LUMINOUS CONCRETE

!!! ATTENTION !!! These panels are coated with a thin layer of photoluminescent concrete. After exposure to sunlight or artificial light, the panels will illuminate in the dark.

.0__IDEA

The concept of 'energy' is a hot item in our present society. Not only because of the increasingly rising energy prices, but also because of global warming. People have to realize that they have to cut on power consumption. The lower the energy consumption, the lower the energy costs and the less the environment is affected (less CO_2 emission). The sun is very important in our search for lower energy consumption (img.01). The sun makes life on earth possible and the sun provides us daily with enormous quantities of energy being sunlight and solar heat. Sunlight provides our daylight and can be converted into electrical energy by means of photovoltaic cells (img.02). Solar heat is used to heat up water (solar boiler) or other liquids. These forms of energy are called passive energy.

Another important concept in our society is 'concrete'. It is an essential material in the building industry. Because of its exceptionally good physical properties concrete is a highly suitable and strong material to construct buildings. Throughout the years concrete technology has evolved tremendously, making it possible to realize very complex and futuristic constructions (img.03). Besides strength properties that guarantee the stability of a building, concrete also has several physical properties that have a huge impact on the life quality of buildings. Because of its enormous thermal inertness concrete is capable of absorbing large amounts of warmth. This way warmth is stored during the daytime in the summer (preventing overheating) and given off at night in the winter (preventing cooling down).

My idea for this competition is to combine the two concepts of 'energy' and 'concrete'. Are there possibilities to add extra physical properties to concrete so it will do more than provide stability to a construction or absorb warmth? Can we attribute a property to concrete so passive energy extraction from the sun can be used for other purposes? Is there an option to store daylight during the day and emit it at night?

Why doesn't concrete illuminate at night?

There are numerous synthetics that own the property to illuminate in the dark (img.04). Often phosphorescent or fluorescent properties have been added to these products. They have been used for decades in all kind of objects (pointers of a watch, starry sky in a nursery, nightlight,...), but lately they are also finding their way into architecture (img.05).

Described below, is the development phase of a new (profitable) type of concrete with examples of possible applications in architecture.


Img.01__The Sun


Img.03__Phaenocenter 'Hadid'


Img.02__Conversion of solar energy by means of photovoltaic cells


Img.04__photoluminescent, synthetic products


Img.05__Photoluminescent interior

.1__THEORETICAL RESEARCH

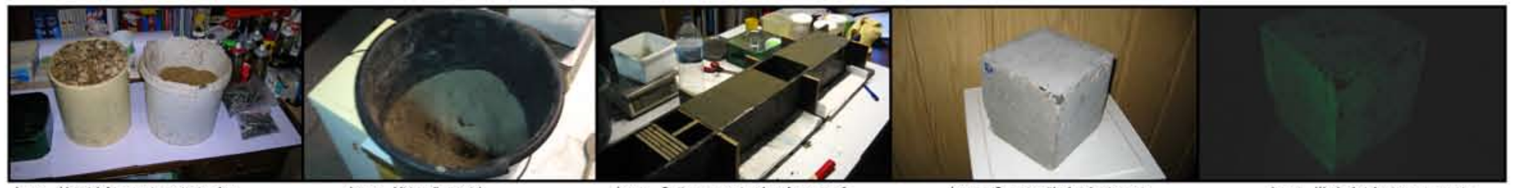
Before starting a practical research, it is important to have a theoretical background of the materials to be examined, that is concrete and luminous material. With luminous material we need to make a distinction between the following concepts: luminescence, photoluminescence, fluorescence, phosphorescence, fluorescence spectra, brightness, radioactivity and wavelength. In my search for material that illuminates, I came across several chemicals: phosphorus, fluorine, zinc sulphide and alexandrite. But none of these chemicals satisfied my needs. Phosphorus is toxic and fluorine doesn't illuminate under the right circumstances. Zinc sulphied works according to the concept of luminescence. Meaning that it radiates light when it is hit by a high energetic electromagnetic radiation. Further research revealed that I didn't need luminescent substances, but photoluminescent substances. Photoluminescence is the emission of light from a material under excitation. Absorption of visible or UV radiation raises molecules to an excited state. Electron absorbs a quantum of energy and jumps to a higher energy orbital. When electron drops back to the ground state, excitation energy can be liberated by emission of light. This led me to a fairly new product based on aluminates (no exact composition available as this is a patent product). This product has some advantages compared to phosphorus: not toxic, high clarity of light, longer glowing time and more available colors. My research on the exact chemical composition of cement showed that a chemical reaction occurs between the photoluminescent substance and cement without any consequences. Additional research on the water-repellent or water-soluble properties of the photoluminescent substance had to be conducted. A water-repellent property is an essential factor in the production of concrete.

.2__PRACTICAL RESEARCH


Img.06__% Cement powder Img.07__% photoluminescent powder Img.08__Mix Img.09__Framing with several samples Img.10__Successful and unsuccessful samples Img.11__Photoluminescent cube of mortar

In a first phase we test if a chemical reaction occurs between the mixture of cement and photoluminescent powder. This reaction should eventually result in a mortar. After making some calculations a quantum of cement (img.06) and a quantum of photoluminescent powder (img.07) is weighed. These 2 quantities are mixed and water is added according to a ½ water/cement factor (img.08). The obtained mixture (sort of wet mortar) is poured into a mold. Different kinds of compositions are made (img.09), ranging from a lot of cement with very little photoluminescent powder to a composition of a mass/volume ratio of 60% cement and 40% photoluminescent powder. During the hardening process necessary tests are done to examine the water-repellent property of the photoluminescent powder. It is clearly visible (img.12) that photoluminescent powder doesn't dissolve in water and gradually sinks to the bottom of the jar. Properties of the powder are also maintained in the water (img.13). Hardening shows that some compositions aren't successful (img.10). Other compositions illuminate, but not enough. After removing the framing each cube is tested individually which leads to surprisingly good results in some cases (img.11). In a second phase cubes are made in different colors. This phase shows that 2 different colors don't produce the same results with the same mass/volume ratio of cement and photoluminescent powder. The reason for this is that the main structure of chemicals in each color differs slightly from the other colors. This different chemical structure is necessary to obtain a different color of the light spectrum. The next step in the development process is producing photoluminescent concrete. Results with cement and photoluminescent powder were positive and led to some sort of photoluminescent mortar. Bearing in mind the composition of traditional concrete, the mass/volume ratio between cement and photoluminescent powder are adjusted. Because of a lesser amount of cement in the concrete composition, we add short iron bars to make up for the deficit in cement (img.14). All materials needed to produce concrete are manually mixed in a bucket (img.15) and water is added according to the normal ½ ratio. Because of a change in the cement composition, less cement per cubic meter is necessary in comparison to traditional concrete. This results in a somewhat too dry concrete structure to be able to pour it nicely into the framing (img.16). The first pressure tests (*check .3 pressure tests*) show the concrete is too weak. I am advised to use more cement. In a second series of cubes the normal amount of cement is taking into account. This results in the necessity of more photoluminescent powder to obtain the correct ratio between cement and photoluminescent powder. Again the concrete is too dry, so the water/cement ratio is increased. This results in a smooth cube (img.17). However, the first test in the dark is a disappointment (img.18). The concrete cube illuminates, but in comparison to the photoluminescent mortar (img.11) its clarity is very weak.


Img.12__Water + photoluminescent powder Img.13__Photoluminescent powder in water


Img.14__Materials for concrete + extra iron bars Img.15__Mixing all materials Img.16__Casting concrete in cubes of 15x15x15cm³ Img.17__Concrete with photoluminescent powder Img.18__Weak photoluminescent concrete

.3__PRESSURE TESTS

Sample	Weight (g)	7 Days (KN)	7 Days (N/mm²)	Weight (g)	28 Days (KN)	28 Days (N/mm²)	Quality of concrete
Traditional concrete	7781	420	18,67	7813	660	29,34	C20/25
70/30 m/V% concrete (70% cement)	7453	260	11,56	7400	380	16,89	xxx
70/30 m/V% ferroconcrete (70 % cement)	7366	300	13,33	7169	440	19,56	C12/15
70/30 m/V% concrete (100% cement)	7647	180	8,00	7278	200	8,89	xxx
50/50 m/V% concrete (100% cement)	7517	240	10,67	7711	460	20,45	C12/15


Img.19__Weighing cube


Img.20__Adjusting pressure test machine


Img.21__Reading results

The first series contains 3 pairs of concrete cubes. The first pair is traditional concrete. The second pair has a reduced amount of cement (about 70%) with a certain amount of photoluminescent powder. This amount is determined by means of the results of tests with cement and photoluminescent powder. The third pair had the same composition as the second pair, but added with some extra iron bars. A first pressure test is done after 7 days. After weighing the cubes (img.19), they are submitted to a pressure test (img.20). The low weight of cube 2 and 3 (a normal concrete cube of 15x15x15 cm³ weighs around 7800g) already gave the impression that these cubes can't stand high pressure. This can be read clearly from the meter indicating a fairly low result (img.21). After 28 days the same pressure test is done. Cube 1 shows the desired strength concrete requires and a quality of C20/25. Cube 2 stays way below the expectations and isn't worthy of the term concrete. The 3rd cube has a very low value and a fairly bad concrete quality of C12/15. On the recommendation of concrete specialists I try to maintain the minimum amount of cement in the concrete composition with the 2nd series of cubes. Meaning that I have to add a larger amount of photoluminescent powder to get the desired m/V ratio of cement and photoluminescent powder. Because of the larger amount of powder a somewhat dry concrete mixture is obtained. Therefore a higher water/cement factor is applied, 3/5 instead of ½. Once more pressure tests are done on day 7 and 28. Once again the strength of the concrete is too weak, which had drastic consequences for cube 4. Cube 5 along with cube 3 reach a C12/15 concrete quality.

LUMINOUS CONCRETE

!!! ATTENTION !!! These panels are coated with a thin layer of photoluminescent concrete. After exposure to sunlight or artificial light, the panels will illuminate in the dark.

.4__CONCLUSION

After the pressure tests the first conclusions can be drawn. Quality of concrete strength is unsatisfactory. This is caused by the new concrete composition or by manually mixing the wrong amounts of cement, gravel, granules, photoluminescent powder and water. With the first pressure tests the lack of concrete strength was mainly due to a low cement quantum. This deficit was covered in the second series, however the desired results didn't follow. The higher water/cement factor could possibly be the cause of this. Provided that additional tests are done, it should be feasible to produce photoluminescent concrete with the proper C20/25 concrete quality. Another problem is the glow effect of the photoluminescent powder. This is clearly visible in image 18. A photoluminescent effect is detected, but it is far beneath the results that were achieved with the mortar cubes. These cubes showed a clear radiation. Some additional tests with more photoluminescent powder obtained a better clarity, but one major disadvantage was related to this: its very high production cost. A few simple calculations resulted in production costs that soared up to 2.000 €/m³. All this negative information made me realize that I would have to go about this differently. I had to develop a concrete with an 'inexpensive', traditionally composed concrete on the inside and a thin, more expensive, layer of photoluminescent concrete on the outside. But how do I solve this problem?

.5__NEW BRAINSTORM

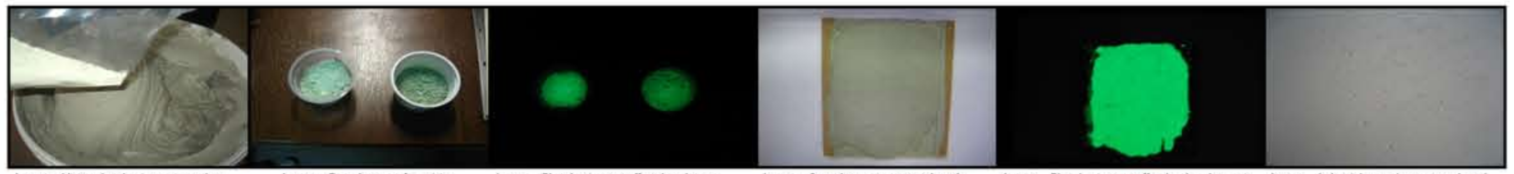
A first idea was to provide the outside of concrete with a photoluminescent material during the hardening phase. This can range from scattering photoluminescent powder over wet concrete to adding photoluminescent glass pebbles in wet concrete (img.22). The disadvantage with this method is that it can't always be used. Framing boards could get in the way or concrete could already be too hard. Another idea is to provide the framing boards with a film with photoluminescent powder or photoluminescent oil (img.23). The advantage here is that every possible framing form can be provided with a photoluminescent outer layer. However, practice shows a different result. The photoluminescent oil doesn't have the desirable physical adhesion to the framing boards and certain oiled parts are disrupted during the casting of concrete. This way we can't obtain an even photoluminescent surface and the clarity of light is unsatisfactory as well. A final idea is to develop a photoluminescent pouring concrete. A thin layer (1 or 2 mm) of photoluminescent concrete (img.24) would be sprayed on the concrete supporting structure. Because of the thin, expensive layer of photoluminescent concrete, the final price per m² turns out better than expected, making the product profitable. Especially the latter idea seemed an interesting reasoning to me. Since the other 2 ideas were technically not that efficient, I thought it was sensible to elaborate idea 3.


Img.22__Photoluminescent glass pebbles


Img.23__Oiled framing board

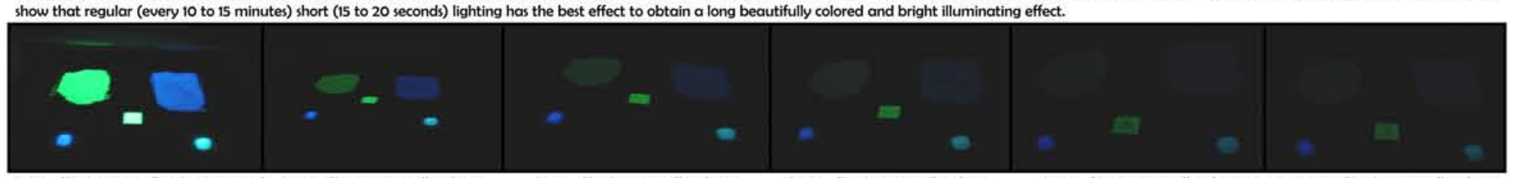

Img.24__Pouring concrete

.6__NEW PRACTICAL RESEARCH


Img.25__Mixing photoluminescent powder + concrete paste Img.26__Dry substance after mixing Img.27__Photoluminescent effect dry substance Img.28__Spread concrete paste on board Img.29__Photoluminescent effect hardened concrete paste Img.30__Industrial poured concrete on board

Theoretical research shows that a mixture of ground concrete (recycling), marble powder and polymers form a perfect paste. The plasticity of this concrete based paste is suitable to be sprayed under pressure after adding thermosetting plastics. This technique enables us to spray thin layers of concrete on all kinds of materials, such as concrete, wood,... After adding the photoluminescent powder to the concrete past (img.25) we obtain a very dry intermediary product (img.26). This dry intermediary product has photoluminescent properties (img.27). The question now is if the chemical reaction caused by adding thermosetting plastics will have consequences for the illumination. This research phase is done manually. The aesthetic result is of a lesser quality, but that is a minor consideration. After adding the thermosetting plastics, the concrete past is spread on an MDF board (img.28). The first test in the dark is done after hardening, which produced very good results with a surprisingly clear light (img.29). Further tests are done with different colors and different amounts of photoluminescent powder. Finally the best result is selected and a board is industrially sprayed with the obtained ratios. The result is shown in image 30.

Another important research is verifying the duration of illumination and clarity of light. The chemical properties of the photoluminescent powder tell us that there is a very clear illumination of the material during 30 minutes to an hour (subject to the absorbed light energy). Its total glow time should be about 10 to 12 hours, however this is along a exponential decreasing curve. Tests in dark rooms with different materials (photoluminescent pouring concrete, photoluminescent mortar cube, photoluminescent powder, photoluminescent glass) all confirm these chemical properties partially. The clarity of light is subject to the absorbed light (sunlight, fluorescent light, daylight,...) and the duration (3 seconds to 30 minutes) of illumination. The glow time is also subject to the absorbed light and the duration. The series of photos below (images 31 to 36) show the illuminating effect of the materials after half an hour of sunlight. The first images show a very clear and bright light. As time goes by (the photos are taking with a 15-minute interval) we can still see an illuminating effect, but the color and clarity are clearly reduced. We should mention that the optical qualities of a camera are less than powers of perception of the human eye. The actual luminous intensity is therefore higher than visible in the images below. Several tests show that regular (every 10 to 15 minutes) short (15 to 20 seconds) lighting has the best effect to obtain a long beautifully colored and bright illuminating effect.


Img.31__Photoluminescent effect after 30 minutes of sunlight Img.32__Photoluminescent effect after 15 minutes Img.33__Photoluminescent effect after 30 minutes Img.34__Photoluminescent effect after 45 minutes Img.35__Photoluminescent effect afters 60 minutes Img.36__Photoluminescent effect after 75 minutes

.7__ARCHITECTURAL APPLICATIONS

Low-energy construction techniques are very important in present architecture. The past few years light (in all shapes and forms) has also found its way to add an extra dimension to buildings. It is therefore obvious that photoluminescent pouring concrete has enormous architectural possibilities. A first application can be found in buildings with exposed concrete. Why can't we finish the final layer of the exposed concrete with photoluminescent pouring concrete. The outlook of buildings will have something mythical and floating. One of 2 examples is the Phaeno Center in Wolfsburg of Zaha Hadid (img.37). In the digitally alteredphoto of the building, the exposed concrete is replaced by photoluminescent pouring concrete. This way the building appears to come off its socle and to float in the sky in the evening and at night (img.38). The second example is the Opera House in Tenerife of Santiago Calatrava (img.39). The floating element can obtain an extra dimension by spraying photoluminescent pouring concrete on it. The floating element becomes a landmark and it obtains something transcendent (img.40). A second architectural application is using the material to build in certain safety measures for emergency situations. During power failures in large buildings (skyscrapers, airports,...) walls, floors and ceilings in photoluminescent concrete could illuminate and visually aid people to find the exit (mg.42).


Img.37__Phaeno-center during daytime Img.38__Phaeno-center at night Img.39__Opera House during daytime Img.40__Opera House at night


Img.41__Illuminated corridor Img.42__Corridor with emergency light Img.43__Highway during daytime Img.44__Highway at night Img.45__Highway at night Img.46__Illuminated median strip

Photoluminescent concrete could also illuminate highways at night. Image 43 to 45 show a standard situation of the Belgian highways. Part of the highway (img.43) is illuminated at night (img.44) to guarantee a certain safety. After midnight the street lighting is switched off and it becomes pitch-dark (img.45). Why not provide the median strip with photoluminescent concrete so drivers have some sort of guidance at night (img.46). This will certainly benefit the safety of our roads at night.

The broad color range (img.47) and the different compositions in m/V ratio between concrete and photoluminescent powder (img.48) provide us with plenty of possibilities. Future techniques should enable artists to make works of art with a concrete sprayer as they do now with graffiti spray cans. The masterpieces will illuminate at night and give a whole new dimension to cities and roads. By using uniform elements (paving tiles, wall tiles, clinkers,...) with a different light intensity certain patterns (ex. a photo,...) can be incorporated in walls or at squares. Urban squares can be upgraded by providing them with photoluminescent objects (works of art, seating units, flower boxes,...). Last but not least we shouldn'tforget the interior design possibilities. For example the coating of certain walls, floors or ceilings in lounge areas (img.49) or discotheques (img.50). The photoluminescent walls – in different colors and light intensities – along with the traditional party lights (stroboscope lights, black lights,...) can produce a great extra visual light effect.


Img.47__color range Img.48__Differnt luminous intensity Img.49__Lounge area Img.50__Discotheque