17
Architectural applications of smart textiles

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Abstract: This chapter starts with an introduction about key themes and important factors in modern architecture. It then gives some general informations about smart materials, which can be divided into the categories of property-changing smart materials, energy-generating and exchanging smart materials, and matter-exchanging smart materials. Then some examples are given of existing smart textiles for architectural applications, which include light-emitting metal mesh, self-cleaning membranes, self-healing textiles, shape memory interior textiles and innovative actuators, made through the use of smart textiles. The chapter ends with future trends for exterior textiles, actuators and interior textiles.

Key words: property-changing smart materials, energy-generating smart materials, energy-exchanging smart materials, matter-exchanging smart materials, adaptive architecture, kinetic architecture, smart building textile, smart polymer actuator.

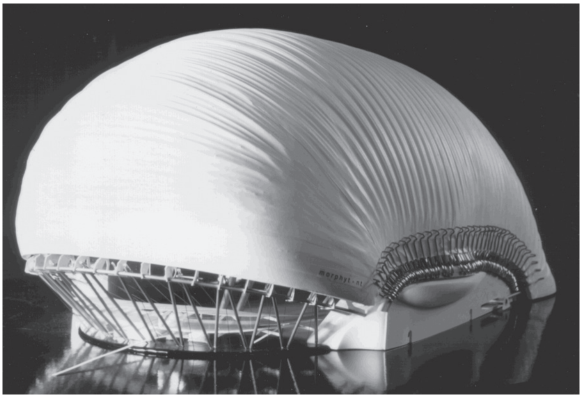
17.1 Introduction: key themes in modern architecture

There are a number of factors that are important when considering materials for modern architecture, including:

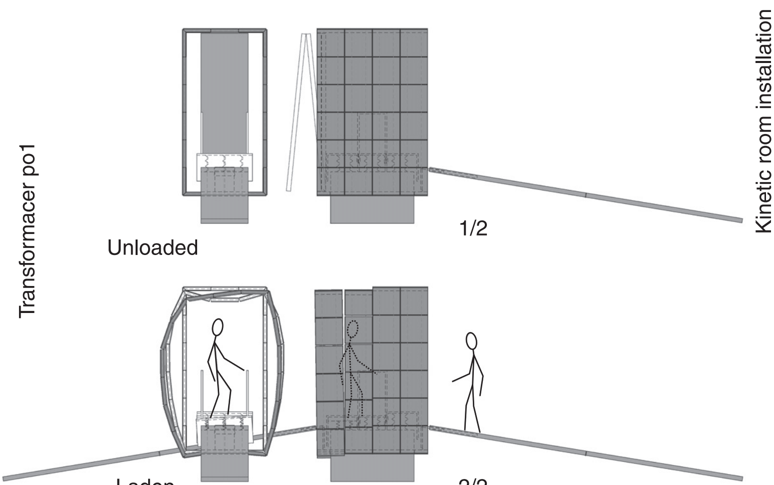
- sustainability
- adaptability
- intelligence.

Sustainability in the architectural context refers to building materials and products that are preferably natural, fully recyclable, or both. Furthermore, it requires that buildings are able to absorb energy and matter (e.g. heat and water) and to generate energy and use storage facilities, so that they no longer require extraction of gas and electricity from local distribution grids. These requirements generally lead to buildings consisting of materials and products made from natural materials such as wood, clay and straw. To be energy and matter self-sufficient, they may need to move (e.g. rotate to track the sun), as well as to include components that can concentrate and/or collect energy and/or collect matter like some smart materials do.

Adaptive or smart materials and structures have components that are able to respond to external and/or internal stimuli by, for example, changing colour and/or creating new geometries or shapes (Fig. 17.1(a,b), Fig. 17.14(a–c), Fig. 17.16(c)) [1–19]. Smart textiles, which are adaptive, could include shape memory alloy wires (Fig. 17.8(a,b)).



(a)



(b)

17.1 (a) Airship hangar *morphyt-nt* with an innovative inflatable, contractible/expandable three-layer membrane. (b) Human weight-controlled/operating building installation called *Transformacer p01*. (Source: Axel Ritter, 1995, 2002.) (Drawings by Axel Ritter, 2002/ modified 2011/2012.)

Intelligent architecture is becoming increasingly important, moving away from devices that work using the electricity grid and towards structures able to convert mechanical energy into electrical energy. One such approach consists in weight controlled mechanical structures able to generate and regulate, for example, the light and electrical power in a home, based on the number of persons in it. Another such application links mobile phones with home automation.

It is now possible to create smart buildings that can react directly or indirectly to their environments. Leading on from this, it is now possible to consider buildings that are able, for example, to heal themselves (e.g. the bentonite-based textiles shown in Fig. 17.7(a,b)), able to clean the air in rooms, or convert harmful substances to harmless substances.

17.2 Smart materials

Depending on physical and/or chemical stimuli, such as light, temperature, pressure, electric or magnetic fields, such as a chemical environment, smart materials are able, for example, to change shape or colour, generate an electrical current, or absorb and store water. Some are able to react with their environment (e.g. convert harmful into harmless substances [3,4,13,14]). Smart materials fall into several categories:

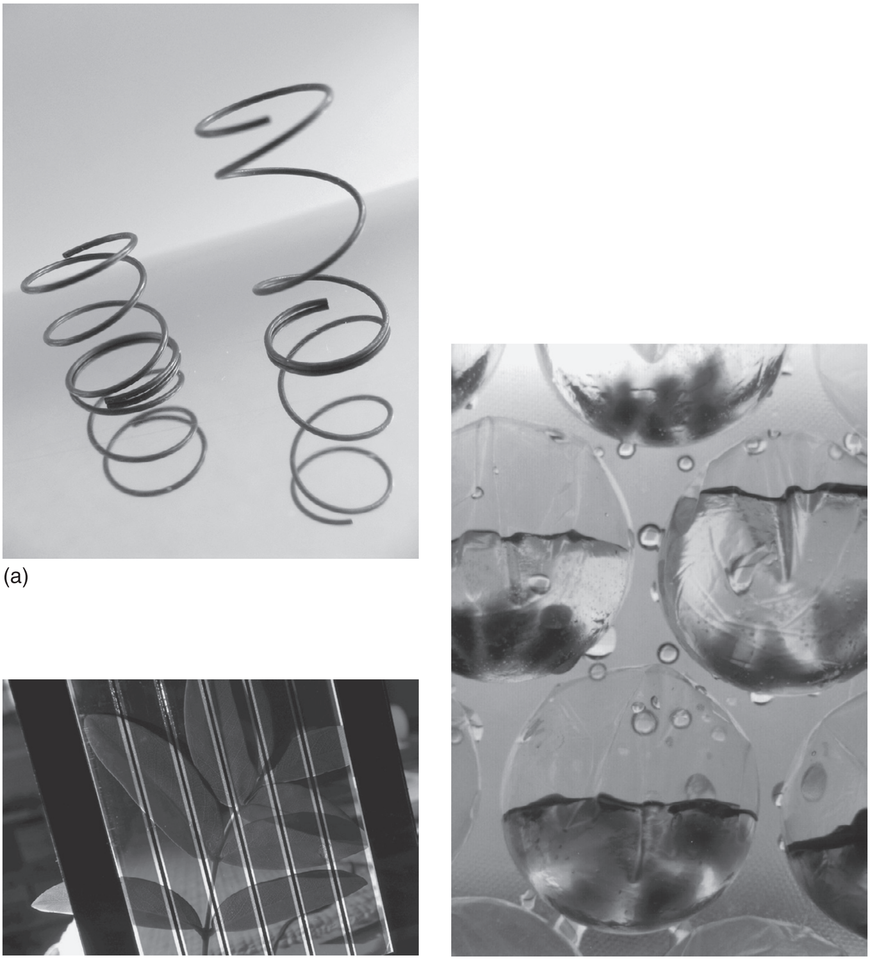
- property-changing smart materials;
- energy-generating and exchanging smart materials;
- matter-exchanging smart materials.

17.2.1 Property-changing smart materials

Shape-changing smart materials for example shape memory alloys, can and are able to change their shape in response to temperature (Fig. 17.2(a)). Such materials might be used in switching operations, such as a sun shade opening or closing in response to the amount of sunlight (Fig. 17.8(a,b)). Other materials can change their optical properties, such as thermochromic paints and electro-optic functional layers. These may be used in switchable glass systems to control the light entering a room and/or on textiles. With adhesion-changing smart materials, adhesion forces at their surfaces depend on parameters such as light, temperature, and electrical or magnetic fields. Examples include photo-adhesive smart materials operating with photo-sensitive titanium dioxide (TiO_2). An example of their use includes membrane-coated buildings, which are self-cleaning and air-improving in response to light conditions (Fig. 17.6(a,b)) [3,4,25].

17.2.2 Energy-generating and exchanging smart materials

Electricity generating smart materials include both well-established silicon-based solar cells, and the lesser-known dye solar cells that mimic the natural process of photosynthesis (Fig. 17.2(b)). The use of these, together with thermo-piezo and mechano-electrically operating systems, make possible the generation of CO_2-neutral electricity independent of the grid system. Applications include textile membranes embedded with piezoelectric elements that generate electrical



(a)

(b)

(c)

17.2 The three different types of smart materials: (a) example of property-changing smart materials, in this case shape memory alloy (SMA) springs showing a two-way effect (photo by Axel Ritter 2011); (b) example of energy-generating and -exchanging smart materials, in this case a dye solar cell (DSC) (photo courtesy of [20]); (c) example of matter-exchanging smart materials, in this case a functioning demonstrator of a *hydroabsorber foil* to control light transmission and improve the climate of rooms/buildings. (Source: Axel Ritter, 1995.) (Photo by Axel Ritter, 1995.)

voltage in response to wind-influenced mechanical pressure, which could be sufficient to switch a display operating with e-ink.

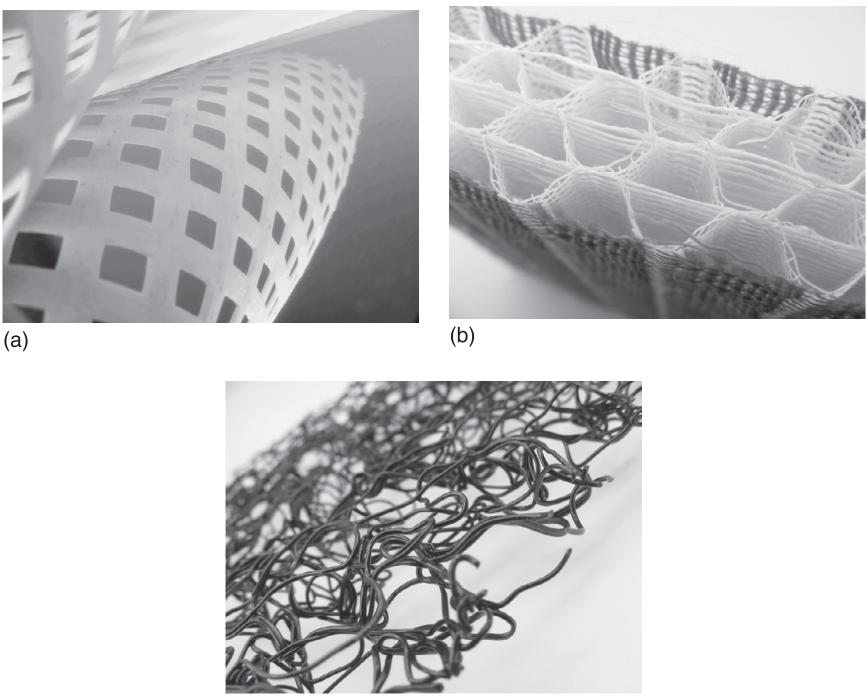
Other smart materials of this type are so-called phase change materials (PCMs), such as salt hydrate (Fig. 17.4b), which can cool rooms passively.

17.2.3 Matter-exchanging smart materials

These include smart materials that are able to absorb, store and/or release matter. Through ad- and absorbents it is possible to absorb water, store it and then release it through different textiles in which the water is embedded. Examples of use include passive cooling effects in façades. These materials are available in different forms, such as powders and granulates. In granulated form, they can be placed into the cavities of membranes (Fig. 17.2(c)).

17.3 Applications

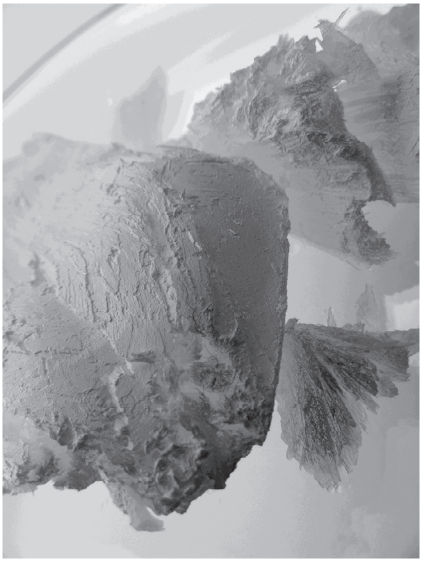
Following are some examples of passive and active in smart-textiles usable components (Fig. 17.3(a–c) and Fig. 17.4(a–c), respectively) and examples of architectural applications.



(a) (b) (c)

17.3 Examples of passive components, which could be used in smart textiles: (a) a square hole raster equipped membrane, made from coated polyether sulphone high tenacity (PES HT) yarn normally used as an architectural device for sun protection [21]; (b) a three-dimensional multilayer structural fabric cushion (unknown manufacturer); (c) a three-dimensional plastic mat normally used to protect against surface erosion [22, 23]. (Photos by Axel Ritter, 2011.)

(a) ((TiO_2))



(b)

(c)

17.4 Examples of active components, which could be used in smart textiles (a) titanium dioxide (b) special phase change material (PCM); (c) water-swellable polyacrylate. These and other active components could be combined, e.g. with the three-dimension multilayer structural fabric cushion to create air-purifying and latent heat-storing textiles. (Photos by Axel Ritter, 2006, 2012, 2010.)

17.3.1 Light-emitting metal mesh

A relatively well-known smart textile for exterior use is a special light-emitting metal mesh (Fig. 17.5(a–c)). Originally designed for building façades, this could also be used for complete colour changes of both façades and interiors. Modifying this type of material might involve application of organic light-emitting diodes, as opposed to the synthetic light-emitting diodes commonly used (Fig. 17.12(a,b)), and the replacement of ordinary metal components with fluorescent and/or phosphorescent metals in various components to achieve interesting and/or energy-saving multi-colour and lighting effects. Another development is a filigran metal mesh with interwoven phosphorescent fibres. Able to deform repeatedly, such a material is able to glow in the dark (Fig. 17.11(a,b)).

17.3.2 Self-cleaning membranes

Self-cleaning membranes refer to textile products able to clean their own surfaces by using the photocatalytic effect. One such membrane consists of a two-dimensionally (2-D) woven fabric made of polyester or glass fibre covered on both sides with polyvinylchloride, with an additional protective adhesive layer and an outer photocatalytic layer embedded with photo-sensitive TiO_2 (Fig. 17.6(a,b)). Another such product is made of glass fibre covered on both sides with polytetrafluoroethylene. A third operates with TiO_2 and the insulation material aerogel.

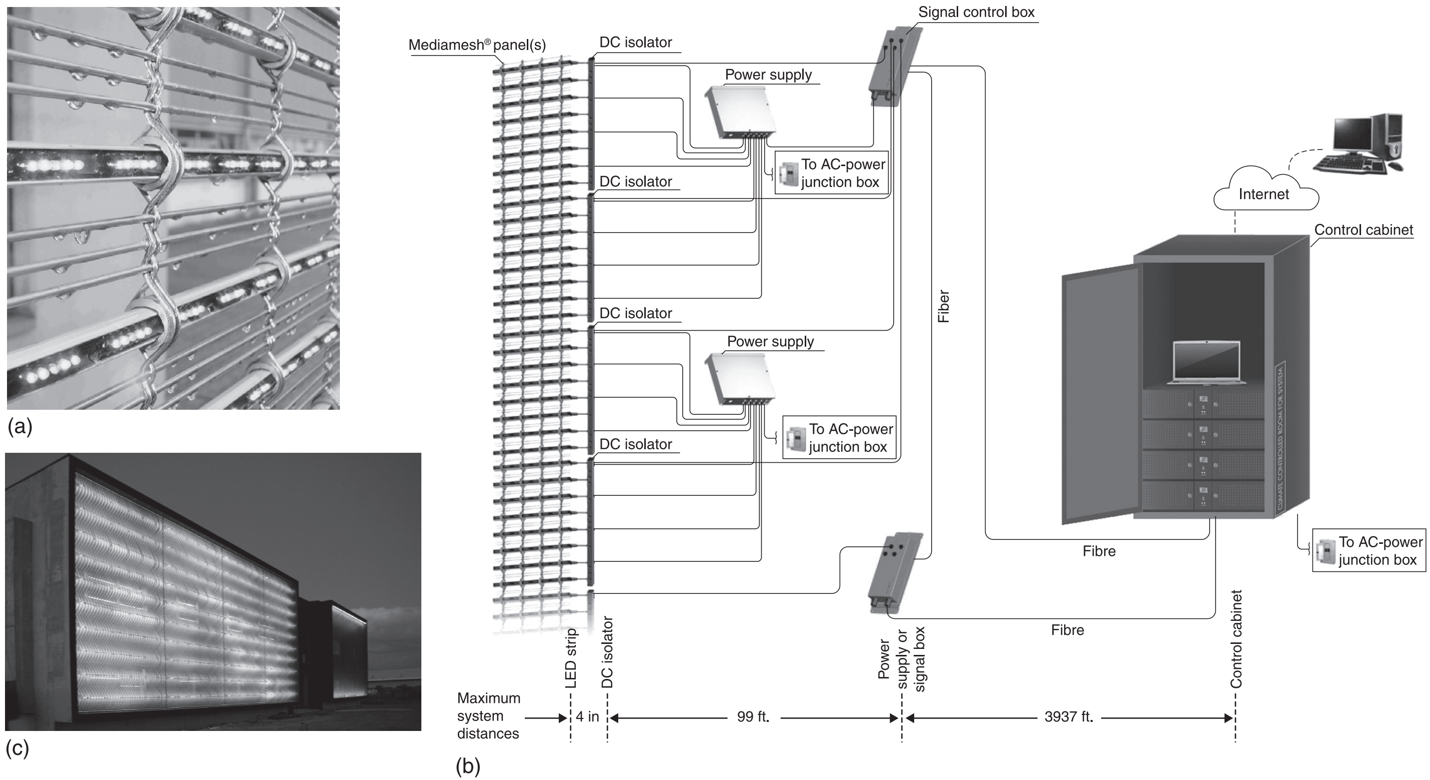
17.3.3 Self-healing textiles

One example of self-healing textiles are geotextiles, including the natural product bentonite on or between two textile layers (Fig. 17.7(a,b)). This material is water swellable and is able to expand and close cracks, etc. Products using bentonite include 'water stop' strips which, for example, isolate concrete parts of a basement against incoming water.

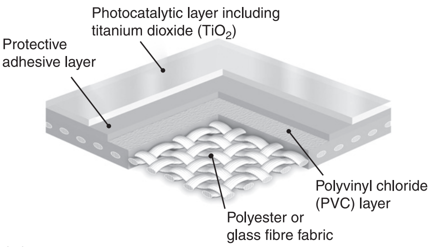
17.3.4 Shape memory interior textiles and other interior textiles

Shape memory interior textiles are able to regulate light and heat transmission, depending on the level of sunlight. They use shape memory alloy wires such as Nitinol. In this case, the material is responsible for the reduction or enlargement of the translucent areas of the textiles. These products are still in the prototype phase (Fig. 17.8(a,b)). Another smart textile using shape memory alloy wires is the temperature controlled hook and loop fastener (Fig. 17.9(a,b) [3,4]).

Other examples of products for the interior use are clay boards with embedded microcapsulated PCM and glass textiles (Fig. 17.10) (PCM, Section 17.2.2).



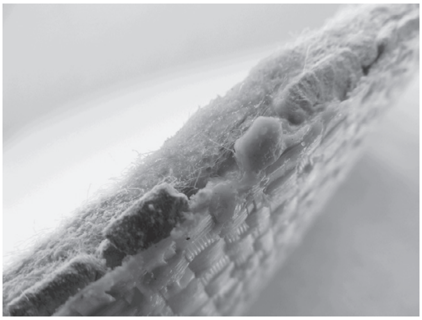
17.5 (a) A smart textile consisting of a metal mesh and LEDs (*Mediamesh*). (b) Wiring diagram of a new version of this textile, with six instead of five LEDs per pixel. (c) Application of similar textiles on the *Atelier a Torcé* (architect: Batir, France). (Photos courtesy of [24].)



(a)

(b)

17.6 (a) PVC-based membrane covered with a photocatalytic layer that has embedded TiO_2. (b) *Busan Bando* Model House (architect: Design Tomorrow Inc.), using a similar membrane. (Graphic and photo courtesy of [26].)



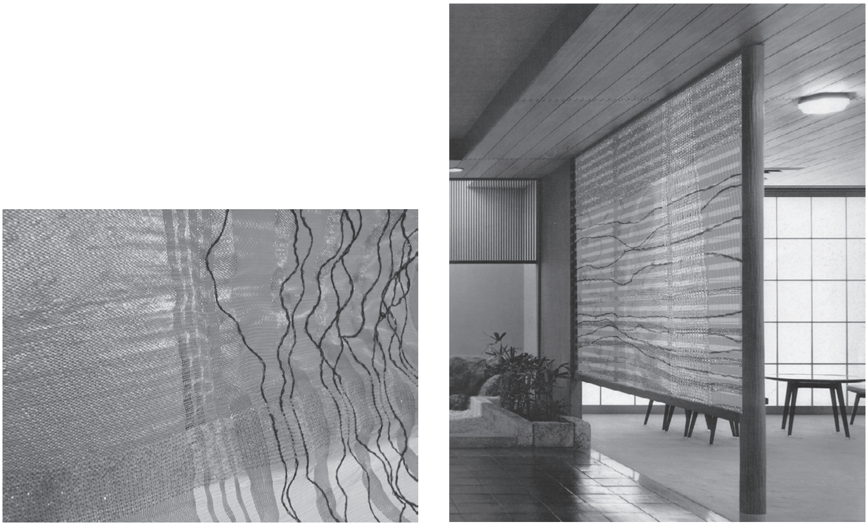
(a)

(b)

17.7 Geotextile with water-swellable bentonite: (a) textile partly activated; (b) Shanghai Airport under construction using this textile (architect: Murphy/Jahn). (Sources: [22, 23].) (Left photo by Axel Ritter, 2012; right photo, courtesy of [22].)

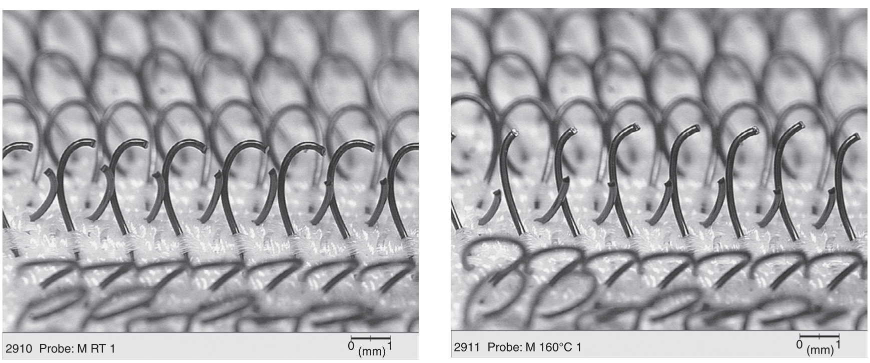
17.3.5 Actuators

Figure 17.13(a,b) show an actuator consisting of eight hydroactive strips that are able to change their length, depending on the humidity of the surrounding air. One end is fixed on the body of the drive, whilst the other end is mounted on a mechanical device that transmits movement to a valve regulating air transmission between indoors and outdoors. Normally, the actuators are found on the top of window frames as part of a humidity controlled, energy self-sufficient, ventilation system. Using such strips in series (as opposed to in parallel) might enable new kinds of fibres for large-scale actuators, for example to be used in the positioning



(a) (b)

17.8 Shape memory interior textiles: (a) detail of a shape memory interior textile with embedded SMA wires; (b) proposal for a room divider using such a smart memory interior textile. (Textiles and photos by Yvonne Chan Vili, 2003.)

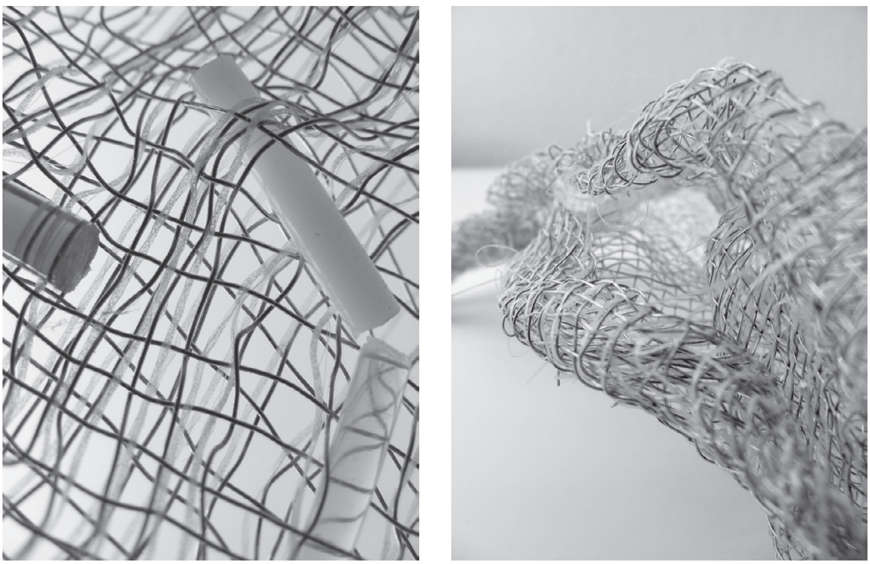


(a) (b)

17.9 Hook and loop fastener with nickel-titanium alloy hooks: (a) closed normal state; (b) open in response to a certain temperature. Textile developed and prototype built by EADS (A. Schuster, 2001). (Photos courtesy of [27].)

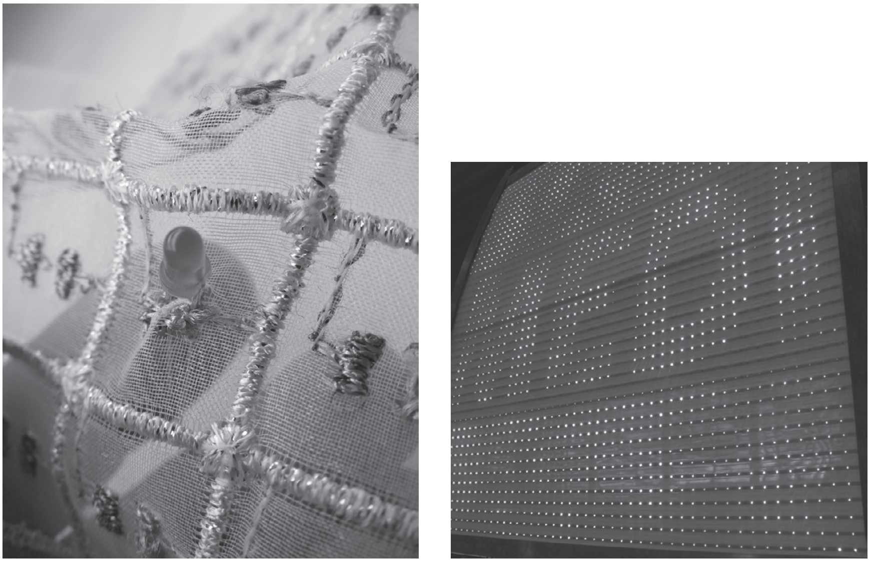
of building elements such as sunshades. This could also lead to large-scale fabrics operating like pinecones, opening and closing in response to humidity. Besides humidity transmission, this could also potentially be used to regulate light and/or noise transmission, filtration of polluted air, etc.

17.10 Detail of clay boards with embedded microcapsuled PCM and glass textiles. (Source: [28].) (Photo by Axel Ritter, 2011.)



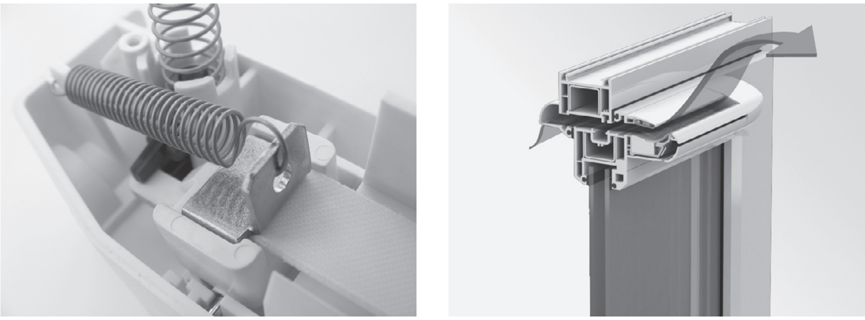
(a) (b)

17.11 Modified metal mesh with embedded phosphorescent fibres and additionally fixed fluorescent and phosphorescent sticks made from plastic polymethylmethacrylate (PMMA) and polyamide (PA): (a) close-up detail; (b) proposal for a building envelope. (Textile developed by Hannaliisa Johnson, 2005. The modification and deformation arrangement to simulate a building envelope was developed by Axel Ritter, 2011. (Photos by Axel Ritter, 2011.)



(a) (b)

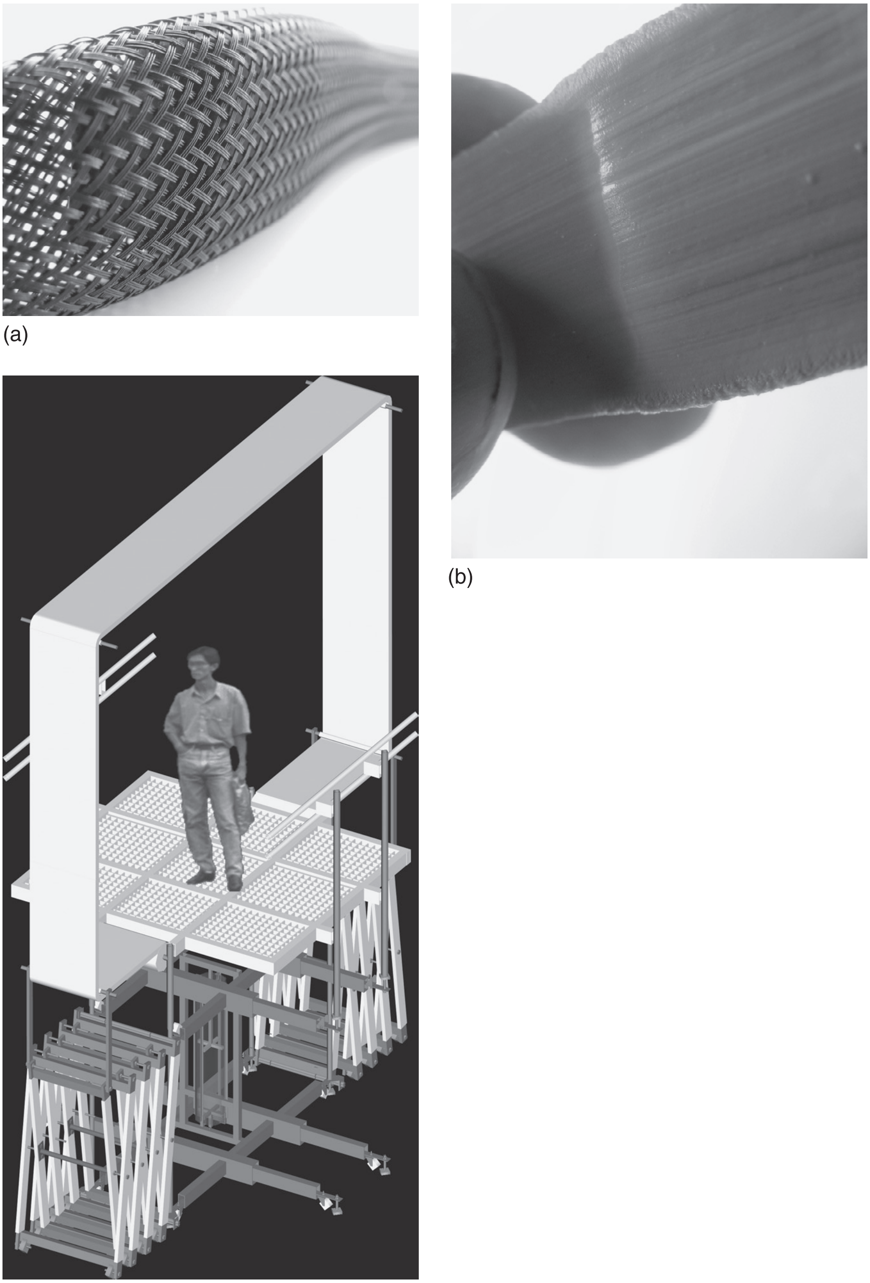
17.12 Two different types of smart textiles with rows of linear orientated LEDs: (a) detail of a textile with a conductive yarn and a connected LED (modification and photo by Axel Ritter, 2011); (b) media screen consisting of a smart textile with rows of linear orientated LEDs as a room divider. (Photo courtesy of [29].)



(a) (b)

17.13 Hygro-active strips and actuators: (a) details of an actuator (drive) consisting of eight strips; (b) rendering of a sectioned system mounted on a window frame. (Source: [30].) (Photo (a) by Axel Ritter, 2011.)

Figure 17.14(a,b), a new development by the author of this chapter, shows an expandable braided sleeve with an inner polymer-based strip able to swell with increase in water content. Depending on the absorption or desorption of water, the strips expand or contract and simultaneously, and the sleeve expands and contracts



(a)

(b)

(c)

17.14 New actuators: (a) detail of *Antriebsstrang II*, a smart-textile prototype developed and built by Axel Ritter 2004; (b) detail of a water-swellable polymer (polyacrylate-based) strip, partly activated; (c) kinetic building structure using such an actuator developed by Axel Ritter 2007. (Photos and graphics by Axel Ritter, 2011, 2009, 2007.)

accordingly. Figure 17.14(c) illustrates a suggested energy and matter self-sufficient kinetic building structure using smart textiles in a large-scale actuator. The actuator is located under a weight-sensitive platform. Platform and actuator movements influence the space-forming textile structure, which changes its geometry accordingly.

In 2009, a group of scientists at the Technical University of Darmstadt developed new actuators using the technique of 'thermobiometals'. These consisted of several different thermo-sensitive composite strips made, for example, from PVC as the active components, and differently-orientated carbon fibres as the passive components, the two combined with conventional two-component adhesives. A proposed architectural application using these materials is shown in Fig. 17.15(a,b). Similar considerations were already made around 1995 by the author and another student at the University of Stuttgart.

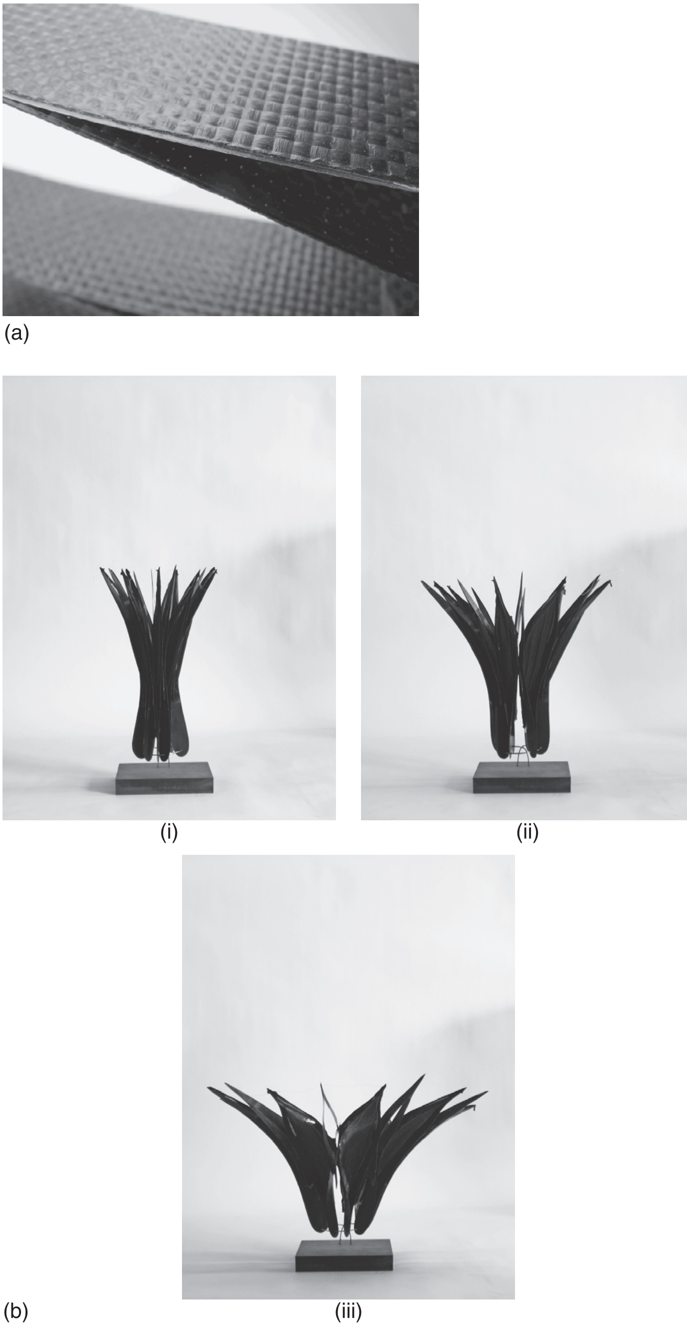
17.4 Future trends

17.4.1 Exterior textiles and actuators

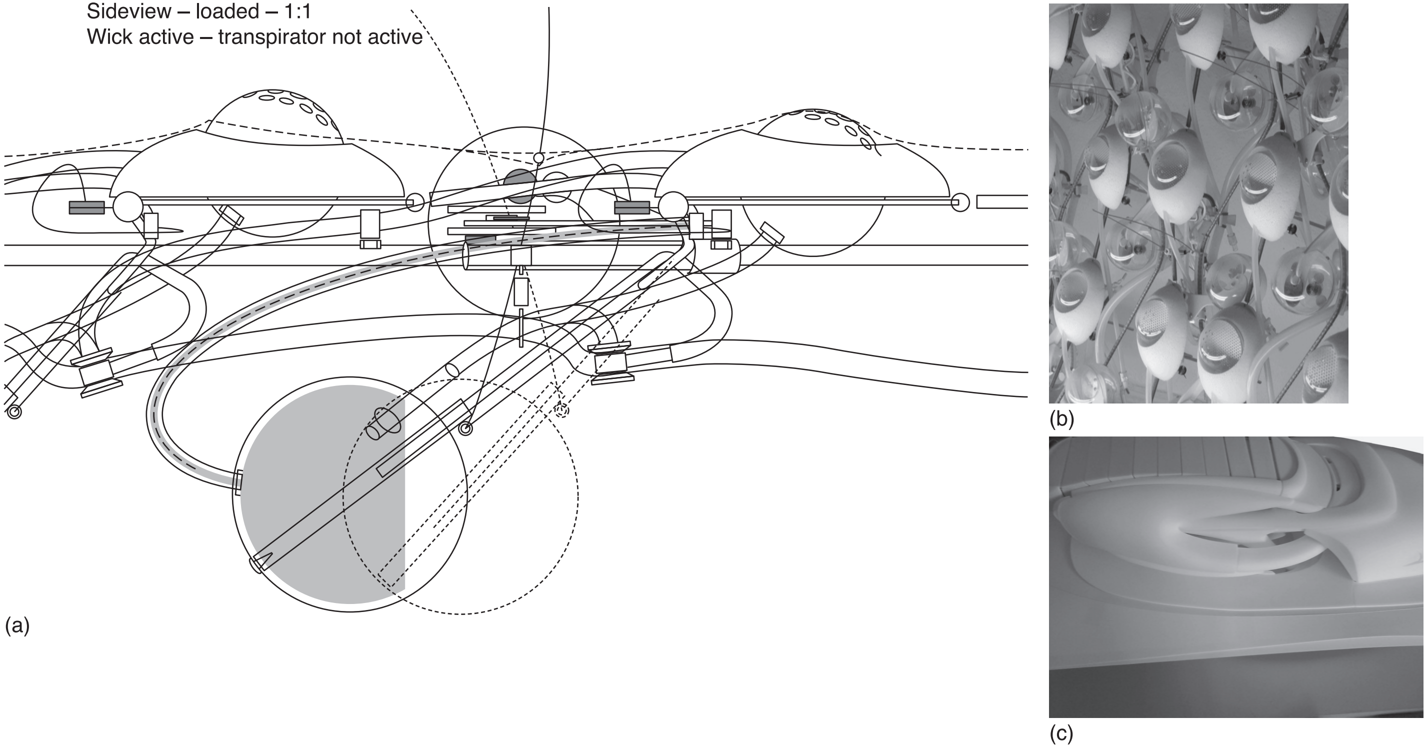
One concept is to create a building skin that behaves like human skin. A demonstrator developed by the author consists of a membrane that can change colour and structure, depending on temperature and humidity, and is able to cool down the temperature of the façade due to changes in temperature and absorbed rainwater (Fig. 17.16(a,b)). Figure 17.16(c) shows a possible architectural application. Another concept is the *_glowingSkin II* project, which is a multifunctional luminescent building and vehicle skin (Fig. 17.17(a,b)). This complex system is able, through the use of light tubes embedded into a flexible heat isolation material and an inner carrying layer made, for example, of strong polyester fabric, to harvest light energy and so save the requirement to use electricity from a grid.

Other proposals include conventional materials covered in gelatine or agar, serving as a food carrier for bacteria, algae, etc., which might be used for environmental monitoring, colour changes, air purification, etc. (Fig. 17.18). Also proposed is the use of nanometer-sized robots able to create different types of textiles with enhanced properties (Fig. 17.20).

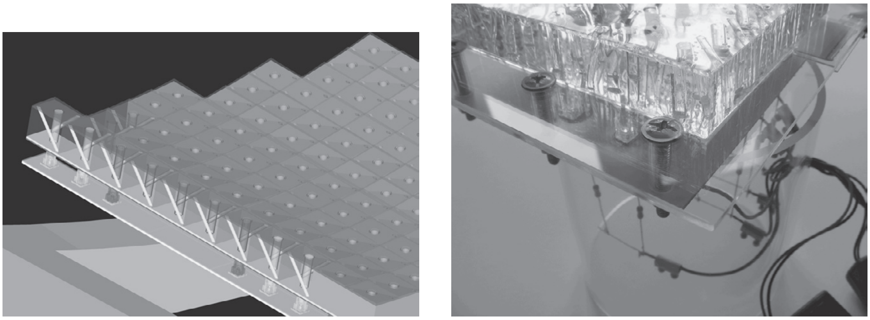
Not far from practical application are new smart-textile actuators developed by the author (Fig. 17.21(a–c)). These operate with super-absorbent polymers (Fig. 17.4(c)) that are able to swell quickly. Instead of using one single surrounding expandable textile, this actuator also has an inner elastic fabric to ensure the water-swelling components can not leave the inside. Applications include sun blinds, etc. and it should also be possible to realize large-area applications such as building skins that are able to cool and change their structure depending on the amount of water absorbed.



17.15 Thermoactive strips and actuators consisting of PVC with carbon fibres. (a) detail of a test carrier, called *Blume* (photo by Axel Ritter, 2011), (b) proposal for an autonomously opening and closing device of a smart building skin [31]. (Other photos courtesy of [31].)



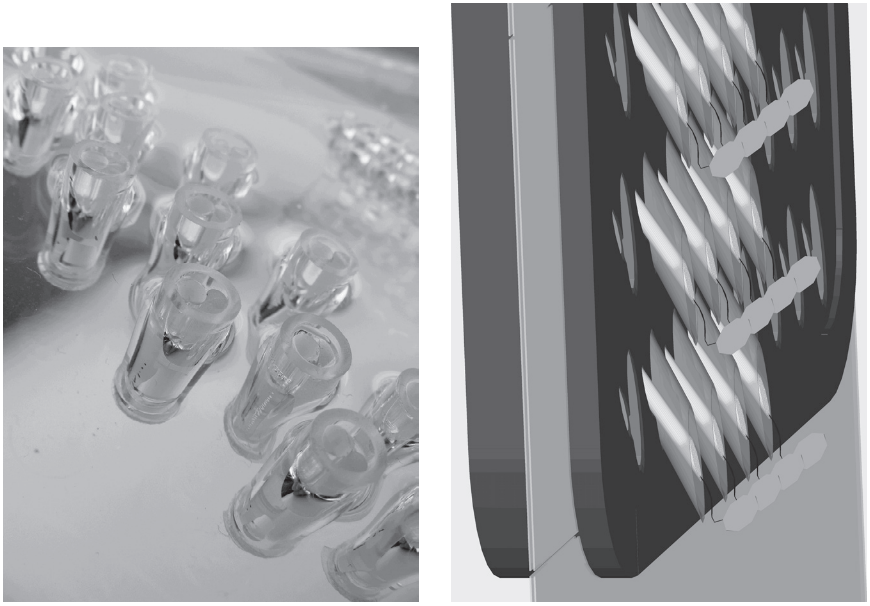
17.16 (a) Drawing of a section of *Polyreagible Mechanomembrane* showing different stages of construction. (b) Detail of the whole water-absorbing, -storing and -releasing system with thermobimetal and hygrobicomposite spiral springs as part of the smart component equipment. (c) Architectural application of the system at the *Futurologisches Zentrum*. (All content by Axel Ritter, 1995, 2007, 2012.)



(a) (b)

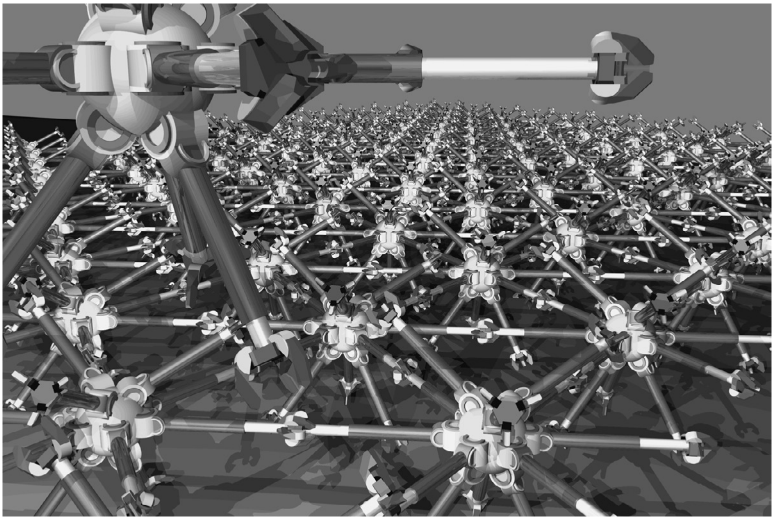
17.17 Multilayered, multifunctional luminescent skin called *_glowingSkin II*, consisting of an inner phosphorescent textile layer, with high power LEDs and a flexible outer layer made of silicone with embedded tiny flexible light tubes: (a) rendering; (b) a functioning demonstrator. (System developed/demonstrator built by Axel Ritter, 2007.) (Photo by Axel Ritter, 2007, 2008.)

17.18 Detail of a green gelatine surface with mold fungus an actual population of mold fungus in a room. (Concept, realization and photo by Axel Ritter, 2011.)

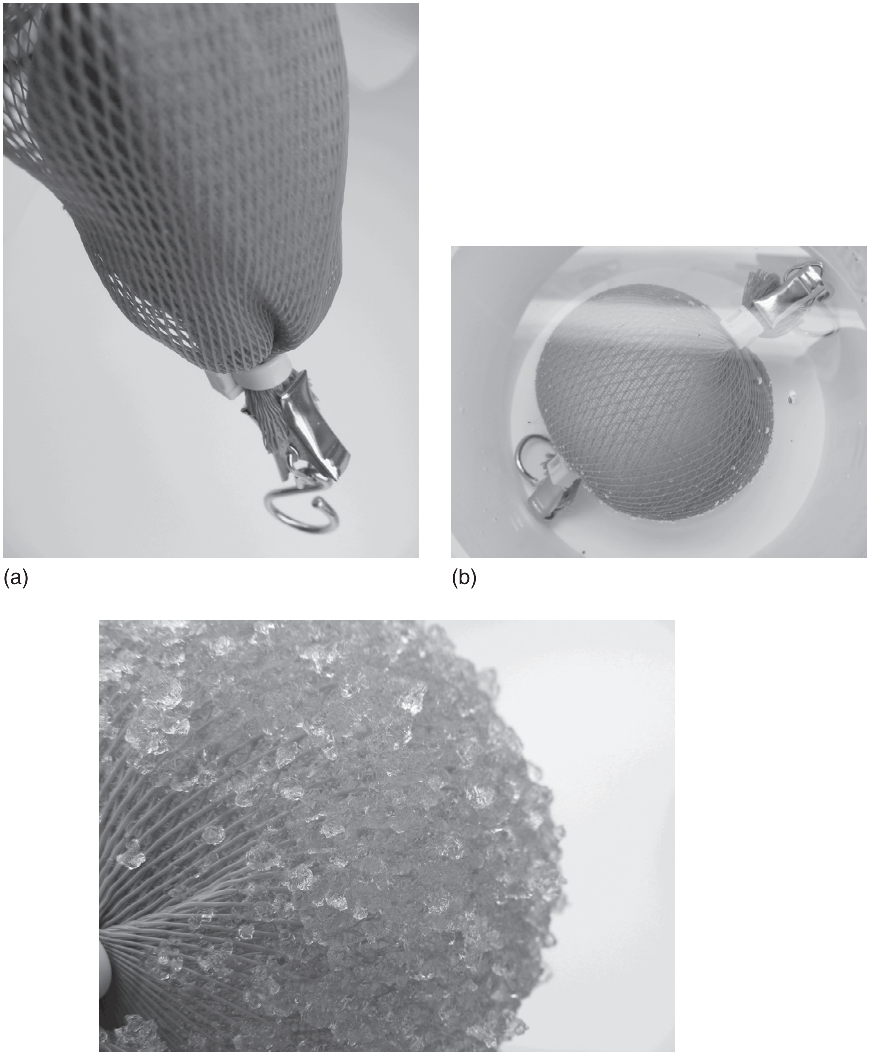


(a) (b)

17.19 Kinetic luminescent skin called *_glowingSkin I*: (a) detail of a functioning demonstrator; (b) proposal for an application as a room divider. (System developed and built by Axel Ritter, 2007). (Concept, realization and photo by Axel Ritter, 2011, 2007.)



17.20 Proposal for a flat structure constructed with *nanobots* [3,4]. (Courtesy of [32].)



(a) (b)

(c)

17.21 New actuator II: (a) detail of *Antriebsstrang II* equipped with a superabsorber 2012, when not activated and at normal length; (b) the entire device in contact with water, which has activated it and the device is nearly fully contracted; (c) detail of the activated surface. (Smart textile/demonstrator developed and built by Axel Ritter, 2012.) (All photos by Axel Ritter, 2012.)

17.4.2 Interior textiles

Figure 17.19(a,b) shows the *_glowingSkin I* project of the author, where a stable frame is embedded into a textile fixed, for example, to the floor and to the ceiling of a house. In the frame there is a translucent insulation element with fluorescent and phosphorescent sticks embedded in a matrix of silicone. The use of these sticks, surrounded by transparent tubes, and with the use of heat-sensitive Nitinol wires (fixed on small mirrors), forms a kinetic structure that is able to create different light effects energy self-sufficiently. Such an arrangement can also be used for room dividers (Fig. 17.19(b)), as ceiling elements, and also for façade elements. Nanotechnology may also be used to transform room interiors according to the wishes of the occupants. For example, a textile wall might convert to a more rigid wood-like wall, with an accompanying change of perfume from flowers to forest. Walls, and if wanted/needed, other building elements, might also change their geometry with this technology (Fig. 17.20).

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25. *TiO_2 Photocatalytic Membrane* product information of Taiyo Kogyo Group, Japan.
26. Taiyo Kogyo Group, Japan.
27. Schuster A EADS Deutschland GmbH, Germany, EADS Innovation Works.
28. Lebast, Germany.
29. LEUROCOM electronic displays, GmbH, Germany.
30. Aereco GmbH, Germany/France.
31. Hauschild M (TU Darmstadt, Germany), Karzel R (FH Köln, Germany), cand Arch Ljubas A cand Waidelich Tim – 1st phase: cand Arch Saskia Mayer cand Arch Frauke Hausi (TU Darmstadt, Germany).
32. J. Storrs Hall, USA.