GREEN BUILDING MATERIALS: A REVIEW OF STATE OF THE ART STUDIES OF INNOVATIVE MATERIALS

P. De Luca[1], I. Carbone[2]* and J. B.Nagy[1]

1. INTRODUCTION

This paper presents a comprehensive survey of the latest international publications (2012–2017) regarding innovative and environmentally sustainable materials that reduce the production of pollutants. It is recognised that world construction is responsible for substantial amounts of harmful emissions.

In particular, the survey collected data on new sustainable solutions and innovative materials, such as cement, wood, glass and ceramics that are essential to minimize the environmental impact of buildings on the ecosystem and to reduce the consumption of natural resources.

Therefore, the paper's intent is to give an overview of the current state of the art and research in the field of bio-building, gathering information on the environmental impacts of these innovative materials and listing the benefits that can be obtained with their use.

The findings of this study support the growing importance of green building as a component of the whole construction market and provide a benchmark against which to measure future changes in the industry over time.

KEYWORDS

innovative materials, sustainable materials, bio-building, green building

2. BACKGROUND

Environmental protection and a determination of the state of "health" of our planet has become an important topic for society. Studies have shown alarming realities: human activities around the world produce too much polluting emissions, leading to the progressive and rapid deterioration of nature and the climate of the earth.

This situation obliges mankind to re-examine the relationship between resource exploitation and habitat quality, thereby developing an ecological conscience that has led to the use of "green" resources while seeking integration between environment, territory and human health.

Bio-building means to recognize and make current centuries of constructive wisdom while paying close attention to the use of non-polluting and recyclable materials, favoring the natural ones available and applying modern techniques and systems. In this context there is an overall respect for the overall environment and what nature offers.

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Consequently, the choice of building materials, their use and the technological choices adopted are of great importance for this purpose. This enables the construction of a building capable of creating suitable conditions of physical and psychological well-being within it, as well as reducing the impact that the construction has on both human health and the ecosystem.

3. METHODOLOGY

This work is the result of bibliographic research carried out through the use of virtual library archives such as Scimago, Caspur, Scopus and Research Gate, ranging from 2012 to 2017. The most important articles considered were taken from international journals that showed evident innovative elements in the field of building materials. Therefore, throughout this paper, the most innovative, recent and cutting-edge sustainable materials will be analysed—those most likely destined to offer a sustainable future for construction.

4. RESULTS AND DISCUSSIONS

The research results testify to the growth in the field of bio-building and highlight the most significant sustainable advances that can be applied to buildings and construction. These results are presented by the type of material:

- cement
- wood
- glass
- ceramic

4.1 Cement-based materials

4.1.1 Light-emitting cement

A group of researchers at Michoacan University of San Nicolás de Hidalgo in Mexico has designed a special cement that absorbs solar energy during the day and emits it at night. This innovation has been published in a book, *Smart and Multifunctional Concrete Toward Sustainable Infrastructures* [1], and related articles [2] were found through sitographic research.

The goal of this research is to reduce energy consumption and pollution caused by traditional cement. This phosphorescent cement could be used to light up roads, highways, cycle paths or buildings.

Typically, cement is an opaque body that doesn't allow the passage of light through its interior. It is in fact a mixture of powder which, when it's added to water, dissolves as an effervescent pill and starts to become a very strong and resistant gel. At the same time, this process also creates crystal flakes in the gel that block incoming sunlight (Rubio 2016).

Because of this, researchers focused on modifying the micro-structure of the cement in order to eliminate crystals and make it completely a gel by adding mixed polymers with luminescent properties, capable of absorbing solar energy and returning it to the environment as light during the night for around 12 hours.

The benefits that can be obtained from this cement are many. Most fluorescent materials currently available are composed of plastic and have a short life span of around three years at most because they decay under exposure to UV light. However, this new kind of cement is sun-resistant and can last up to 100 years. It is also environmentally friendly; in fact, it saves on electric lighting and therefore has a low environmental impact. Lastly, it can be manufactured inexpensively.

The Mexican project is not the first example of a phosphorescent surface used to illuminate areas and paths: in the Netherlands there is a phosphorescent cycle track inspired by Van Gogh's starry night (Figure 1). In this case, however, light is provided by a special paint and not by the material itself of which the pavement is made.

Currently, the research team is working on commercializing the product, which will be available in green and blue variants.

4.1.2 Martian Concrete

A group of scientists at Nortwestern University in Illinois has been able to create a new and innovative ecocement, a construction material that can withstand the particular conditions of the red planet. Relatively simple to produce and 100% recyclable, this concrete does not need water and combines sulfur with raw materials available in the planet's crust.

The innovation appears in *Construction and Building Materials* [3] magazine, 2016 and research has found no other related studies.

The main obstacle this team led by Lin Wan, Roman Wendner and Gianluca Cusatis had to deal with is that on Mars water is a scarce resource, and present largely in the form of ice. As explained in a report summarizing their study, the ability to build cement lies in sulfur. When used as a glue and heated up to 240 degrees, it passes from the solid state to the liquid state. It is then combined with elements and minerals on Mars's surface and left to cool (Wan et al., 2016).

The results, however, are not certain. Scientists and engineers have been experimenting for decades with the use of sulfur in concrete on earth with unsatisfactory results. In addition, the particular circumstances of Mars make the challenge even more complex. For example, sulfur can crack at low temperatures and in a vacuum it becomes a gas. In addition, during the

FIGURE 1. Cycle path inspired by Van Gogh starry night

(www.studioroosegaarde.net).

cooling process, sulfur particles shrink and tend to create cavities that threaten the quality of the material.

To solve these problems, the team of scientists conducted several tests with ecocements produced with different percentages of molten sulfur while faithfully simulating Martian soil, which mainly contains silica, titanium, aluminum and iron. After observing the resistance and breakdown mechanisms of each sample, it was determined that the best mix for Martian architecture is half composed of 50% sulfur and 50% the soil on the planet. The blend guarantees a 50 megapascal resistance. An inert diameter below 1 mm decreases the likelihood of forming gaps inside the cement. There are excellent prospects for reuse of materials as the ecocement; it is 100% recyclable as the sulfur can be brought back to the melting point to give the compound a new shape.

4.1.3 Self-healing of cracked concrete: A bacterial approach

Although concrete is the world's most used building material, it has a serious flaw: it can easily crack when under tension. If these cracks become too large, they will lead to corrosion of the steel reinforcement, which not only results in an unattractive appearance, but also jeopardizes the structure's mechanical qualities.

Researchers from the Technology University of Delft [4], Holland, have developed a truly ingenious and ecological solution to the fragility of cement, which will allow this material to have a much longer life span.

Professor Hendrik Jonkers, a microbiologist at Delft University and a finalist at the recent 10th annual European Inventor Awards, created a kind of self-repairing cement by adding bacteria to sand, water and debris mixture. This technology allows concrete to repair microfractures in a completely autonomous manner and without the intervention of man.

Jonkers chose bacillus bacteria for the purpose, because they thrive in alkaline conditions and produce spores that can survive for decades without food or oxygen. The bacteria requires a source of food with which to produce the lime necessary to heal the cracks. The first idea was to mix bacteria with sugar, but this would weaken the concrete structure. After a series of experiments, Jonkers chose calcium lactate, setting the bacteria and calcium lactate into capsules made from biodegradable plastic and adding the capsules to the wet concrete mix.

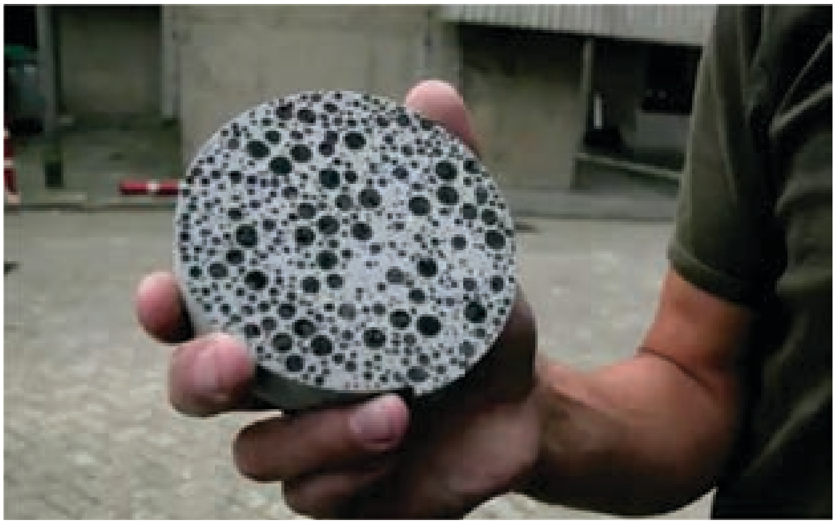
When cracks eventually begin to form in the concrete, water enters and opens the capsules, activating the bacteria (Figure 2). So the bacteria germinate and multiply by feeding on the lactate, and in doing so they combine the calcium with carbonate ions to form calcite, or limestone, which closes up the cracks.

The use of bacterial concrete can in theory lead to substantial savings, especially for steel reinforced concrete. As a consequence, durability issues can be tackled in a new and more economical way when designing concrete structures. Current research is focusing on creating the right conditions for the bacteria to produce as much calcite as possible and on optimizing the distribution of food for the bacteria.

4.1.4 Smog-eating Cement

Pollution is one of the biggest concerns of the world right now and engineers are coming up with creative solutions to fight it. The "smog-eating" cement developed by chemist Luigi Cassar and a team of researchers from the Italcementi Group was included in the list of finalists for the European Inventor Award 2014 in the European Patent Office (EPO) category "Industry" [5].

FIGURE 2. The aggregate of this concrete contains bacterial spores that fill in any cracks in the material.



(Delft University of Technology)

This particular cement has been marketed since 2006 under the name of TX Active (the new photocatalytic active principle, capable of capturing pollutants in the air) and it's considered to be a valuable antidote to pollution, but Cassar's studies date back to 1991 when he started working in Italcementi.

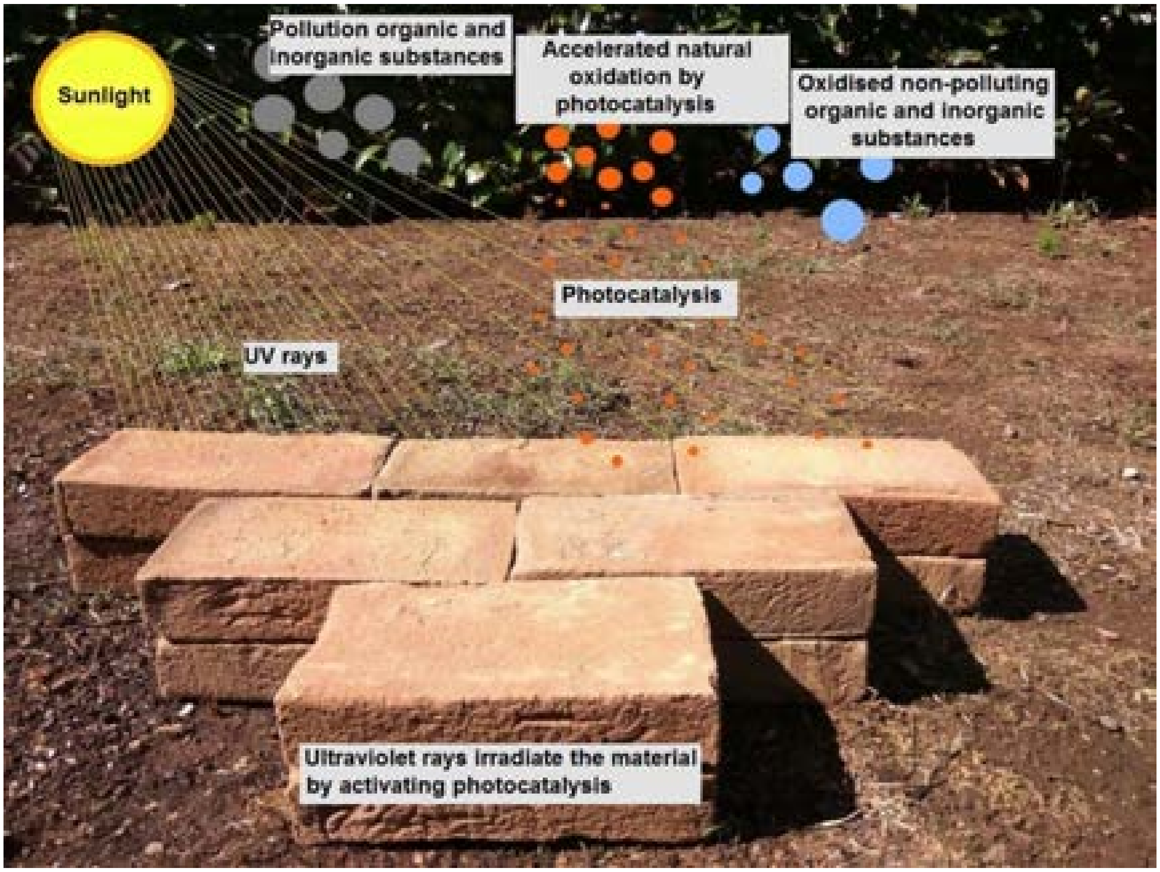
The development of the new material arises from the need of designers to use a product capable of resisting the action of pollutants in time. This is not just a matter of aesthetics but also economical: the façades of smog-blackened buildings require periodic and expensive cleaning and painting.

Italian researchers have modified the chemical composition of cement by introducing titanium dioxide, which has the ability to activate the oxygen molecules present in the air. As Figure 3 shows, it triggers a photocatalysis process, which accelerates the natural oxidation process by which oxygen decomposes contaminants and transforms them into nitrates and carbonates, i.e. substances that are easily washed by rainwater. The cleaning process of the material is similar to the air-cleaning process.

The same chemical composition can be used for the production of exterior and interior paints, floors, tiles, prefabricated panels, safety or soundproof barriers. Laboratory trials, alongside field studies have shown that the façade of a five-story building made of smog-eating cement costs 15% more, but reduces air pollution by 20%. So, if the buildings of a big city were all made using this product, air pollution would be reduced by 50% (Cassar 2014).

The "smog-eating" cement has already been used for the spectacular construction of the Dives in Misericordia church in Rome—designed by American architect Richard Meier—with its enormous, sparkling white concrete sails. Other relevant examples of this self-cleaning cement are the Air France headquarter at Paris Charles De Gaulle International Airport, the brand new Italcementi R&D Center i.lab in Bergamo, Vodafone Village in Milan—20.000 m^2 of photocatalyst surface which represent the biggest building ever realized with this material.

FIGURE 3. Light (solar or artificial) is absorbed by titanium dioxide that activates the oxygen molecules present in the air. Activated oxygen acts on the contaminants, disintegrating them and transforming them into nitrates and carbonates, which are then easily washed away with rain water.



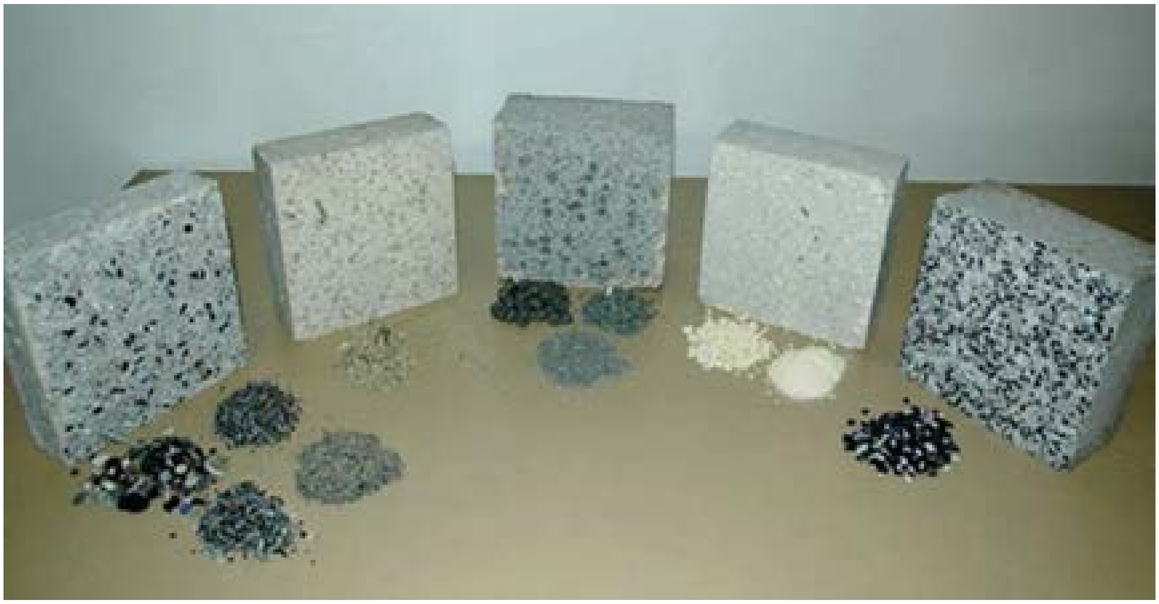
4.1.5 Sus-Con

SUS-CON (Sustainable, Innovative and Energy-efficient CONcrete) is a project conceived and conducted by the Consortium CETMA [6], Design Center, Design & Materials Technology of Brindisi. It has two objectives: to develop innovative technologies to integrate second-tier raw materials, usually destinated for the landfill, in lightweight concrete production cycle, and to create 100% new products with recycled materials and high insulation characteristics (Figure 4). This has allowed the creation of an eco-cement completely made of secondary raw materials as binders and aggregates.

In the past, much research concernig the use of several kinds of urban wastes in building material industrial process have been published, such as waste's plastic material for concrete production [7]. According to the SUS-CON project, among the materials selected for recovery are tires, mixed plastics derived from urban waste, polyurethane foams recovered from discontinued refrigerators, plastics from electrical and electronic equipment, and by-products of the steel production process.

The project started with the analysis of the built-in energy, the energy needed to produce, transport and then dispose of a certain product, which should be as low as possible to reduce

FIGURE 4. Novel SUS CON concrete with 100 % secondary materials



(© SUS-CON Consortium–7thFP, under Grant Agreement No 285463–CETMA).

environmental impact. The result of the research was therefore the production of a lightweight, ecological and economically sustainable cementitious product, characterized by low absorbed energy, low CO_2 emissions in the production cycle, and better performance in terms of ductility, thermal and acoustic insulation. These outcomes can be verified in terms of mechanical properties and fire resistance, which can be used both for premixed and prefabricated applications.

The first products obtained with this light, environmentally friendly and sustainable material were panels and blocks used for the construction of three demonstration buildings in Spain, Turkey and Romania. Thermal insulation performance was monitored and the results were better than those obtained with similar products already on the market. The material also contributes to improving the energy efficiency of buildings, reducing the energy consumption needed for air-conditioning. In terms of fire resistance, the panels were classified EI 240 with performance four times higher than those already commercialized.

But a very interesting aspect of the project is its replicability. In particular, new prototypes of recycled concrete have been made in Turkey using different waste products from those of the original experiment and obtaining similar results.

4.2 Wood-based materials

4.2.1 The biomimetic pavilions: Hygroskin and Hygroscope

Architect and professor at the institute for computational design, University of Stuttgart, Achim Menges, in collaboration with his colleagues Steffen Reichert and Oliver David Krieg have developed two really innovative structures that take advantage of natural wood's properties. These are two "meteorosensitive"pavilions called Hygroscope (exhibited at the Center Pompidou in Paris) and Hygroskin [8] (on permanent exhibition at the Frac Center in Orlèans).

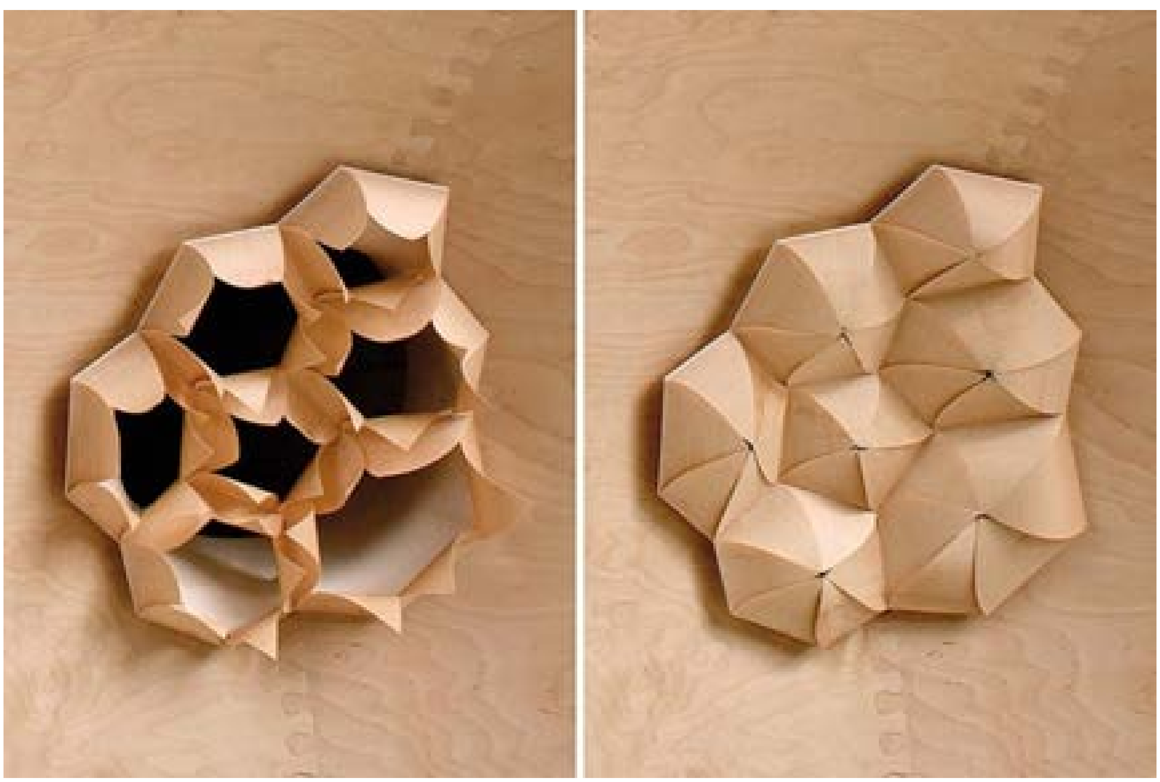
The principle shared by these two works is that of biomimetic, a branch of technology inspired by "invented" solutions from nature. The researchers observed the intrinsic characteristics of wood, especially its hygroscopicity, namely its ability to take in moisture from the atmosphere when dry and yield moisture to the atmosphere when wet, thereby maintaining a moisture content in equilibrium with the surrounding relative humidity. This hygroscopic mechanism requires no energy or metabolic process to run, as it is completely fostered by natural changes in climate. So there is no energy consumption.

This concept is perfectly applied to the Hygroskin Pavilion, which is made of a steel structure covered with concave spruce panels. The structure is divided into 28 sections, each of which has a circular hole in the center that allows light to penetrate inside. The openings consist of a mesh structure and a 1.100 thin triangular wooden sheets, which close if the humidity is high and reappear when the internal temperature rises. The structure reacts to a range of humidity between 30% on a sunny day and 90% on a rainy day.

The wood's flexibility in relation to humidity levels allows for a sensible system where the panels open and close independently, as shown in Figure 5, in response to time changes that require no electrical or mechanical power (Menges et al., 2014).

The second biomimetic pavilion, Hygroscope, uses the same principle as the first one, but it has a much more complex structure. It is on permanent exhibition at the Pompidou Center, where designers have created two identical copies placed in two glass bowls: the climatic conditions of Paris are simulated into the first, while the museum's humidity levels are relevant for the

FIGURE 5. Close-up photo of a HygroSkin opening adapted to weather changes: it opens at low relative humidity (left) and closes at high relative humidity (right)



(©ICD University of Stuttgart).

latter. It is a complex system consisting of 4000 maple wood elements, each of which is unique in shape and size and digitally manufactured.

The peculiarity of this pavilion, if compared to the previous one, corresponds to the petals of each opening activating differently and individually depending on the variations in humidity, on the fibers orientation, and their size and thickness. In this way, they always obtain different shapes which respond to even minimum changes in climate conditions.

4.2.2 Wood foam

The need to reduce pollution generated by the construction industry to make it more sustainable and efficient has led a team of researches from Fraunhofer Institute [9], Wilhelm-Klauditz-Institut (WKI) in Braunschweig, to develop an innovative wood-insulating foam with remarkable performances.

This wood foam can replace the classic high-impact plastic foams, derived from petrochemicals, because it is a light, efficient and completely natural product made from sustainable raw materials (Thole 2014). Another of its advantages is that unlike conventional foam products, wood foam can be easily recycled after use.

Scientists produce the foam by grinding wood very finely until the tiny wood particles become a slimy mass. Suddenly, they add gas to this suspension to expand it into a frothy foam that is then hardened. The hardening process is aided by natural substances contained in the wood itself (Figure 6). In an alternative method, specific chemical processes are used to produce the final product.

The resulting wood foam has good resistance to humidity and pressure, and excellent insulation similar to that of conventional plastic foams. In fact, it is an ideal material for home insulation, where the aim is to keep the heat inside and create a cozy environment for the building's occupants.

FIGURE 6. The wood spray solidifies, forming totally biodegradable insulating panels

(© Photo Fraunhofer WKI | Manuela Lingnau).

The Braunschweig-based scientists are currently experimenting with different types of wood to discover which tree species make the best basis for their product. Furthermore, they are working out suitable processes for mass-producing wood foams on an industrial scale. This innovative material could also be used in areas different from insulation, such as packaging. Packing materials made from wood foam would provide a long-term alternative to another oil-based product: expanded polystyrene.

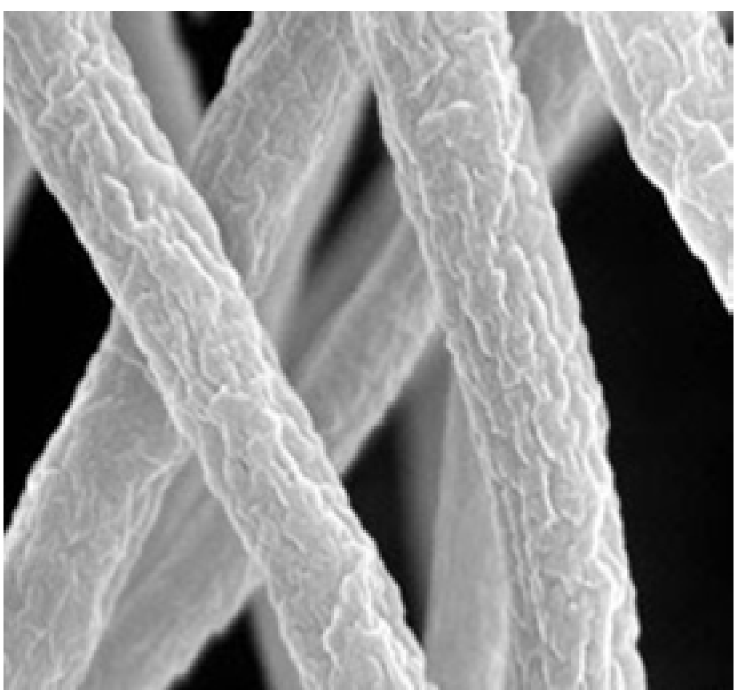
4.2.3 Cellulose Nanocrystals from wood waste

The Forest Products Laboratory [10] of the US Forest Service has opened a US $1.7 million pilot plant for the production of cellulose nanocrystals (CNC) from wood by-product materials such as wood chips and sawdust. The goal is to realize a completely innovative, more durable, lighter and cheaper material than carbon fiber and kevlar.

Nanocrystals are produced by wood pulp processing, from which lignin is extracted, the element that gives wood rigidity and strength. From this processing a suspension of cellulose fibers in water of very small size is obtained—about 10 micron in width and about 1 mm in length, respectively (Figure 7). In order to make the compound resistant, further cellulose fibers have to be smoothed, obtaining a three-dimensional grid. The lattice is compressed and compacted, and the air inside the cavities is eliminated by an acid; the aim of this third step in the production process is to achieve an exceptionally high rigidity and traction, comparable to that of carbon fibers, which are, however, considerably more expensive: about 10 times higher!

One of the major advantages of cellulose nanocrystals compared to carbon fiber or kevlar is its cheapness, since wood waste can be used for its production. This allows for the recycling

FIGURE 7. Transmission electron microscopy (TEM)-micrograph of electrospun polymethyl methacrylate fibers



(USDA Forest Service, Forest Products Laboratory).

of waste materials and, at the same time, it also gives space to the rural sector in applications different from the norm. Moreover, the use of natural and renewable materials reduces the need for fossil fuels and reduces greenhouse gas emissions duirng the production process.

The only limit seems to be water so far. It is not possible to use the material outside or in particularly humid conditions. Obviously, researchers want to overcome this difficulty: probably the use of a particular coating or special paint could increase the hydrophobic ability of the material and thereby obtain a truly unique product.

4.2.4 Transparent wood

A group of researchers from the KTH Royal Institute of Technology in Stockholm has developed Optically Transparent Wood (TW), shown in Figure 8, a new material that could greatly impact the way we develop our architectural projects. The aim is to enrich the traditional properties of wood, one of the most reliable and frequently used building materials. And for a good reason: it's strong, cheap, and, if properly managed, renewable.

Published in *Biomacromolecules* [11] a journal of the American Chemical Society, the process of creating transparent timber is covered. The process involves the removal of the chemical lignin—a natural wood fibre found in cell walls—from the former material (Figure 9). That makes wood "beautifully white," the researchers explain, but it does not help make it transparent because the wood itself stops light (Berglund 2016).

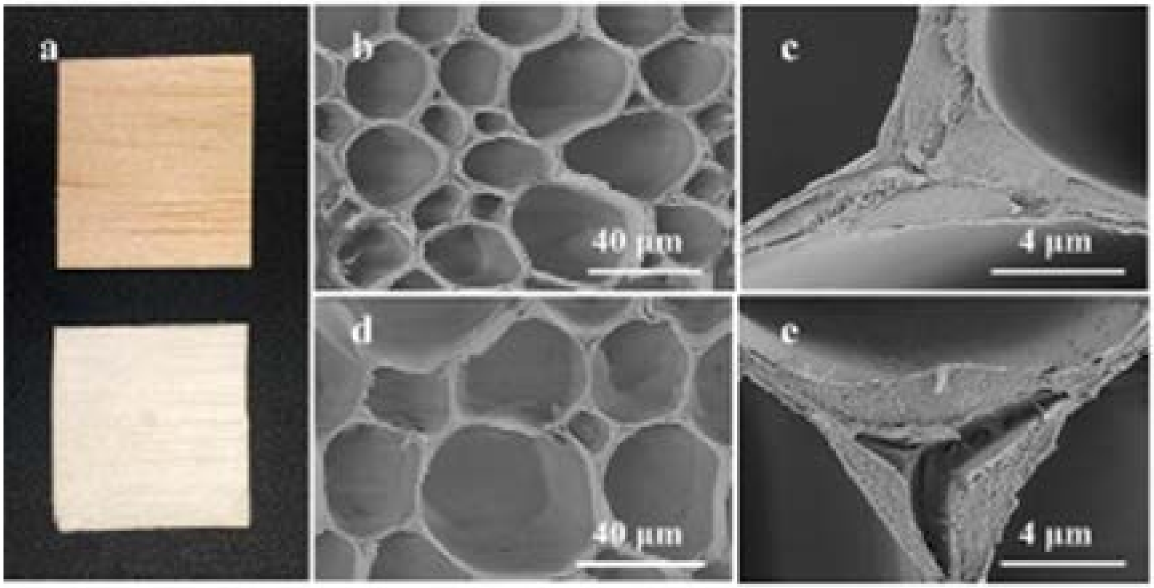
But by embedding the white wood with a transparent polymer known as prepolymerized methyl methacrylate (PMMA), the team was able to alter its refractive index to achieve light transmittance of up to 85 percent, while still retaining the familiar wood structure.

This transparent wood could also replace window glass and make them stronger and cheaper. Moreover, these windows could let the light filter inside and, depending on the transparency level, maintain privacy for the occupants.

FIGURE 8. A close-up look at the transparent wood created by Dr. Lars Berglund and co-authors

(Image by Peter Larsson, KTH Royal Inst of Technology, Stockholm).

FIGURE 9. Delignification of wood: (a) an optical image of wood before (up) and after (down) delignification. Low magnification (b, c) images of original wood (OW) cross section showing the micro structure of wood. Low magnification (d, e) images of delignified wood (DLW) cross section supporting the presence of a well-preserved wood structure.



(Published with the permission of the American Chemical Society).

The research team is currently experimenting with different types of wood, especially those from renewable sources and recycling, in order to see if they can improve transparency while ensuring acceptable production costs.

4.3 Glass-based materials

4.3.1 Smart glass light and heat regulation

Researchers at the Lawrence Berkeley National Laboratory (Berkeley Lab), California, have designed a system to adjust the amount of light and heat that passes through the glass, according to external weather conditions, with the aim of making smart windows even smarter. This new technology has been published in the journal *Nature* [12].

Unlike existing technologies, the coating provides selective control over visible light and heat-producing near-infrared light (NIR—Near Infrared Radiation) independently, so windows can maximize both energy savings and occupant comfort in a wide range of climates (Milliron 2013). This means occupants can have natural lighting indoors, without undesired extra heat, reducing the need for both air-conditioning and artificial lighting.

The new material is a thin coating of indium tin oxide nanocrystals—that can be set up on demand by an electrical impulse—embedded in a glassy matrix of niobium oxide. The nanocrystals, which are transparent at rest, are placed on two different layers: the activation of the first layer allows the infrared light (heat-sensitive) to be blocked, while the second one allows a good part of visible light to be blocked, thus making the glass matt. Then, the window can be controlled remotely by switching to a dark mode, holding both light and heat, or to a bright, fully transparent mode. The material created is electrochromic because it is capable of transmitting or blocking the light radiation on the basis of the electric potential applied.

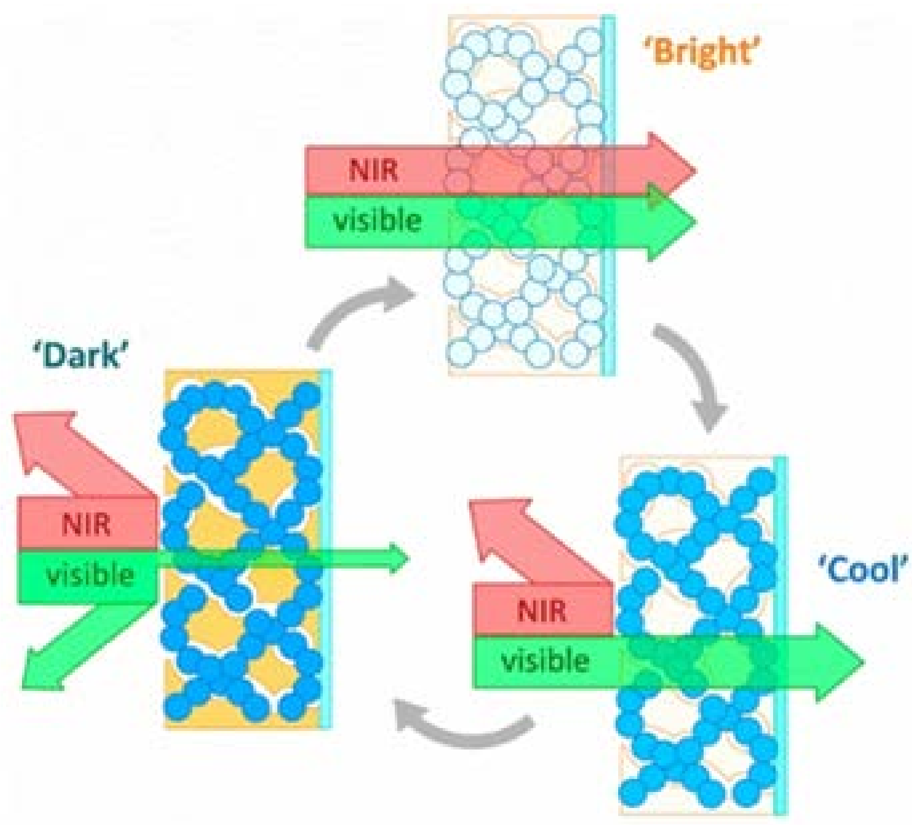
Two years later, the researchers improved their discoveries by creating an electrochromic material that allows the selective passage of light while stopping heat or cold. In particular, it is possible to request the heat block by activating the cool mode, while using the warm mode will arrest the cold. (Figure 10). Therefore, this three-layer shape of the intelligent window provides a personalized and optimal control of heat, light and transparency.

In the paper, published in the journal *Nano Letters* [13], the team shows that the new material can selectively modulate the sun's rays by applying a small tension. In detail, it manages 90% of the near-infrared solar radiation (NIR) and 80% of visible light (Milliron 2015). Moreover, since switching from one mode to the other is a matter of few minutes and not of hours anymore, the product may reach the marketplace soon with a shorter term goal of optimizing the manufacturing process to minimize production costs.

4.3.2 Smart glazing with micro-mirrors

The smart window industry is making a new step forward thanks to the contribution of a research team at the Politecnico di Lausanne (EPFL). The researchers developed a new glass characterised by a thin layer of micro-mirrors ranging from 0.15 to 0.2 millimeters. Their aim is to modulate sunlight, improving natural lighting and air conditioning, thus reducing

FIGURE 10. Representation of dark mode, bright mode and cool mode



(Published with the permission of the American Chemical Society).

both heating and cooling costs in the building. This innovation, published in the *International Solar Energy* magazine [14], will be tested for the first time in a futuristic construction built in Dübendorf, Switzerland.

A high-precision laser is used to cut the micro-mirrors, embedded in a polymer film that is placed between the layers of double-glazed windows. This system consists of a one-dimensional array of parabolic reflective surfaces coupled with an another array of secondary reflective surfaces.

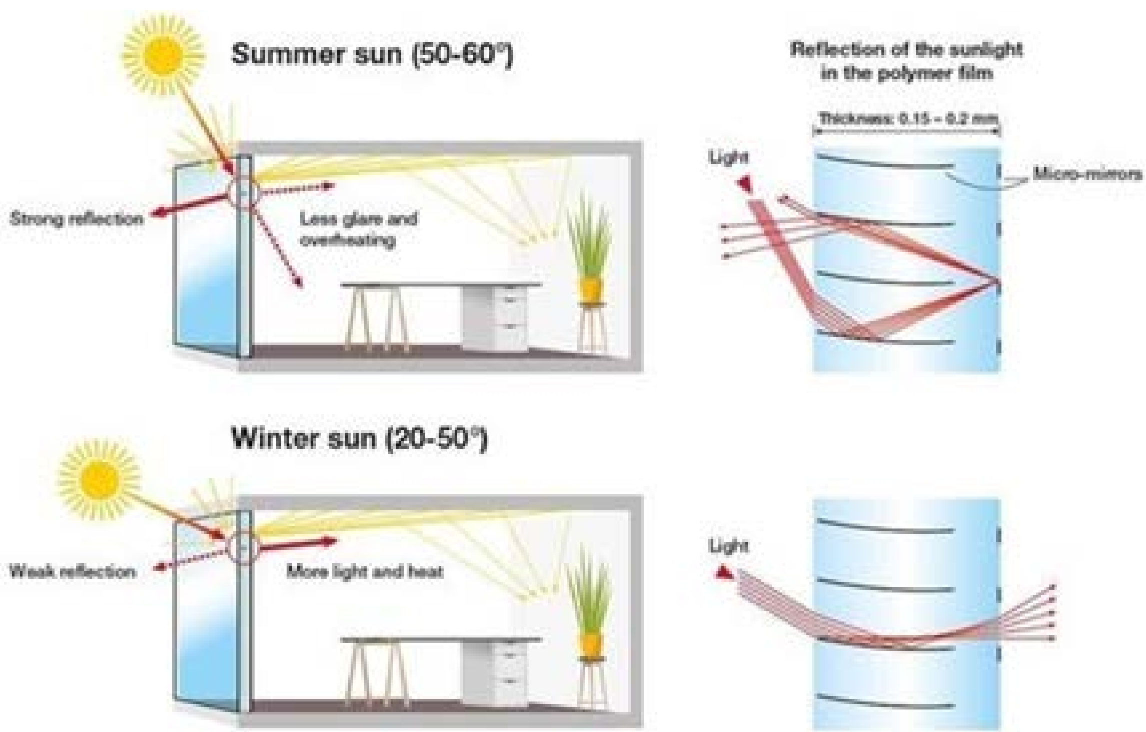
As Figure 11 shows, the inclination of the sun's rays varies according to the season. In summer, the micro-mirrors reflect light and heat back to the outside of the building, avoiding direct sunlight and the overheating of the environments. In winter, the micro-mirrors redirect light into the building and thereby improving the occupants' visual comfort (Schüler 2016).

This smart-glazing system offers other advantages as well. The preliminary hypotheses developed by the researches suggest that the system could reduce the thermal load (both heating and cooling) by 10%-20% compared to traditional window glazing. It can improve visual comfort as well by distributing light evenly throughout the room and eliminating sharp contrasts and glares. It also brings a higher amount of light: up to 150% of light reaches the back of the room and more than triple the amount of light hits the ceiling. Finally, the system was designed to last longer than traditional slatted venetian blinds.

4.3.3 Glass bricks stronger than concrete

The Dutch architecture company MVRDV, working with the Delft University of Technology and ABT engineering firm, has built a new transparent glass brick façade to reproduce the

FIGURE 11. Micro-mirror window operation in summer and winter



(© EPFL Infographic: Pascal Coderay).

original brick façade of a former townhouse in Amsterdam, which is now the location of a Chanel boutique.

This innovation, published in the *Glass Structures & Engineering* magazine [15], aims to combine the city's traditional architectural style with the international architecture of the big metropolis, providing a solution to the loss of local style in commercial areas around the world.

In the building, glass bricks are alternated gradually with classic clay bricks as one moves upwards, giving the feeling that the building floats above the road. This brick layout is due to the presence of the commercial area at the bottom of the building, while, in the upper levels, there are living spaces for which opaque clay bricks are best suited.

Due to the breakable nature of the materials, an extremely high level of accuracy and craftsmanship was required and a technical development team has to supervise the process. Since this construction is the first of its kind, new construction methods and tools had to be utilized: it was necessary to use high-tech lasers for brick cutting and laboratory grade UV-lamps to fix the glue used to compact the bricks (Oikonomopoulou et al.,2017). Milk was also used, as its low transparency made it an ideal liquid to make reflective surfaces and to levelling the first layer of bricks.

In addition to being aesthetically pleasing, the glass bricks are tough. They're stronger than concrete, and are capable of withstanding the force of a car crash. In fact, strength tests by the Delft University of Technology team proved that the glass-construction was in many ways stronger than concrete.

One of the main advantages of glass is that the material is completely recyclable; for instance, during the installation, several imperfect bricks were melted down and remoulded. Thanks to this method, in the future, the whole façade could be regenerated with the same procedure.

4.3.4 Glass fiber panels

To help reduce the energy consumption of buildings, a team of Spanish researchers devised a prototype fiberglass prefabricated façade that could maximize solar energy by absorbing and releasing it into the room for heating environments, and it could perfectly improve the heat insulation. The prototype was built by the Sustainable Construction Division of the Tecnalia Research Center, in San Sebastian, and the project [16] results are on the main portal of the European Commission, CORDIS.

The prefabricated panel was obtained from a mixture of glass fiber and organic binders and it was decided to apply the "pilot model" to a Merida building. The tests to which the fiberglass wall was exposed for its performance were oriented in three main directions: fire resistance, water and wind resistance, thermal insulation and acoustic insulation.

The experiment was carried out to evaluate the fire resistance level of the panel, which more than anything else, concerned the researchers, as revealed by Architect Julen Larraz Astudillo. The reason lies in the strength of the panel: the materials that make it are glass fiber and organic binders. The test showed more than satisfactory results, with values perfectly in line with the standards dictated by the European Union.

The water resistance has been verified by checking the holding of the technological units. The results have led to the conclusion that the wall works if the rainwater does not come into contact with the inside, positioned just behind the technological units. In the event that this condition occurs, the system may be easily affected by deterioration. The resistance to wind power would appear to be very high: the façade is capable of withstanding a pressure of about 305 kg / mq without any sign of collapse.

The most interesting aspect in terms of energy is the thermal insulation. The fact that the panel was linked to the original building's prospect through the holes made the presence of "drafts," small spaces posible that permit the air to pass inside. Actually, the tests not only did not detect defects from the point of view of the thermal insulation, but not even the acoustic profile. Holes, in other words, do not let air or sounds pass.

After a careful study and meticulous checks, Spanish researchers hope that the patented system can be a first step towards the future, an innovation in the field of energy saving in architecture.

4.3.5 The hydrophobic and self-cleaning glass

A group of researchers from the ENEA of the Faenza Materials Technology Unit has designed hydrophobic and self-cleaning glass [17], an important Italian patent that is inspired by lotus leaves which, with their particular surface roughness, do not allow water to accumulate, but make it slip away.

In fact, the surface of the lotus leaves is always perfectly clean even though they are located near marshy ponds. This is possible thanks to a process known as a "lotus effect," which uses the particular conformation of the surface of the leaves themselves. The leaf surface is not as smooth as it appears to the naked eye, but rippled by nanometric projections that minimize the contact of everything that falls on the plant. Therefore, when a drop of water lands on it, it can not stand on the leaf, but keeps rolling over it. As the water moves over the leaf's surface, all the impurities it intercepts are dragged away, thus performing a real cleaning job.

The natural strategy of the lotus flower has been imitated by applying a layer of ceramic material that recreates the wrinkled appearance of the plant's leaves. The ceramic coating is deposited with a thickness of a few tens of nanometers (a billion times smaller than one meter) and is able to deeply change the behavior of the materials. The surface of the ceramic material, combined with the presence of organic molecules on the surface, makes possible a behaviour of total water repellence. Glasses made in this way are able to conduct electricity and reflect heat at the same time.

Thanks to this coating the surfaces do not become dirty and are protected from oxidation. Water accumulation and ice formation are not allowed, and friction in the water movement is reduced. Numerous applications of this material is posible in the fields of construction and naval and aerospace industries.

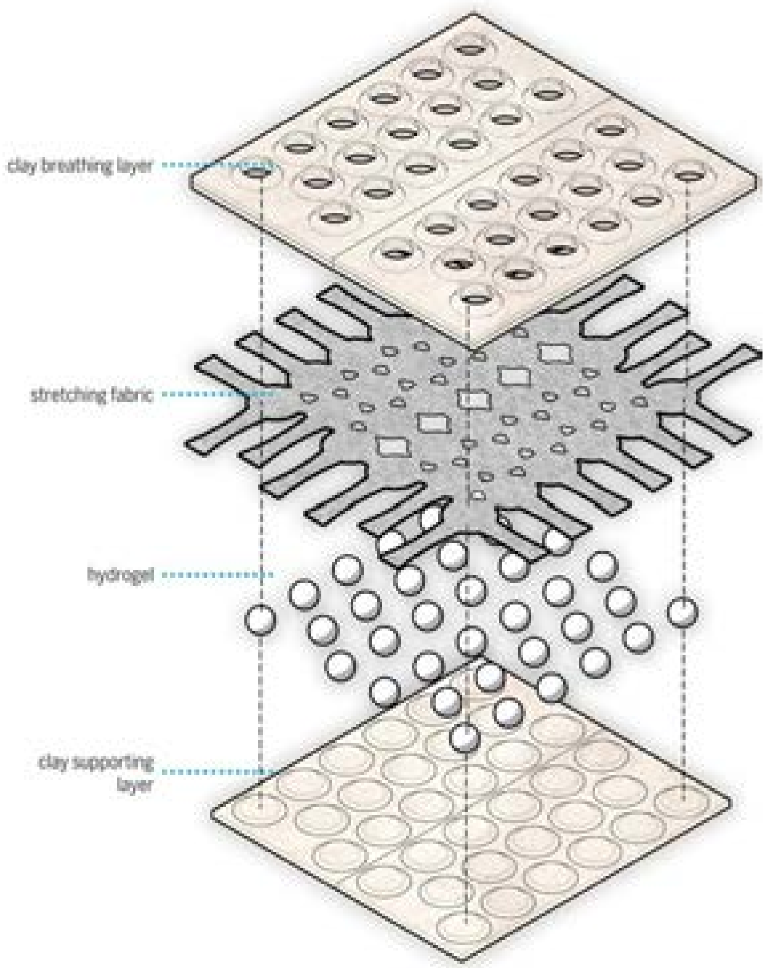
4.4 Ceramic-based materials

4.4.1 Hydroceramic

An interesting innovation in the field of bio-building comes from the Institute of Advanced Architecture of Catalonia [18], where three young researchers have devised and developed a self-freshening wall called "hydroceramic," which works as an evaporative cooling device using the combination of a hydrogel with supporting materials, such as ceramics and fabric (Markopoulou 2014).

The wall is made of three layers (see Figure 12). There is a first layer of clay, equipped with numerous conical holes that let in the water and the hydrogel air, then there is a second layer of tissue that absorbs water and transmits liquid—and that, thanks to its elasticity, allows volume changes in the hydrogel. Finally, a third layer is the hydrogel which has a smaller thickness than the first one and is provided with additional holes to maximize the cooling effect.

FIGURE 12. Final system consisting of the clay layers with hydrogel and stretching fabric in between. Hydroceramic is a project of the Institute for Advanced Architecture of Catalonia developed by students: Elena Mitrofanova, Akanksha Rathee, Pongtida Santayanon with the support of Senior Faculty Areti Markopoulou, Faculty assistant Alexandre Dubor and Moritz Belge.



(IAAC–Institute for Advanced Architecture of Catalonia).

The benefits that can be obtained are many. According to laboratory tests, when the outdoor air temperature rises, the water inside the wall evaporates and consequently the indoor environment temperature is reduced by about 5 or 6 degrees and the humidity increases about 200%. Therefore, a high energy saving is achieved because the use of active and energizing conditioning systems is avoided. In addition, there is a reduction in costs, because the system used by the wall is based on a simple and natural process; consequently, the materials used are cheap and they are easy to find.

The only critical point of the project is the need to feed the intermediate layer with more water, but the research team have proposed a great solution, i.e. to use rainwater previously harvested and stored for this use. In this way, the wall could absorb rainwater and hold it until excess heat is generated and then the harvested rainwater would come into action.

4.4.2 Heat storage ceramic

Researchers at the University of Tokyo have discovered a new kind of material that can accumulate thermal energy over a long period of time and gradually release it thanks to a slight pressure. This is heat-storage ceramic, which is patented by a team led by Professor Ohkoshi of the University of Tokyo's Faculty of Science and published in *Nature* [19].

The retention of thermal energy is a feature of many materials, but the peculiarity of this ceramic is that it can store energy for a long time and release it only on demand, such as a battery: there will be enough a pressure on each block to allow the energy to be released (just 60 Mega Pascal). Besides the direct application of heat, thermal energy can be stored by passing an electric current through the material or irradiating it with light. It enables the repeated absorption and the release of heat energy by a variety of methods (Tokoro 2015).

The material is made of titanium and oxygen atoms could be used, both are used in solar energy production systems and for an efficient use of energy in industrial processes. Its thermal capabilities are remarkable. Its can absorb and release an amount of energy of 230 kJ / L, equal to about 70% of the latent heating of the water's melting point.

Additional research on ceramic materials were carried out, such as the study of activated ceramic materials with deposition of photocatalytic titano-silicate micro-crystals [20]. The Stripe-type-lambda-trititanium pentoxide that compose this ceramic is a simple titanium oxide, made of many elements and environmentally-friendly because it is totally natural.

The present heat-storage ceramic is expected to be a new candidate for use in solar heat power generation systems, which are actively being promoted by European countries, and also for an efficient use in the generation of heat for industrial use. This material can also be used for advanced electronic devices such as pressure-sensitive sheets, reusable heating pads, pressure-sensitive conductivity sensors, electric current driven type resistance, random access memory (ReRAM), and devices with optical memory.

4.4.3 Seamless ceramic floor

Floor choice reflects all the necessary requirements for carrying out various activities: comfort, hygiene, practicality, easy cleaning, maintenance, durability and sustainability.

Italian and European technicians have worked on the CeramicaContinua® [21] project to create a uniform, durable, secure, sustainable floor. The features of this innovative ceramic floor have only been tested in the lab and on small surfaces, though reproducing actual usage conditions.

The project offers surfaces with great chromatic uniformity that are free from veins and variations. They are also homogeneous, monolithic, robust, soft and light at the same time. CeramicaContinua® is today the only floor without junctions (Figure 13). It is the best option on the market thanks to its peculiar features such as the quality, the strength, the life span combined also with the great beauty of the material itself.

Materials are produced with ceramics recycling before and after its use. It is a unique seamless floor manufactured from the high performances of recycling techniques. Usually the ceramic tiles are fired in high-temperature kilns, but to realize the Ceramica Continua®, a cold process is required and no electricity is needed.

The floor is laid out by overlaying 7–8 layers, depending on the pre-existent foundation. Above the screed are placed ceramic and mineral fibers used to create a very solid carpet able to cushion possible ground movements without damaging the floor. Ceramic layers are preserved

FIGURE 13. Ceramic floor without junctions

(www.ceramicacontinua.it).

by protective systems and ceramic fillers that increase the durability of the floor and protect it from wear.

In addition, the product has a minimum thickness of 3 mm, that makes it suitable for installation on pre-existing floors and reducing the demolition waste in restructuring. Despite the very small thickness, however, the continuous ceramic flooring guarantees high performance and durability.

The product does not emit formaldehyde and V.O.C., which are harmful to the installer and to the occupants of the rooms where it is installed, even in the presence of underfloor heating. It is also an antibacterial product that is very effective in the killing of many bacterial species that live in the environment.

5. CONCLUSIONS

The research has highlighted a new attitude by some designers who propose innovative solutions for building, with the aim of regaining harmony between nature and the built environment. In particular, the new attitude seeks to improve the comfort of buildings by selecting those with higher performance, lower cost and limited environmental impact. It is important to emphasize the role of research and information in the field of sustainability. In fact, the purpose of this paper is to give greater emphasis to newly developed materials that are generally not widely known other than to academics.

The analysis has shown that the innovative materials examined above, taking into account all aspects of sustainability (environmental, economic and social), have many advantages. In fact, they have a low environmental impact with low energetic production processes. They have comparable costs, if not lower, to alternatives available on the market, while maintaining high standards of living comfort. In addition, being natural source materials, they have proven to be a more sophisticated eco-sustainable alternative to conventional synthetic materials. The research goal is to meet the needs of current generations without sacrificing the needs of future generations.

Through alternative construction solutions for new buildings, considerable energy savings can be achieved, both for the choice of new materials to be used and for the use of new methods that reduce fuel consumption and polluting emissions, while improving human health. The bio-building revolution covered in this paper offers solutions to many global issues associated with climate change, human health and the quality of the environment.

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