The necessary permanent WiFi health monitoring of the structures as condition for the smart buildings in smart cities

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Abstract

In the past our safety "standard" were much lower than now. We felt comfortable driving cars without a seat belt, without exterior rear mirror, without ABS nor Air-Bag. Today our cars are equipped with sensors and controls much better than the airplanes that flew in second World War.

Our continuous request of comfort goes hand in hand with the increasing safety for our life. Most of the machines and equipments around us enjoy of sophisticated control system, but civil structures not yet. Only few special bridges, mainly suspension or cable stay bridges, have some permanent tools to control them, and provide alert communication in case of suspect behaviour. "Normal", simple bridges miss this type of controls. Buildings, monuments, schools, hospitals, strategic buildings (Civil protection, Municipality, Police Stations, TV stations, communication centers…), all miss monitoring system for structural safety. Most of "smart solutions" refer to domotic (house automation) aspect like temperature, heating/air conditioning, lights, burglar alarm. All of them miss structural health control, forgetting problem like earthquake, structure aging, material decay and so on.Increasing the structural safety control of the buildings with smart devices means to increase the global safety for the cities.

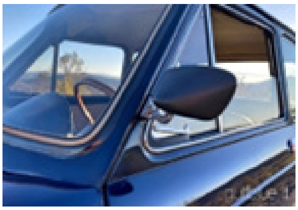
The paper introduces some experiences of the authors in this field, and presents some possible scenario for the future.

Keyword: *Infrastructures, health structure monitoring, IoT for structures, monitoring network*

Introduction

In the '60s the safety request from the population, at the work and in private life, was much lower than now. The big-boom of the market was pushing much ahead, and most population, mainly European, were coming from the II World War disaster, and were accustomed to the survival situation, and did not pretend too much from the already satisfactory conditions offered by the technology. Of course this reduced safety produced much injuries and casualties, even though not so much, if compared to the reduced safety level. At that time machines, mechanical and electronic devices, cars, electronic tools were all missing the "standard" measurements which now we are accustomed to. For instance, the cars were carring only the central rear mirror, and not yet using the lateral ones. Safety belts appeared only around 1975, and the air-bag some decade later, along to ABS and other controls.

FIG.1,2,3,4 – The cars in the '60. Only the central rear mirror. One decade later appear the first lateral rear mirror- (IoT Bridge-AB, Sweden, P. Rosegren,2017)

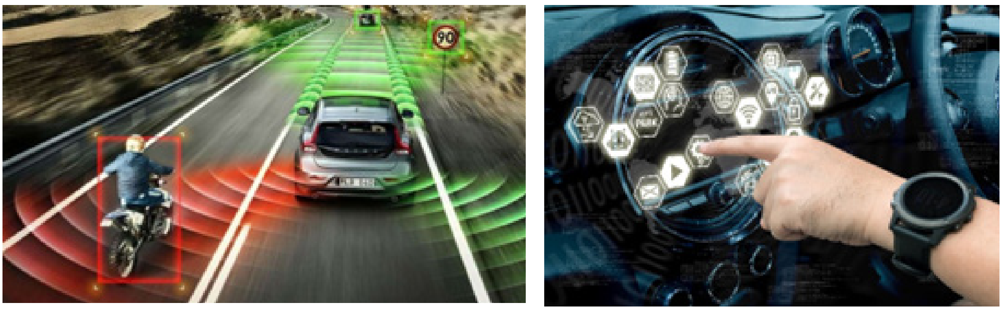


The increasing number of cars, drivers, and passenger pushed the designer to consider more the safety for the cars, and not only the comfort, the economy of transportation, the reduced cost of the maintenance. This approach brought the cars in the context of safety, being passive or active. Then we saw the evolution of the safety belt, first only for the front seats, later for all the passengers, then the ABS (anti brake system), to control in automatic way the differential slippage of the wheels, on driving on the snow, on the mud or simply experiencing aquaplaning during a strong rainfall. One investigation in USA by the Transportation Department and NHTSA (National Highway Traffic Safety Administration) evaluated around 15.000 lives saved in US between 2013 and 2017 (4 years) thanks to the use of the safety belt in the car, and about 12.000 in the same period for the action of the airbags.

FIG.5 – The cars. In the late '70 appears the safety belt.
(IoT Bridge-AB, Sweden, P. Rosegren,2017)

FIG.6 – The cars. Airbag becomes compulsory at the end of last century
(Motori.it, on-line magazine,)

FIG. 7,8 - The cars. In the last decade the car are equipped with all kind of sensors
(IoT Bridge-AB, Sweden, P. Rosegren,2017)



For instance the airbags, despite being invented in the '60s, were installed first time on a car about 20 years later, and become compulsory in the late '90.

Considering this progress in the safety for the car, we can move also to the other "component" of our life, like infrastructures, bridges, buildings, and any other environment where we will pass through during our life.

Infrastructures

FIG.9 – The Västerbron bridge, in Stockolm, built on 1935, equipped with device within IoT platform (IoT Bridge-AB, Sweden, P. Rosegren,2017)

Let look at the Västerbron bridge, in Stockolm, built on 1935, with 600 m total span, and a traffic flow of 50.000 vehicles per day. We will discover that in 2019 the bridge has been included in one pionieristic project related to the permanent control of the traffic, vibration, displacement, stress. In one word the structural health of the bridge has been put under permanent control. In Sweden even a harvesting prototype was installed on the Old Lidingö Bridge, 166 daily train passage, collecting energy useful to power at least the structural health monitoring system.

FIG.10 - An energy harvester prototype, installed on the Old Lidingö Bridge (Rosengren et al., 2017)

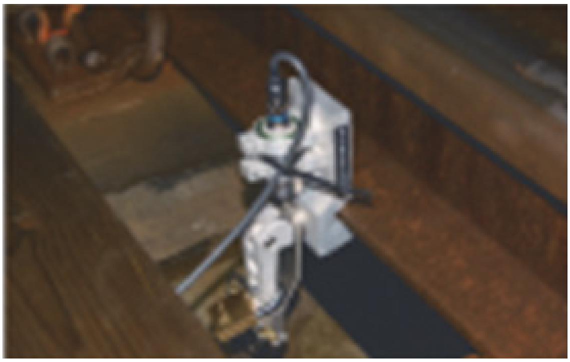
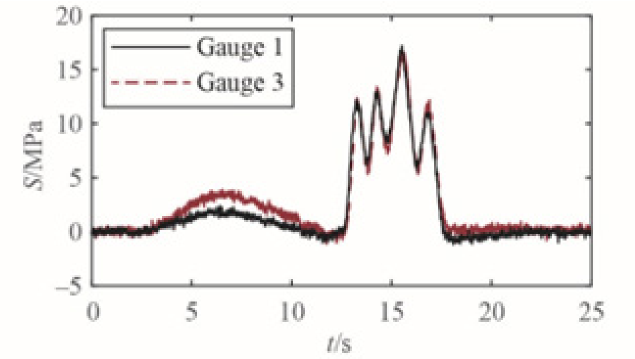


FIG.11 - Stress history at the passage of a train on a bridge (Rosengren et al., 2017)



Today great importance is giving, more and more, to the structural health monitoring, not only for short term but mostly as permanent control. The permanent control reduces dramatically the risk of sudden collapse, since a long term monitoring can result in accumulation of data about the state of the structure, and possibly also about its mechanical change. The accurate measurement of stress and deformation and vibration can give a trend of the behaviour of the structure. The reduced risk in this case can be accompanied by a suitable maintenance, which will prevent further damage to the structure. The Tacoma Bridge collapse few weeks after the completion of the structure. Despite some warning given by previous shacking of the deck under strong wind, no specific measurement could be done at that time, no sensors were installed on it in order to monitor the behaviour and the unusual swing of the bridge.

FIG.12 – November 1940.Tacoma Bridge collapsed
for the vibrations induced by the wind

FIG.13 – An imaginary scenario of total control of Brooklin Bridge, in N.Y., by VackerGlobal Co., Dubai

Buildings

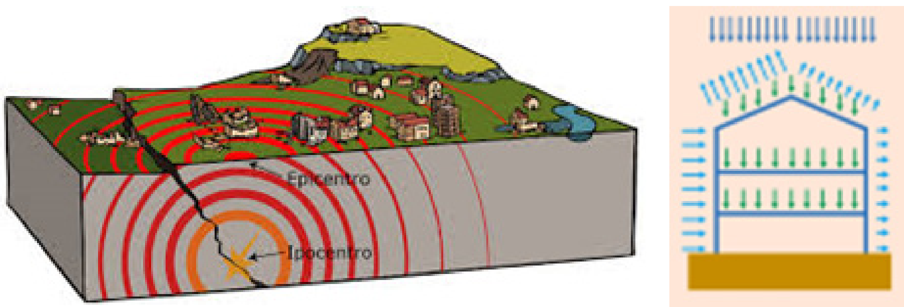
If the infrastructures contribute to the development of the regions, facilitating movements and trade, and then their safety is considered very important, as well as the cost for repair damage and replace the satisfactory safety level, the buildings are even more important for the human life.

The scenario of living in a not safe building, considering the possible vulnerability for wind, fire, or earthquake cannot keep calm anybody. And like in the infrastructure we can classify the road with different importance, considering as main road artery some highway and then classifying other smaller one as secondary road, even for the buildings we could have a sort of classification of buildings in term or importance of the "content". And in this case hospitals and schools can play a main role among the all the other buildings in the city.

FIG.14 –HOSPITAL and school should be considered as main environment to control in term of safety

From the point of view of the risk, for the buildings also we can mention two main factors. One is related to the loads, it means that a monitoring activity should consider in the time all the active loads on the structure, being live load from the people living in the building or wind or earthquake coming from the natural event. An adequate permanent monitoring system should work within four different spaces. One is the collection of the data, it means the external load (for instance, the wind speed or the intensity of the earthquake or the crowding level), but also the stress connected to all these events. The second one is the alert in case some measurements overpass the trigger level assigned for the sensors (displacement, stress, acceleration). Then, after this level, it is possible to imagine two more levels. One is related to the classic activity of maintenance, since the continuous monitoring can give a clear situation of the stress inside the structural elements, and a well alerted building maintenance operator can interpretate the signal coming from the structure and react correspondingly, increasing the safety level. On the other hand, the collected data can be sent to a specific program (so called artificial intelligence) which is able not only to file and classify the single event, but also to elaborate a probability function that finally give a trend of the structure behaviour and foreseen future situation. For instance a repeated strong wind can suggest the installation of a TMD (tuned mass damper) tuned on the load history suffered previously by the building.

FIG.15 – Earthquakes and other loads should be monitored in order to have the continuous control of the structure.



But also the aging and the decay of the structure should be monitored, since the safety of a structure is based on the intensity of the loads and on the quality of the material. Suitable sensors should then installed on the structure in order to measure the coming loads as well as the stresses in the material and its level of integrity.

FIG.16 – The corrosion of the rebars in the concrete affect the quality of the material, and the resistance of the structural element can be much lower than what expected in the original design.

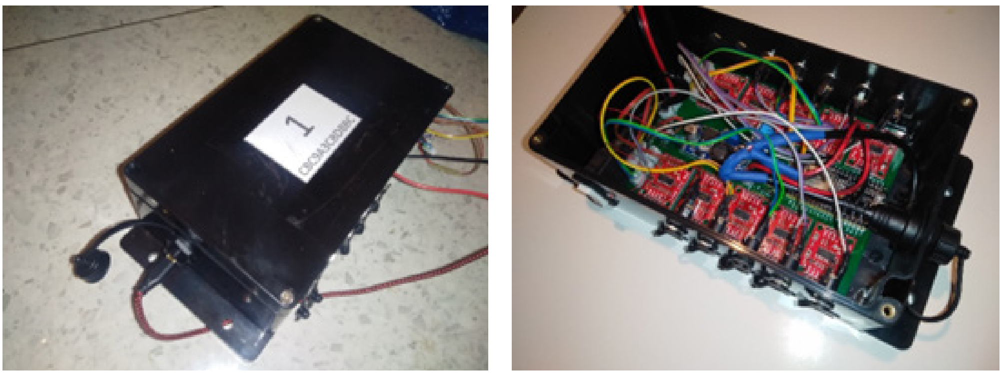
Inside our houses since several years we have some quite efficient "assistant" of our "life-at-home". We mean the control of the heating system, or air conditioned, or the sensor for the gas leakage, and even the burglar system. Often one system can be connect several devices and sensors, and sometime this "network" can be very efficient, if the software controlling the system can take advantages from the complementary measurements by different sensors. Usually this kind of approach is called "domotic", it means "home automation", considering the humans relieved from daily control of home temperature, and consequently switch on or off the heating system.

FIG. 17. – Typical application of "home automation", related mainly to control the comfort inside the houses.

In the “home automation” there is not yet any refer to the structural safety of the building. But the platform for the home automation, so called IoT, is quite efficient and smart. Then it seems a reasonable idea to extend the number and type of sensors to those one able to give answer about the structural health of the building. We can imagine to use the same “platform” already happily used in home automation and transfer under control other type of value. Acceleration, vibration, displacement, stresses, all the mechanical parameters can be measured and recorded somewhere, and even transmitted on line for a remote monitoring and control. We are then talking about the “IoT for the structures”, where the sensors are obviously different, but the communication system between the devices is very similar, if not exactly the same, to that used for home automation.

All the building can be monitored in its mainly structural parameters, and we can have a sort of log where all the “structural” activity will be recorded, and even elaborated if we can equip the system also with a AI (artificial intelligence) engine, able to connect together the values coming from different sensors in different moment of the life. The cost of this kind of devices is very low, at the moment, and there is a flowering of new compact and more efficient devices, which help in distributing all over the structure the sensors without impact much on the visual of the inhabitant.

FIG. 18. – Some devices “IoT for structure” made by the authors, in the research team “Moni2BSafe” at University of Rome “Tor Vergata”. It is visible the hexadecimal number, meaning the wifi tag of the device.



Indeed the best application of these devices will be when it will be installed on the structure “during” the construction, in order to have some sensors not on the skin of the structure, but inside the body of the structure elements. We develop a family of this sensors, and we did some interesting application on several civil structures. One of this is the Exposition Palace in Turin, Italy, designed by Pierluigi Nervi on 1960. We measured for about eight months the displacement of some cracks, the temperature inside the building and the vibration of the main arch.

All the information collected in Wifi in Turin were then transmitted to Rome (at University main collecting point) via wifi/Internet.

FIG. 19. – The inner part of huge barrel vault of Exposition Palace in Turin, by P.L.Nervi. On the right the moment of sensors installation

FIG. 20. – The installed system at Exhibition Palace in Turin has also a solar panel (left), an automatic control camera (center) and several sensors (right) to measure the crack evolution in some observed part.

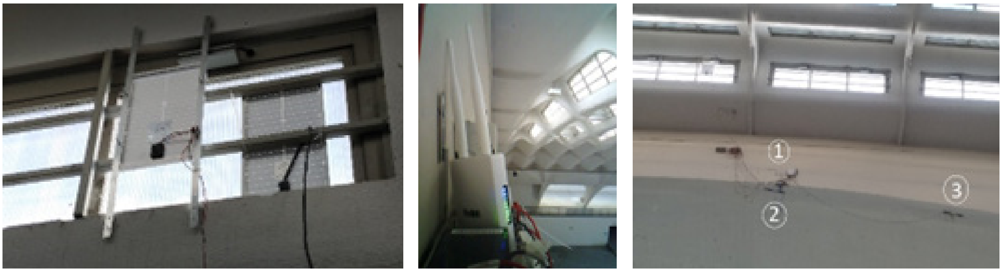
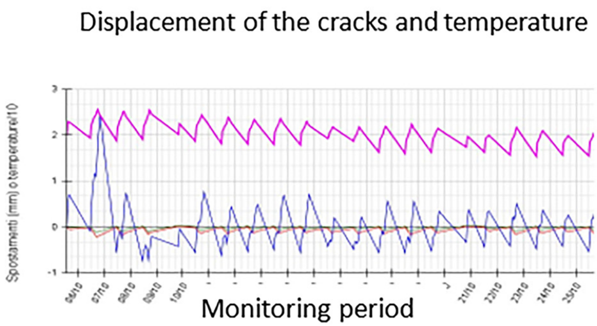


FIG. 21. – One recorded chart from one device installed to measure the trend of the cracks in the concrete.



Another work by P.L.Nervi is in progress to monitor is the Pirelli Skyscraper, in Milano. In that building (30 floors) has been installed 40 piezo-accelerometers and 24 mems accelerometers. The system is all Wifi, with a backbone of 6 access point connected by net cable, should control the vibrations of the tall building. The result between piezo-accelerometer and mems, when the control will end, will be compared, in order to evaluate the noise and the sensibility of the two systems.

One very interesting experiment on the Wifi system has been carried out in China, in collaboration with the University of Yangzhou. Our aim has been to check the stress on the structural element of a pedestrian bridge made by steel truss when the "bridge" will be uplifting between two buildings up to the 25th floor.

FIG. 22. – The Pirelli skyscraper by P.L.Nervi. On the right the location of each sensors

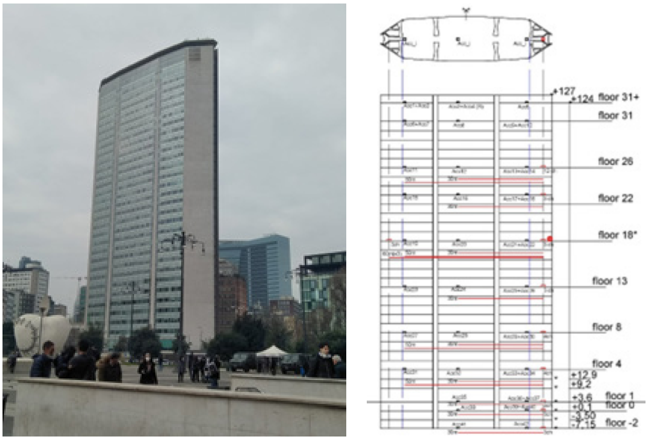


FIG. 23. – The twin Towers n Yangzhou, China, and (right) the pedestrian bridge to be uplifted. On the right the architecture of Wifi control with multiple access points.

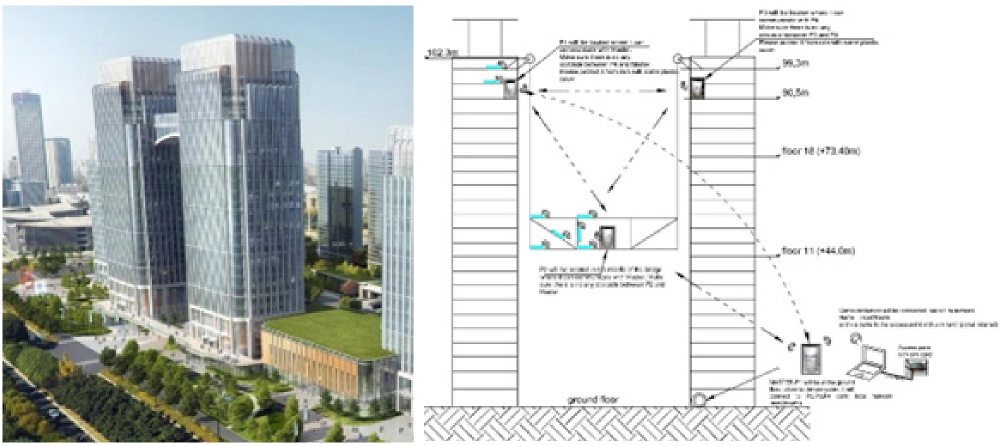
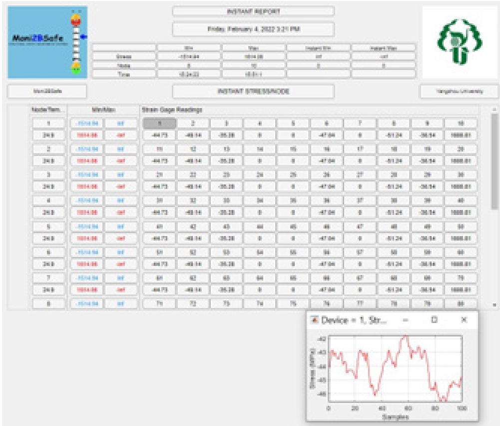


FIG. 24. – The control panel during the uplifting of the bridge to control 240 stress sensors.

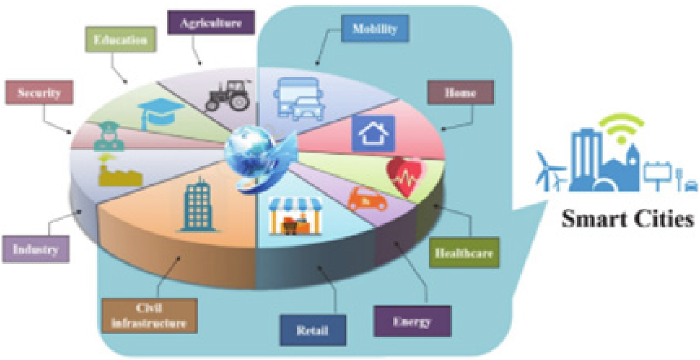


Conclusion

Today the electronics allow us to access high quality devices and sensors, get measurements not possible in the past, and, most important, we can distribute all over the structure the sensors since they are wireless and the transmission is performed on the air, via several options for the Wifi or Bluetooth, or similar. The cost of this devices is reducing continuously, and the building can easily install a global monitoring system with a cost less than 2% of the building, giving back a quite high level of structural safety and helping the maintenance staff to select much better the intervention in order to keep working safe the structure.

The method and the platform proposed is already quite known, and in the very near future we could experience permanent monitoring of buildings, bridges (real bridges), towers, and any other structure of our city landscape.

FIG.25 - An overview of IoT applications within the concept of Smart Cities. From Alavi et al. (2018).



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