to pre-dominate the future with the ‘new materials’, occupying a significant place in the first group of technological innovations, (Table 4.1).

Table 4.1. Güleç’s Classification of New Technologies (1989, 29)

New technologies grouped under two headings:	
High Research and Development-dense Technologies	Research and Development Technologies
a- Information Technologies	a- Biotechnology
b- Micro-electronics	
c- Telecommunication Technologies	b- Energy Technologies
d- New Materials	

It can be concluded that research and development of new materials will be one of the determinants of future wealth, and new materials’ application areas are closely related to their economic and industrial values.

4.1.1. Smart Materials as New Materials

Before dealing with the application areas of new materials, it is essential to highlight that new materials embody ‘smart materials’, which offer a technological explosion that traditional materials can no longer provide.

As for the materials that “have been pre-processed and/or designed to offer only a limited set of responses to external stimuli”, the word ‘dumb’ is a word which suggests those materials which are optimized so as to meet the necessities and the conditions that are to be juxtaposed. Yet, these materials do not have such optimization capabilities so that they can sense their environment, process data and respond (unlike those found in natural systems). The materials and the structures in natural systems have such characteristics as ‘smart’ or ‘intelligent’, since they integrate information technology with structural engineering or actuation or locomotion (Friend 1996).

Similarly, there are many future possibilities of applications for smart or intelligent materials and structures having sensing, processing and response capabilities. To illustrate, such ‘smart’ materials offer advantages to civil engineers, who normally operate only within the limitations of the dumb materials they have access to. Civil engineering structures can be constructed by the help of smart materials, which give data processing, performance data, location of construction defects, detection of undesired potential hazards, such as extreme vibration, and they can also offer some minor aid to the structure of construction in the form of self-repair. This is best defined by ‘The Office of Science and Technology Foresight Programme’ of the United Kingdom, as follows:

> ‘Smart materials ... will have an increasing range of applications [and] the underlying sciences in this area ... must be maintained at a standard which helps achieve technological objectives', which means that smart materials and structures must solve engineering problems with hitherto unachievable efficiency, and provide an opportunity for new wealth-creating products (Friend 1996).

As to be derived from this statement, the application areas of smart materials are wide enough to solve engineering problems that cannot be solved by dumb materials. According to Fulton (1992) new (smart) materials have an endless variety of unknown potentials that can be explored by designers, who have to get away with the limitations of conventional materials and open up their minds for the new field of opportunities offered by smart materials. Smart materials, therefore, are estimated to be more efficient in solving future problems, offering more future opportunities and similarly contributing more to wealth and welfare.

The capabilities of smart materials vary from sensing an environment to becoming adapted to an environment. As they have “sensual” (Friend 1996) capabilities that are most beneficial to engineers, and as they can adapt to changing engineering challenges, they will be more on demand in the future. Moreover, as they “can move, vibrate and yield many other real-time responses”, they will become integrated parts of future constructions. The advantages of smart materials open up a wide range of areas of usage, from aircraft wings to satellites and even to trains. As for aircraft wings, adaptive smart materials are to be exploited for the regulation of aero-elastic forms of wings. From vibration control to applications in vehicles and households, they offer many application possibilities. As they develop further on, smart materials will be eventually used as “touch-sensitive domestic utensils, appliances and utilities”. Such domestic applications have now gained an incredible momentum in research and development. However, their importance for the future world and their contribution to the future wealth and welfare are required to be grasped by the global community and public, not just by professionals involved in new product development. To that end, smart materials are to be notified to people as the domineering materials of their future (Friend 1996).

4.2. Industry Sectors Pioneering the Use of Smart Materials

Smart materials which are intelligent materials have been used in many sectors that rely on futuristic expectations in the form of innovations to solve problems. From the U.S Navy to coffee makers, from seat and chair makers to experimenters, smart materials have been in demand for more practical and functional solutions by a variety of sectors. With their tolerances to change in temperature, capability to remember, functioning as absorbents and yielding many other capabilities to solve and overcome problems, smart materials are extensively getting used in sectors which then become agents that promote a widespread usage of such materials:

> They [smart materials] are developed for a highly specific application, perhaps for use in aerospace industry. Later they are discovered and used as gimmicks by manufacturers or designers operating in a totally different field. The final step is further development, which often leads to new applications of a functional nature (Van Onna 2003, intro).

Table 4.2. Industry Sectors Making Use of Smart Materials

Which industry sectors are important to spreading the uptake of smart materials?
4.2.1. Defence
4.2.2. Aerospace
4.2.3. Architecture
4.2.4. Art
4.2.5. Textile
4.2.6. Mechatronics
4.2.7. Recycling
4.2.8. Health
4.2.9. Industrial Design

4.2.1 Defence

The defence industry has always been one of the leading industries receiving large sums of money, due to security reasons of nations. Since it is directly related with national security, the industry calls for sometimes highly imaginative and exotic solutions and sometimes for logical and practical ones. Almost always a leading factor in determining the frontiers of recent technology, the defence industry demands innovative attempts in product manufacture. Smart materials are likely to become one of the indispensable aspects of the defence industry, in that their usages are almost limitless. From their capability in being manipulated to a different shape from their original, with their endless functionality and use in various challenging environments, products made out of smart materials have reached a point of high demand. The capability to change and recover their original state is one of the aspects of SMPs that could immensely contribute to the performance of aircrafts. As the first example, a morphing aircraft structure programme has been initiated by the Defence Advanced Research Projects Agency (DARPA). Two tests have been made by the Agency in line with the programme (Gale 2005).

Table 4.3. Smart Materials in the Defence Industry

Product Examples of Defence Industry			
Name of project	Who?	Smart material	For what purpose?
Morphing Aircraft Structures programme	Defence Advanced Research Projects Agency (DARPA), the main R&D group for the US Department of Defence	SMP	Their capability in change and recovery of the original state is one of the aspects of SMPs that could immensely contribute to the performance of aircrafts. Change shape in flight
Investigation of the Rheological Characteristics of Shear Thickening Fluids for Potential Applications in Body Armour	Ngothai et al 2008	STF (Kevlar implemented with STF)	Vehicle suspension and body armour

Another application of smart materials in the defence industry has been observed in the practical uses that shear thickening fluids (STFs) have offered. The potential behaviour of such fluids is now being applied to research dedicated to the development of vehicle suspension and body armour. As body armour is a defence shield that is designed to protect the high risk regions of the body such as the head and the chest, where a blow could be fatal, STFs are now offering new applications to this end. For instance, when Kevlar is implemented with STF, it is found out that the new liquid becomes lighter and gives a good level of protection (Ngothai et al 2008).

4.2.2. Aerospace

According to Aydıncak (2003), from the Department of Aerospace Engineering at Middle East Technical University, Ankara, it is anticipated that as soon as smart materials are used sensibly and to the point, many aerospace problems will be solved.

For instance, control panels that extend to the wings of an airplane on which SMAs are used in place of hinges are now being developed. This advantage offered by SMAs can be used to overcome limitations of conventional airplane wing designs. Wings designed to function at high speeds fail to function at low speeds, and vice versa. By integrating SMAs to airplane wings, geometrically changing wings can be contemplated as part of the aeroplane design process. However, for the time being, radical or extreme changes in dimension have not been obtained from SMAs. For this reason, the amount of smart material application on wings is yet insufficient to suspend the plane in the air, when the speed of the plane decreases. However, as Aydıncak foresees, the next step for aerospace designers is to make extensive use of smart materials in the wing structure to minimize aerodynamic losses and to maximize speed-wing concordance (Aydıncak 2003).

Table 4.4. Smart Materials in the Aerospace Industry

Product Examples of Aerospace Industry			
Name of project	Who?	Which smart material?	For what purpose?
Control Panels as Extending to the Wings of an Airplane	Not yet solved	SMA	To overcome the limitations of airplane wing design To minimize aerodynamic losses and to maximize speed-wing concordance
Design of a Smart Material Actuator for Rotor Control	Study to conceptually define by Staub and Merkley	Magneto-strictive material	Cyclic and active control, leads to a reduced manoeuvre envelope due to weight and volume constraints.
USAF Shape-changing Technology	Lockheed Company	Shape changing smart materials	For military aircrafts as the next generation which would be integrated into the U.S. air force USAF's part to create a more effective air fighter planes that could perform a variety of missions
	NASA	Piezoelectric Shape memory alloys	Developing bending and stretching capabilities in wings and hingless apparatuses Change shape with thermoelectric input have been worked on
Phase I Darpa Programme	Midé Company	SMA	Helicopter wings rotor vibration, sound and loss of efficiency

Like airplane wings, helicopter propeller blades are confronted with a similar limitation. For helicopters, it is not possible to eliminate such problems as rotor vibration, sound and loss of efficiency. Through the use of smart materials, the actuator produced for the 'Phase I Darpa Programme' by the Midé Company has been successfully applied to overcome such problems. Another research project is targeted at minimizing the sound level. Aydıncak (2003) foresees that in 20-30 years, smart material application in planes and helicopters will be quite usual.

There has also been a conceptual study dedicated to the definition of on-blade smart material actuators. For an extensive usage of actuators, their design drivers, goals, and requirements are defined (Staub and Merkley 1997). The design of the cyclic and active (high speed) control actuator and feasibility of the collective (low speed) actuator and stroke multiplier are investigated for a previously developed hybrid actuator concept. Upon such investigation, it is found out that:

> Sizing of actuator components based on AH-64 servo flap requirements shows that collective control using shape memory alloys is well within the capability of the material. Cyclic and active control using magnetostrictive material, leads to a reduced manoeuvre envelope due to weight and volume constraints. The promise of smart materials can be realized incrementally as the materials and actuator design approaches mature. Future improvements in smart material performance and actuator technology, and additional rotor system design changes to reduce load and motion requirements should provide the full AH-64 manoeuvre envelope. (Staub and Merkley 1997)

Therefore, smart material actuators, control using shape memory alloys, and cyclic and active control using magnetostrictive material, can be exploited in future actuator designs: for example, optimised actuator technology can be a perfect solution for the reduction of sound, load reduction and to meet motion requirements of helicopters.

Such potential developments in helicopters and aeroplanes are not too far-fetched, as there are other examples that are in line with such ideas. For instance, experiments have been carried out by Lockheed Company on shape changing technology (Norris 2003). The technology is to be developed to meet the needs for military aircrafts, as the next generation would be integrated into the U.S. air force. The main purpose of running a programme supported by shape changing smart materials technology is on the USAF's part to create more effective air fighter planes that could perform a variety of missions. The programme is dedicated to developing air vehicles having the capability of changing their geometrical forms according to required conditions and specifications. The programme has various components associated with the capabilities of shape changing smart materials. For instance, virtual control surfaces are within the concepts associated with their capability to disappear in air fighters when they are not engaged in combat situations. Another concept is developing fuselages that alter the amount of fuel that is being consumed by means of smart materials that have the capability to constrict. Moreover, continuous control surfaces and airplane inlets that adapt to different flight speeds are such concepts that stretch our imaginations but which open up new horizons in smart material exploitation (Norris 2003).

Currently, there is an attempt to develop model wing designs that could be optimized for providing combinations of best shape shifting with regard to wing area, aspect ratio, sweep, twist and dihedral. Therefore, continuous efforts are put into development and demonstration of technologies to support the aerospace industry, and research is carried out on "seamless, aerodynamically efficient aerial vehicle capable of radical shape change" (Norris 2003). Furthermore, known as morphing technologies, elastomeric matrix materials that have the capability to slide within the matrix to obtain high deformation output, or CMT structures that yield continuous mould line technology, are being researched for their capability to stretch and shrink as well as bend and twist to about thirty percent values.

Among NASA's efforts on smart materials use in the aerospace industry are some recent applications of "resin transfer mouldings, piezoelectric (which contract and expand on application of electric current) and shape memory alloys" that change shape with thermoelectric input (Norris 2003, 1).

On the other hand, DARPA and NASA have collaborated in joint venture research on morphing studies to achieve superior mach-resistant wing designs with a high rate of change in aspect ratio, wing area, and wing twist and sweep angle (Norris 2003).

4.2.3. Architecture

Professionals within architecture have been experimenting with alternative concrete allowing degrees of light transmission. Being the evolved version of conventional concrete, light-transmitting concrete is developed with the addition of glass fibre into the aggregate, offering durability and ease of utility properties at least as good as conventional concrete. Moreover, if the aggregate is enriched with graphite or steel fibres, it is possible to obtain concrete that can be detected by radar because it becomes a heated form of concrete with the application of electricity or if ferrite is applied to the concrete, radio waves are refracted (Yapıdergisi 2007).

Carbon nano particles are used in the coating industry due to the fact that they are very smooth and they are dirt proof. This capability is because of the strength of the nano particles, so much so that they resist scratch by any outside forces. Architecture is also much related to heat insulation, for which end PCC (protective ceramic coating) is to be used extensively in the future for heat insulation. Thanks to NASA's aerospace technologies development research, PCC, which has been used as a heat shield of a very thin layer developed so as to protect space shuttles from extreme friction as they enter the earth atmosphere, this material can be applied as a perfect fireproof coating to ceramics, plywood, steel, plastic or cotton wool, (Kushnir 2001 cited in Orhon 2007). PZT paints introduce the capability of transmitting electric current only if force is applied on to them. They yield electric tension to the environment in line with an increase of pressure and contraction tensions of the materials on to which they are applied. By monitoring the tension, the structural behaviour can be observed. This paint was used with this very same purpose on Gateshead Millennium Bridge in 2000. The paint industry has been producing for some time self-cleaning paints, which are light sensitive, or paints that can change colour, again when exposed to light. In the future, owing to smart super coatings that are to be developed, ordinary contraction materials will attain significant qualities, too. For future buildings, such materials that will provide self-cleaning materials, which do not require maintenance, facades that cannot be scratched, or security against fire hazards will become ordinary characteristics (Orhon 2007).

Table 4.5. Smart Materials in Architecture

Product Examples of Architecture	
Which smart material?	For what purpose?
Glass fibre into the aggregate	Light Transmission
Graphite or steel fibres into aggregate	Detection
Carbon nano particles	Smooth, dirt proof
Protective ceramic coating	Heat insulation
PZT paints	Structural behaviour can be observed
Light sensitive paints	Self-cleaning
Shape memory alloys	Sprinkler systems for fire inspection. Sun breakers on the facades sun control by situating them to the most convenient position by themselves in accordance with the condition of the sun and the heat that it emits. Earthquake detection.
Fibre-optic sensors	Fault inspection purposes in multi-storey, bigger buildings Monitoring any engineered structure for inspection of changes in the long term behaviour

Like varnish, there is also thermo chromic ink, which when mixed with concrete and heated by nickel chromium wires, changes colour according to the critical temperature reached. Not only heat or weight sensitive, but also sensitive to the light, thermo chromic ink is a technology that requires further experimentation. A major problem with the ink itself is that it is not very visible if used with printing systems but it can be activated more to become brighter in colour intensity under a powerful light source (Orhon 2007).

The safety of materials used in architecture will be solved by smart material technology. In multi-storey big buildings, a faulty part can be identified by fibre-optic sensors. The working principle is that the fibre optics transfer light without breaking it. If there is a faulty part (corroded or cracked), the light is refracted and the malfunctioning part, if any, can be detected. Moreover, porous glass fibre or polypropylene mixture additive material fills the cracks and the structure heals itself (Orhon 2007).

Shape memory alloys are both used in mechanical applications in engines and in sprinkler systems for fire inspection. Also, sun breakers on the facades of buildings can be made by such alloys. These elements will perform the duty of sun control by situating themselves to the most convenient position unaided in accordance with the condition of the sun and the heat that it emits. With their aforesaid capabilities, they may be used for earthquake detection or as heat control systems. As they are produced by expensive metals for the time being, they are not *currently* used in building applications. This economic barrier may be overcome in the near future when alloyed metals such as titanium get cheaper or when new shape memory alloys are invented and grow in number (Orhon 2007).

Durability is another advantage to be obtained in the use of smart materials. They can be used for monitoring any engineered structure for inspection of changes, such as those in a bridge, in the long term behaviour. If behavioural difference is monitored, the smart material is expected to provide some precautionary warning concerning structural decomposition. The comparison between the original design and the current condition will yield data concerning some minor interventions with the structure of the bridge whilst also detecting radical and unaffordable repairs. On the one hand, smart materials contribute to the safety of civil engineered structures. They can be offered to the construction sector as repairing materials, thus extending the lifespan of the structure and minimizing the cost of maintenance. On the other hand, smart materials and structures that possess a sensing function are applicable also to domestic use, such as for monitoring safe storage and cooking in food packaging (Friend 1996).

Smart materials have been finding applications in the field of construction and they are helpful in offering industrial design solutions. Especially among smart materials which yield titanium-dioxide are those which have the capability to interact with organic or inorganic air pollutants. As they can be integrated in ecological paints, these materials can be used in direct contact with the air environment, and they contribute to the decreasing of the level of the nitrogen-oxide in the environment, reducing it by sixty percent (Yapıdergisi 2004).

Therefore, smart materials have been in the field of architecture in parallel with their newness as of “new materials and new uses for existing materials, exploited by such leading companies ... [with their] more effective, more efficient and more environmentally sensitive” properties (Bell and Rand 2006, 10).

4.2.4. Art

Smart materials, although associated with almost always the economic benefits they may introduce into industries, can also be used extensively as art materials. For instance, shape memory alloys, as they can change form in response to temperature, can be used in sculpture. Shape memory alloy could be transformed into an art form as an interactive sculpture, and will claim new shapes throughout the day and night in response to the changing outside temperatures. Of course, smart materials will have a future as new sources of inspiration for artistic creation, as in the example of Japanese artist Kiyoyuki Kikutake who exhibits his ‘Earth’ at Tokyo Modern Arts Museum. This example of fine art is not made from a smart a material but from stainless steel, on which thermo chromic paint is applied, so that the entire structure changes its colour from yellow to red during changes in temperature. The same structure then reclaims its original colour and appears quite different from its earlier state in the morning or later in the afternoon (Yapıdergisi 2007).

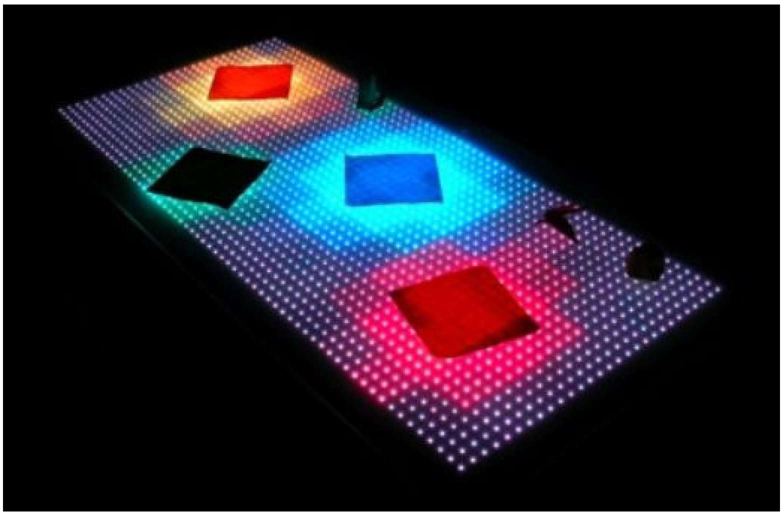

Figure 4.1 RGBy desk (http://mi-lab.org/files/2007/11/mail.jpg)

Like Kikutake’s Earth, another Japanese artist and computer scientist, Dr. Ichi Kanaya, blends the capabilities of smart materials with artistic practices in ‘The RGBy desk’ (figure 4.1.) with collaborating designers Makoto Hirahara and Shinya Matsuyama of Japan’s Studio Mongoose. When some coloured paper is put on the surface of the so-called “future furniture”, the tabletop made of LED senses the color of them. It changes its own colors to match the colors put on it by the help of photo sensors and multicolored LEDs (Media Interaction Lab 2007 and Technabob 2007).

Figure 4.2. Touch Me Wallpaper
(http://www.designboom.com/contemporary/wallpaper2.html)

Another project is developed by Zane Berzina whose artwork, ‘TouchMe Wallpaper’ (2005) (figure 4.2), is exhibited at the Victoria and Albert Museum, London. The project is dedicated to the production of illumination of furniture when the thermo chromic ink on it responds to the body heat of the user by changing colour. Heat-responsive ink enables the painted surface to yield patterns of human hands that have just touched the painted surface. As the body temperature is transferred onto the paint and absorbed by it, the colour in the contacted area changes until the heat transferred cools, when the paint reverts to its original colour.

Figure 4.3. Mute Room (Blownell 2006)

A final example is ‘Mute Room’ (figure 4.3), in which polyester foam suitable for products including mattresses, chairs or any type of seating, functions as memory foam and temporarily takes the shape of anything that applies some weight onto it. The foam has the capability to retain its original shape sometime after the load is removed. The material can be used for ergonomic needs and for structures that interact with the human body. Moreover, it may be made use of by artists and designers to create any environment with a playful wall or ceiling (Blownell 2006).

4.2.5. Textile

The future of the textile industry is likely to be shaped by new innovations that have their bases on smart materials. Smart materials can be projected into a wider scope of application in the production of textile products because smart materials offer additional properties that would enrich the usage and outlook of textile products. Among such additional properties are electric transmitting yarn made of smart materials, and energy-producing materials implemented in textile products, both of which will promote and encourage more innovations.

Efforts in experimenting with smart materials in the textile industry have been sustained. One such effort is a project under the title of Reflex 2010, whose aim is "product development with smart materials" (Centexbel TIS-Reflex 2010). The project makes use of, or at least is designed to exploit, new technologies offered by smart materials that are to be integrated in textile production processes. Another purpose of introducing smart materials into the production of textile products is to promote competitiveness in innovation through the extensive use of technology. The suppliers of smart material technology are required to work in collaboration with textile producers. To this end, information sharing, technology exchange and the ways in which the textile industry can make use of smart materials in future productions are needed to be established. This is why information flow between technology suppliers and producers of textile products is so important. Also, the need for such communication has to be developed in line with a thorough study and research dedicated to the future needs of the textile industry. Provided that the future needs are projected and decided upon, technology suppliers will find their tasks of offering the most adequate smart material technology to textile producers. Reflex 2010 not only investigates the ways in which products can be developed by the help of smart materials, but also establishes a common and firm ground where textile producers and suppliers of smart technologies can meet. Especially dedicated to the collaboration between textiles related companies and technology suppliers, the project establishes roadmaps as guidelines for further collaboration among actors.

The Reflex 2010 Project combines markets, consumers, technologies and suppliers as well as producers within its system of assessment. By this way it aims to further its scope of interest by being relevant to even the most local pockets of textile industry and to companies offering specific ICT (Information and Communication Technologies) solutions. These solutions are known to be developed by more updated information exchange. The project, therefore, is basically dedicated to opening up information exchange channels, which are believed to support and promote the textile industry among many other areas of global production by use of smart materials.

To illustrate how smart materials can be used in textile products, a new material that has been developed by Georgia University researchers is worth highlighting. The material converts movements into electrical energy. This transformative capability is then used in producing textile yarn having the capability to conduct electricity. Prof. Zhong Lin Wang, the head of the research team states:

> These are yarns that are like those used in textile but they are conductors. We coil zinc oxide nanowires on the yarns, which in fact resemble the brushes with which we clean bottles. We take two yarns and we coat their one side and we leave their other side uncoated. As we place them onto each other and pull and push them to and fro, the nanowires above begin to wind those under, which produce electrical current. (Translated from Berkan 2008)

To the optimism of Professor Wang, Prof. George Stylios states that the solution offered by Georgia University researchers is not so easy in its application, in that, he says the pace of movement has to be made faster, and a larger number of fibres must be used so that a change in colour or in the structure of the cloth can be obtained. He proves his point of view by suggesting that one square meter of such cloth weaved out of such yarn produces only eighty milliwatts of energy. For this reason it is not, for the time being, applicable to textile production, but it may be used in such technological appliances as iPods or mobile phones in place of batteries. Such yarn offers intoxic, clean energy and it will eliminate dischargeable conventional batteries, which are a great threat to environmental safety. Since the yarn makes use of the conversion of kinetic energy into electric energy, it is also applicable to the transformation of wind energy into electrical energy. But the application of this is not yet found to be likely to be applicable in textile production.

On the other hand, one of the most successful applications of smart materials in textile production is an example by the DuPont Company. The example is a new fabric called 'chameleon' (figure 4.4), which is a cloth developed in EIC (an innovator in developing new materials and processes for defence, energy, health and consumer applications) Laboratories, to enable "electro-chromic camouflage" (Tang 2003). The intention is to blend the wearer of the cloth with their environment so that he or she may be invisible as if a chameleon, changing colour according to the dominant colours in the environment.

Figure 4.4. Chameleon Clothing
(http://www.ananova.com/news/story/sm_747591.html?menu=news)

Another successful application of smart materials into textile production is in the field of electronic textiles or ‘Electric Plaid’ (figure 4.5) colour-changing textile. An example of such a textile is exhibited in the Cooper Hewitt National Design Museum, which reveals a fabric of soft woven textile that can change colour, although not dyed by electronic ink (Tang 2003).

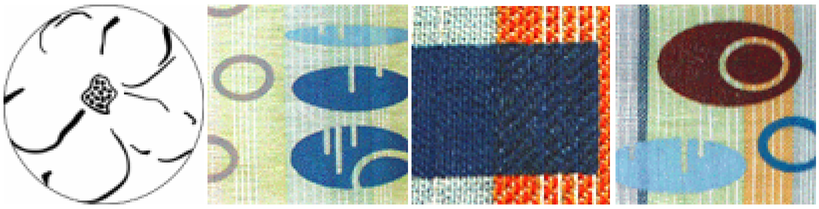

Figure 4.5. Electric Plaid (http://www. ifmachines.com/eplaid.html)

A third successful example is a design by designer Mi-Jeong Baek for Yanko Design (2007). The design is for early infant usage and is entitled as ‘The Daddy & Baby Clothing Set’. The fabric is body heat sensitive. When body heat is transferred to the fabric, thermo chromic patterns begin to appear, thus revealing the intensity of love and care that one shows to the baby.

Another example is by Maggie Orth, who combined cotton, rayon, conductive yarns, thermo chromic ink, electronic components, drive electronics, and software to design what she has called ‘Dynamic Double Weave 2003’ (figure 4.6). This is a hand woven colour changing fabric dyed in thermo chromic ink and which is electronically controllable (Fiberscene 2006).

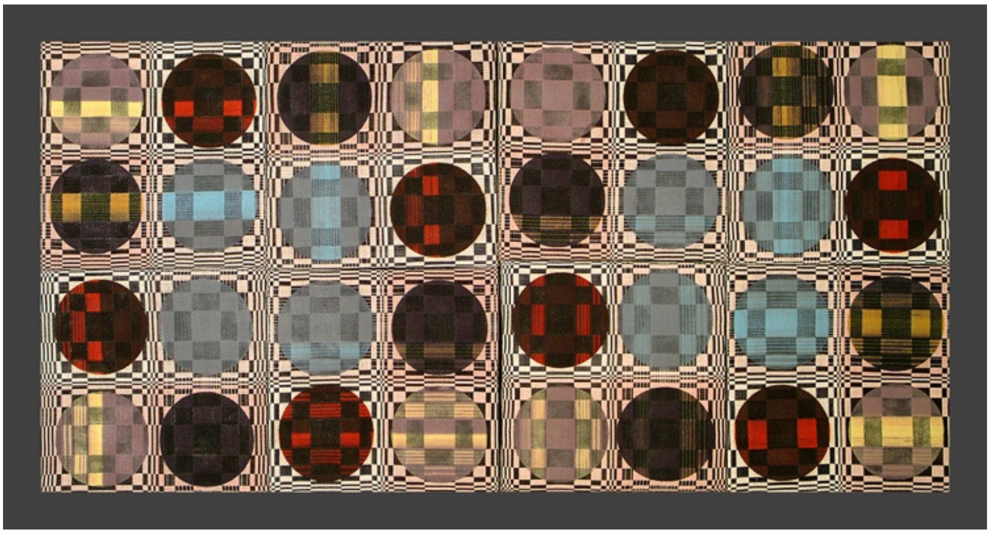

Figure 4.6. Dynamic Double Weave 2003
http://www.fiberscene.com/galleries/gallery33.html

4.2.6. Mechatronics

Smart materials are also applicable to the field of mechatronics or mechatronic systems, in the form of structures capable of sensing, containing optical fibre sensors, piezoceramics, electrostrictive, magnetostrictive and shape memory actuators. Since their application to mechatronics is varied, smart materials can be used as a hybrid mixture of mechanical and electronic systems. Smart materials with their variable atomic or molecular levels are already in use in mechatronics within the automotive and construction industries. Examples in the former include ABS (anti-lock braking system) in cars and active ride control systems in road vehicles, and in the latter as vibration control systems of tall buildings in Japan. As mechatronics is the combination of mechanical engineering, electrical engineering and computer engineering, it traditionally requires a heavy load of integrated systems. Smart materials can offer some advantages. Smart sensors and actuators can be integral to the material in the form of fibres that monitor the amount of load in a structure or the damage that it undergoes under a certain period of time. Therefore smart materials can be and are used for vibration and shape monitoring in such structures as bridges, dams, aircrafts and similar adaptive structures where piezoceramic, electrostrictive, magnetostrictive and shape memory actuators are embedded.

In the newsletter, Purdue University (2007), Professor Gary Krutz's efforts on how research is dedicated to the production of technology embedded in the form of a smart material in the entire structure of the tire, 'smart tire', (figures 4.7.a. and 4.7.b) serving as a sensor that sends information to a computer. This effort in integrating a smart material sensor into tire production could be developed for tire safety or for detecting tire damages before they become hazardous. Tests are conducted on prototypes so as to develop systems of rapid detection of damages in tires, which are also detected under harsh testing conditions. Among such laboratory-originated tests are possible external damages, difficult to detect or prevent, including failures due to gap damages within treads, which can be missed despite the efforts of good maintenance and detailed inspection. The research also develops a sensing system that detects any changes in the rubber. Smart materials are designed to convey early alerts and they operate as a warning system that could be used for saving time, money and energy in the replacement or exchanging of tires. Serving as sensors, smart materials can also detect failures in air pressure or lack of balance among tires, which also negatively contribute to the lifespan of tires and safety. Leading the research and experimentation, the supervisor Professor Gary Krutz says,

> … there are external injuries that can occur in tires that are not always propagated or affected by improper inflation, such as a road hazard like a rock or loose concrete, that can do damage to a tire without actually causing it to go flat. This sensor technology searches for these types of problems as well (Purdue University Newsletter 2007).

Professor Krutz highlights smart materials and their sensory capability as a new technology to promote tire safety, but he also implies that the technology developed can be used in a much broader range of areas in which tires function for all purposes and under every load, such as passenger cars, trucks, construction equipment, lawn and garden equipment, mining vehicles, and airplanes. Moreover, tests on this recent tire technology were held on more than 100 different products in every item that could be thought to be an applicable product for smart materials. The wide range of applications identified includes isolators, seals, orthopaedic devices, and aeroplane wing composites.

Figure 4.7.a. Smart Tire (http://jalopnik.com/335927/reinventing-the-wheel-invention-flat+detecting-smart-tires)

Figure 4.7.b. Smart Tire (http://www.engadget.com/bloggers/evan-blass/page/6/)

4.2.7 Recycling

Smart materials can also be used to assist the disassembly of manufactured products after their lifespan is over. However, in this respect, it is required first to develop the application areas of smart materials, so that they can be used as parts during the assembly of products.

Efforts have been invested in the disassembly of manufactured products but there still exist some basic design changes in the production of products. A project dedicated to an easy and active disassembly using smart materials has already been completed (Cordis 2000). The project highlighted a range of smart materials that could aid product disassembly; for instance, adhesives that lose their adhesion and low melting point alloys. Out of the research the project has directed, four types of disassembly plants were proposed to assist in disassembly, based on activation by hot air, hot water, microwaves and induction, out of which hot air was found to be the only common instigator that helps disassembly of products yielding smart materials. Tests have been carried out for the disassembly of plastics, printed wiring boards and plates but the results have been frustrating. To overcome the frustration, disassembly experimentation has been carried out using microwave radiation and induction, but still it has been found out that selective heating interferes with absorption of radiation, which is another frustration. Therefore, the project has concluded that unless radical design changes are made during production, the disassembly process is liable to failure.

On the other hand, active disassembly of products made out of smart material components is an environmentally friendly solution because they provide many easily recycled fractions. In parallel with this, plastic recycling is found to be economically feasible by use of active disassembly, especially in the recovery of large plastic pieces that are easily identified and sorted. Moreover, since the use of smart materials in production allows less cross contamination, it leads to purer material fractions. The project, named ‘Active Disassembly using Smart Materials’, has offered “pre-partitioning” as in plastic or aluminium “into various material streams” (Cordis 2000). By this method, secondary aluminium, which is the recycled form of primary aluminium, is found to yield the original properties of aluminium but is preferred for use in die casting specifically.

4.2.8. Health

A smart material developed by Zhermack Inc., under the trademark ‘Colorise VPS Impression Material’ (figure 4.8) has been introduced for dentistry. The material is basically a thermo chromic material having the capability of yielding visually perceptive indication of elapsed time through a change of colour by the environmental temperature. The material is vinyl polysiloxane (VPS), which employs colour change as a function of time. The dentist’s task is easy, in that he observes only the change in colour and he does not need to follow any clock or time sequence other than what the material indicates, in a scala of colours that transform from green to yellow.

Figure 4.8. Colorise VPS Impression Material
(www.ozdent.com.au/Portals/25/chromative2.jpg)

The material is used in the making of dental plastic impression trays. The change in colour yields reliably applicable solutions in ‘oral fluids’ as well. The Managing Director of the company, Barbara Maragni (quoted in Zhermack 2007), states:

> Dental professionals really appreciate the visual status indication of Colorise VPS Impression Material, because it keeps their minds ‘off the clock’ and instead clearly focused on the task at hand.

The material is produced in nine different viscosities to yield a variety of colour spectrums, each defined for different temperatures.

Figure 4.9. Moderating temperature (http://www.packagedesignmag.com/issues/2005.04/feat-cold-chain.shtml)

Smart materials grouped under phase-change materials (PCMs) offer industrial solutions to stabilise an interior temperature as they have the capability to absorb extreme temperatures. Such materials are not only used in combination with “polystyrene, urethane, advanced plastic foams, captured-air-in-bags, vacuum panels, and even refrigerated freight containers” (Cook 2005), but also as package indicators for products that require stable temperatures for preservation. In one example, a label on a product indicates temperature difference varying between -30° C to 40° C. Between these two temperatures, the smart material functions as a temperature regulator. PCMs play a vital role especially in the medicine industry as they yield indicators of hazardous exposition to intolerable extremities of temperature changes in medicines. Especially thermo chromic inks (figure 4.9) offer such solutions and they have already become popular as ‘electronic temperature data loggers’ for fifteen years now. Data loggers work in connection with any computer to transmit data of temperature change to any monitoring centre around the world.

Another example applied to medicines (as well as food products) enable an automatic monitoring of the amount of time that has passed since the date of production. The indication system can be activated with the opening of the package (Beylerian et al. 2007, 229).

Touch sensitive textile products are being produced by Eleksen Company to be used in health. The product they have produced ‘smart shirts’ to be used in checking patients’ health. The shirt is capable of reporting signs about the health of the patient as real time (Beylerian et al. 2007, 31).

Another example of smart materials applied in textile is based on biomimicry which is that branch of smart materials that imitate nature. Stomatex, which is a brand name has created a textile that imitated “transpiration of plant leaves ... that allow body heat and perspiration to exit through tiny pores” (Beylerian et al. 2007, 73). Under the same brand name clothing for athletics and health care that adapt to temperature changes are being produced.

4.2.9. Industrial Design

Owain Pedgley (2009) in his article, *Influence of Stakeholders on Industrial Design Materials and Manufacturing Selection*, researches into industrial designers’ selection of product materials and manufacturing processes, an activity that has significant impact from project stakeholders. These stakeholders, namely users, clients, manufacturers/vendors and designers/design team members are investigated to find out in which ways they may affect or influence the flow of selection activities. The researcher has found out that, with the exception of clients, the flow of activity begins with the designer and extends to the stakeholder, whilst the opposite is found not to be valid. He identifies industrial design as a blend of designer-maker and design engineer perspectives. A similar finding is by Fulton (1992, 73/74), who states “designers themselves must undertake their own fundamental research. This means employing methods from both science and art to predict human needs and prepare to meet them.” Fulton continues by discussing the position of potential users and their perceptions in the process of design. He comments on the fact that not only the designer’s or the clients’ intentions, but also the target users’ ways of thinking, have to be considered for the design and selection of materials.

Pedgley determines that materials and manufacturing processes lie at the heart of industrial design. By making use of both, industrial designers generate design ideas that take into consideration the influences of stakeholders, out of which conceptual phases of product design are programmed towards more detailed objectives in realizing the manufactured product. The difference between industrial designers and engineers is that the latter are less influenced by users’ influences, as these are typically less relevant to solving engineering problems. Since a starting point of industrial design is an assessment of stakeholder influences, users’ needs for product utility and aesthetics attributable to materials are an important part of the process. As Pedgley states, each industrial designer is expected to give priority to “generating visions, concepts and proposals that fulfil peoples’ needs and aspirations for new products” (2009, 2). Smart materials can conceivably contribute to the generation of visions, concepts and proposals, by offering new and more practical or attractive solutions for products. Pedgley continues by underlining the fact that industrial designers should be concerned with an effort or endeavour to “make new products especially attractive to people through a combination of fitness for purpose and appeal to the senses” (2009, 2). It is to be understood that new products, offering new syntheses between ‘form and function’ are required. However, since form and function are to be synthesised by an industrial designer, whose primary motivation is understanding and responding to users and less on engineering accomplishment, a shortfall can exist regarding necessary feedback or information on new materials. At this point, industrial designers may find it most practical to confer with vendors who are a more reliable "source of new material developments and material samples" (2009, 9). In this way, industrial designers may combine newly emerging user needs with newly emerging materials, to design products with new forms and functionality. On this point, Pedgley contends that there is a need for industrial designers to appreciate work practices of both design engineers and designer-makers. Design engineers make their decisions on the utility and form of a new product by first selecting optimum materials to meet performance criteria, and then screening these materials against ease of manufacture, cost or other criteria. Designer-makers, on the other hand, are more concerned with "sensorial-based" selection (2009, 10), considering those materials that could enable them to produce distinctive finishes and decorations for direct appeal to purchasers. When these contrasting approaches are considered, there is an inevitable necessity to establish channels of information exchange so that all three professions could cooperate. Now that smart materials offer a relatively new field of design possibilities, they will automatically bring together industrial designers, designer makers, design engineers, engineers and eventually stakeholders whose demand and motivation lead to the improvement of new materials, manufacturing information sources and user-centred efforts in the production of new products out of new materials.

One example of integrating users into the design and production process has been led by Philips in The Netherlands. Philips has initiated research termed 'experience research', which is a way of finding out how people experience technology. Since experience is the starting point, every innovation effort is built up onto normal activities and interaction of consumers with new technologies. In other words, Philips observes people in the actual, real life interactive environment to detect natural responses of consumers to newer technologies. In this way, innovations are driven by demands of people about relevant, meaningful and simple technologies that could both motivate them and answer their actual needs. Since 'simplicity' is a key corporate word for Philips, work in its Experience Lab and Simplicity Lab are being guided by user needs research and its connections to product innovations that exploit smart materials. Therefore, it can be projected that smart materials are to be relied more in the future to meet such ends as simplicity, meaningfulness and relevancy to the experiences of consumers, first tested in a virtual medium, and then applied to real life situations.

Consumers or users can receive simple, direct and relevant signals from smart material applications. A striking example to such an application which yields signals of road conditions as of temperature to drivers who respond to the innovation naturally. A special kind of varnish made of a polymer with a thermo chromic pigment can be applied on pavements and roads. For instance the varnish may indicate an icy situation on roads and can warn drivers for slippery road conditions and alert authorities to treat the roads. The system is applicable to sidewalks and driveways where cold temperatures affect safety during winter. The varnish has not yet been tested during the summer time when ultraviolet radiation will be increased, affecting the colour potential or colour changing ability of the varnish. What is required from its application is that it should not lose the ability under heavy traffic load or extreme heat.

The same characteristics of the varnish can also be applied to pool thermometers and frozen vegetable packages as an indicator of difference in temperature. Being sensitive to temperature changes, thermo chromic pigment responds to one degree Celsius by turning bright pink. But if the temperature rises to above 2 degrees Celsius, the bright pink colour vanishes. This capability is applicable to a wide range of products and services where there is a temperature change within the specified range.

4.2.9.1. Examples of Smart Materials Use in Industrial Design

Garden Chapel: Chapel with photocatalytic, self-cleaning membrane skin

An application of smart materials for construction and used by industrial designers is Garden Chapel (figure 4.10) for the Hyatt Regency Hotel in Osaka, Japan, constructed with photocatalytic, self-cleaning membrane skin. The Chapel was produced by the Obayashi Corporation. The construction is covered by a monosmart material, which has the capability to adhere to concrete surfaces, thus transforming them into a self-cleaning surface. Specifically, the material is titanium oxide, which forms a white membrane that has the capability to interact with rain to wash away dirt. This is a good advantage for industrial designers to specify for large surfaces that need regular cleaning or painting. As the surface coating eliminates the need for painting, it can reduce costs in the longer term (Ritter 2007).

Figure 4.10. Garden Chapel (Ritter 2007)

View directional films

The application of smart material technology to the film industry opens-up new possibilities of application for indutrial designers. Known as a ‘control film’ or ‘privacy film’, a polimeric material can be extensively used in many fields of application such as camera film or street and computer displays. The film offers the possibility for the viewer to see through it. Since the film is a composition of shaped grooves or ‘micro louvers’, the viewer can see through it only in a certain direction and not in others (figure 4.11 view directional film). The direction to be decided on is to be determined by the designer, who establishes the impact of the view to meet a certain aesthetic or functional need. Therefore, the film is designed to give a clear image only if viewed from a certain angle of vision. The film with this capability is used for deliberate concealing of a view, a surprise outlook of another view from a certain angle of perception, or a clear vision at a specific location, all of which offer considerable product possibilities for industrial designers (Addington and Schodek 2005).

Figure 4.11.View directional film (Addington and Schodek 2005)

Lumisty: Filtering polyester film-intelligent material

Another example is Lumisty, a filtering polyester film-intelligent material which provides an optical illusion between a fully transparent to an obscured fogged impression when applied to any window. For example, the film is applied in the shop window of Issey Miyake’s clothing boutique in SoHo. The advantage of the film is that any passer-by can view into the shop window only if he is situated directly in front of the window itself.

Fabriled: Led signage woven into flexible fabric

LED based components offer creative solutions to industrial designers. LED based electronics can be applied directly to cotton fabric, as they can be woven or integrated into it. Moreover, they can be programmed, they are flexible and they weigh very little, all of which are advantages for their application as point-of-purchase displays, signage, and message boards. Fabriled (figure 4.12) was invented by Sarnoff (previously RCA Labs) for a variety of applications to be used as lightweight displays (Blownell 2006).

Figure 4.12. Fabriled (Blownell 2006).

Temporal Light: Electroluminescent Wall Tiles

Electroluminescence is a capability that can be obtained from smart materials. Electroluminescent wire can be integrated into resin so as to produce illumination solutions (figure 4.13). The system composed of wire and resin can be arranged in order to respond to any shadow that is projected onto them to give temporal image impressions. Such tiles are used to illuminate spaces and each tile can function as a pixel (Blownell 2006).

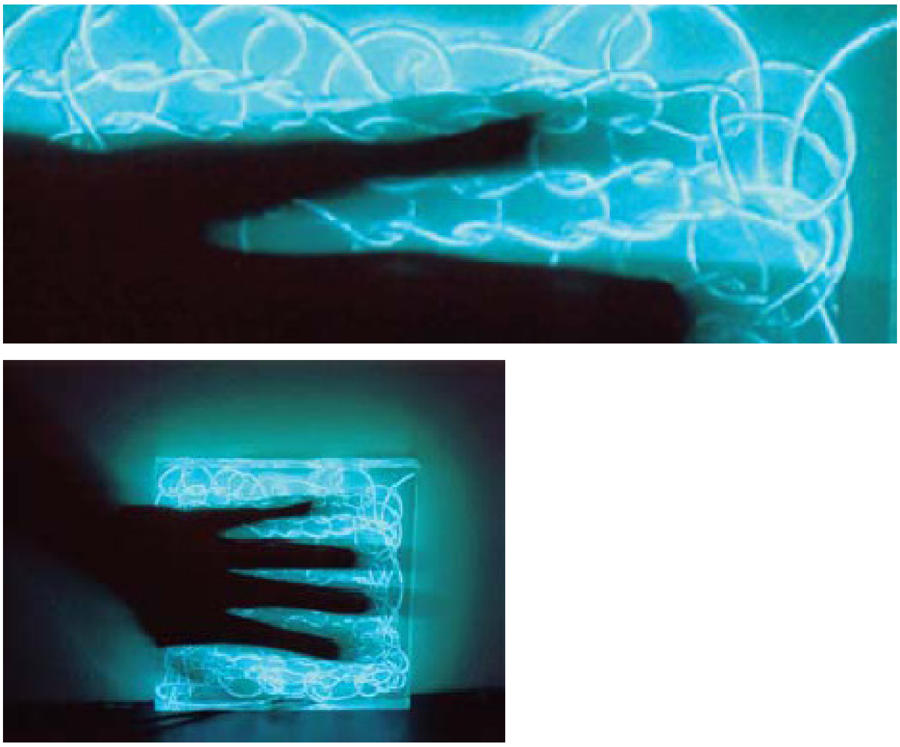

Figure 4.13. Temporal Light: Electroluminescent Wall Tiles (Blownell 2006)

Digital Dawn: Electroluminescent window covering

Electroluminescence is also used in another application, for window coverings, created by Rachel Wingfield. The designer has used the luminosity capability to act as a substitute for traditional window blinds. The idea is that the blind, which is coated with a reactive surface responding to varying levels of light, is a duplication of the natural process of photosynthesis. The blind (figure 4.14 Digital Dawn) bears ‘organic foliage’ that grows by the help of light sensitive sensors. When the ambient environmental light diminishes, the foliage on the window blinds begins to grow in different shapes and impressions (Blownell 2006).

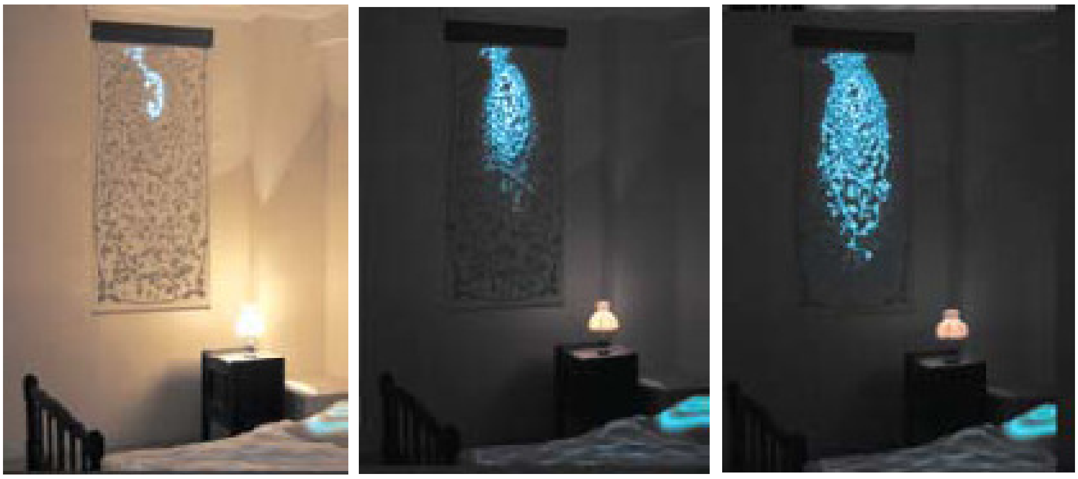

Figure 4.14. Digital Dawn (Blownell 2006)

Luna: Phosphorescent Cast Glass

Phosphorescence, being a characteristic of light emitting smart materials, can be used by industrial designers to create amazing effects. Such an example is a building material under the trademark name of ‘Luna’ (figure 4.15), named in recognition of the moon or craziness. The material is a cast glass with a phosphorescent chemical, which absorbs light during the daytime and glows in the dark (Blownell 2006).

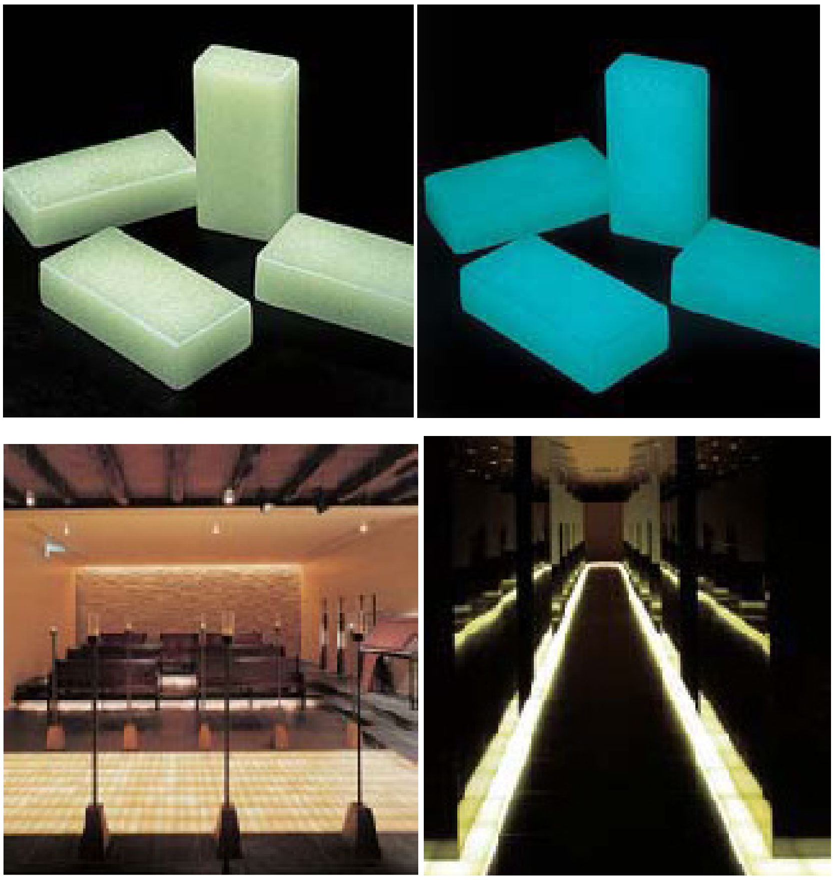

Figure 4.15. Luna (Blownell 2006)

Kinetic Glass: Morphing Transparent Surface

Kinetic Glass (figure 4.16) is a lightweight and thin layer that can function as if a separator or a wall, which can be given a potential to respond to undesired changes in the environment. Its response can be manipulated by “switches or sensors and ... micro processors and complex algorithms” (Blownell 2006). Kinetic glass detects hazardous levels of carbon dioxide and not only provides warning to the inhabitants of a building, but also protects the building itself by curling or closing the flaps of its gills so as not to permit the excess of carbon dioxide from penetrating the building interior (Blownell 2006).

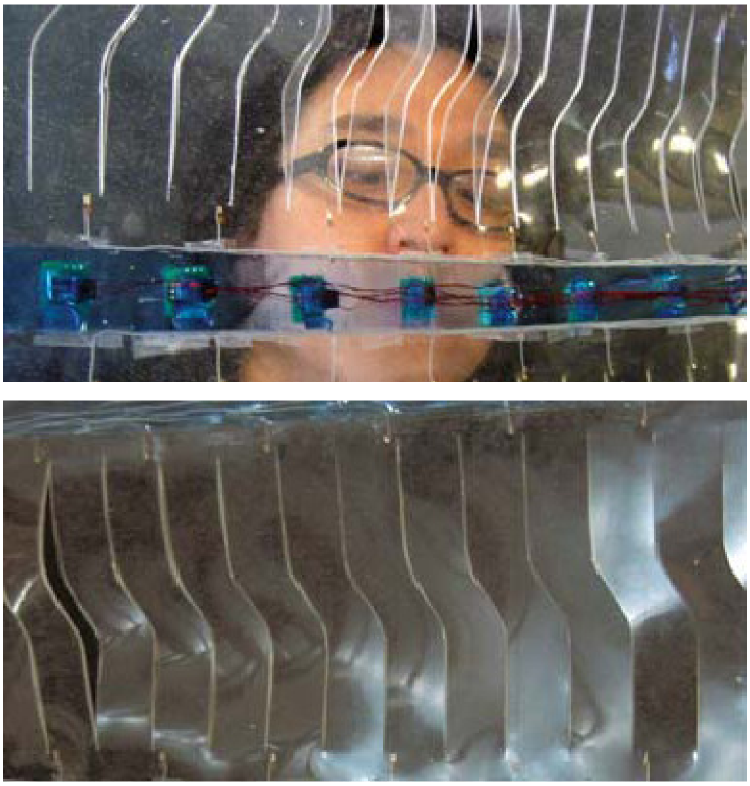

Figure 4.16. Kinetic Glass (Blownell 2006)

Smart ventilation systems will eventually eliminate the necessity for an electric source to instigate the movement of flaps and be practically applicable either inside or outside of a building without any obligation to be established at certain locations. The possibilities of its exploitation are not only unlimited but also they can be coordinated with electricity which expends the potential of the system more if, for instance, linked to sensors. Moreover, SMAs function as temperature sensors, and actuators: when activated they either open or close the louvers of the ventilation system. This capability can be altered according to customer demands because they may be activated at different temperatures so that they can deliver different responses. A ventilation system constructed using SMA material may be used as a cooling mechanism of a building at night when the outside temperature is cool. The mechanism simply opens at night to let in cool air and closes during the daytime in order to preserve the cool air within the building.

Besides the primary and essential functions of SMAs, it is also possible to make use of their properties for secondary level system functions. For instance, as in manual or automatic opening procedures, the user can control the ways in which a ventilation system may function when activating an ‘overrule’ function. Another example is usable for easy cleaning purposes, provided that the smart material is used in an integrated and removable fly screen. Also, SMAs may ease installation under different conditions. A large range of application areas requiring ventilation can be conceived, for example buildings, caravans, mobile homes, green houses, garden sheds, and verandas (Verberkmoes) (figure 4.17 Door, Eric Verberkmoes).

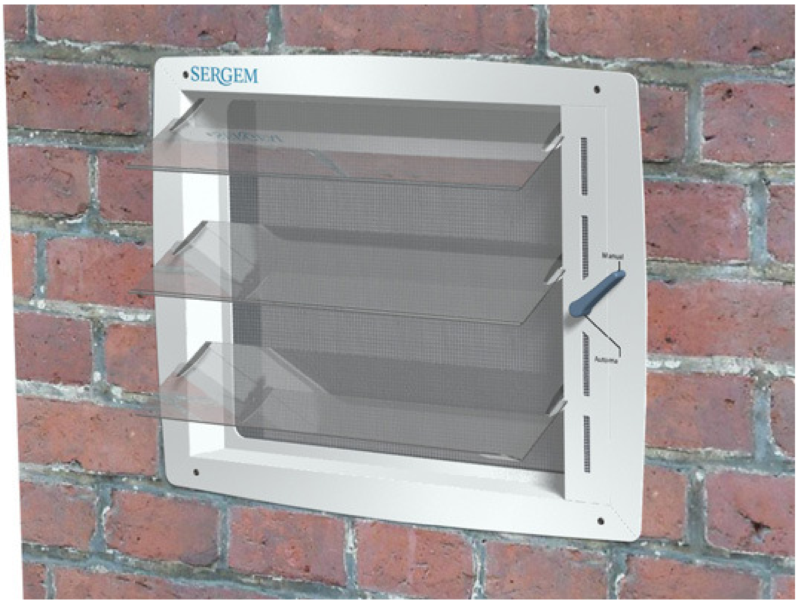

Figure 4.17. Door, Eric Verberkmoes

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Smart materials offer human-friendly practical utilisation with their innovation potentials, new realms for industrial designers and direct benefit to economies and industries, all of which are integrated into table 5.1 (Proposal for an Information Hierarchy for Smart Materials Communication for Industrial Design) – a significant compilation of the author of the thesis - in this chapter to establish channels of communication. This distinct contribution of smart materials is due to the technological superiority over conventional technology. The fundamental principle in smart materials technology is the sensitivity of the material in the field of its application, its capability of sending received "sensual" (Friend 1996) data to be processed, and finally to retrieve the delivered signal so as to position itself in the most suitable and responsive way to the demanding environment. Sensitivity to the environment, and a capability of transmitting and synthesizing data, are capabilities that can be equalled with the synthetic expression of the nervous system. When there is such an affinity between expressions obtained by smart materials and the human brain, it can be put forward that such materials instigate inventiveness and innovations, which can become an automatic extension of human- materials collaboration.

The author, in this thesis, has synthesized that besides their sensitivity to the environment, smart materials are clearly distinguishable from conventional materials with opportunities they provide for industrial design. First, smart materials yield capabilities of communication (temperature indication through colour signal).

Second, they can lead designers to establish more economical systems (saving heating, cooling, and lighting costs) than those offered by conventional materials. Third, positive contributes of smart materials can be extended to the realm of industrial design, as they are “contradiction solving” (Mann 2009) – meaning that they provide opposite characteristics in the solution of complex problems. Fourth, they offer new design possibilities (filling a gap between traditional mono-functional and controllable, multi-functional materials). Fifth, they provide appeal of outlook (creating interesting and attractive products). And finally, they have much more flexibility of adaptation (as in all of these cases) in comparison with conventional materials.

5.1. The Innovation Potentials in Utilising Smart Materials

When characteristics of smart materials are examined, it is useful to consider their properties under a categorisation system, as discussed in chapter 2, under the headings ‘property changing, energy exchanging, and matter exchanging’. Besides the categorisation, smart materials can also be evaluated according to their differences from conventional materials in their characteristics. Such characteristics are transiency, selectivity, immediacy, self-actuation and directness. Moreover, they can be differentiated from conventional materials according to their capabilities of property change and energy exchange, discrete size / location and reversibility / directionality. However, when categorization, characterization and capability are all synthesized in line with the innovation potentials that smart materials offer, they are found to yield two significant opportunities against conventional materials: these are their communication capabilities and their potential contribution to decreasing high costs of energy.

5.1.1. Communication Capability

Communication capability can be defined as a potential in a material with which some signal can be communicated and perceived dynamically by the five human senses. Although smart materials are found to lack one of the sensuous capabilities, gustatory (taste), they exhibit other four capabilities; visual (sight), tactile (touch), auditory (sound) and olfactory (smell). This is a significant advantage of smart materials against conventional materials, and it must be conveyed to innovators such as industrial designers who can make use of such ‘human-like’ capabilities in future innovation opportunities.

Visual Capability

The most common application of signal-sending, is through the exploitation of smart materials that produce visual signals, the most common of which is a change in colour spectrum. Smart materials that display visual signals may yield direct communication capability through the use of colour-changing smart materials. Colour-changing smart materials can act in response to temperature, light, mechanical energy, electrical energy or chemicals. This capability that appeals directly to human visual perception can be a means of direct communication between any product and the user of the product, which becomes an innovation potential to be worked on by industrial designers.

Already known applications of such a potential are labels of chilled beverages, where a thermo-chromic ink changes colour to indicate optimum drinking temperature (Slain and Romano 2007). The same capability can be used in the prevention of counterfeiting of beverages. A label, painted in chromic ink, eliminates the suspicion whether the beverage is genuine or counterfeit. This application will be used more in the future so that genuine and counterfeit products can be easily differentiated. In building up consumer faith and reliability, such an ink serves a two way confidence as the product directly communicates any problem to the consumer by making them alert to dangers. Especially in alcoholic drinks, which can be fatal if alcohol other than ethyl alcohol is used, such a threat to health and life can be ultimately eliminated. An emerging disaster, in Turkey, which has caused many casualties, has been due to the consumption of counterfeited classical Turkish Raki, a problem that could have been easily solved through the usage of a colour-changing label.

Moreover, since thermo chromic ink is heat sensitive, as another example, it is applicable even to a boiling egg on whose tag reveals the optimum and desired internal viscosity for eating (Hoyle 2006). This application would automatically eliminate time sequencing of, say, a boiling egg from one to five minutes with a simple thermo chromic print on the egg that is easy to observe as it changes colour. Another example of colour change is as a function of time, which reveals itself with a higher speed and definition that indicates the time needed by a dentist to work on a patient's tooth. Being a time indicator, which can be altered according to certain time segments, smart materials are likely to be a very useful replacement for a conventional clock. Therefore, visual display is itself an innovation potential that promises the widest field of innovations as it is an indicator which is easy to perceive, practical for application and is customer or user friendly.

Tactile Capability

Besides visual displays, smart materials are also capable of yielding signals that can be tactile. Energy exchanging materials, for instance, yield such mechanical deformation capability to cause an output in electrical energy. This energy as a signal can be used in various means, since it can be "detected, conditioned and interpreted" (Addington and Schodek 2005, 110). Such smart materials expose the characteristics of a "mechanical force actuation device", which can be felt as a tactile signal as well as visually observed. The tactile signal can also be obtained from smart materials, which yield thermal energy, converted into a visual signal if transformed into a device that measures temperature (Addington and Schodek 2005).

Auditory Capability

Another innovation potential of smart materials is through their auditory capabilities or communication of sound signals; thus, such materials serve as auditory signal sources. Sound production is accomplished by electricity-generating and shape-changing smart materials. They transform changes in air pressure and light into sound expressions. Deformation is obtained by an applied electric current and it is due to sensitivity to light intensity, a change in which results in a change in the amount of sound signals produced.

Olfactory Capability

Finally, smart materials have innovation potentials that can be owed to their combined auditory and olfactory capabilities. A smart material can function as a sound absorber or an acoustic panel that covers broad surfaces. Such panels or boards can be used as devices that either attract odours and pollutants to themselves or convert them. Although such a smart material does not produce odour signals itself, it functions as a material that can eliminate unpleasant odours. Its capability in producing an odourless environment is its capability to appeal to the human nose, thus signalling a clean environment.

5.1.2. Saving Costs: Heating, Cooling, Lighting

Besides their affinities with human sensory perceptions, which contribute to the innovation potentials of smart materials that are preferable in place of conventional materials, costs saving capabilities of smart materials also exist as an advantage to be communicated to industrial designers. As industrial production requires ever more cost-effective innovations, smart materials are likely to replace conventional materials in a near future.

Smart materials are applicable to lowering the routine cost of heating, cooling and lighting in buildings, as well as other domestic expenditures. One example of such applications is an electro-chromic window, which can adjust from transparent to opaque according to the daylight stimulus it receives. According to Fehrenbacher (2006), the glassware regulates the amount of light passing through when activated by a light switch, which regulates the voltage to be transmitted through the windows. Windows that change opacity levels not only serve as curtains but also as energy saving devices, in that they satisfy the need for, and reduce the cost of air conditioning. The glass loses its transparency into a foggy looking frosted glass.

Another use of smart materials can be observed in phase changing materials (PCMs), which are materials that have the capability to absorb temperature extremes, thus performing as temperature stabilizers. PCMs can function as heat storing elements Owing to such characteristics; they can be applied to building facades as heat absorbents.

5.2. Smart Materials as Problem Solvers for Industrial Designers

Besides their innovation potentials that can be utilized by industrial designers, smart materials offer other indispensible opportunities of exploitation. Among such opportunities, there is a highly complex pattern for decision making which needs a relatively definite pattern to be evaluated as of design review. Design review is the capability to judge and evaluate any material through a revision of every aspect that defines design phase with which a material is projected to become a finished product. To achieve this end, a system in the form of a pattern for communicating every crucial step to lead to innovations. Design review is, therefore,

> Design review is a system that involves gathering and evaluating objective knowledge about product design quality and the concrete plans for making it a reality, suggesting improvements at each point, and confirming that the process is ready to preceed to the next phase (Voight 1996, 3-4).

Checking out each step exposes the opportunities related with smart materials usage. This can be done through an established hierarchy of priorities which enables effective and efficient evaluation of opportunities. Such an approach makes it more practical to

- cultivate more experts who can come up with useful DR findings, stated in terms that designers understand [as of required language build up]
- build a database for information on past successes and failures, as well as technical data.Include keyword search and other user friendly functions.
- improve our administration of DR to keep it running smoothly and to ward off quality problems (Voight 1996, 62)

The opportunities smart materials offer are that they provide easy solutions for complex problems, and offer new design possibilities, with appeal of outlook and flexibility of adaptation.

5.2.1. Smart Materials for Solving Problems Requiring Characteristics of Dichotomies and/or Binary Oppositions

Smart materials can yield characteristics of binary oppositions, as they can become bigger and smaller, viscous and non-viscous, flexible and stiff; or dichotomous characteristics in that they can be red and blue at different times. Such capabilities make them useful for design applications requiring some kind of transformative capability that cannot be provided with conventional materials. For instance, a bulletproof vest needs to be stiff enough not to let any bullet pass through. On the other hand, the person who wears the vest needs it to be as flexible as a t-shirt so as to be comfortable. According to Mann (2009, 7), the new offer of smart materials to designers and engineers is the “Active Protection System (APS)”, which is simply a material with a stiffening response to a mechanical stimulus but under low-loading conditions remains flaccid. Such capability of flexibility is now being tested in bulletproof vests and shin-pads for soccer players. However, these application areas can be extended only if commercial possibilities and design capabilities are increased and the material costs decreased. A smart material with binary opposition capability, which is originally flexible but which stiffens upon the application of an external force, can be helpful in meeting these contradictory design specifications.

Such binary oppositions as characteristics of some smart materials can be used in glass systems, as mentioned earlier under the heading of ‘saving costs’. Another similar example is observed in photo-chromic smart materials used in visors. The photo-chromic visor darkens according to the amount of daylight it receives, which enables users’ eyes to better adapt to a change in the intensity of light, thus enabling users to have a more stable perceptive capability.

Designers and innovators who work on and with smart materials can optimise their innovative products by using smart materials with dichotomous or binary oppositional capabilities; or use smart materials as a counterbalance by contradicting any given material that creates a problem.

5.2.2. Smart Materials to Fill a Gap between Traditional Mono-functional and Controllable Multifunctional Materials

As taken from natural models, new material systems are being introduced into industry. Natural models are complex systems derived from nature. There exists evolutionary transformation in nature, with which objects of nature develop new capabilities to adapt to changing environmental needs. However, the process of adaptation in industry is reliant on much investment as well as research and development expenditure, so it cannot easily occur because the exploitation of ‘uni-functional materials’, also known as ‘traditional materials’, cannot transcend beyond their traditional applications (Melnykowycz 2007). In order to urge transcendence beyond such applications, smart materials offer solutions.

New material systems are compositions of uni-functional materials and new, multifunctional materials. The integration of certain new materials into uni-functional materials yields new exploitation possibilities. Likewise, new compositions or compound systems offer solutions to problems that cannot be solved by traditional materials alone. To achieve this, and to produce material systems that adapt better to their environment, smart material systems are being established. These systems have three components, comprising “the active material, the passive material and the control system” (Melnykowycz 2007). While the active material is the actuator or the sensor element, which responds to the environment by receiving information from it, the passive material is the host structure (traditional material, unresponsive to the environment, lacking smart characteristics), which is the material into which the smart material is implemented. Apart from these two, the control system is the mechanism or program that gathers information from sensor elements and which controls actuation of the material. By working together, these three principles can be used to serve a variety of design needs (Melnykowycz 2007).

Another gap filling capability that smart materials fulfil is in devices of parts that take over mechanical functions provided by traditional materials. According to Buchholz and Gehm (2007), smart materials can offer a movement without a need for a motor drive, engine or hydraulics. These can be used on huge surfaces where they can receive large doses of heat and changes in temperature, stress and magnetic fields. As they can change their shape, strength and stiffness, they are applicable to plane wings, air dams (devices adjusted to automobile fronts to improve aerodynamics and reduce turbulence), large vehicles and many others.

The ways in which the passive material is to be enhanced by the active smart material in the process of producing a new system needs new expertise and specialist experience. Since smart materials are in their infancy of exploitation, it is not easy to determine which smart materials will contribute to an optimum functioning of a material system. Therefore, material selection is not easy for industrial designers, who are expected to produce optimised new products making use of material advantages. Industrial designers have to be knowledgable about the properties of smart materials if they are to make use of them effectively in new product designs, but this is a complex matter because smart materials have the capability to yield more than one property.

Out of their many properties, smart materials are a challenge to industrial designers because they are multifunctional and may "serve as sensors, transducers or actuators ... to form an interconnected whole system" (Addington and Schodek 2005, 109) that can be activated or controlled to produce an overall intended action or to possess desired response characteristics. An industrial designer, therefore, has to be informed about the fact that many smart materials serve multiple functions, and that, not every function which is used in a new product yields optimum advantages. Thus, a reservoir of information technology is required to enlighten industrial designers in their exploitation of smart materials as they integrate them with traditional materials to create new design product proposals (Addington and Schodek 2005, 109).

5.2.3. Material Selection and Creating Appealing Products through Product Design

Traditional materials selection in industrial and product design is usually directed towards satisfying functional needs of consumers, whilst emotional needs or benefits are met to a lesser extent through materials choices. With this in mind, smart materials have potential to enrich and enhance the material-based aesthetics of products. Therefore, they are used more by designers who not only seek technical and mechanical advantages but also seek more charming and appealing designs. Smart materials, therefore, can be immediately striking in their appeal to people and thus convey an especially positive or charming first impression, which is not always achieved with traditional materials (Delft University of Technology 2007). Ferrieri (1991, 18) points at a newly growing interest in the material itself as

> once again taking centre stage [because] ... it is now part of design ... entirely inventible, and now capable of providing higher and higher degrees of performance as well as new interfaces loaded with imaginary contents that respond to the new demands of sensory communications.

The appeal of smart materials to human senses can be appreciated both in their capability of communicating their extraordinary outlook, and in their presence hinting for new design possibilities. For example, they can yield an appealing aura through their capability to change colour. They can be direct replacements for many traditional materials, such as plastic, which can be made into a temperature sensitive or colour-changing product. Colour changing pencils, which are heat sensitive, are appealing to students who find a continuous change in the pencil as long as they hold it. Receiving its heat source from a light bulb, colour-changing thermo chromic lampshades transform into extravagant and exotic colour displays. A toilet seat, which gives off an indication of the time elapsed since it was last used, serves a double purpose: the novelty and appeal of the colour change, and the information on the duration since last use.

Colour indication in line with heat change can be made applicable to more popular products of consumption and may provide a wider market share for producers of products that change colour. For this reason, such products may convey very high-tech impressions that are closely related with a sense of ‘newness’ of the product. This can be an important element of sales strategies for new products. Similarly, thermo-chromic material is wide in use. To illustrate, a colour-changing shirt is possible, in that, it can be dyed in thermo chromic material or paint, or a figure can be printed on it with thermo chromic ink. Such a shirt is appealing to customers as it transforms in colour and, therefore, has something unique to offer over competitor products. The same idea is applicable to the field of tattoo applications, business cards and many other areas. Photo chromic tattoos, for instance, make use of photo chromic ink, which is transparent indoors but which turns into a very bright colour outdoors, under the sun rays. Another application is business cards that are printed in heat sensitive and colour-changing materials. They respond to body temperatures during their transfer from one hand to the other, thereby attracting the attention of the person to whom they are delivered.

An application of smart materials to increase product appeal is privacy glass, used in the dressing rooms of large high street stores. This product is a dressing cabinet that transforms into two variations of glass exhibit: transparent and opaque, both of which become appealing qualities to consumers as well as providing the essential function of privacy. The privacy glass makes use of polymer liquid crystal optics. Between two sheets of glass, there is a liquid crystal film, which is covered with a transparent electrical conductive coating. When electricity is applied, the liquid crystals begin to change in electron arrangement, which causes the elimination of transparency of the glass, thus affording privacy between the person inside the dressing room and those people who are outside.

5.3. Contribution of the Thesis to the Broad Area of Smart Materials and Industrial Design

5.3.1. Highlighting the Use of Smart Materials in Shaping the Future

The author of the thesis considers that smart materials are likely to be the most recent opportunity of humankind to take a significant leap to a promising future. In our everyday language, we are familiar with terms such as the industrial revolution, computer age or microchip millennium, but now we can speak of the smart materials age. In this opportunity offered by smart materials, the evolution of humankind can gain great dynamism. However, for a true revolution to come about, collaborations between designers and engineers are vital. It is essential that the right communication channels should be established and kept fully open so that these professions can co-operate for the benefit of future societies. With this revolution, all human systems such as economies, industrial, political, sociological and even philosophical systems will transform. Therefore, besides its many advantages and benefits as positive contributions, a smart materials revolution can potentially deliver undesired or unexpected results. For instance, popularist presentation of smart materials can create an unnecessary aura of supremity of smart materials over conventional materials, which may be over-inflated (i.e. marketing-led, company ‘talk’, gimmicks) by those who can abuse smart materials for new popularist benefits. To prevent this unethical and scientifically unreliable approach, first, right communication of smart materials be established so as to create the right perception of them. By this way, interaction among reliable actors be established. Among such actors are designers and engineers who must cooperate under the rules of universal ethics. Otherwise, although positively depicted, smart materials and their characteristics may be exploited for the worse to raise new ethical questions. In this thesis, therefore, the author has highlighted the relevant communication channels and the necessity for a positive and scientific collaboration between designers, engineers and materials developers.

5.3.2. Organising Information on Smart Materials as a New Paradigm: Establishing Communication

With this thesis, essential groundwork for communication has been initiated. Moreover, it has been highlighted that smart materials establish a new paradigm that should not be ignored, so that they will contribute directly to the formation and development of innovative ideas for new products. The work reported in the thesis has intended to facilitate designers in bringing smart materials into their materials decision-making. It has also found out that communication has to be made widespread through various channels. In addition, it has suggested that newer channels of communication be established for the appreciation of smart materials, and that as a class of material, smart materials are gradually applied as replacements to conventional materials in the quest for product innovation and sustainable national progress and development. Therefore, the issues raised in this thesis can contribute to a wider consciousness on the contribution of smart materials to the economy.

As materials are one of the factors that instigate creativity in product design, and as innovation is a sought-after attribute for designers, smart materials can be viewed as new materials that motivate designers to be creative and innovative. However, within Turkey, awareness of smart materials is not adequate. As Turkey has not taken an active role in such revolutions as the industrial revolution, the electric revolution, and the computer and microchip revolution, it is with smart materials that Turkey may actively participate in a technological revolution. Since the knowledge on smart materials may be considered at its initial phase generated in the West, Turkey is well placed to compete in the forthcoming developmental stages of smart materials. As is commonly appreciated, newly industrialising countries can do well at contributing to developments in emerging technologies. Therefore, this thesis points at this opportunity and establishes a basic ground to initiate further steps in embracing smart materials technology. To create awareness among designers and engineers, especially in Turkey, the thesis has offered a prototype of communication hierarchy concerning relevant information on smart materials. This prototype is expected to open up a broader route of communication supported by, for example, trade magazines, journals, web and alike, to spread wider the opportunities and capabilities provided by smart materials. Being one of the contributing efforts in the literature, the thesis emphasizes that smart materials can be better appreciated if correct channels of communication concerning smart materials technology are established. If designers can be made aware of the fact that smart materials are a new paradigm, they can be guided into making new innovations, obtaining patent certificates and bringing in global capital. The thesis, therefore, can help in achieving national benefits in a global arena. Innovativeness is of utmost significance for a nation. Even if a large number of smart materials are protected under patent rights, new systems that can be developed from their combinations can be sought by future researchers in obtaining new patent rights.

5.3.3. Information Hierarchy for Smart Materials Communication for Industrial Design

This thesis has proposed information hierarchy based on a compilation of essential facets of smart materials. A designer, while starting the process of design, is introduced or invited to go over the findings to become familiar with smart material properties and applications. If we are to summarize the method, route or channel for information hierarchy in smart materials communication, it is that first a smart materials 'language' need be developed. This language can be developed through a common production of new literature, lexicon and jargon, and its components are to be enriched through pictures, illustrations, diagrammes, charts, tables, videos, case studies, demonstration products and all simulacra to communicate denotative and connotative meanings to transmit and communicate right impressions of smart materials. Second, definition, details, technical and non-technical specifications of smart materials be transmitted for familiarity and awareness building; third, motivations for utilising smart materials over traditional materials be identified; and finally, creativity in exploitation be encouraged.

Table 5.1. 'A Proposal for an Information Hierarchy for Smart Materials Communication for Industrial Design' provides a flowchart summary of the stages proposed necessary for achieving effective smart materials communication. Accordingly, by referring to the table 5.1., it is proposed that the experiential knowledge of industrial designers with regard to smart materials usage and language will expand considerably. As with all descriptive models, it is necessary to make a decision on the kind of classification to adopt. In this case, a new classification was developed by the author, based on the opportunities that smart materials provide designers. This decision was taken owing to the fact that smart materials necessitate extra explanations that are not compatible with traditional material descriptions based simply on combinations of properties spanning, for example, physical, chemical, energy and so forth.

Table 5.1. Proposal for an Information Hierarchy for Smart Materials Communication for Industrial Design

Terminologies ➡	Familiarity and Awareness-Building		➡	Motivation for Use ➡	Creation
New Language	**Definition**	**Details**	**Behavioral Patterns**	**Opportunities**	**Application**
New literature New jargon New lexicon ↓ Simplicity of communication via: *Pictures,* *Illustrations* *Diagrams,* *Charts, Tables,* *Videos,* *Case studies,* *Demonstration products,* *Simulacra* ↓ Interest building, knowledge and information ↓ To be transmitted via appropriate communication channels	Difference from conventional , uni-functional and dumb materials ↓ Highlight smart materials as new, high-technology materials ↓ Semantic properties: -Denotative -Connotative -Semiotic	Characteristics, Capabilities, Categorisations, ↓ Product and material samples related general information on multiple detail levels	**Non-Technical** Perceived Sensorial properties: *visual, auditory, tactile,olfactory* *transparency, opaqueness lighting, heat gloss, physical attributes and alike* **Technical** Chemical, physical, mechanical properties satisfying engineering needs (*process and geometry properties*)	Innovation Potentials: *-Communication capability* *-Saving costs: heating, cooling, lighting* Problem-Solving Opportunities: *-Smart materials solving problems that require characteristics of dichotomies and/or binary oppositions* *-Smart materials to fill in gap between traditional mono-functional and controllable multifunctional materials* *-Material selection and creating appealing products through product design processes* ↓ Sectors of exploitation Commercial properties	From ideal mindset to optimum mindset *Product requirements, utility and functionality, fitness for purpose and appeal to senses,* *New materials analyses and syntheses between form and function, objectives and constraints, desired features, similarities and inspiration,* User-needs, Desired functions, Ergonomy Supplier information and portfolio, exhibit for customer presentations (*the product and the material to be held, touched and looked at from all sides*) Materials –inspired innovation Working memory High-order or meta needs (*ideas, sensory and emotional fulfilment, cultural experiences and entertainment that stimulate the intellect*): Experiential knowledge; *Cognitive* *Aesthetic (product personality, shape, use, function, manufacturing,production technique)* *Self-actualising* *Self-transcendent*

There must be a bridge of communication formed between scientists, designers, engineers and most of all economic markets for successful commercialisation and sufficient revenues. The future for smart materials is likely to be commercially very promising and the trend of their usage will radically increase, although their current economic and commercial status is not yet near their full potential.

Material needs are to be determined and examined for marketing strategies and benefits. Determining such needs and finding economical and practical solutions to them requires consultancy between industrial designers and engineers. Both parties are required to exchange their priorities in a medium of mutual communication. Mutuality is a required tendency, which can be constructed on a common language and an agreement on the Information Hierarchy for Smart Materials Communication for Industrial Design. If such a reciprocal interaction is not established, neither industrial designers nor engineers can make use of innovation potentials that smart materials offer: Neither can optimise the opportunities that are presented by smart materials.

5.4. Conclusions

As new materials emerge and existing ones are enhanced, they provide new sources for design. However, providing their knowledge remains as a problem as the technical information, datasheets, books and so on, may not be as effective as having acquaintance with the material itself. Databases and Networks, Sample Packs, Conferences, Workshops, SMEs, Reports, Consulting, Books, Research Centers, Companies, and Academia are discovered to be all currently in use as information sources for providing the related knowledge for smart materials. As they are analysed with how they accomplish the information sharing, they open and show how to start discovering ways to reach smart materials knowledge. Such media cannot function properly unless they are included in a system. This thesis has focused mainly on identifying and situating each component or issue related to the smart materials universe, and conveying the results through the Information Hierarchy for Smart Materials Communication for Industrial Design.

5.4.1. Answers to Research Questions

The thesis set out to answer several research questions. The conclusions to the thesis can be expressed in relation to the questions that were posed.

Q1. What kinds of capabilities do smart materials have?

The capabilities smart materials provide can be grouped according to yielding human sensory perceptions or reflexive reactions to stimuli that come from the environment. This makes smart materials approach to the boundary of human existence more than any other material used in the past. Therefore, they offer a reunion and reconciliation between the human world and the material world. Besides, human-like capabilities, they offer capabilities of property change and energy exchange, discrete size / location and reversibility / directionality, all of which make them distinct as having transformative capability, reciprocal energy transmission, economy and compactness in size, and retention of original phases.

These capabilities make smart materials distinct from traditional materials and accordingly provide many problem-solving solutions for industrial designers. Such solutions go in parallel with the innovation potentials of smart materials, which are the outcomes of their capabilities. Among their capabilities are also such factors as the capability to communicate signals, being economical, capability with dual nature, capability to function together with traditional materials or to yield multifunctional capabilities, and finally a capability to exhibit appealing features on products.

The capabilities of smart materials multiply when their characteristics such as transiency, selectivity, immediacy, self-actuation and directness are considered. With such characteristics, they can be used in systems claiming roles of acting as sensors, transducers or actuators. Their potentials, therefore, can be increased if their characteristics, roles and opportunities are synthesized. In other words, if an industrial designer synthesizes smart materials in a cross-examination of their characteristics, properties, roles and opportunities, he / she is more likely to arrive at a hybrid synthesis of capabilities. The process seems to offer infinite combinations for innovation of deriving new capabilities out of the known capabilities of smart materials.

Q2. How can smart materials knowledge be provided to industrial designers so that they can develop new products?

In order that an industrial designer develop new products by using smart materials, he/she not only needs to attain profound knowledge and information about the materials but also needs to follow a guiding path that leads to a cross-examination of characteristics, properties, roles and opportunities. In the route of cross examination, it is recommended that the industrial designer collaborates with a knowledgeable engineer and benefits from technical consultations. By the end of cross examination, the industrial designer has to be well satisfied with the knowledge that is provided for him so that he can develop new products.

For the time being, there are already exploited channels of information for smart materials, spanning databases and networks, sample packs, conferences, workshops, SMEs, reports, consulting, books, research centers, companies, and academia. These channels are helping to eliminate barriers of communication by disseminating smart materials information to a variety of audiences. Their main contribution in providing knowledge is through an effort to promote, broaden and spread the usage of smart materials.

Yet, none of the above channels is a perfect solution for providing smart materials knowledge to industrial designers. This is because although they are honest and updated efforts, they lack a systematised approach and do not offer the guidance that is implicit in the Information Hierarchy for Smart Materials Communication for Industrial Design constructed through this thesis. This new approach provides smart materials knowledge to industrial designers by following certain parameters. From a language which yields smart materials terminology (jargon and lexicon) to their definitions and details of their technical and non-technical properties, the proposed Information Hierarchy is intended as a layered approach to building familiarity and awareness in industrial designers. The information hierarchy also embodies a motivating impetus of smart materials for exploitation in new products by presenting them at a sufficiently broad level of communication to induce creativity and innovation.

Q3. Through what sort of a process do new materials reach a level of utilization and how do they meet consumers' needs?

New materials reach a level of utilization after a complex process of information hierachy, as conveyed by the Information Hierarchy for Smart Materials Communication for Industrial Design. However, due to the multi-faceted nature of the table 5.1., and the almost infinite combinations that it suggests, it can be extrapolated that a level of utilization can be achieved through group work of research and development in the form of workshops. In simpler terms, the level of utilization of new materials to the most optimum level can be achieved through teamwork. Each member in the team has to be an authority in a specific element of the Information Hierarchy. Otherwise, with only individual effort, an optimum result is less likely to be achieved.

Currently, smart materials are utilised in prominent industries such as defence, aerospace, architecture, art, textile, mechatronics, recycling, health and industrial design. Although the efforts put by these industries into the development of new products cannot be ignored, they have not yet reached an optimum level of utilisation. Despite the fact that they make use of a reservoir of knowledge to be projected onto future designs, such industries would likely benefit from the systematic perspective offered by the Information Hierarchy for Smart Materials Communication for Industrial Design. With its guidance, new materials and products stand a better chance of usage and to meeting with the demands and desires of users. The key point is that personnel working in the aforementioned industries be informed about the new language of communicating smart materials by also concentrating on details, opportunities and application credentials.

Q4. What role do (or can) industrial designers have in encouraging the uptake of smart materials in products?

Industrial designers by profession undertake the role of conceiving new products and responding to new design challenges. In relation to smart materials, as with conventional materials, the industrial designer's objective is to match materials, user needs / desires, and innovative solutions. To achieve this, they have to rely on updated and accurate information about new materials, conveying both technical and non-technical qualities. Though it is much easier to obtain information on technical qualities, it is through the efforts of industrial designers that non-technical qualities of smart materials may be explored and systemized.

In order to explore the realm of non-technical qualities of smart materials, industrial designers should refer to the 'creativity/application' step of the Information Hierarchy for Smart Materials Communication for Industrial Design. At this step, they can receive guidance in how to contribute to the creativity base for smart materials. To make use of the guidance supplied by the findings of the thesis, industrial designers can follow a route which begins with them getting prepared to develop an optimum mindset, whose basis is an alertness to non-technical attributes of smart materials, such as perceived sensorial attributes (transparency, gloss, tactile qualities, physical attributes ,visual, auditory, tactile etc.). While doing so, industrial designers should also keep up with an ideal mindset, as always, keeping data of technical attributes.

With a mindset based on the Information Hierarchy, industrial designers will also be able to accept the new opportunity that smart materials offer to them: materials – inspired innovation. Put simply, smart materials offer new design and innovation possibilities. Moreover, industrial designers' contribution to the evolution of smart materials usage can be backed up by them to attain experiential knowledge, a composition of higher order needs (as opposed to basic needs) regarding their cognitive, aesthetic (product personality – shape, use, function, manufacturing), self-actualising, and self-transcendent components. Industrial designers, therefore, have to be understanding of such higher order needs with the inspiration they get from smart materials to achieve future product requirements, new syntheses between form and function, utility and functionality, fitness for purpose and appeal to the senses. Finally, since smart materials are a new realm with seemingly endless inspirational probabilities, industrial designers should try to develop their working memory which will be developed in the form of a reservoir of data about smart materials derived out of experiential knowledge.

Q5. What are the factors that may urge, necessitate and broaden the usage of smart materials?

The factors that urge the usage of smart materials mostly appear in the nature of smart materials, that is, they yield such capabilities that they open up new routes of opportunities for industrial designers. Among such opportunities that arise from their capabilities are communication, economy, contradiction solving, new design possibilities, appeal of outlook and flexibility of adaptation.

With such a reservoir of capabilities, smart materials naturally broaden the field of application and choice of taste by also acting as inspiration for industrial designers. Any project developed on the exploitation of smart material is likely to have priority of preference by the future users of smart materials products. A typical exemplary case as to why and how smart materials are preferable is introduced below.

With an awareness and impetus of discovery on smart materials, the author (2009) applied to the 'New Ideas and New Jobs' competition organized by Middle East Technical University, Turkey. The project she offered was selected as one of the six most promising projects, which will compete for the final prize. Even though the project is centred on the use of 'thermo-chromic paint', which is under patent protection rights, the application of the paint to the proposed system is currently not under any patent protection. The project involved a camouflage system based on the use of smart materials for solving problems requiring characteristics of dichotomies and/or binary oppositions. By using thermo-chromic paint, a camouflage is possible having a capability to display 'colour A' or transform into 'colour B' when and where required.

As is seen from above, a universal necessity for 'camouflage' urges the use of a smart material in whose nature there is a practical solution for the problem. Its capability automatically takes over any capability in the conventional sense (for instance, military vehicles painted in standard camouflage colours of brown, green and beige). The factor that urges the use of smart paint in this case is an updated military need for a permanent solution for camouflage, negating repainting or duplication of vehicles in different camouflages.

Therefore, the factors that urge, necessitate and broaden the usage of smart materials, as it is also in the case of the author's project, can be summarized as follows.

- Materials-inspired innovation capability.

- Demand of the industry for ‘smart’ materials.
- Updated channels of information through which smart materials are widespread and promoted.
- High-order needs: ideas, sensory and emotional fulfillment, cultural experiences and entertainment that stimulate the intellect.
- Economy: their potential to be exploited economically.

Q6. What are the major barriers that may hinder the wide spreading of smart materials use?

As with everything that is new, the basic problem with smart materials appears to be the ‘acceptance’ of the new material. For smart materials to receive more acceptance and greater recognition, it is required that channels of information and specifically the Information Hierarchy for Smart Materials Communication for Industrial Design developed in the thesis be applied. Without a systematized approach, communication between industrial designers and engineers cannot be established properly. If the appropriate communication is lacking or missing, it establishes considerable hindrance of information exchange among the actors. By this way, missing information or disinformation become the basic barriers that hinder the wide spreading of smart materials use.

Moreover, in parallel with the lack of communication, there is a lack of familiarity with new materials. When there is no familiarity, the application areas of smart materials remain unexplored. In turn, the lack of familiarity leads to a lack of relevant and reliable knowledge, resulting in the opportunities that smart materials can offer being ambiguous.

Another barrier is the traditionally oriented mind, referred to in this dissertation as the ideal mindset. This state of mind has to be kept of secondary importance while priority should be given to the optimum mindset. This means that as materials evolve from conventional to smart, they will contribute to progress of technology.

A third and final barrier is that there is not yet established precision about the market value or added value to be obtained from products made out of smart materials. When there is no precision in estimated revenues from smart material usage, naturally there is less investment on their research and development. However, if their economic value were estimated based on their potential market share, they would be considered as a priority for investment.

5.5. Limitations of the Study

In the pursuit and preparation of this thesis, certain limitations have emerged from the virginity of the field of study. First, the basic quantity of literature was found not to be concise and well developed, as there is no common language that is shared by literature writers. However, it is estimated that, in a decade or so, there may appear an immense literary context dedicated to smart materials.

Another limitation confronted has been due to the vastness of the field of the study. An individual effort as exhibited with this thesis has been on the edge of too much challenge and complexity. This, of course, is owed in part to the research questions that were set and the overall ambition to reveal the state of current play in the smart materials arena. As the subject of smart materials evolves and becomes mature, the communication needs will become more specific and with it will come specific requirements for research and development. The field is currently too young for those requirements to be identified. For this matter, the usefulness of the hierarchy proposed in this thesis is yet to be tested. For further research, the information hierarchy may be applied in an educational or professional context and tested out.

5.6. Recommendations for Further Research

For further research, division of labour has to be established in parallel with teamwork on the smart material universe. The universe requires much expertise, so that a number of teams with specific expertise in each step of the Information Hierarchy for Smart Materials Communication for Industrial Design have to be ideally integrated for future research efforts. The teamwork has also to be backed up by computer programmers, whose duty has to be the construction of a database compatible with the Information Hierarchy.

As a second recommendation, future research should be dedicated to the economic potential that smart materials can offer. With such a research, the market share and added value of smart materials would have to be evaluated. This economic research would be significant for a country such as Turkey, which has potential to accomplish much economic gain from smart materials exploitation. As they offer a significant chance for newly industrializing countries, smart materials can enable one route to economic growth and offer a chance to keep pace with industrialised countries and their technologies. However, economic potential of smart materials is also to be recommended so as to scan some negative aspects of smart materials. For instance, technically, their usage may become much more costly than that of conventional materials. This automatically makes them financially unfeasible for commercial purposes, thus creating market risk for investors. Therefore, financial resources and efforts for Research & Development are required, and smart materials have to be certified by standardization marks such as CE, ISO, TUV for sustainability and reliability. Finally, smart materials may become a matter of new ethical discussions in the future. For this reason, their ethical dimension has to be brought into discussion by social moral codes.

A final recommendation is that smart materials appear to offer great opportunities to set collaborative projects to students from a variety of disciplines whether in

University or through professional training. In this sense, it is the role of education to dedicate further research so as to put the information hierarchy to practical use in industry.

Appraisal of the roadmaps and drawbacks above would be valuable for further research on future smart materials culture and universe.

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