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The Efficiency of the Intelligent Materials in the Patient Room

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Abstract

The paper investigates the efficiency of using the intelligent materials in the patient room of the health care buildings, as they have a role in the infection control and the various aspects of healing the patients. The purpose of the paper is to focus on these new materials to be used as sustainable materials in the healthcare buildings. Two main concepts concerning the intelligent materials are discussed, the first one figures the intelligent materials nowadays, and how they act as sustainable materials while the second one represents the opinion of how these materials can be used in the patient room with efficiency to be a part of the healing process of the patients.

Keywords

intelligent materials; Smart materials; infection control; the healing aspects; the ambient environment; the patient rooms.

1. The preamble

Nowadays intelligent materials are called the "Welfare" which is a technology that offers many solutions to human beings' healthcare, especially in architecture. They play a vital role in reshaping the means of life as they could replace the traditional materials or reshape their performance. They are examined and used in various buildings, but each one of them represents a specific prototype in the project which it is a part of. Although smart materials sounded to be efficient in both environmental and economic aspects, there are no categories for these materials to be used in the health care buildings until now. At the same time, the patient room is a complicated issue in these buildings because there are various topics to take in consideration other than its design and functionality. One of these considerations is the materials used in it, which directly affect the environmental circumstances present in this room. (Cullinan, 2010)

Moreover, the traditional materials used in patient room have various problems as follows:

• The glass used in the windows has problems while constructing this room, as they need many applications to suit the various needs they are designed for, such as: the clear visibility, the reduction of heat transition and harmful sun rays, the glare and the patient privacy.

• The materials used in the final finishing of the room or in the furniture have no capability to be easily cleaned, so they can lead to the propagation of infection inside the room.

• The efflorescence of the masonry and the concrete mold discoloration formed due to the humidity are means of lung infection.
• The materials concerning sound insulation, such as: cladding materials of the partitions, finishing floors or false ceilings, are not matching the indoor quality efficiency as they emit various toxics.

At the same time, the health care fabric industry faces significant challenges nowadays. Many agencies such as; The Healthy Building Network (HBN) and Health Care Without Harm (HCWH) work with health care institutions to enhance the functionality and performance in fabrics without compromising environmental safety or human health as they move the market to develop and produce greener and healthier building materials. Also, many sectors of the market including the fabric industry have responded by removing or substituting some of the worst-in-class chemicals from their products, and they also invested dollars while attempting to research into bio-based materials and safer alternatives. As a result, significant methods have been developed to reduce the risk of environmental exposures for hospital staff, patients, and the larger global community such as producing green materials and products which provide solutions to environmental problems. (Silas, 2007)

1.1. The liability issue

Multiple researches were conducted in the field of constructing the patient room and they ended up focusing only on the following: the zonings of the room content, the relations between the main topics of the room, the indoor quality and the proposed traditional materials used in the room. It was noticed that there were no researches targeting the relation between the new trends of the technological materials and the aspects of healing the patient in form of efficiency. In spite of the presence of hundreds of millions of patients globally that are affected each year by healthcare-associated infections (HAIs), due to the inefficient materials used in the patient rooms. In 2011, around 75,000 U.S. hospital patients died in the United States of America with HAIs. (Harris, 2017)

The questions are: In the health care buildings, could the intelligent materials improve the quality of the patient room if they were involved in its construction? And what is the level of their efficiency in such spaces ?

1.2. The objectives

This research aims to focus on the following: firstly, the relation between the intelligent materials and the patient room. Secondly, the effect of these materials on both, the ambient environment and the infection control which represent the physiological needs of the patient leading to his healing .

1.3. The hypothesis

It is considered that intelligent materials are sustainable materials which can enhance the internal environment of the patient room and lead to the patient's healing.

1.4. The methodology

In order to achieve the objectives, this study has followed two approaches. First, it used a literature review to introduce the intelligent materials in form of sustainable materials. Second, it has been relied on assessment approach to study the relation between the healing aspects in the patient room and the functional performance of the intelligent materials. Finally, the results insist that the usage of the intelligent materials in the patient room will enhance the components and the construction of the patient room.

Table 1. **Nomenclature**

HBN	Healthy Building Network
HCWH	Health Care Without Harm
UV	Ultra Violet
TiO_2	Titanium Dioxide
ZnO	Zinc Oxide
CeO	Cero Oxide
VIPs	Vacuum Insulation Panels
HVAC	Heat, Ventilation and Air Conditioning
ULEHB	Ultra Low Energy High Brightness Light
HAIs	the Healthcare-Associated Infections
WHO	World Health Organization

2. The intelligent materials

The intelligent materials appeared at the end of the twentieth century, they reached the architectural industry and managed the buildings to control most of their systems. These materials have two phases: the first one represented the ability to perform sensing and actuating functions, similar to those in living systems, and their basic components are: sensors, control and actuators. (Akhras, 2012), (Sun, 2015)

The second phase is known as the huge development which invaded the chemical and industrial fields through the appearance of the nano technology. This nano technology produced nano materials which enhanced the efficiency of the materials and solved many problems in the environmental control issues. (Konarzewska, 2017)

2.1. The intelligent materials in the first phase

These materials are called smart materials which are forms of sensors and actuators and divided into two types as follows:

2.1.1. Type 1:

Materials undergo changes in one or more of their properties (chemical, electrical, magnetic, mechanical, or thermal) in direct response to external stimuli in the surrounding environment. As the external stimuli represent the energy input to the material which affects its internal energy and alter its microstructure, so the result is the change in the materials property, (Vavan, 2014) as shown in fig (1).

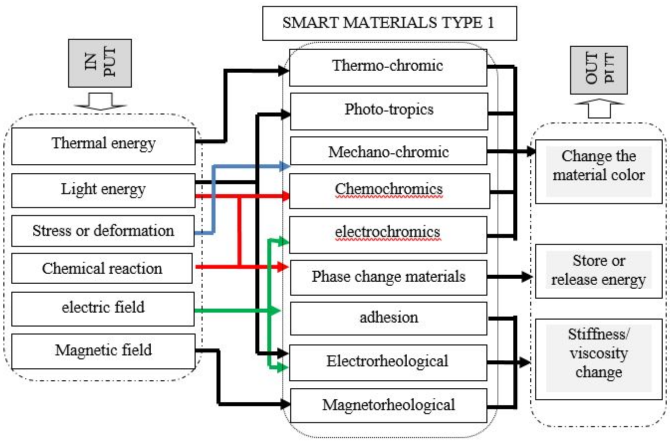

Figure 1. type 1 of smart materials that undergoesproperty change with response to an external energy (Vavan, 2014) edited by the authors.

2.1.2. Type 2:

Smart material transforms energy from one form to another. As the energy input to the material changes the energy state of its composition, but does not alter the materials property. (Sun, 2015), (Vavan, 2014), (Konarzewska, 2017), (Mahdavinejad, Bemanian & Khaksar, 2011) shown in fig (2)

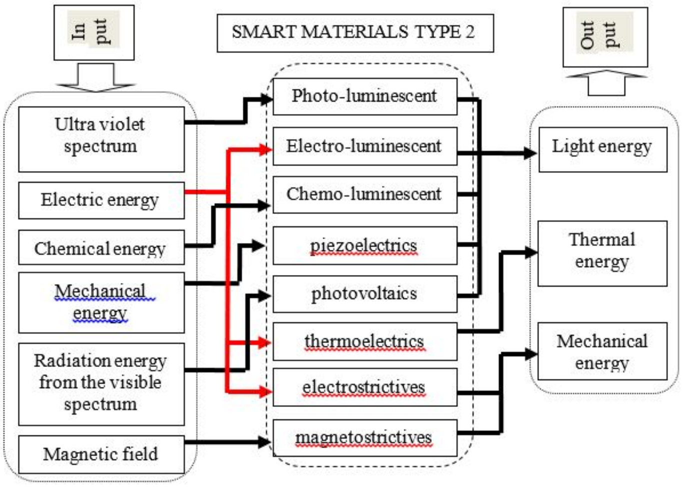

Figure 2. type 2 of smart materials that transforms energyfrom one form to another. (Sun, 2015), (Vavan, 2014), (Konarzewska, 2017),(Mahdavinejad,Bemanian & Khaksar, 2011) edited by the authors

2.2. The intelligent materials in the second phase

They are called Nano scaled materials and they have four types; Nano particles, Nanowires, Nano films and Bulk Nano material, as shown in fig (3). These materials, which are reduced to nano-scale, can show very different properties compared to what they exhibit on a macro-scale; they are involved in unique applications. For instance, opaque copper substances become transparent and inert platinum materials attain catalytic properties . ("Smart Nanomaterials in Construction Works and Their Applications", 2019)

The most famous applications in the industrial and architectural fields appeared to be coatings; however, nanotechnology can add permanent effects and provide high durability fabrics due to the large surface area-to-volume ratio and high surface energy of nanoparticles. The previous researches show that coating with nano-particles can enhance the textiles with properties such as anti-bacterial, water-repellence, UV-protection and self-cleaning, while still maintaining breath-ability and tactile properties of the textile. (Vavan, 2014) , (Sun, 2015)

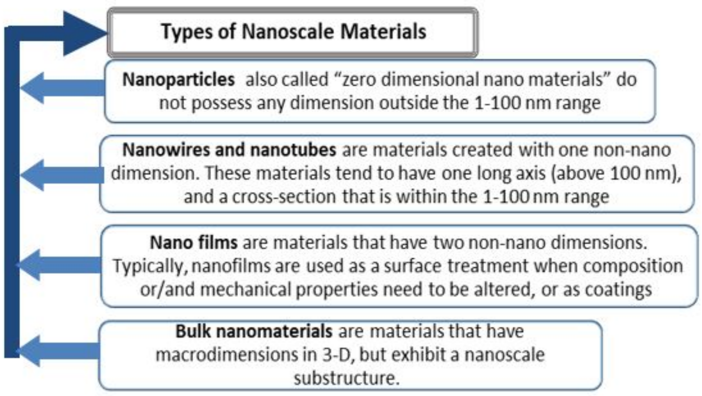

Figure 3. the types of Nano materials and their properties (Vavan, 2014) edited by the authors

2.3. The intelligent materials as sustainable materials

Sustainability in the materials calls for the environmental and economic efficiency, and the intelligent materials fulfills these two efficiencies; they are a type of advanced technologies, they settle between the low tech and the high-tech applications. these materials are presumed to be very classy; they can direct and distinct substitute for much larger systems. They can solve the obdurate problem of ever-increasing energy use by building systems. Designing mainly with smart materials is essentially just mapping the relationships between energy forms and state changes. The material chosen would be the simplest and most straightforward to produce the desired effect. Choosing the material does not determine the effect, rather the material is determined by the effect. Smart materials may simplify the systems used in the buildings. (Addington, 2014)
Intelligent materials are mainly designed to cope with the smart maintenance as they are responsible for the following:

- Optimizing the response of complex systems. This is done by establishing early warning systems, enhancing the range of survivability conditions and/or providing adaptive response to cope with unforeseen conditions and situations.
- Providing better control for the used systems. This could lead to improving the design and performance of new geometries for special applications.
- Improving the functionality of the system by a proper preventive maintenance and performance optimization.
- Improving the health monitoring of the system and better control of its active, adaptive or smart functions.
- Nano materials can help achieving a more sustainable environment, such as: improving energy efficiency and reducing greenhouse gases.
- The use of surface properties of the materials offers a mean of achieving greater energy efficiency and sustainable architectural design. (Akhras, 2012), (Atwa, Al-Kattan, & Elwan, 2015)
- Smart materials offer solutions of great new aesthetic effects and make an innovative field of inspiration for architects, designers and artists. They change color or appearance, are able to emit sound and odor, reveal refined patterns, change shape, and are able to produce kinetic movement or display interactive images. With their special aesthetic features they attract the attention of building users and public space participants, being more noticeable than other more functional smart solutions. There are more of these kinds of solutions in architecture, art and design because they are simpler and require less effort to make experimental surfaces or sculptures. (Ritter, 2007)

3. The role of the intelligent materials in healing the patient in his room

3.1. The factors of healing and its relation to the materials in the patient room

The infection control and the ambient environment are considered to be the two major factors that could optimize the patient well-being and comfort. (Cullinan, 2010) And they both are in common relation with the materials used in constructing the patient room, as shown in Fig (5)

3.2. The role of the intelligent materials in the infection control

Lately, intelligent materials shared in a wide scope in the infection control, as; they played a role in enhancing the cleaning process, shared in purifying the air and attacked the bacteria and the factors producing it as follows:

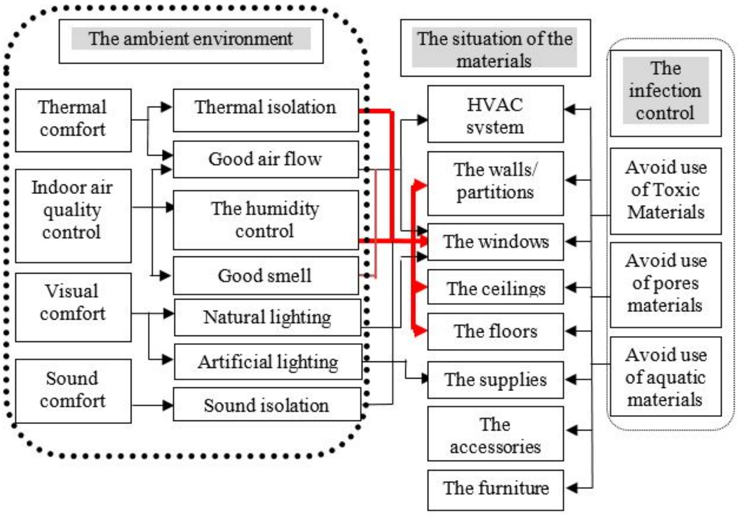

Figure 4. the relation between the materials and theambient environment and the infection control. (Cullinan,2010) (edit by theauthors).

3.2.1. Materials enhance the cleaning process:

Self-cleaning / easy to clean Nano Coatings which are either lotus effect or self- cleaning photo catalysis, as titanium dioxide (TiO_2). Self- cleaning lotus effect is to be called (Hydrophobic-water trickles), they are microscopically rough, not smooth and well suited for surfaces exposed to sufficient quantities of water. It needs low maintenance. While self-cleaning photo catalysis are Hydrophilic surfaces as the deposited dirt is broken down in the presence of UV light and little amount of water, (Leydecker, 2008) as shown in fig (5).

Figure 5. the application of self-cleaning of glass (Leydecker, 2008).

3.2.2. Air purifying materials:

Adding nano silica to the concrete purifies the air while exposing to sun light, as it eliminates the bad smile and the waste products in the void, but without ignoring the natural ventilation to permit air which help in reducing humidity. (Leydecker, 2008), (Hanafi, 2012)

3.2.3. Anti- bacterial materials:

coatings have very high surface area to volume ratio of the nanoparticles, which means that the ions can be emitted more easily and therefore kill bacteria more effectively. (Hanafi, 2012) They are in form of Chemical vapor deposition, Dip, Meniscus, Spray and plasma. Nano silver particles can be used in coating textiles as silver ions prevent the cells from absorbing bacteria and it makes stain less effect on various products as shown in fig (6). Also, nano Tio2 is used as anti-bacterial coating for various metallic products. And is used in making anti-bacterial cement tents (Leydecker, 2008), as shown in fig (7). These coatings are used in Berlin, in operating theater floors and walls to lessening the risk of infection. (Nanotechnology product catalog for professionals, 2013)

Figure 6. samples of the products can use nano silverparticles to be anti- bacterial (Hanafi,2012)

Figure 7. Abacterial cement tents (Leydecker , 2008)

Moreover, there are inorganic nano materials used as coatings to absorb the ultra violet rays, so they reduce the harmful effect of these rays on the organic products. The nano materials used are; titanium dioxide (Ti02), zinc oxide (ZnO), Cero oxide (CeO).

3.2.4. Water proving effect

Nano zinc oxide is used in the manufacture of textiles and it gives the product extra property which is water proving, as a result it prevents the attachment of the bacteria to these textiles. ("Nano-Technology", 2019)

3.2.5. The cure of salts and humidity

Pre-sealing nanotechnology produced admixtures as; Nano silicon, which can be added in the process of manufacturing pressed concrete products (Tech-Dry Masonry). These admixtures significantly reduce water absorption in the concrete, and hence reduce the presence of unsightly long-term efflorescence and concrete mold discoloration, as a result it prevents the presence of any bacteria on the surface of the masonry, and any further treatment for these surfaces. (Tech-Dry® Australia, 2019)

3.2.6. The infection detector

There are smart materials of phase change property, used as furniture finishing layer that show thermo-chromic prints as a proof of receiving bodies of high temperature, as a result they indicate the presence of the infection in the space. (Sun, 2015) shown in fig(8).

Figure 8. to the right the thermo- chromic bed (Ritter, 2007) , and to the left thermo- chromic pair chair with middle table (Mahdavinejad, Bemanian & Khaksar, 2011)

3.3. The role of the intelligent materials in enhancing the ambient environment

3.3.1. Enhancing the thermal/ sound insulation

a.Nano insulators as; nano foam, powder or glass fibers succeeded to be used as the filling materials in the Vacuum Insulation Panels (VIPs) which are one of the innovations that have maximum thermal insulation and minimal insulation thickness. Its cladding skin is made of plastic foil or of stainless steel. It is to be used for both new building constructions and the renovation work, and can be applied to walls as well as floors as shown in Operating theatre, Goslar, Germany fig(9) (Atwa, Al-Kattan, & Elwan, 2015, p. 3551-3564)

Figure 9. (VIPs) panels used in Operating theatre, Goslar,(Atwa, Al-Kattan, &Elwan, 2015, p. 3551-3564)

b.Temperature regulators as; Phase Change Material (PCMs) always made from Paraffin and salt hydrates. They can be imbedded inside the panels used in the outer envelope of the building. They regulate the heating and cooling demands, as the gained/ lost energy through the panels is to be consumed in changing the physical state of the paraffin from the solid state to the liquid one, and visa verse. They are economically efficient as a thickness of 1 mm of paraffin can be used to reduce 5 Co of temperature. (Kancane, 2016), (Fokaides, Kylili & Kalogirou, 2015)

c.Eliminating noise: The Smart Material Actuated Rotor Technology (SMART) aims to reduce the vibrations and to eliminate the noise of helicopters and aeroplanes by up to 80% as it is used to be the envelope of aeroplanes as shown in fig (11). (Akhras, 2012)

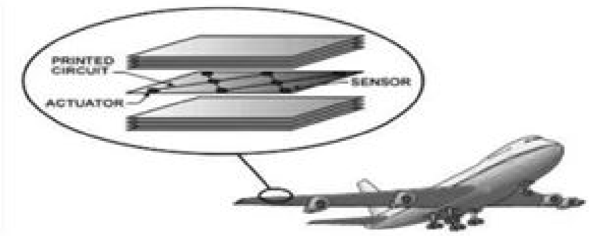

Figure 10. the insulating envelope of the aero planes (Akhras,2012)

3.3.2. The role of enhancing the HVAC system

Smart dusts used as smart sensors which can communicate till 100m far to optimize the HVAC systems. They can communicate wireless via the radio to promote temperature, humidity, luminance intensity and vibrations. (Seeboth, Schneider & Patzak, 2000)

3.3.3. The role of artificial lighting efficiency

a.Organic nano polymers: are energy producer/transformer and are used instead of silicon in photo voltaic units to absorb solar energy and convert it into electric one. They reduce the cost of operating electricity and produce three times watts of energy more than that produced from the traditional photo voltaic units. And no poisoned materials can appear while manufacturing them. (Shiha, 2014) , (Senjen, 2009)

b.Quantum dots: are nano crystalline particles containing only a few hundred atoms that when expose to incident light they emit radiation of a particular color such as Cadmium Selenide CdSe. These dots emit only one wavelength of light when excited. Thus, they represent an aspect glorifying the economic light as, and can be used in the design of the reflective surface that will be exposed to incident light, as; floors, walls and ceilings. ("Applications Of Carbon Nanotubes", 2019)

c.Organic composites (carbon nanotube): used in Ultra Low Energy High Brightness Light (ULEHB), that reduces energy running costs and reduce the emissions of carbon dioxide. It has potential benefits as it can be used as variable mood lighting over a whole wall or the ceiling of any space. ULEHB can be related to the sustainable energy as, it can produce the same quality of light as the best 100 watt light bulb, but it consumes only a fraction of the energy and lasts many times longer. It is expected to use in the market in various fields, as, it can be used in the exhibitions, street lighting, commercial lighting, public buildings and offices lighting, also it can be used in the hospitals. ("Applications Of Carbon Nanotubes", 2019)

3.3.4. The role of enhancing the natural lighting/ thermal insulation

a.Thermo-chromic /photo chromic/ chemo chromic: they are smart materials which change their color by receiving excess heat, ultra violet, infra-red spectrum or by means of chemical catalysts. These chromic can be managed to reach the thermal and light comfort, as they can control light and heat through the building envelope. They are named according to the kind of actuators they are exposed to, as, they are called thermo-chromic if the actuator is heat, photochromic if the actuator is light, and chemo-chromic if the actuator is a chemical catalyst. As shown in fig (12). (Mahdavinejad, Bemanian & Khaksar, 2011)

Figure 11. the Cars display store in Singapore ascontrolling the size of the smart application , the color of the light radiation and the light intensityin the windows. (Mahdavinejad,Bemanian & Khaksar, 2011)

b. (Electro-chromic materials and Suspended particles applications): Electro-chromic materials change color while applying electrical voltage. Electro-chromic windows darken when a voltage is applied and become transparent when the voltage is removed. (Leydecker, 2008) as shown in Fig (13). The electricity rearranges the suspended particles to permit the needed light, as the range of light emission begins from 1% till 57%. ("How Smart Windows Work", 2019)

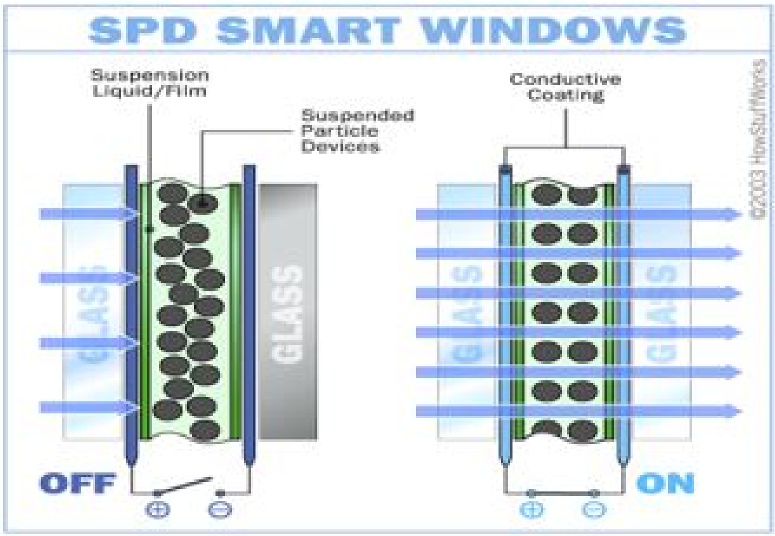

Figure 12. the system of the Suspended particles applied in the windows ("How Smart Windows Work", 2019)

c.Aerogel: It is a transparent gill material impeded inside a multi-layer glass windows, 99.8 % of its volume is composed of air, with density of 3mgm/cm, so it is three times denser than air, and it is considered to be a good heat isolator (it resamples 10-20 cm glass thickness as heat isolation), when exposed to direct sun rays it solidify to be semi-transparent, and its transparency depends on the intensity of light and the sun light rays angles.
The silica gill used in double glass windows reduces the heat emissive factor of glass and optimizes the light transmittance factor. Aerogel used in glass windows are sound isolators and scatters light ray to cure glare. (Atwa, Al-Kattan, & Elwan, 2015, p. 3551-3564), ("Coagulation technology co., LTD", 2019)

d.Nano gill: The Nano dimension is of vital importance for the pore interstices of the foam, as the air molecules trapped within the minute Nano pores; each with a mean size of just 20nm, unable to move, lending the aerogel its excellent thermal insulation properties. It can be used as an insulating fill material in various kinds of cavities – between glass panels, U-profile glass or acrylic glass multi-wall panels – and is therefore well suited for use in external envelopes of buildings. That way aerogels can help reduce heating and cooling costs significantly. Because it is translucent, aerogel exhibits good light transmission, spreading light evenly and pleasantly. In addition to its thermal insulating properties, aerogel also acts as a sound insulator according to the same basic principle. With its above-average thermal and sound insulation properties aerogel contributes towards energy efficiency, which is its primary functional property. (Hatch Tensile Membrane Structures, 2019)

e.Nano coatings as ceramic nano films: they convert the color of the glass to be darker while exposed to more heat energy as shown in IMI Kolkata Centre fig (14). These coatings reduce the electric energy used to control the chromic system. It can reduce 57 watts. Moreover, Nano films give strength to the glass, absorb the infra-red and ultra violet rays and reduce 3-3 co of the latent heat. (Abou-ghazala, Fared, & Al-Shami, 2014)

Figure 13. internal shoot of IMI Kolkata centre- Kolkata,West Bengal, India. (Abou-ghazala,Fared, & Al-Shami, 2014)

4. Results and discussion:

4.1. The categories of applications of intelligent materials in the patient room as aspects of healing the patient

4.1.1. The applications within the structural system (structural elements and claddings), these applications shown previously can enhance the following:

- Noise isolation
- Thermal isolation
- Humidity control
- The Anti- bacterial effect

4.1.2. The applications within the fittings (HVAC systems, light systems), can enhance the following:

- Optimize smart control within sensors
- Air purifying
- Reduce the usage of electricity by emitting light and producing light.

4.1.3. The applications within the finishing materials (paintings, floors, ceilings, corner curing doors and windows), can enhance the following:

- The protection from the ultra violet rays
- The protection from bacteria
- The cleaning process, As shown in fig (15)

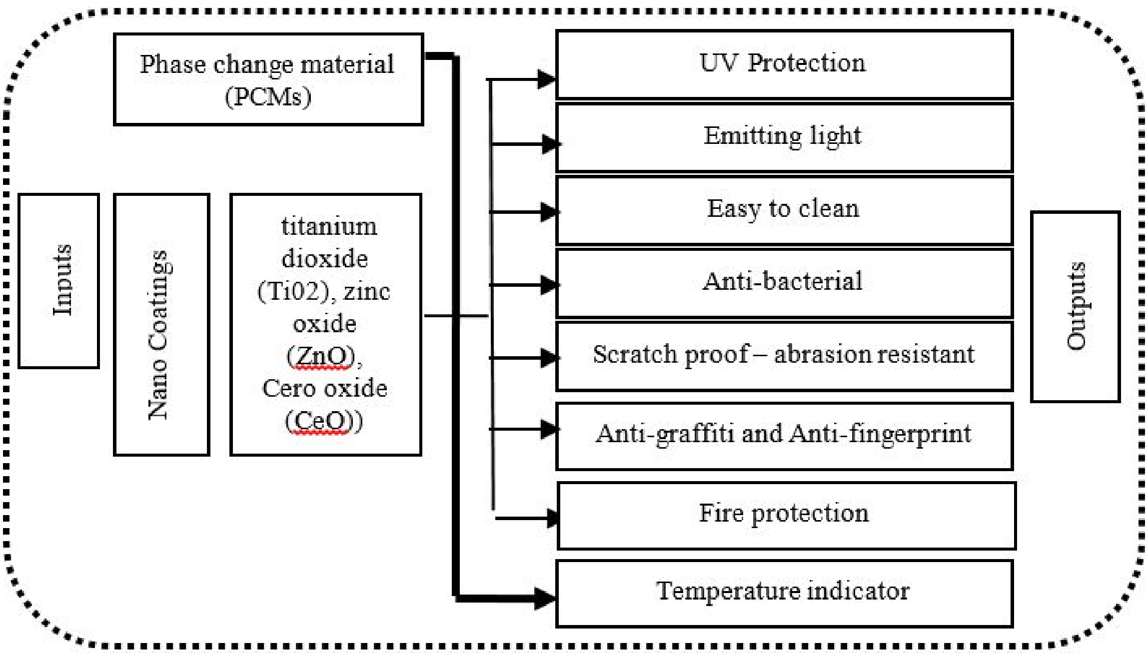

Figure 14. the inputs and outputs of smart and nanomaterials on the finishing (the authors)

4.2. The applications within the furniture and the installs that the patient or the guest or the stuff needs, can enhance the following:

- Heat control
- UV protection
- The process of cleaning
- Infection control

4.3. Applications within openings (windows), can enhance the following:

- Lighting and heat control
- UV protection
- The process of cleaning
- Infection control
- Energy efficiency
- Privacy. As shown in fig (16)

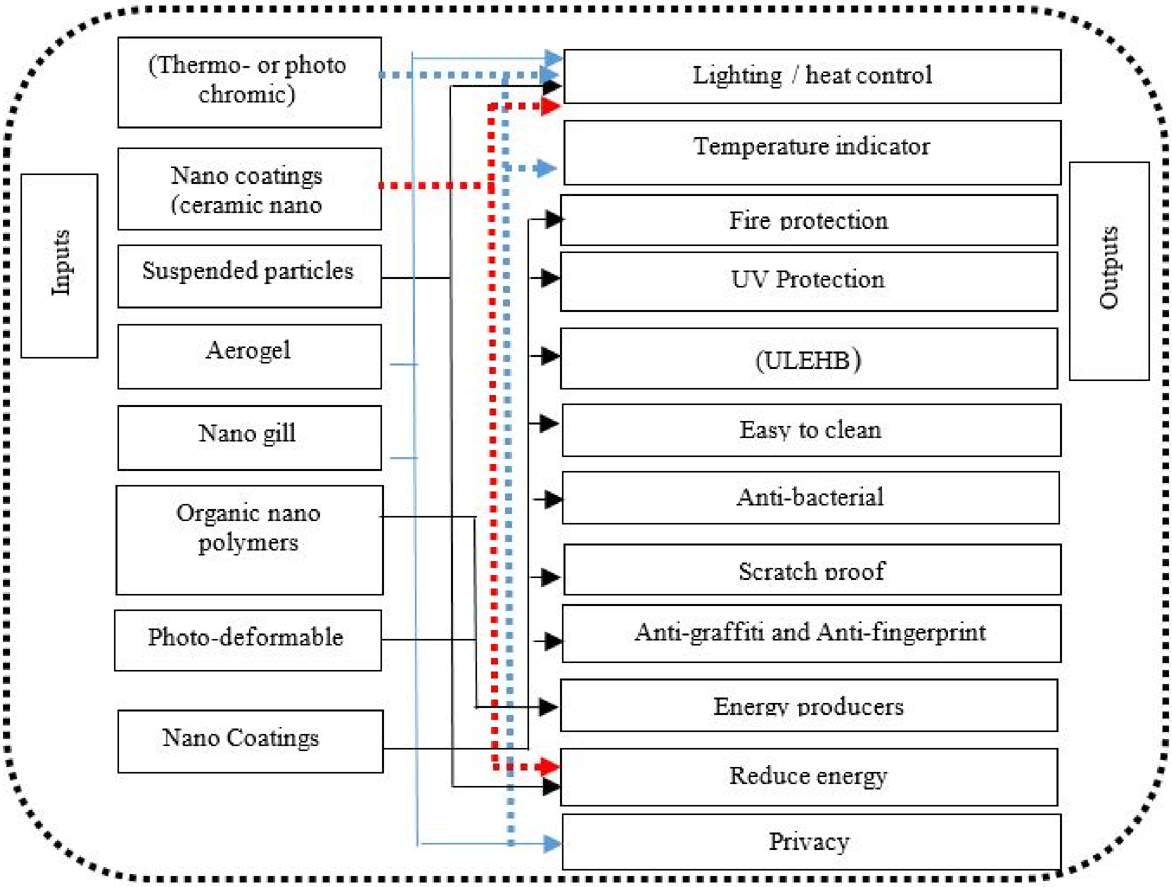

Figure 15. the inputs and outputs of smart and nanomaterials on the openings (windows)

4.4. The intelligent materials have a good impact on the patient

4.4.1. The good quality of life for the patient

The World Health Organization (WHO) outlines health as ‘a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity’. Moreover, the Green Guide for Health Care states that the two key ideologies of the healthy building as those that keeps the health of the building occupants and the health of the global community. The therapeutic environment is explicit and depends on many factors, as it mainly doesn't depend on the treatment of the physical body, but it also to support the psycho-social and spiritual needs of patients and their families as well as the staff around the patient. As well it needs to produce quantitative goals on patients' clinical outcomes and staff effectiveness. These are all positive criteria that can be reached by regarding the choice of materials and interior finishes, and with respect to connection to the natural world without any harm to the patient. And by displaying the advantages of the intelligent materials; they can cope the needed goals for the good quality of life can be afforded by the materials.

4.4.2. Optimizing the aspects of healing

a. Optimize Day lighting: Using smart and nano materials can optimize day lighting that regulates the circadian system which plays an important role in the healing process of the patient. The circadian system leads to the regulation of the body functions; as regulating the digestive system, sleeping patterns, hormone regulations and even body temperatures. Through this system, day lighting aids in healing through reducing depression, shortening hospital stays, and improving sleep. Patients in day light rooms have less pain, less stress, and are calmer. In addition, the staff performance and job satisfaction are increased, creating a work environment where doctors and nurses are more effective.

b. Prevent the growth of molds and bacteria:

Nano materials offers ease of cleaning, sanitizing and have the ability to prevent growth and transmission of molds, bacteria and other pathogens on the surfaces of the patient room. As these surfaces can be daily polluted by pathogens that can cause HAIs. (Harris, 2017)

4.4.3. The enhancement of the green rating system

The health care buildings especially the hospitals are large consumers of natural resources and energy, and (32%) of the initial budget for a healthcare facility is consumed in interior finishing and interior construction (Shohet, Lavy-Leibovich & Bar-On, 2003). While referring to the rating systems of the green buildings all over the world; the two main categories concerns energy and material efficiency; especially in the green pyramid concerning Egypt. As they concern the building life cycle from its construction till its maintenance, and the intelligent materials have their proof in the reduction of energy, at the same time the nano materials are forms of high quality products that have their special properties, which allow them to last for long times without consuming any natural resources. (Guenther & Vittori, 2013)

Moreover, intelligent materials have goals in the innovation aspect which is the green rating systems appreciate. They can reduce the usage of water in the cleaning process in the space as they call for the self-cleaning aspects, and they can enhance the indoor air quality, which affect the healing process.

5. Conclusions

Intelligent Materials have their potential impact on the patient room and its fabrication. They can perform like living systems that can enhance the ambient environment and the infection control of the patient room. Moreover, they will represent new opportunities to solve various problems and lead the building structure and architecture to be in an optimum level. Their use can open up new possibilities for sustainable design strategies and provide new trends for functions, which would help the interaction between the patient room and its users .

They could also reduce energy, and they have an economic impact in establishing healthy patient rooms.

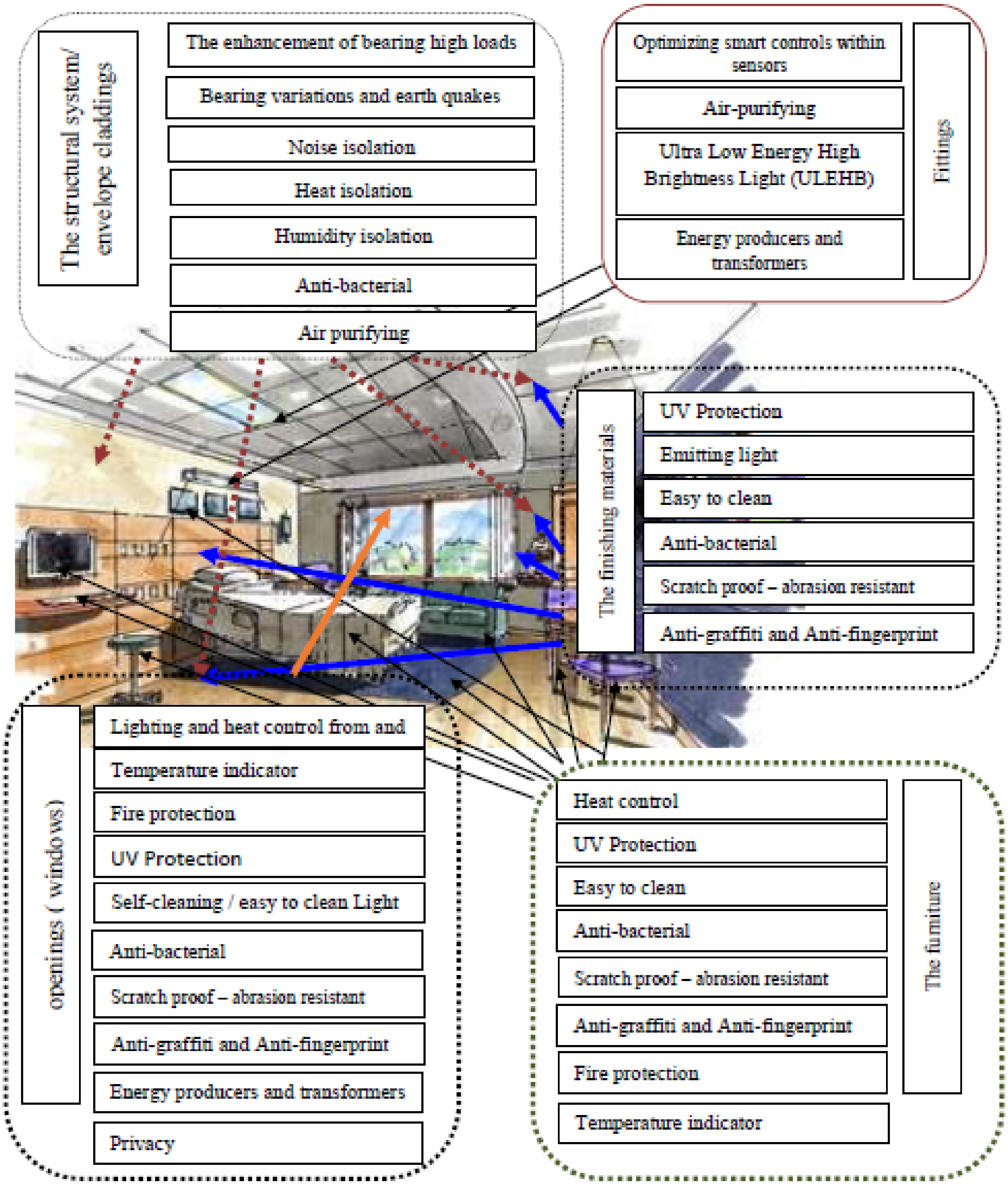

Figure 16. shows the afforded intelligent materials in the patient room.

6. References

1. Addington, M. (2010). Smart Materials and Sustainability. [ebook] Austin, Texas: The University of Texas at Austin. Available at: https://www.soa.utexas.edu/sites/default/disk/technologies/technologies/09_03_fa_addington_ml.pdf [Accessed 25 Jul. 2019].

2. Akhras, G. (2012, June). Smart & Nano Systems - Applications for NDE and Perspectives. Paper presented at The 4th international conference CANDU In-service Inspection Workshop and NDT, Toronto, Ontario, Canada.

3. Abou-ghazala, A., Fared, A., & Al-Shami, A. (2014). Building materials and smart nanoparticles - Entrance to increase the efficiency and integration of Smart Buildings. Journal of Jazan University.

4. Atwa, M., Al-Kattan, A., & Elwan, A. (2015). TOWARDS NANO ARCHITECTURE:NANOMATERIAL IN ARCHITECTURE - A REVIEW OF FUNCTIONS AND APPLICATIONS. International Journal of Recent Scientific Research, 6(4), 3551-3564. Retrieved from https://www.recentscientific.com/sites/default/files/2274_0.pdf

5. Konarzewska, B. (2017). Smart Materials in Architecture: Useful Tools with Practical Applications or Fascinating Inventions for Experimental Design? {IOP} Conference Series: Materials Science and Engineering, 245, 52098. https://doi.org/10.1088/1757-899x/245/5/052098

6. Cullinan, K., & Wolf, M. (2010). The Patient Room: what is the ideal solution?[Ebook]. Design Dilemma, DEA 4350. Retrieved from https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/a/3723/files/2013/09/The-patient-room-what-is-the-ideal-solution-26h3eox.pdf

7. Harris, D. (2017). A Material World: A Comparative Study of Flooring Material Influence on Patient Safety, Satisfaction, and Quality of Care. Journal of Interior Design, 42(1), 85-104. doi:10.1111/joid.12100

8. Guenther, R., & Vittori, G. (2013). Sustainable Healthcare Architecture. Hoboken, NJ: John Wiley & Sons.

9. Hanafi, A. (2012, March). Nano technology and Sustainable Building Design and Construction:with Focus on Passive Building Systems. Paper presented at Fourth International Conference on-Nano-Technology In Construction: Nano echnology For Green And Sustainable Construction, Cairo, Egypt.

10. Leydecker, S. (2008). Nano Materials: in Architecture, Interior Architecture and Design. Berlin , Germany: Springer Science & Business Media.

11. Ritter, A. (2006). Smart Materials in Architecture, Interior Architecture and Design. Berlin , Germany: Springer Science & Business Media.

12. Seeboth, A., Schneider, J., & Patzak, A. (2000). Materials for intelligent sun protecting glazing. Solar Energy Materials And Solar Cells, 60(3), 263-277. doi: 10.1016/s0927-0248(99)00087-2

13. Senjen, R. (2009). Nanotechnologies in the 21st Century – Challenges and Opportunities to Green Nanotechnologies (1). European Environmental Bureau (EEB).

14. Shiha, E. (2014). Methodology of Utilizing Buildings Roofs to Achieve Urban Sustainability in Crowded Neighborhoods- Feasibility of Using Nanotechnology as an Advanced Approach for Treatment (Compiled and Presneted PHD thesis). El Mataria Faculty of engineering, Helwan University, Cairo, Egypt.

15. Shohet, I., Lavy-Leibovich, S., & Bar-On, D. (2003). Integrated maintenance monitoring of hospital buildings. Construction Management And Economics, 21(2), 219-228. doi: 10.1080/0144619032000079734

16. Silas, J., Hansen, J., Lent, T., Health Care Without Harm., & Healthy Building Network. (2007). The Future of fabric: Health care. Arlington, VA: Health Care Without Harm.

17. Sun B. (2015, September 14), Smart materials and structures. Lecture at Swiss Federal Institute of Technology Zurich (ETH), Zurich. Published by Cape Peninsula Univeresity of Technology, Cape Town, South Afica.
18.Vavan S. (2014). Application of smart in Retrofitting homes can help housing energy efficiency, Faculty of architecture of Union University in Belgrade.

18. Mahdavinejad, M., Bemanian, M., & Khaksar, N. (2011). Choosing Efficient Types of Smart Windows in Tropical Region Regarding to Their Advantages and Productivities. Retrieved from http://www.ipcsit.com/vol5/60-ICCCM2011-B3006.pdf

19. Nanotechnology product catalog for professionals. (2013). Retrieved May 4, 2013, from http://www.nanovations.com.au/Press Release/Nano_in_construction.pdf

20. Smart Nanomaterials in Construction Works and Their Applications. (2019). Retrieved 25 July 2019, from http://theconstructor.org/building/smart-materials/smart-nano-materials-in-construction-industry/5638/

21. Tech-Dry® Australia — Concrete & Masonry Protection (2019). Retrieved 25 July 2019, from https://www.techdry.com.au/

22. Antar, M. (2019). Nano-Technology. Retrieved 25 July 2019, from http://profmohamedantar.blogspot.com/2010/12/blog-post_8421.html

23. Kancane, L., Vanaga, R., & Blumberga, A. (2016). Modeling of Building Envelope's Thermal Properties by Applying Phase Change Materials. Energy Procedia, 95, 175-180. doi: 10.1016/j.egypro.2016.09.041

24. Fokaides, P., Kylili, A., & Kalogirou, S. (2015). Phase change materials (PCMs) integrated into transparent building elements: a review. Materials For Renewable And Sustainable Energy, 4(2). doi: 10.1007/s40243-015-0047-8

25. Applications Of Carbon Nanotubes. (2019). Retrieved 25 July 2019, from https://www.mknano.com/Carbon-Nanotubes/

26. Suspended Particle Devices - How Smart Windows Work. (2019). Retrieved 25 July 2019, from https://home.howstuffworks.com/home-improvement/construction/green/smart-window2.htm

27. Coagulation technology co., LTD. (2019). Retrieved 25 July 2019, from http://www.agel-tech.com/hthk/info_2341_itemid_311.html

28. Hatch Tensile Membrane Structures. (2019). Retrieved 25 July 2019, from http://www.textile-structures.com/Technical-Fabric-Tensotherm.html