Use of Monitoring in Smart Cities

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ABSTRACT: *Slovenian National Building and Civil Engineering Institute (ZAG) is one of the main players on the field of development of building materials and technologies in Slovenia and also widely in Europe. ZAG is developing monitoring of building environment, including buildings, engineering structures and infrastructure. Monitoring was included in a number of national and EU research projects with ZAG being coordinator or partner (eg. SPENS, ARCHES, SMART RAIL, SENSE, TRIMM, COST EFFECTIVE). A huge amount of data from these activities were used by a limited number of endusers for detailed analysis of particular building environment, but could also be used by any other entity for development of innovative applications supporting safe, adaptable, automated, comfortable, resilient, etc. smart cities. ZAG will support interested entities with comprehensive expert knowledge from the field of civil engineering, will continuously contribute data from existing monitoring systems and will also create new ones.*

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1. Introduction / UVOD

In the past, ZAG has been involved in a number of international activities that fulfil the objective of a smart city, in the areas of buildings and infrastructure. ZAG's research activities on this field were mainly focused on various kinds of monitoring, data logging and analysing, as well as interpretation of data. Monitoring results, whether it is building or infrastructure monitoring, were used for the optimization of building/infrastructure use as well as for the related maintenance activities.

2. Past and Current Achievements, Products, Services

2.1 Monitoring Data from Buildings

With a respect to buildings, ZAG was involved in several research projects involving monitoring of various physical parameters of building structure, building skin and technical installation within the building. Particularly, our activities were focused on development of concepts and components to convert the facades of 'high-rise buildings' into multifunctional, energy gaining entities, aiming to have a substantial effect on the energy conservation potential in the EU25 and the associated CO2 mitigation.

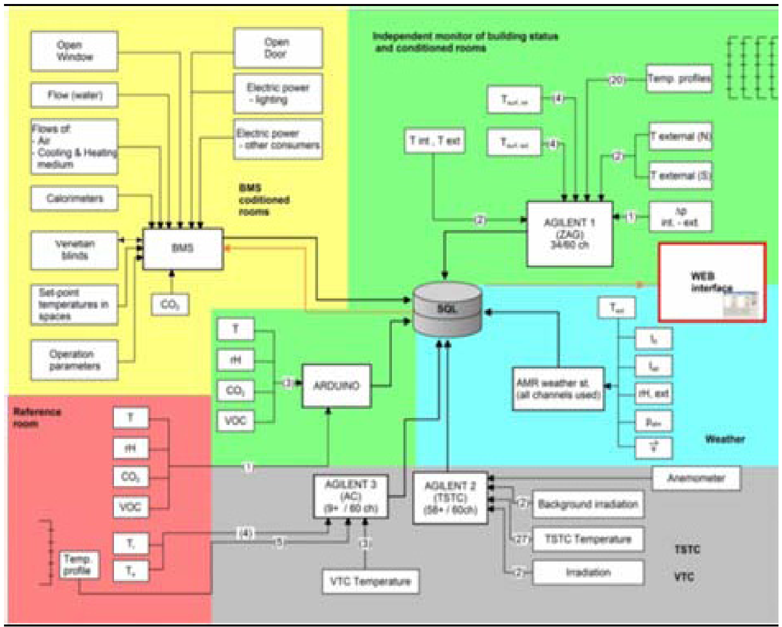

Figure 1. General scheme of the monitoring system

2.1.1 Cost Effective Project

Monitoring of the system performance was based on measurements of all relevant parameters. The measurements were used to evaluate the energy consumption of the building after renovation regarding the improvement of building envelope, integrated HVAC system, electrical systems, lighting as well as to assess the thermal comfort of the indoor environment.

The system itself was based on:

1. Data, measured with permanent measurement system integrated in Building Management System (BMS).

2. Additional measured data, not necessary for the BMS but useful for performance evaluation.

General scheme of the system is shown on **Error! Reference source not found.**.

A Building Management System (BMS) in the case of COST EFFECTIVE project [1] was a computer-based control system installed in the building that monitored and controlled all building's subsystems. It was managing the HVAC system and room automation. It collected measured values and gave commands to each part according to measured values and logic build in BMS automatically. It allowed data exchange between CAD (Computer aided measuring system), control system, automation stations and elements of room automation. Logic and set values were changeable by operator.

Monitoring of the system performance was based on measurements of parameters with measuring devices. The measurements were be used to evaluate the system as described in monitoring protocol. The site was equipped with all necessary measurement devices, energy meters, controllers, operation parameters, etc. for gathering processing and storing the data in the BMS to be shifted to SQL base. Measuring devices (sensors) were installed according to general scheme of the monitoring system and included:

• *Energy (heat/cold) & temperature sensors;* Power release for each part of the heating and cooling system was monitored by energy calorimeter Allmess CF-E II together with PT 100. The same device combination was used in the heating/cooling ceiling elements (radiation panels) of each office and in all other devices for providing the energy: in the installed solar-thermal components (VTCs and TSTCs), in adsorption machine, in compressor chiller (back-up for cooling), in district heating pipe (back-up source for heating), etc.

• *Ventilation;* Mechanical ventilation system (with the recuperation of energy) for fresh air supply to the offices was equipped with integrated electronic air flow rate controllers ERP-1 and sensors DPWT011000.

• *Electricity;* Installed electricity meters in electric distribution nodes measured electricity consumption separately.

• *Room temperature, humidity and CO2 measurement and regulation;* Room temperature and humidity measurement and regulation was done by DPWT011000 sensor, CAREL DP series electronic probe, which was designed to be used in combination with the corresponding CAREL controllers. Installed LC-WRF04 sensors measures CO_2 level.

• *Additional indoor environment parameters;* Each office was additionally equipped with digital humidity and temperature sensors Sensirion SHT21 for indoor air temperature (ºC) and relative humidity (%rH), Carbon Dioxide Sensor for CO2 concentration (ppm), air quality Control sensor MQ135 (VOC), thermocouples type T sensors for the indoor/outdoor air temperature and surface temperature (internal, external) and 5 thermocouples type T sensors on stack for indoor air temperature gradient. All sensors are connected to Arduino based board.

• *End user behaviour in the offices;* Opening of the office windows was controlled by magnetic on/off contact (MS CR4 – KU6). Opening of the entrance door was controlled and recorded by electronic access (magnetic lock).

• *Weather;* AMR 2890 (5 channels) weather station measured external conditions: air temperature (ºC), relative humidity (%), air pressure (hPa), wind speed (km/h), rainfall (mm) and global and diffuse irradiation (W/m2). The AMR meteo multisensor FMA-510 and Kipp-Zonnen pyranometer were placed on the roof of the building.

2.2 Monitoring Data from Infrastructure

As regards infrastructure, ZAG has in recent years contributed to the *Forever Open Road* (FOR) programme, developed by the FEHRL association (European National Road Research Centres). This revolutionary concept is built around common understanding that *advanced* and *affordable* transport infrastructure is one of the keys to improve mobility of people and goods and to create the economic opportunities of tomorrow.

Basic drivers of FOR [2] are that infrastructure has to be:

• *Adaptable*, as being able to adapt to increasing travel volumes and to changes in demand for public transport, cycling and walking;

• *Automated*, as incorporating a fully integrated information, monitoring and control system; communicating between road users, vehicles and operators, and

• *Resilient*, as being capable to adapt itself to the impacts of extreme weather conditions and climate change, and ensuring adequate service levels of the road network under extreme weather conditions.

An example of a conceivable automated road of the near future is given in Figure 2.

A number of projects with concrete ZAG involvement have already been labelled as FOR activities, including FP7 projects TRIMM and BridgeMon, which are described in following text.

2.2.1 TRIMM Project

TRIMM (Tomorrow's Road Infrastructure Monitoring and Management) was a FP7 project that ended in 2014. It investigated and developed a number of road infrastructure monitoring and management techniques that could, in short term, improve functionality of road infrastructure (pavements and bridges) and thus increase safety, environmental friendliness and mobility of road transport. ZAG was a leading partner who was in charge for three working tasks.

The following two areas, pavements and bridges, are related to smart cities and smart infrastructure.

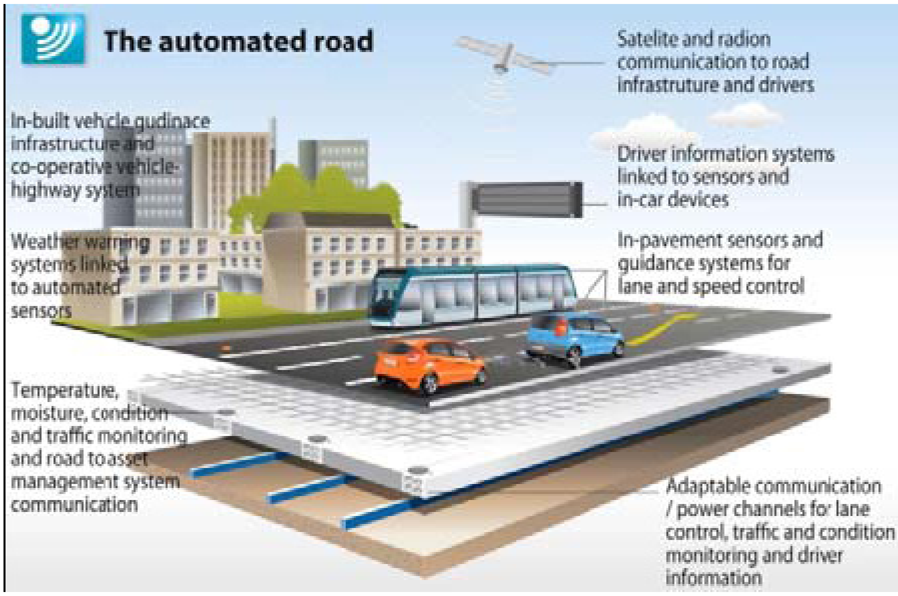

Figure 2. Automated road conceived in the FOR programme

One of the project objectives in the area of pavement quality was to equip several standard vehicles with equipment that allows ride quality to be assessed without the need to install specialised hightech sensors. The approach draws on the use of measurements provided on the vehicle CAN Bus and on data provided by smartphones. Test drives have then been carried out with these vehicles and data collected from these devices. In addition the work has asked passengers about their opinions on the quality of the roads that was driven over. The recorded data has been assessed and the work carried out to identify a potential KPI (Key Performance Indicator) that can be obtained from the data.

In the area of bridges, sensing technologies can in combination with advanced procedures for evaluation of monitoring data provide additional information about bridge condition, which can be used for more accurate assessment of structural performance and decision making in the maintenance. The real-time information can provide early warning of occurring damage and therefore allows reducing the traffic jams and repairing costs, since the repair measures can be executed at a stage that requires lower investment.

The monitoring systems can be designed to monitor corrosion progress, material fatigue, mechanical functionality of load-bearing elements, functionality of joints and bearings, amount of cracking activity in the bridge, etc. Socio-economic impact of occurrence of defects or of structural collapse should also be considered.

Within TRIMM ZAG was involved into development of the following bridge monitoring techniques [3]:

• *Corrosion monitoring;* Corrosion monitoring systems are intended for concrete bridges and provide information on corrosion rates and reduction of reinforcement bar diameters. Using this information, the reduced load bearing capacity can be calculated. If the monitoring system operates over a longer period, prediction of future corrosion rates, diameter reductions and reductions of load-bearing capacity can be produced.

• *Monitoring of material fatigue;* It can provide more accurate assessment of fatigue damage accumulation when compared to design calculations. The procedure includes identification of actual traffic loads using bridge weigh-in-motion (BWIM) systems developed by ZAG and its SME partner and/or strain measurements at affected locations. The monitoring system provides information only about fatigue damage accumulated within the monitoring period. Past and future fatigue damages must be estimated.

• *Monitoring of functionality of joints and bearings.* It aimed to detect presence of movement restrictions at these elements and thus change in their performance. The methodology applies a BWIM system and can be recommended on single span bridges with span length up to 40 m. The system provides a warning that triggers recommendation to preform visual inspection that results in potential rehabilitation measures.

• *Cracking activity;* Cracking activity can be monitored using Acoustic Emission technique to provide information about level of traffic load, at which the bridge damage is progressing. The technique can be used on bridges with serious damage and traffic limitations or when bridge closure is being considered.

2.2.2 BRIDGEMON Project

Bridgemon was another FP7 project that finished in 2014. It involved 2 Slovenian partners, ZAG and a SME Cestel d.o.o. ZAG was one of the two main research providers in the project and Cestel was the beneficiary of the results in the area of improved BWIM technology [4].

Traffic loading is one of the key parameters governing the design and assessment of bridges and pavements. As such, the ability to monitor the actual traffic loading on a particular bridge or road can be of great benefit to infrastructure managers who, with limited budgets, are required to make informed decisions regarding repair or maintenance strategies for road infrastructure. BWIM is a weighing technology that, by instrumenting the existing bridges, provides real-time and accurate traffic loading information in a form of *axle loads of all vehicles* that pass the bridge at normal speed. This information is used to fill the traffic databases that are used for various traffic and infrastructure applications and to prevent overloaded vehicles from damaging the infrastructure and causing unfair competition to the hauliers that follow the rules. Overloaded vehicles also drive with considerably higher risks which can end tragically (figure 3).

Figure 3. Overloaded vehicle crashing into a house

The BWIM technology has been developed at ZAG since the early 1990s and has been for the last 15 years, after the cooperation with Cestel started, implemented in over 20 countries around the world. The objective achieved within Bridgemon project was to improve accuracy and long-term stability of the results and to adopt it to railway bridges [5].

3. Proposals for E-cities

Structure and infrastructure monitoring, which in our opinion is very important subject for smart cities and communities is mostly done by trained inspectors but is highly subjective and results in inconsistency of results. In addition, these results are used inefficiently, with remedial measures being slow and often causing disruption to traffic. Today only a small number of large structures are monitored electronically, while smaller structures that can also cause major traffic disruptions and pose safety issues are not monitored at all. Two major reasons for such situation are:

• Cost of conventional monitoring campaigns and

• Amount of data that monitoring is generating and is difficult to assess.

This could change if monitoring systems would:

• Give more consistent results, less reliant on human judgement,

• Cause less traffic disruptions and

• Be far less expensive to potentially allow monitoring of most transport infrastructure in the future.

These objectives could be achieved using (amongst other things):

1. Smart sensors on infrastructure that are interrogated using drones, i.e., pilotless drones would download the condition data from the infrastructure on a regular basis.

2. High number of low-cost sensors built into infrastructure that would send data to the cloud.

3. Crowd Sourcing, i.e. accessing sensors in the smart phones of the travelling public and using them to detect the condition of infrastructure.

The most near to implementation is the crowd sourcing concept, using smart phones of users connected into social GPS and traffic networks. In particular, it could be used to monitor pavement roughness and sound levels around bridge joints which can change dramatically if the condition of joints deteriorates. It is important that defective expansion joints are identified and repaired quickly as failure to do so can lead to serious problems that may require the joints to be replaced which is very expensive and disruptive to road users. The same is valid for ruts and pit-holes in pavement. Collecting large amount of relatively low-quality data (accelerations, geo locations) would detect changes in condition of pavement and structures and, as a result, trigger inspections that would result in timely interventions. It has been estimated that maintenance costs can be reduced by as much as 30% as a result of early detection of defects. It shall be pointed out that today infrastructure monitoring activities are rarely pursued in cities.

Implementing this concept would allow more traffic infrastructure to be kept in service for longer – in effect, the life of infrastructure will be extended. Maintenance cost will be optimised through better monitoring as this would lead to preventive actions and better planning of major works. All of this would result in less traffic jams, higher safety and cleaner environment, which will have a positive impact on citizens living in and commuting to or from the cities.

4. Conclusions

Focusing on intelligent buildings and intelligent infrastructure (i.e. innovative monitoring systems integrated into building environment) in Smart cities aims at providing a step change in the use of technology to manage our cities, including buildings, engineering structures and infrastructure buildings, as well as to contribute towards providing safety, comfort, healthy and mobility. This kind of integrated monitoring systems combined with other data acquisitions (e.g. crowd sourcing) enable a huge amount of information which can be used for analyses of city communities and further development of various innovative applications, supporting better life in cities.

The research in area will enable communications systems linking building environment with its user (e.g. building, residents and building manager; road, driver, vehicle and the road operator, etc). It is expected that in this way, the city network management will be improved (e.g. a higher efficiency of passenger and freight transport with less energy consumption and less GHG emissions, etc).

The work approach includes a very high frequency of monitoring passages over a particular length of road, much more often than with highly sophisticated monitoring devices or by dedicated inspections. A real-time monitoring produces very large amounts of the data collected making the communication of the information to the road manager rather difficult. Here, the e-cloud service and support seem to be more than appropriate for the treatment and the first interpretation of these data.

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