Some technical challenges in the design of rotating towers

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ABSTRACT: A new generation of buildings are about to start in several world cities – the Rotating Towers of David Fisher - starting the era of "Dynamic Architecture". It introduces the new concept of multifunctional structures. This contribution goes through the technical challenges coming with the movable parts of the architectural innovation. This mainly means to adopt a wireless sensor network for monitoring and control. Furthermore, the noise aspects are discussed. Wind turbines are reported in the literature as rather noising. Their coupling with residential spaces requires a sophisticated preliminary estimation of the produced noise.

1 INTRODUCTION

A new generation of buildings are about to start in several world cities – the Rotating Towers of David Fisher - starting the era of "Dynamic Architecture". It introduces the new concept of multifunctional structures. The system is made of superimposed rotating storeys floors. Each of them rotates separately, causing the building to change their shape continuously. In addition, wind turbines are installed between the floors and solar panels on the top of each rotating block. Thus making the building to be self sufficient, producing its own energy.

These buildings are going to be completely pre assembled in a factory and then, mechanically, assembled on site. Indeed, the dynamic building are kind of "machines", with a machine maintenance time scale fully consistent with that of any control system one could desire to install. This contribution goes through the technical challenges coming with the movable parts of the architectural innovation. This mainly means to adopt a wireless sensor network for monitoring and control.

Furthermore, the noise aspects are discussed. Wind turbines are reported in the literature as rather noising. Their coupling with residential spaces requires a sophisticated preliminary estimation of the produced noise.

2 ROTATING TOWERS

A fertile field for realizing this concept is the area of very tall buildings (Pelli et al. 1997) and in particular the new innovative building which is planned to be constructed in the near future in Dubai. The real estate of this city is engaged in a wide project leading the city to become an international hub for an innovative skyscraper. The new high rise building will keep changing its shape and will generate a surplus of energy with respect to the expected demand of the building occupancy.

Among the first buildings where wind turbines were included is the one in Bahrain (Ragheb 2008, 2009a and b). The two towers are 240 meters high, connected by three 30-meters-span-bridges at different elevations. These bridges are supporting three massive horizontal-axis wind-turbines. Through the turbines positioning and the unique aerodynamic design of the towers, the onshore Gulf breeze is funnelled into the path of the turbines, helping to create power generation efficiency. The power produced by these turbines is enough to cover 35 % of the towers needs (Casciati et al., 2009).

Recently, a new innovative architectural work is being introduced (Fisher 2008 and 2010). 'The tower in motion' is a revolutionary project by Dynamic Architecture, the new innovative concept having been introduced by the third author.

This project is characterized by three fundamental properties:

1. each floor will have the ability to rotate independently each of the other; this rotation will impart to the tower a continuously changing shape as shown in Figure 1;
2. the production of its own energy from the wind, by wind-turbines, and from the sun, by solar panels;
3. the construction process of the tower will adopt a new technology based on prefabricated modules which are assembled on site, apart from the central concrete core which is built on site using traditional techniques. In other words, 90% of the building is produced in an industrial park, then transported to the site and finally connected to the concrete core.

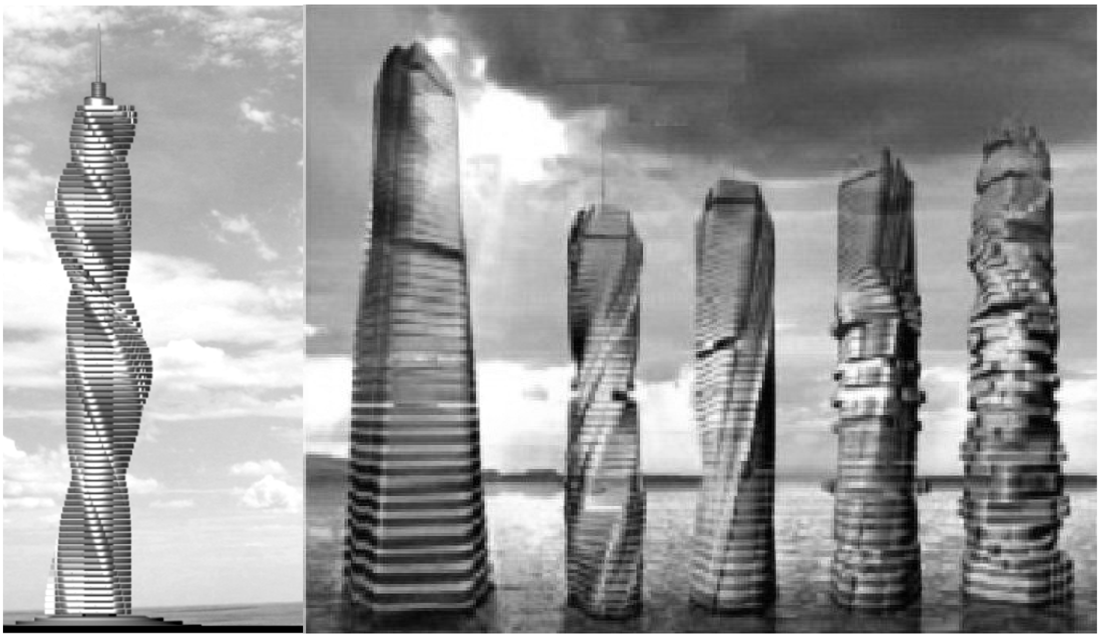

Figure 1. The rotating floor tower and shape changing (Fisher 2008).

3 ELECTRICAL ENERGY PRODUCTION

The dynamic-architecture building will be able to generate electric power for itself . This energy will be produced by two kinds of resources. One of them relies on solar panels (Fig. 2); to be placed on the roof of each floor. They will only cover 20% of the roof surface, but, taking the advantage from the roof rotation these panels would be exposed to the sunlight for the maximum possible time.

Figure 2. Power generation by solar panels (Fisher 2008).

However, the wind turbines are the main source of energy production in the rotating tower. The tower consists of 78 floors. Starting from the tenth floor, one vertical-axis wind turbine (VAWT) will be placed in the space between two consequent floors as shown in Figure 3. The turbines will be connected to a single generator located in the same floor: the goal is to transform the wind energy into electrical power. The average wind velocity in Dubai, at the height of the turbines, is 16 meter/sec. Assuming 2,300 hour of this wind velocity in one year, the produced energy may supply enough energy as would be consumed by the residents of the whole tower. (Fisher 2008).

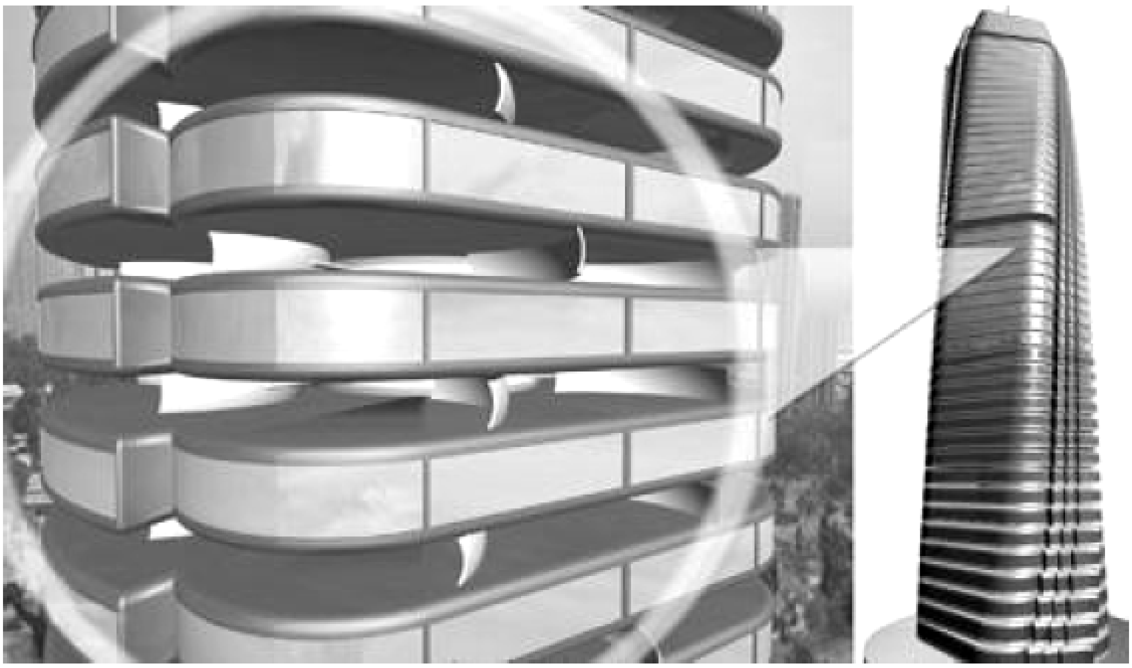

Figure 3. Vertical axis turbines located between floors all along the tower height (Fisher 2008).

4 MONITORING BY GPS

In the last few years, the Global Navigation Satellite Systems (GNNS) have proved to be useful for different types of monitoring applications for complex structural systems (such as suspension and cable stayed bridges, tall towers, etc.). Among all the Satellite Systems (the Russian Glonass, the future European Galileo, the Chinese BeiDou, and the Japanese QZSS), the US Global Positioning System (GPS) is becoming an alternative to common accelerometers to measure the dynamic response of these long-period structures (Kijewsji-Correa et al., 2006). High-precision GPS technology has been applied to monitor wind-induced deformation of tall flexible buildings (Hristopulos et al., 2007) and to assess the vibrations of suspension and cable-stayed bridges (Meng et al. 2006). Most of these applications were developed by installing GPS receivers at key locations to capture static and dynamic displacements of structures in real time and in all weather conditions. Moreover the GPS offers continuous long term acquisitions.

Recently, several researches (Casciati-Fuggini, 2009a and 2009b) showed that GPS network can be well utilized in Structural Health Monitoring (SHM) of tall and flexible structures subjected to oscillations produced by wind actions. Wind forces induce displacements response in both longitudinal and transversal wind directions, but due to the irregularity in shape of most of the structures; torsional effects are also produced, which are more complex to be detected during full-scale experimental tests (Al Saleh et al., 2009). These torsional effects are mainly due to the fact that the centre of mass does not coincide with the stiffness centre of the building. In detecting the induced torsional effects, the sensors placement on the structure has to be considered in order to identify a preferable topology (i.e. sensor combination and location) able to provide information on the torsional response. For this purpose, a network of GPS receivers, installed along a tall building can provide sufficient accuracy in detecting the induced torsional response of the structure.

The Structural Health Monitoring for the Guangzhou New TV Tower (GNTVT) was recently developed by the Hong Kong Polytechnic University for both in construction and in-service real-time monitoring. (Ni et al., 2009). The construction of the Guangzhou New TV Tower (GNTVT) was recently ended in Guangzhou, China. It is a super-tall structure with a height of 610 m. This tube-in-tube structure comprises a reinforced concrete inner tube and a steel outer tube adopting concrete-filled-tube (CFT) columns. The outer tube consists of 24 CFT columns, uniformly spaced in an oval shape while inclined in the vertical direction. The oval section decreases with altitude from 50m by 80m at ground level to the minimum dimensions of 20.65m by 27.5m at 280 m height, and then increases to 41m by 55m at the top level of the tube (454 m height). The columns are interconnected transversely by steel ring beams and bracings. While the inner tube is an oval shape as well but with constant dimensions of 14m by 17m in plan (Figure 4). The tower system identification is approached in (Faravelli et al, 2010), among others.

The displacement response of this tower was acquired by three GPS receivers placed at the top level of the tower. The way to process these displacement data in order to detect the torsional behaviour of this tall building is the main concern of (Al Saleh et al, 2009). A comparison with an elaboration of the data recorded by mono-axial accelerometers placed close to the GPS receivers was also carried out. The goal here was to check the accuracy of GPS, with respect to accelerometers, in detecting torsional movements.

Attention was focused on the identification of a preferable topology (i.e., sensor combination and location) able to provide information on the torsional response of the structure when exposed to strong wind events, as typhoons commonly happen in that area.

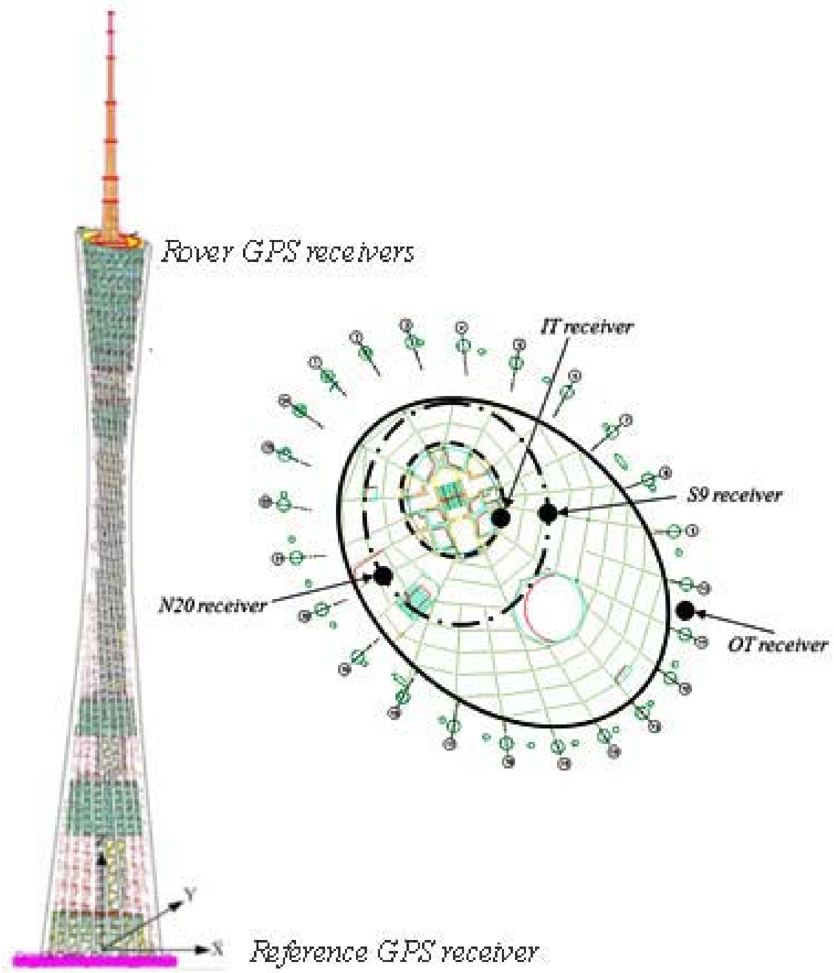

Figure 4. Location of the measurement points for GPS sensors (vertical and plan view). The figure also shows the oval shape at the top plane section (450m height) in which the numbers 9 and 20 at the edge indicates the position of *S9* and *N20* receivers. Three GPS rover sensors are placed at the top level and the reference one at the base.

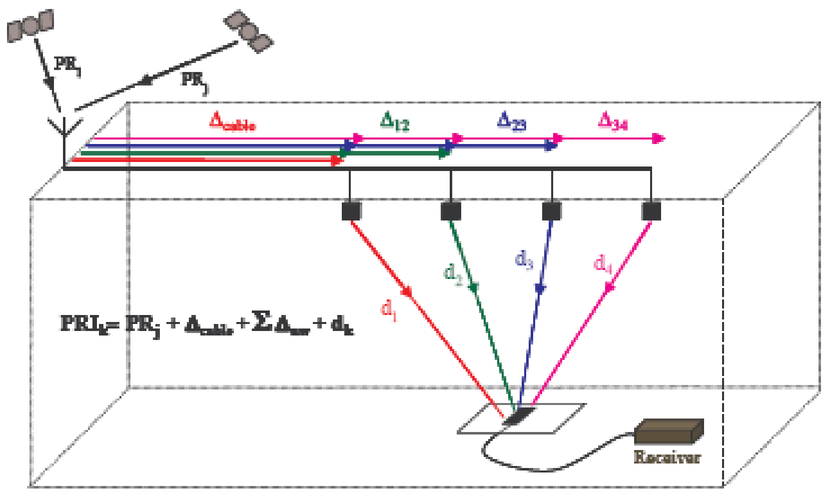

Figure 5. Basic principle of inside amplified GPS receiver unit.

Figure 4 shows the location of the base reference GPS receiver at the bottom of the tower, and the three rover GPS placed on the top level of the tower: two at the edges and one approximately in the centre of the section. The three sensors are respectively named as North20# (N20), South9# (S9) and Inner tube (IT). Each of the three receivers records the North, East and Vertical coordinates of the point where they are placed.

In a rotating tower, the roof of each floor is only partially covered by the upper storeys and this should allow a satellite visibility from each floor which is not available in standard buildings. Nevertheless, the multipath effect (Casciati-Chen, 2010) must be corrected and this aspect is presently investigated. Solutions adopting inside amplifiers (Figure 5) are also taken into consideration.

5 WIND TURBINE NOISE

It is well known that wind turbines are noisy. The noise come from the blades, from the supporting frame as well as from their interaction. Figure 5 provides a sketch of the design to be managed.

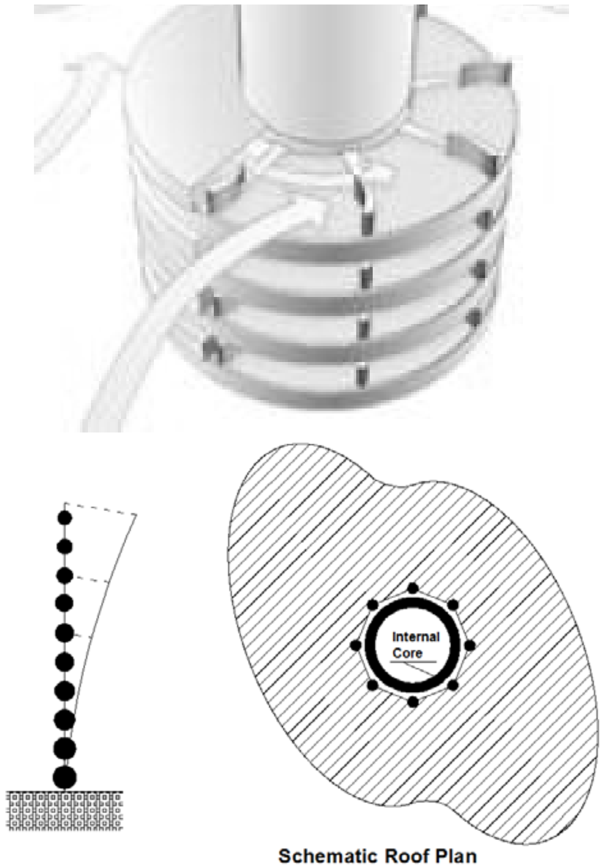

Figure 5 – Wind turbines and a simplified numerical model to account for the structure-turbine coupling.

Numerical models can be built and the global response of each wind turbine can be analysed and corrected by running numerical analyses. However, most of the coupling effects depend on the way the turbine is linked with the central reinforced concrete cantilever, designed to have a pipe section. Thus, an intensive experimental campaign (Kim, 2007) must be foreseen as soon as each turbine is mounted.

The noise reduction will then be managed by either passive (Soong-Dargush, 1997) or semiactive (Casciati et al., 2006) control devices. The only active control till now implemented (Reinhorn et al, 1998) was recently dismissed.

6 SMART SENSORS

As illustrated in (Faravelli et al., 2011), a tower is traditionally equipped with different types (say 16) of sensors in number of 1000 or more. Among them accelerometers, strain gages and GPS units. Due to the large structural periods and to the duration of the hazardous events (wind, typhoons) records of 24 hours must be collected and stored in a single computer to avoid synchronization issues. Thus the sensors are preferred to be wireless and with electronic components mounted on them to allow the right management of data and data transmission.

Fast alert decisions can be achieved in real time, but the expected main benefit of such a sensor network is that structural health monitoring (SHM) is made available in terms of both damage detection and data localization (Al Saleh, 2010).

Furthermore, when the high rise building is a rotating tower, the sensor network associated with SHM must be integrated with that driving the motion of each floor and the wind turbine rotation. Special attention must be paid to the different dominating frequencies.

7 CONCLUSIONS

The innovative ideas of Professor Kobori (Kobori, 2003; Casciati-Al Saleh, 2009) in the area of structural control impacted on the incompatibility of the structural control dynamic issues with the static conception of conventional building, mainly because of the different maintenance time scales required for the structural system and the control machinery.

An innovative building with a dynamic conception was recently introduced by the third author and his associates: the movement in the building generates energy but also has an aesthetic character. The maintenance time scale is now consistent with structural control demand and, hence, the building is a good candidate to be equipped with structural control solutions.

The paper mainly goes through the technical challenges coming with the movable parts of the architectural innovation.

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