Intelligent safety and emergency lighting solutions in disaster situations

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Abstract

Disasters. They always happen, with a probability of occurrence that is almost independent of the high-speed development of our technology, economy and society as a whole.
The most important measure humanity can take is to focus on reducing the loss of human lives and to plan intelligently the measures that need to be taken in order to reach a high level of overall disaster resilience.
We will bring into discussion some of the challenges that can appear when people need to find their way out from interior spaces in case of disaster. Some of those disasters can cause electric power outage in the building, leaving the evacuation routes visibility relying only on the electrical emergency lighting systems and we will see that those systems are not always infallible.
***Case study** : the "ice storm" phenomenon that impacted Canada in December 2013. At the height of the storm over 300,000 Toronto Hydro customers had no electricity or heating.[1]*
***Unexpected problem** : Basements and other interior areas without natural light in multiple high-rise buildings in Toronto have been left in complete darkness due to the failure of the safety lighting systems, endangering the evacuation of the people inside.*
A new problem arose : can there be an alternative solution for visually signaling the escape routes ?
***Objectives:** Technological solutions for this impasse exist, but are being used in other applications : interior decorations, entertainment industry, exploration research and military industry .*
Those possible alternative solutions are: phosphorescent elements and chemical light tubes.
We will analyze how and if we can implement these technologies through smart design on a large scale for the emergency evacuation paths.

Case study solution : *project (Toronto - Arc Condominiums) emergency escape route signaling through design and innovative use of phosphorescent mosaic.*
[1] "Ice storm: Toronto Hydro CEO promises power within hours to remaining customers | Toronto Star". Thestar.com. 29 December 2013. Retrieved 23 February 2014.

Keywords*: emergency lighting, safety lighting, photo luminescent mosaic.*

1. Introduction

Disasters. They always happen, with a probability of occurrence that is almost independent of the high-speed development of our technology, economy and society as a whole.

Natural disasters : earthquakes, wildfires, floods, volcanoes, landslides, severe solar storms, extreme temperatures, tsunamis, disease epidemics and insect/animal plagues - they were always happening and they will happen again in the future.

On top of that we have the anthropogenic hazards, technological or the man-made disasters: industrial accidents, explosions, fires, terrorist attacks, complex emergencies or conflicts, a.s.o.

Some of the deadliest disasters in our world history were caused by human actions.

According to the Hyogo Framework for Action [2] created in 2005, disaster resilience is determined by the degree to which individuals, communities and public and private organizations are capable of organizing themselves to learn from disasters in the past and reduce their risks to future ones, at international, regional, national and local levels.

Disasters can rarely be controlled, it is very difficult to be predicted and most of the times they can not be stopped.

In this context, the most important measure humanity can take is to focus on reducing the loss of human lives and to plan intelligently the measures that need to be taken in order to reach a high level of overall disaster resilience.

Historical data are showing us that the world has seen a significant reduction in disaster deaths by means of creating more resilient infrastructure, emergency preparedness, and response systems.

In the early-to-mid 20th century, the annual death toll from disasters was huge, often reaching over one million per year. In recent decades we have seen a substantial decline in the number of deaths, fewer than 20,000 die, and in the last ten years, this has often been less than 10,000 (per year).[4]

We will bring into discussion some of the challenges that can appear when people need to find their way out from interior spaces in case of disaster. Some of those disasters can cause electric power outage in the building, leaving the evacuation routes visibility relying only on the emergency lighting systems.

Every single type of emergency light today is depending on electric or electronic technology in one way or another.

Currently, the safety lights rely on two major categories of power sources: rechargeable batteries and electric energy directly from the power grid that charges the batteries when they drain. We will see that safety lighting today is depending on regular maintenance and periodical replacement of elements in order to work.

What technology can we use to eliminate these shortcomings?

1.1. Our way out of the building: how easy is to get out ? - Evacuation routes

In an emergency situation people need to find their way out fast and easy.

The way out may be a sinuous route on corridors and open interior spaces followed by an even more difficult road down the evacuation stairs.

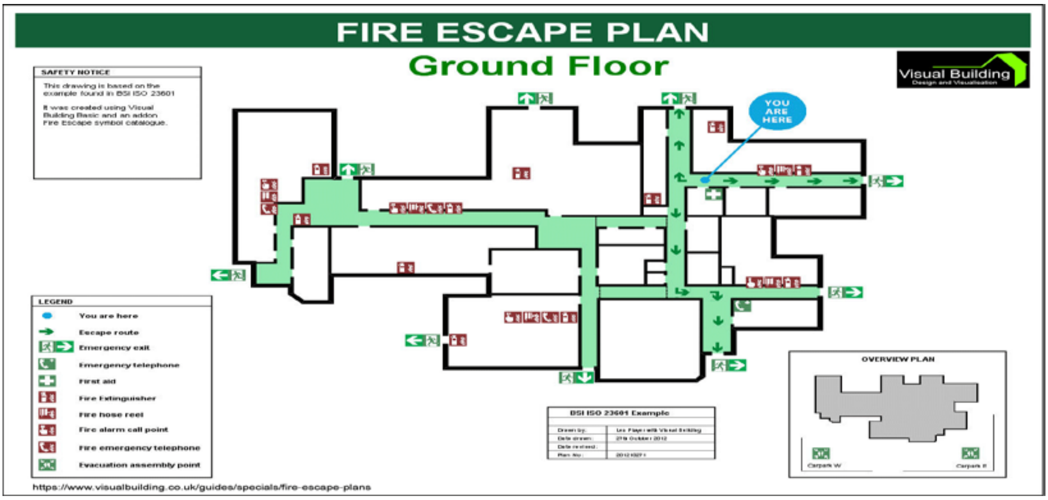

Fig. 1. Fire escape plan example
Source: *https://www.visualbuilding.co.uk/guides/specials/fire-escape-plans*

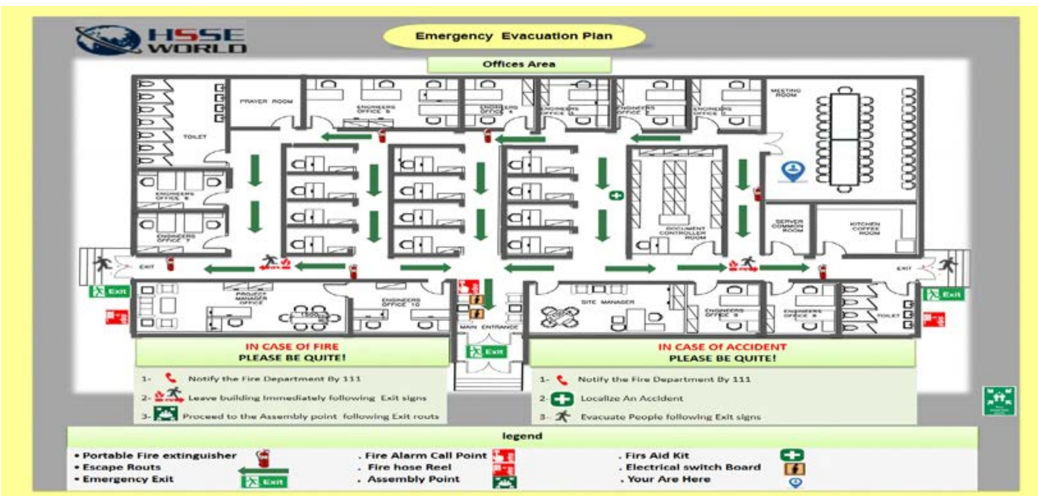

Fig. 2. Fire escape plan example
Source: *https://hsseworld.com/fire-emergency-evacuation-plan-and-the-fire-procedure/*

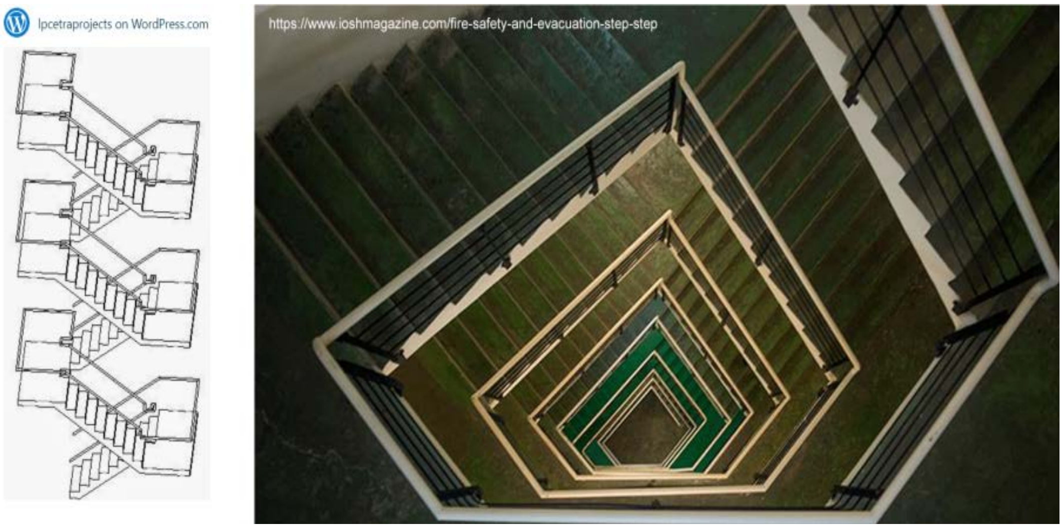

Fig. 3. Different types of interior evacuation stairs
Source: *https://lpcetraprojects.files.wordpress.com/2015/06/7547c-multistorey07.jpg*
https://www.ioshmagazine.com/fire-safety-and-evacuation-step-step

Very often those routes are in the interior of the building with no possibility of receiving natural light. If a disaster happens at night time, natural light from windows or glazed doors cannot be counted on.

This is what we call the "pitch black" situation.

Why can this happen and what alternative solutions should we seek in order to avoid this situation ?

We will try to find some answers to all those questions in the following chapters.

1.2. How much light do we need in order to see our way out in the dark ? - International standards

Emergency lighting plays a vital role at critical times in guiding people that need to escape quickly and safely from a building.

Specific requirements for emergency lighting are set out in law, and international standards. [1]

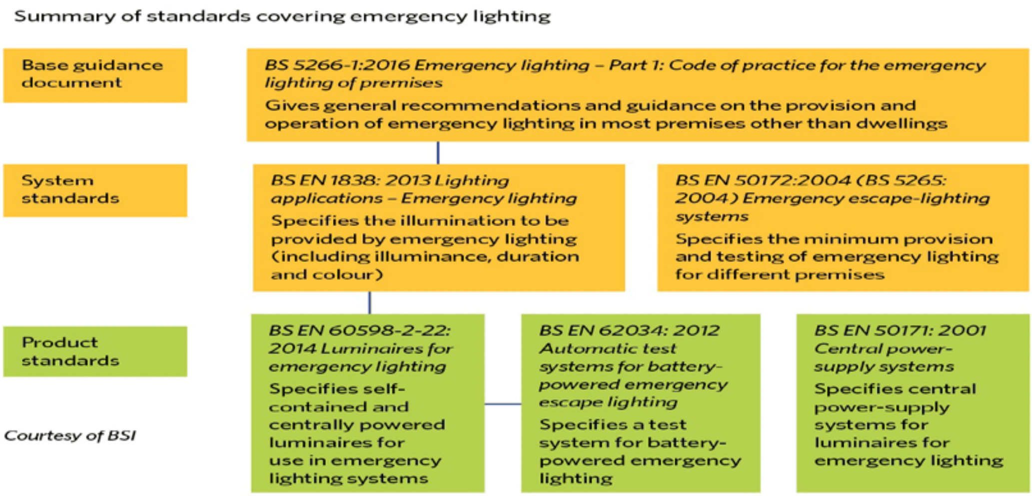

Fig. 4. Summery of standards covering emergency lighting
Source: *https://www.cibsejournal.com/general/emergency-lighting-standards/*

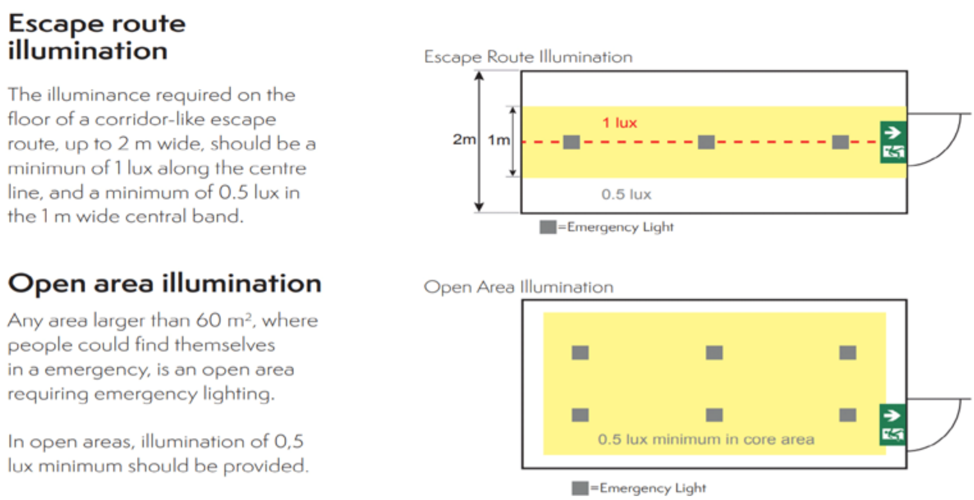

Fig. 5. International standards
Source: *https://www.teknoware.com/*

Above we can see just a few examples of standards regarding minimum illuminance levels on the escape routes.

Those standards have some major requirements:

- a general minimum luminance (visually perceived brightness) of specific interior spaces. The spaces in the building are categorized by their importance ,as per how many people are living, working or passing through those spaces daily or how vital are those spaces in the emergency exit path trajectory,

- how the light fixtures are distributed in the building (distances between fixtures, distance to the floor, a.s.o.),
- how long the emergency light system needs to be able to stay open.

For example, according to the international safety standards, emergency exits and escape routes must be illuminated by a minimum of 1 Lux at all times and in the event of a power failure, emergency lighting must be able to provide this level of illumination for a minimum of **one hour.**

2. Why can it happen ? - What type of hazards can trigger the malfunction of the emergency escape lighting system ?

2.1. The batteries

In general, the emergency light systems rely on rechargeable batteries connected to the electric power grid and they are required to last 4 years, as per EN60598 2 – 22 which states: “Self-Contained Luminaries shall incorporate batteries which are designed for at least 4 years of normal operation. [3]

For example, service life for nickel cadmium batteries is mentioned by the manufacturers as being 4 years.

In order to make sure the safety lights will turn on in case of power outage, the central battery unit and the emergency exit lights need to be maintained regularly and batteries need to be replaced after the battery life time has passed, usually every 4 years.

Looking at the international regulations regarding emergency lighting shown before, we will notice that the number of safety lighting devices and exit signals in a building is significant. Those devices need to be placed at every node of the emergency exit path, on every single floor, above or next to every single door, and all of them need periodical maintenance and battery replacement. The maintenance requires also periodical testing of the entire system, so the batteries are drained to some extent during testing and also during idle times between use, so electricity is consumed in order to get fully recharged again. This comes with a cost, raising the expenses of electric bills and periodical expenses on acquiring new batteries that need to be replaced every 4 years.

The building management team or the owners of the building sometimes fail to perform all the tasks required in order to maintain in perfect shape the emergency lighting system because they forget, they neglect or they lack the funds to do so.

For each of this reasons the emergency exit light system can fail to work at a time in need.

2.2. Solar powered emergency lighting system

The solar power industry boom in the last decade has brought lots of enthusiasm also in the emergency lighting system users.

We will find in the market various types of solar powered emergency lighting systems. We need though to take into consideration that the solar cells and the adjacent cables increase the number of component parts of the lighting fixture, increasing the risk of mechanical damage. On top of that, those fixtures still need a chargeable battery that require maintenance as we mentioned in the previous chapter. Another important observation is that solar panels need direct sunlight exposure in order to charge and this fact narrows down the possible areas we can place those lighting fixtures to outside spaces alone or in close proximity to a window or a glazed surface that receives natural daylight.

2.3. Electronic components failure causes

Every single type of emergency light today is depending on electric or electronic technology in one way or another.

Electronic components are not indestructible and they have a wide range of failure modes. These can be classified in various ways, such as by cause or time. Failures can be caused by excess temperature, excess current or voltage, ionizing radiation, mechanical shock, stress, impact, severe solar storm or even an electromagnetic pulse attack.

All those types of hazards are likely to happen quite often, except the last two where there are still scientific debates about how probable their occurrence can be in the future.

"It is possible that a nuclear EMP may never happen where you live. On the other hand, a severe solar storm that will destroy most of the world's power grids appears nearly inevitable at this point. Protection against the damage of a severe solar storm could be done easily and rather inexpensively by the electrical utilities; however it is not being done, and there are few signs that it will be done." [5]

A severe solar storm (super-storm) happens when the sun opens its coronal holes and a massive amount of electromagnetic radiation is spread into space. When this radiation hits our planet's magnetosphere, it triggers a geomagnetic storm, that could destroy the majority of our power grid transformers possibly all over the world . We are looking in this case of a possible worldwide electric power loss and the damages would be so severe that it could take years until all electric and electronic systems worldwide get replaced with new ones.

The last solar super-storm took place in 1859, but back then the power grid was not yet in place. The only technology we had at that time was the telegraph, and it's function was disrupted by the fact that the solar flares have set most of the telegraph pylons on fire.

In 1921 another large solar storm happened, for a shorter period of time than the previous one, affecting a smaller geographical area.

We cannot exclude the future possibility that a solar storm can happen, so it is always better to be prepared for it.

2.4. The smoke can reduce the visibility of the emergency escape lighting system

Fire is one of the most dangerous, lethal and destructive disaster.

The smoke that is created by fire inside a building is not only toxic but is a secondary element, along flames, that can obstruct the safe access to emergency exit paths.

When fire occurs it is most likely that the electric system of the building is affected, leading to electric power outage. This will trigger the emergency light system to start working.

The propagated smoke is usually dark and thick and it tends to accumulate on the upper space of the room, just under the ceiling, covering the safety light fixtures that are usually placed on the ceiling and reducing the amount of light that has to reach the floor and the surrounding space.

Lately we will find more and more examples of emergency lights placed on the walls at a lower level than the ceiling in order to avoid this issue, but the majority of buildings still have the old standard system of ceiling mounted emergency lights.

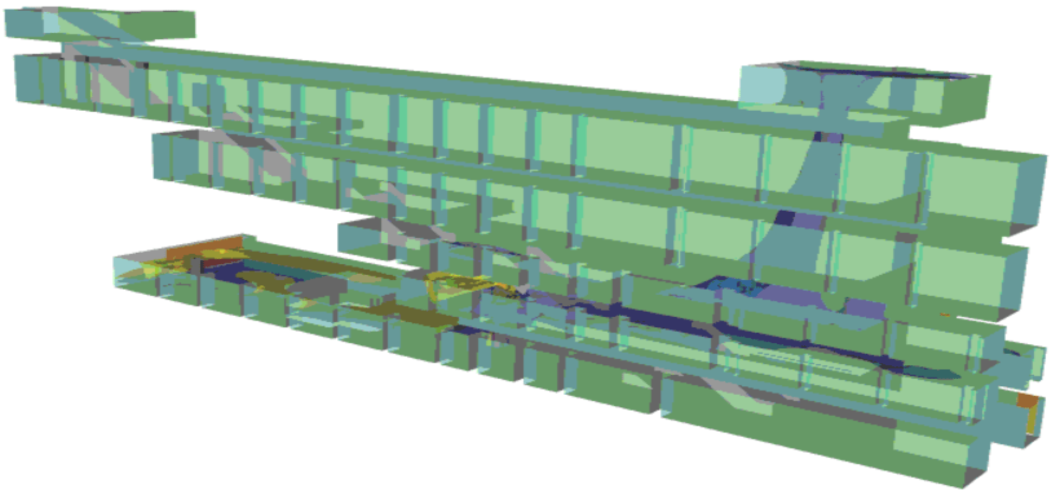

Fig. 6. CFD simulation of fire and smoke propagation in the National Museum of Contemporary Art in Athens

Source: *https://simtec-europe.si/*

Fig. 7. Smoke propagation in the interior of a building
Source: *https://www.elp.uk.com/ (with modifications)*

Fig. 8. Smoke propagation in the interior of a building
Source: *https://aboutlux.com/ (with modifications)*

We will see that the alternative solution we will analyse at the end has the advantage of being placed mostly on the floor, so the smoke propagation will not affect the light visibility at all.

2.5. Electric power outage due to a natural disaster : frozen rain / ice storm

The electric power outage in urban networks is a phenomenon that occurs frequently in case of hazard: seismic event, flood, fire, hurricane, tsunami and many other types of disaster.

This phenomenon is largely due to the fact that the electricity transmission system in the city is largely performed by cables located above the ground, exposed to climate factors, physical aggression (supporting poles may break or even cables may be damaged by mechanical factors - wind, ice weight, etc.).

Case study:

In December 2013 we witnessed the “frozen rain”/ “ice storm” phenomenon that impacted the central and eastern portions of Canada.

The first wave of freezing rain began on 20 December; it coated the city in a significant but manageable quantity of ice. The second, more powerful wave of rain struck the city in the early morning of 22 December.

Utility poles and tree branches collapsed under the weight of the thick ice accumulation. At the height of the storm over 300,000 Toronto Hydro customers had no electricity or heating.[7]

Toronto, Canada's largest city, was one of the hardest hit by the ice storm.

By 24 December, four days after the storm, 69,800 customers throughout the city were still without electricity.[6] Approximately 1,000 people spent Christmas Eve in the warming centers. On 29 December, Hydro One diverted its crews to assist Toronto Hydro to help restore power to over 6,000 people in the city who were still without power.

Unexpected problem:

This natural phenomenon severely affected the city. Many basement areas and other areas without natural light in multiple buildings in Toronto have been left in complete darkness due to power outages or the failure the safety lighting systems, endangering the evacuation of the people inside.

Solutions

A new problem arose : How can we find an alternative solution of signaling through light fixtures the escape routes from dark closed spaces and how can we visually point out in a total darkness situation elements in the building structure that must be bypassed during the evacuation (support pillars, corners) or must be traveled in a certain direction (stairs, access ramps) ?

Technological solutions for this impasse exist, but are being used in other applications : interior decorations, entertainment industry, exploration research and military industry .

Those possible alternative solutions are: phosphorescent elements and light-stick items (chemical light tubes)

We will analyze how and if we can implement these technologies through smart design on a large scale for the emergency evacuation paths.

3.1. Chem-light

A glow stick is a self-contained, short-term light-source. It consists of a translucent plastic tube containing isolated substances that, when combined, make light through chemiluminescence, so it does not require an external energy source. This type of light is continuous, cannot be turned off and can be used only once.

Chemical light (chem-lights) offer a type of punctual light of short duration (a few hours maximum), but sufficient to be able to guide the user towards the exit or to explore a dark area (in the case of military uses, speleological, archaeological research, a.s.o.).

The major disadvantage of this technology if we try to consider it for widespread use in enclosed spaces is that it emits light for a short period of time, after which the tube (the chem light container) becomes inert and in order to reactivate the light we must replace the entire amount of chemical substances that create fluorescence through the chemical reaction between them.

Because of this major inconvenience it will be very difficult to create a viable solution that can be implemented at large scale in order to offer alternative light solution for the emergency escape routes in public or private buildings.

But still, the fact that this type of light source does not require an external energy source in order to work is notable and worthy of further investigation and research.

3.2. Phosphorescent elements

The solution with phosphorescent elements is very interesting and it was the solution I proposed at the request of the Arc Condominiums Management Board after the frozen rain phenomenon in Toronto 2013 have affected the building.

Phosphorus, extremely unstable and reactive in its natural state, can be included in glass or plastics and those elements can be used to outline the volume and the edges of an interior space in case of total darkness with lines and surfaces that glow in the dark.

The phosphorescent elements contain photo-luminescent pigments that absorb and store energy from appropriate artificial lighting and sunlight and they can undergo the process of being recharged with light repeatedly.

Appropriate artificial lighting means any light source that emits sufficient energy in the visible blue or invisible UV portion(s) of the electromagnetic spectrum, or both.

Through smart design we can compensate the fact that those phosphorescent elements have less light power than what is required by law for the standard emergency lighting systems, especially if we take into consideration the fact that in a total darkness environment even a less powerful light source is very visible and it is the only element that we will notice from the entire space around us. If one element is not highlighted by light and it is in the path of our emergency exit route, let’s say it is pillar or a couple of steps, or a threshold - we will not see it in the dark , we will hit it or we will stumble on it and this will endanger our health and our success in exiting fast and safe from the building in a disaster situation.

Let’s see what photoluminescent elements are available on the market today and what is the difference between them.

3.2.a. Phosphorescent coatings and stickers

- **“Glow-in-the-dark” coatings** contain photo-luminescent pigments mixed in epoxy or acrylic liquid stains.

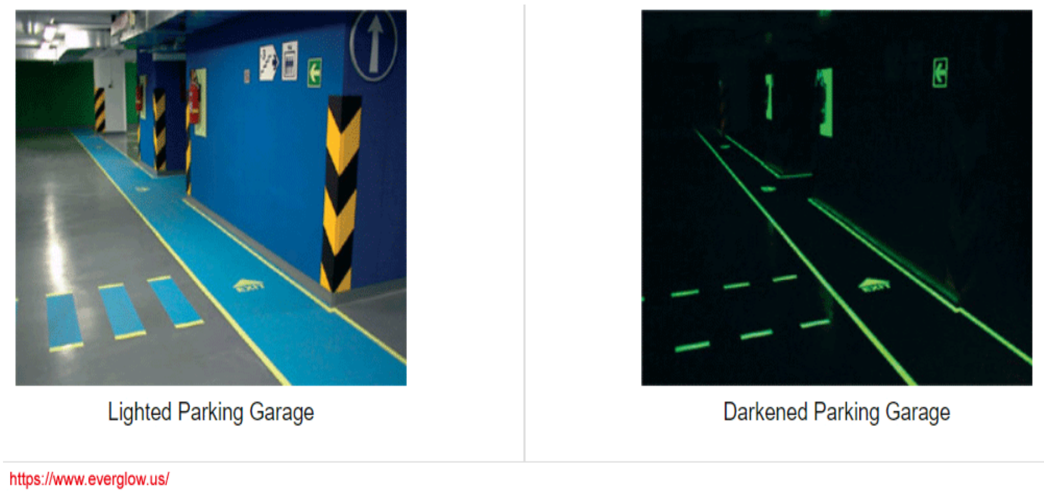

Fig. 9. Photo-luminescent epoxy coating
Source: *https://www.everglow.us/*

Reading through the technical data sheets that some of those manufacturers provide we will see that the luminous performance is quite impressive.

The coatings and stains have unfortunately a short life spam as they can sustain chemical damage from cleaners, thinners, clear coat or other paints, process chemicals, process fumes or environmental damage such as acid rain. If intended for horizontal surfaces people will step on like emergency exit paths it can sustain mechanical damage as well.

We also have to read carefully the hazard identification warnings, as most of those stains can cause serious eye irritation, skin irritation, allergic skin reaction and they are toxic to aquatic life with long lasting effects.

- **Phosphorescent stickers** are manufactured using a very thin layer of the same photo-luminescent pigments that absorb and store energy from artificial lighting or natural light.

More and more manufacturers worldwide are producing a wide range of phosphorescent elements like stickers, signs, markers, films, and tapes that can be glued to the walls, floor, stairs and exit doors.

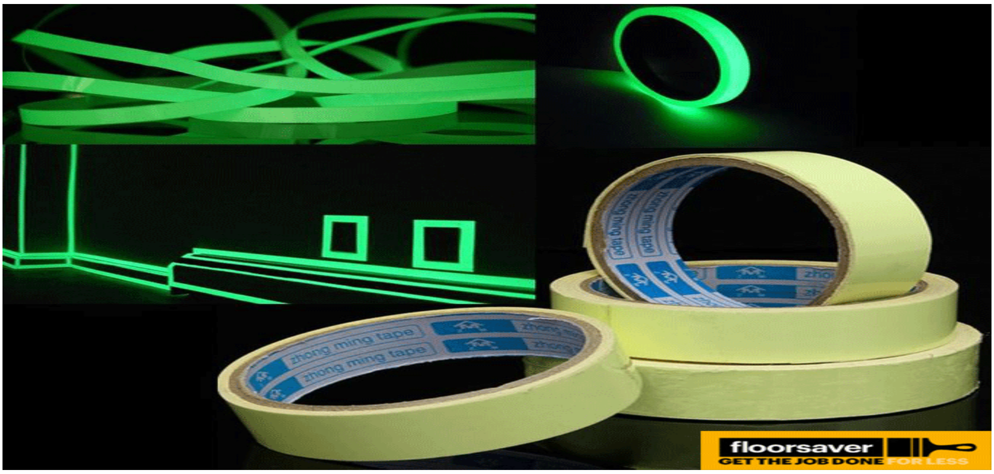

Fig. 10. Photoluminescent tape
Source: *https://www.floorsaver.co.uk/*

Those elements can be glued on any building element, part of the construction, furniture or equipment that can be an obstacle on the emergency escape route and can inflict injury or slowing egress during an emergency.

All those building elements need to be highlighted in order to avoid confusion that will slow an evacuation:

- Stairs and Ramps to clearly and safely show beginning, course and end.
- Handrails must be visible from the top and must show the course of the stairs
- Landings to show the leading edge (step landing) and perimeter of the exit path

Fig. 11. EverGlow "glow in the dark" signs, markers, films, and tapes for emergency exit paths markings
Source: *https://www.everglow.us/*

Luminaire Type	Minimum Charging Illumination	Maximum Afterglow Duration	Minimum Color Temperature	Lighting Industry Nomenclature
Fluorescent	1 ft-c	90 minutes	4,000 K	cool white
Metal Halide			4,000 – 4,500 K	
Mercury-Vapor			3,500 – 4,000 K	
LED (blue LED with phosphor)			2,700 – 4,500 K	soft or warm white to bright or cool white
Halogen			2,700 – 3,000 K	soft or warm white to bright or cool white
Incandescent			2,700 – 3,000 K	
Sodium-Vapor	does not reliably charge SrAl pigments		1,800 - 2,700 K	warm white
Neon			various	various

https://www.everglow.us/

EVERGLOW

Fig. 12. EverGlow "glow in the dark" signs, markers, films, and tapes technical information
Source: *https://www.lelong.com.my/*

3.2.b. Phosphorescent mosaics

Phosphorescent mosaic is manufactured using recycled glass that incorporates photo-luminescent pigments that absorb and store energy from appropriate artificial lighting or sunlight.

This type of mosaic has a high resistance to wear and have a glow time of **6 hours**, longer than the luminescent stains or tapes, due to the fact that the mosaic tiles are much thicker so they can incorporate a bigger quantity of photo-luminescent pigments per msq.

Phosphorescent mosaic can be placed on any surface of the building, on the floor, on the walls, on the stairs, it is as strong and reliable as any type of glass mosaic, it can be easily cleaned,it is chemical resistant, stain resistant, water resistant, frost resistant, it is not toxic, non flammable and its luminescence will not fade in time.

It also comes in white color (emitting white color glow), allowing a better color integration in any interior color scheme design and color pallet.

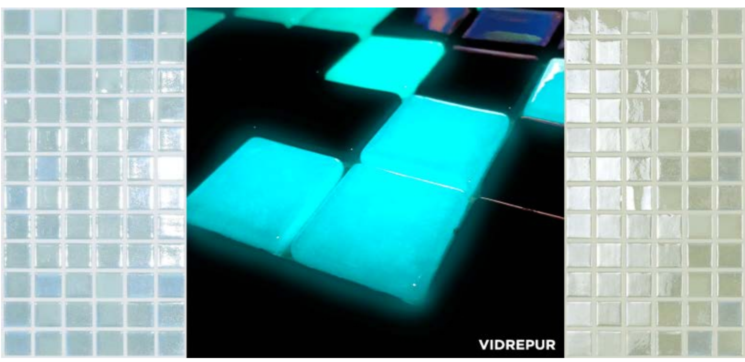

Fig. 13. Vidrepur luminescent glass mosaic tiles
Source : *Monica Frangulea*

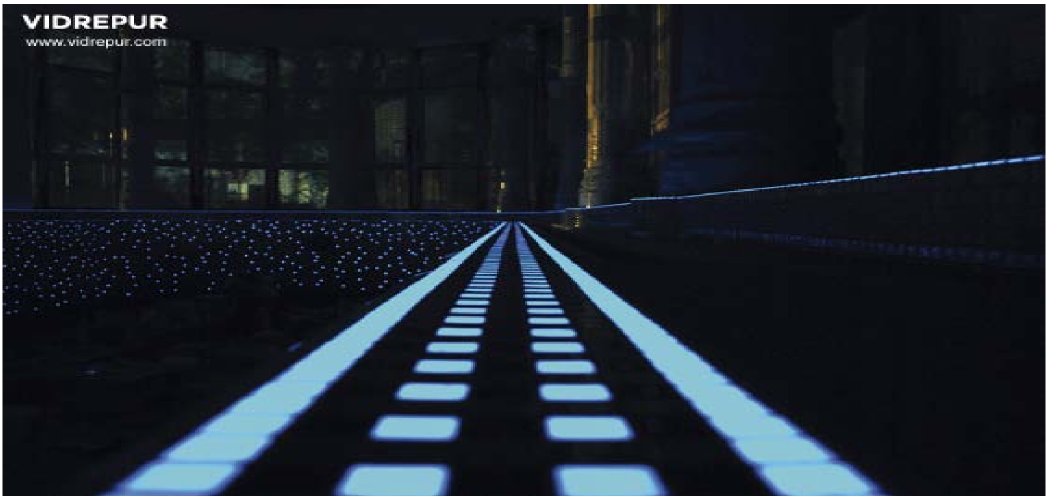

Fig. 14. Vidrepur luminescent glass mosaic tiles
Source : *https://vidrepur.com/en/*

3.3. Case study - Arc Condominiums

We will see now an example of such a project that I have done in 2014, after the frozen rain phenomenon affected Toronto in the winter of 2013.

I was requested by the Arc Condominiums Management Board to give an alternative solution of signaling the emergency exit paths in the entire building.

Arc Condominiums is a massive high-rise building of over 200 condo units,16 floors high, with 4 underground levels, interior pool, spa, gym, conference rooms and 5 emergency exit stairs.

Fig. 15. Arc Condominiums Building – Toronto
Source: *Toronto Real Estate Guide, The Nikolay & Tatiana Real Estate Team. Sutton Group- Admiral Realty Brokerage*

During the terrible ice storm, an elder person living in the building went to the storage unit she had in one of the underground levels of the building when a total power outage occurred and the emergency light system did not work. So she found herself in a pitch-black situation in an open interior space over 100m long and 30m wide full with over one hundred concrete pillars that she could not see. Actually she could not see anything and she was able to find her way out of the basement and up the stairs using only the screen light of her cell phone. It took her 2 hours to do that. At a exterior temperature of -15 degrees, the interior temperature of the space she was in started to drop rapidly, putting her health and eventually even her life in great danger.

The reasons why the emergency exit lighting system did not work are immaterial at this point and we have already seen before what causes can lead to this type of malfunction.

Taking in consideration the size of the building, the solution tried to use a minimum amount of luminescent glass mosaic tiles in order to reduce costs as much as possible.

The remarkable aspect of this type of solution is that it involves only an initial investment and it does not require any financial effort after, as it will recharge by itself in perpetuity just from the artificial light that is used on the interior circulated areas that works regularly all the time.

The solution propose narrow stripes of mosaic tiles to be placed on every sharp edge of structural pillars, wall corners and also as a belt placed 1m high on all peripheral and interior walls of the enclosed public spaces and exit paths.

On the floor there can be a central stripe 60cm wide or more that have black mosaic flash marks and other symbols that can help guiding the people on the paths towards the nearest exits. The exit doors in some areas will be fully covered with luminescent glass mosaic so as to be visible from a big distance.

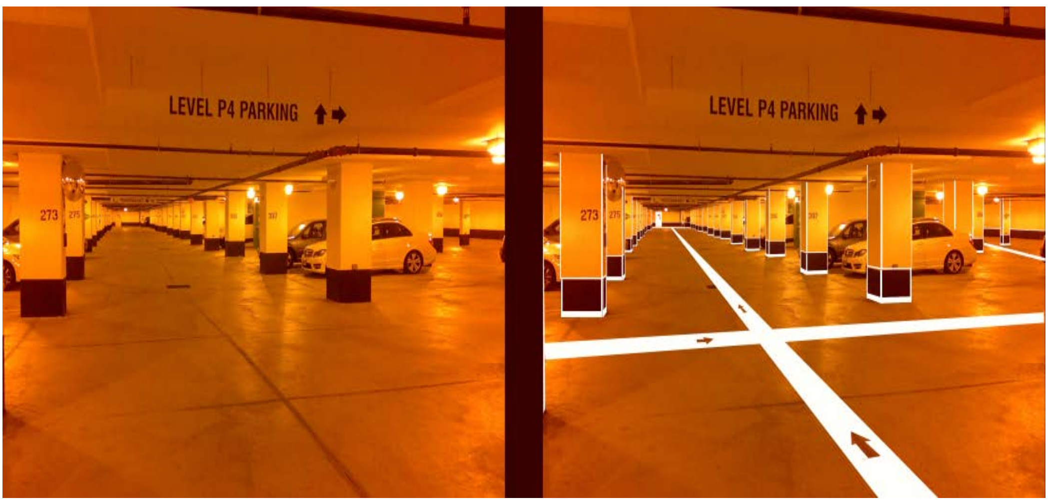

Fig. 16. Underground parking and tenants storage units area level -4 Arc Condominiums Building – Toronto
Alternative emergency signaling system using luminescent mosaic - regular light system working
Source: *Monica Frangulea*

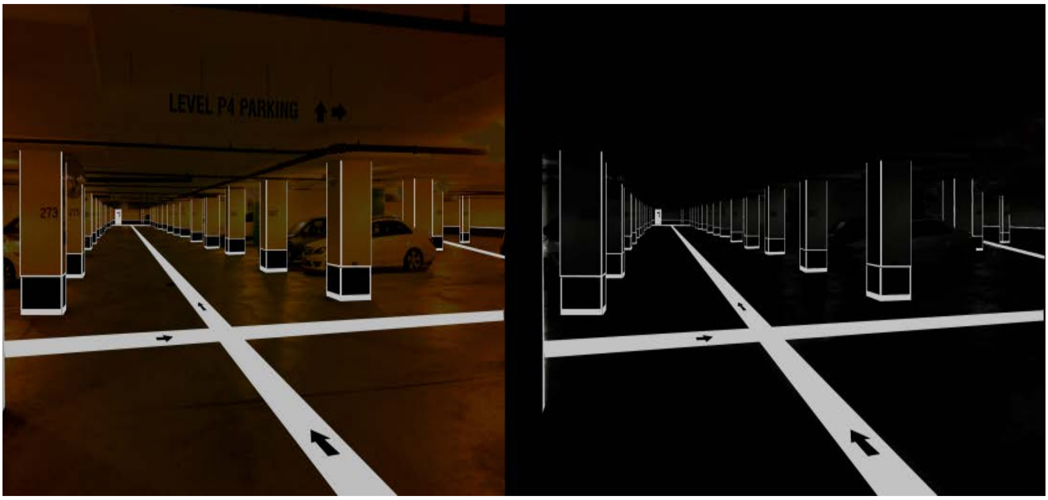

Fig. 17. Underground parking and tenants storage units area level -4 Arc Condominiums Building – Toronto
Alternative emergency signaling system using luminescent mosaic - only emergency light system working - electric power outage and emergency light system not working
Source: *Monica Frangulea*

For the emergency exit stairs the solution is simple, highlighting every single step with an horizontal stripe placed on the top of the under-step, a continuous stripe on the edge wall following the stair profile and a stripe at the railway level :

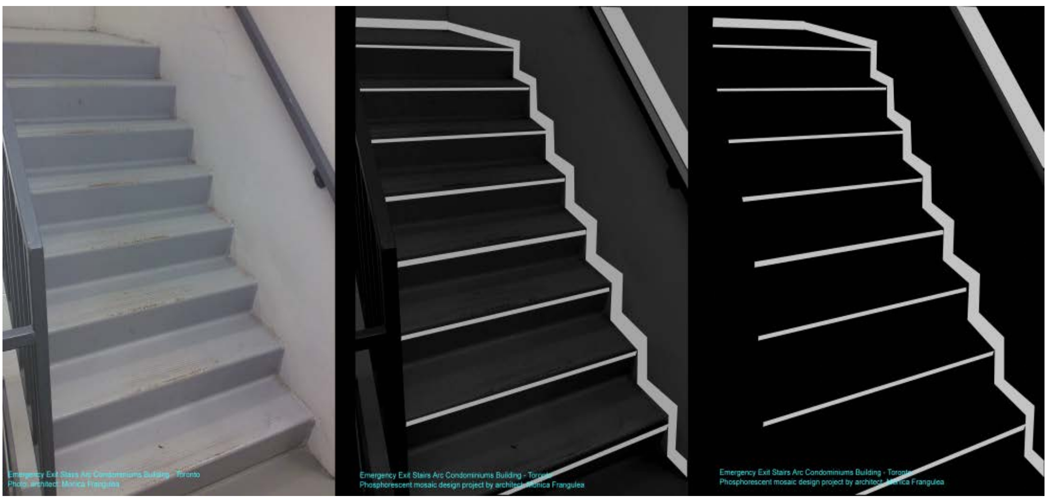

Fig. 18. Emergency exit stairs Arc Condominiums Building – Toronto
Alternative emergency signaling system using luminescent mosaic - only emergency light system working - electric power outage and emergency light system not working
Source: *Monica Frangulea*

The total cost of implementing this solution (materials and labour) for the entire building proved to be smaller than the cost of one replacement of the batteries for all the emergency light fixtures (that needs to be spent every 4 years, as explained on the previous chapters).

4. Conclusion

Photo-luminescent elements represent a viable alternative solution as a safety feature that can be implemented through smart design on a large scale for the emergency evacuation paths and not only and this family of products deserves further analysis and future development effort, in order to create better products that can be used in the construction industry of the future.

Acknowledgments

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