A MANAGERIAL APPROACH IN TERMS OF STRUCTURAL HEALTH MONITORING, IN THE CONTEXT OF COMPONENT ANALYSIS COVERED BY THE SCIENCE OF TERRESTRIAL MEASUREMENTS

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ABSTRACT:

As is known, Structural Health Monitoring(SHM) is an extremely complex and relatively expensive activity, and the current offer of tools, methods and technologies is extremely varied, which can lead to a virtually infinite number of structural monitoring systems that can be customized for each case. Thus, a strict organization of the structural monitoring activity is imperative to best adapt the SHM solution to the monitored case. We present in the paper, both the components, aspects, the main activities covered, the SHM axioms, generally the important issues that must be known and considered when choosing the strategy to adapt a SHM solution for a given case and the proper management of the SHM activity for the results to reflect reality and meet the requests of beneficiaries. We must not ignore the designers who will have the opportunity to check the chosen design solutions and the in situ behavior of the monitored objective. In parallel, the authors analyzes the evolution "Tracking the behavior over time of constructions" from operating in the static regime to the dynamic, integrated into the comprehensive concept of "*Structural Health Monitoring*". The authors identifies the role of the *Science of Terrestrial Measurements* in SHM and the components covered.

Keywords: Structural Health Monitoring(SHM), Science of Terrestrial Measurements, Tracking the behavior over time of constructions, operating in the static regime to the dynamic.

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1.Introduction

Tracking the behavior over time of land and constructions has always been a distinct branch of engineering surveying and although work in this field, finding movements of resistance elements tracked in a regime close to the static, a few millimeters per year, has been integrated in to Structural Health Monitoring, it is clear that any construction in the category of bridges (with exceptional design parameters) or very tall buildings should be monitored both in static regime, as a result of subsidence, landslides and the rheology of construction materials, and in dynamic regime, the effect of wind, sunshine plus bridge traffic[1]. To have a unified monitoring concept "tracking the behavior of land and buildings" had to be included in "Structural Health Monitoring", the surveying activity specific to the field, gaining the attribute " Surveying Structural Dynamic Monitoring". Structural Health Monitoring, however, is a much more comprehensive field because it includes the health of a building considered as a whole, not only in terms of geometry and motion parameters produced by exciting forces[1, 2]. There are three concepts with reference to structural monitoring:

1. Tracking the behavior over time of buildings in a static regime - TBTSR
2. Tracking the behavior over time of buildings in a dynamic regime - TBTDR
3. Structural Health Monitoring – SHM

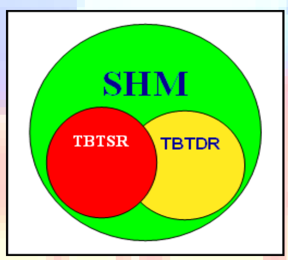

Figure 1. Is tracking the behavior over time of buildings in static and dynamic regime an activity that solves some of the problems of Structural Health Monitoring?

We accept, however, that, as shown in Figure 1. the first two activities (TBTSR and TBTDR) be integrated in the broader concept of SHM.

2. General considerations of the tracking the behavior over time of constructions

It should be noted that **Tracking the behavior over time of constructions** is carried out both during the execution phase (Figure 2.), being included in the set of topographic works which ensure compliance with the design, and after completion; the monitoring period extends to cover the whole life of the objective[1].

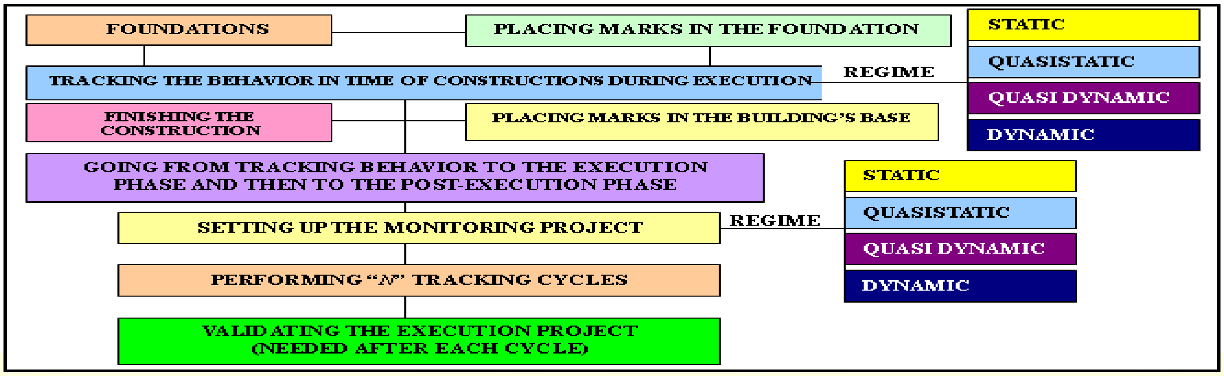

Figure 2. Topographical works while monitoring the behavior of buildings

Current tracking is a construction monitoring activity that consists of observing and recording aspects, phenomena and parameters that can indicate changes in the building's ability to meet the strength, stability and durability requirements established by the project. Special tracking is an activity of tracking the behavior of constructions consisting in measuring, recording, processing and interpreting parameter values that define the extent to which buildings retain their strength, stability and durability requirements established by the project. Thus, Figure 2., shows how we can intervene using SHM methods and instruments and its components.

The activity, ***Tracking behavior over time of land and buildings,*** have a history of over 150 years [4], which merges with the advent of optical-mechanical instruments for measuring angles and level differences, theodolites, level, has dealt with quasi-static structural monitoring. In fact, between the observation cycles, at an interval of several months to several years, based on the evolution of the phenomenon of subsidence and landslides, there were deviations of a few millimeters or fractions of a millimeter. In this context monitoring was considered static. The known method is the middle precision geometric leveling and angular intersection regularly comparing, through measuring cycles, the position of mobile markings, mounted on the structure, to benchmarks considered fixed, mounted in areas considered stable over time.

In 1889 George A. Fuller (1851-1900) created, in Chicago, the Tacoma Building[5], the first structure ever built whose exterior walls were not load-bearing, columns and beams assuming the role of structural elements, thus being the first frame structure. It was obvious that the svelte structure required monitoring not only for static actions, such as land settlement under the foundation, but also for dynamic actions such as the action of wind. "Tracking behavior over time in dynamic regime"**,** appeared and was formed as a need to monitoring the behavior of structures in dynamic regime. An effect of those anterior presented was reconsideration of calculus methods, of standards, of concepts regarding mathematical modeling in the projecting process of constructions, but it must be pointed a very important fact: no design method can be validated unless after an analysis regarding the behavior through execution and in time of the construction under the action of disturbing factor's action, wind, earthquake, unequal sunny, at this chapter the geodesic measurements being the ones that give possible answers. Modern continuous methods, appealing to modern techniques do not exclude but complement methods considered classic, so that the monitoring of the health of constructions now comprises all these methods, from middle precision geometric leveling for static analysis of settlements to the use of fiber optic sensors and to monitoring the oscillations of structures in kinematic regime.

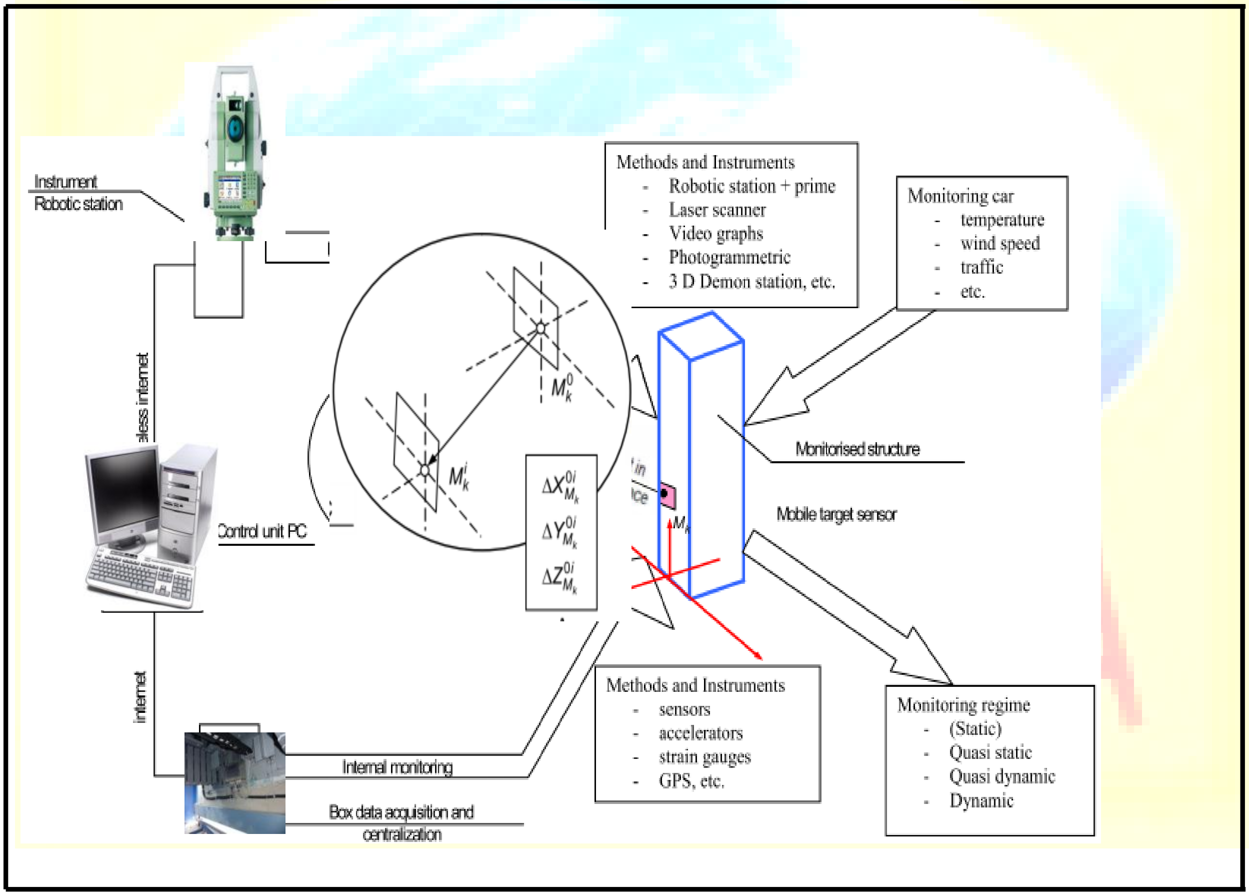

Figure 3. Tracking behavior over time in dynamic regime(TBTDR). Causes and methods.

Since the difference between SM and SHM is derived from non-topographical causes, like the evolution of the state of construction materials (rheology, corosion, etc.), the analysis by the designer of the risk of an object, we will keep the wording SM in the paper to define the new concept of tracking behavior of buildings under different effects of static or kinematic stress factors. The concept was later extended to all categories of SM constructions, incorporating

"Tracking behavior over time", meaning that long-term effects are detected by conventional means and those taking place now are detected by the new SM methods. Four common causes of the opportunity of introducing continuous monitoring under kinematic regime in these structures: uneven exposure to sunlight, wind, earthquakes, usage or stand-by mode of the structure. Recreating the optimal design cycle of special reinforced concrete and metal structures in a certain space: in-situ behavior under the action of some stresses variable in time (wind, temperature, exploitation), implies monitoring them in dynamic regime (figure 3). Among the applications of SURVEYING in the field of Structural monitoring (figure 3), the "dynamic" part refers to the study, recording and processing of characteristic parameters of external influences, as well as of the geometry of structures, under the action of some variations of some stresses in a short period of time (at most 24 hours). For special structures, the "behavior at temperature variations" lies within dynamic analysis, implying a diurnal variation of the geometry, therefore measurable parameters using classical means. Also the "behavior under the action of wind" or under load lies within dynamic analysis, generating a variation of the geometry, with optimal data collecting periods between 0.01-1 s. In this case, the classical operating means of SURVEYING are not operable. Dynamic monitoring is used to determine the natural frequencies of the structure, mode shape and how the damping systems mounted on the structure have an effect. Dynamic monitoring, where input excitation is not caused by test engineers, is called testing the action of vibrations made by the environment, i.e. excitation from wind, waves, human activity, traffic, etc.. With continuous dynamic monitoring, a lot of data is created. In order to limit the amount of such data, only records of phenomena of interest are saved, the remaining data being ignored because it can block the system due to the volume, without any major contribution. If we analyze the behavior of structures monitored we see that we can identify two ways depending on the frequency of structural movements:

- Quasi-static monitoring,
- Quasi-dynamic monitoring,

Quasi-static monitoring is the best known refers to monitoring very tall or very svelte structures under the effect of patchy sunshine. Studies on smoke chimneys show that over 24 hours the top of the structure follows a predictable elliptical path, but which must be verified in situ. The monitoring methodology may be adopted from the static field, with an hourly recording frequency of the verticality of the building, or from the dynamic field, through interpolation. In this case we can talk about a behavior and quasi-static monitoring.

Quasi-dynamic monitoring is widely used because virtually all dynamic monitoring is transformed in to this regime. Otherwise, the huge amount of information resulting from a continuous process might crash the system. In this case, pseudo-dynamic or quasi-dynamic monitoring means an action repeated with a frequency from a few seconds to a few minutes. By interpolating the data we will be able to define the continuous, dynamic behavior of a structure, its characteristic movement being reversible, and by extrapolating we will define the static behavior, its characteristic movement being irreversible.

3. Defining and analyzing Structural Health Monitoring components in the context of the components covered by terrestrial measurements science

Structural Health Monitoring(SHM) is a non-destructive in-situ structural sensing and evaluation method that uses a variety of sensors attached to, or embedded in, a structure to monitor the structural response, analyze the structural characteristics for the purpose of estimating the severity of damage/deterioration and evaluating the consequences thereof on the structure in terms of response, capacity, and service-life[6, 7, 8].(Figure 4.). Various sensors and other technologies and devices obtain data that will be centralized, transmitted, processed and interpreted to continuously determine the health of the construction. SHM includes such tools, methodologies and techniques traditionally called Non-Destructive Testing (NDT) and Non-Destructive Evaluation (NDE). Analyzing Figure 4. on the definition of SHM, we can identify the role of tracking behavior over time in different regimes (Static - TBTSR, or Dynamic - TBTSR) from the first part of the definition, the one referring to structural determination and assessment method, in situ & non-destructive, using a variety of internal / external sensors that monitor structural response and that analyze structural characteristics, stating that TBTS/DR acts only in the field of geometric monitoring and cannot be extended to areas of physical-chemical analysis of structures. Basically, together with the definition of SHM, it defines TBTS/DR in order to suggest an estimation of determinations and asses possible consequences produced to the structure regarding answer capacity lineservice Figure 5. presents the main components of SHM, including of course TBTSR and TBTDR, and their role in monitoring. To highlight the role of terrestrial measurements in SHM and the components covered, they are highlighted in the following figures using the red background. Regardless of the monitoring system, tracking the behavior over time in differents regimes must provide the following monitoring components:

1 The design of the structural geometric monitoring procedure in the requested regime.

2 Installing the system on the structure monitored for registration of causes (eg. environmental factors) and effects.

3 Structural monitoring system initialization.

4 Registration, continuous data transmission (TBTDR) or completion of monitoring cycles (TBTSR).

5 Interpretation of data, analysis of the cause / effect ratio.

Structural Monitoring, more precisely Structural Health Monitoring (SHM), provides for the registration of structural and environmental parameters, and other factors that stress it. The main structures monitored and the main artificial effects measured are presented in Figure 6. Monitored parameters (regarding the nature of the stress factors) are presented in Figure 7. and the most common SHM monitored parameters of the structure are presented in Figure 8. Involving the components of terrestrial measurements science is highlighted by a red background. Generally, SHM activity during execution differs from that in the service period, but some of the sensors can stay, thus cutting the cost of the overall process.

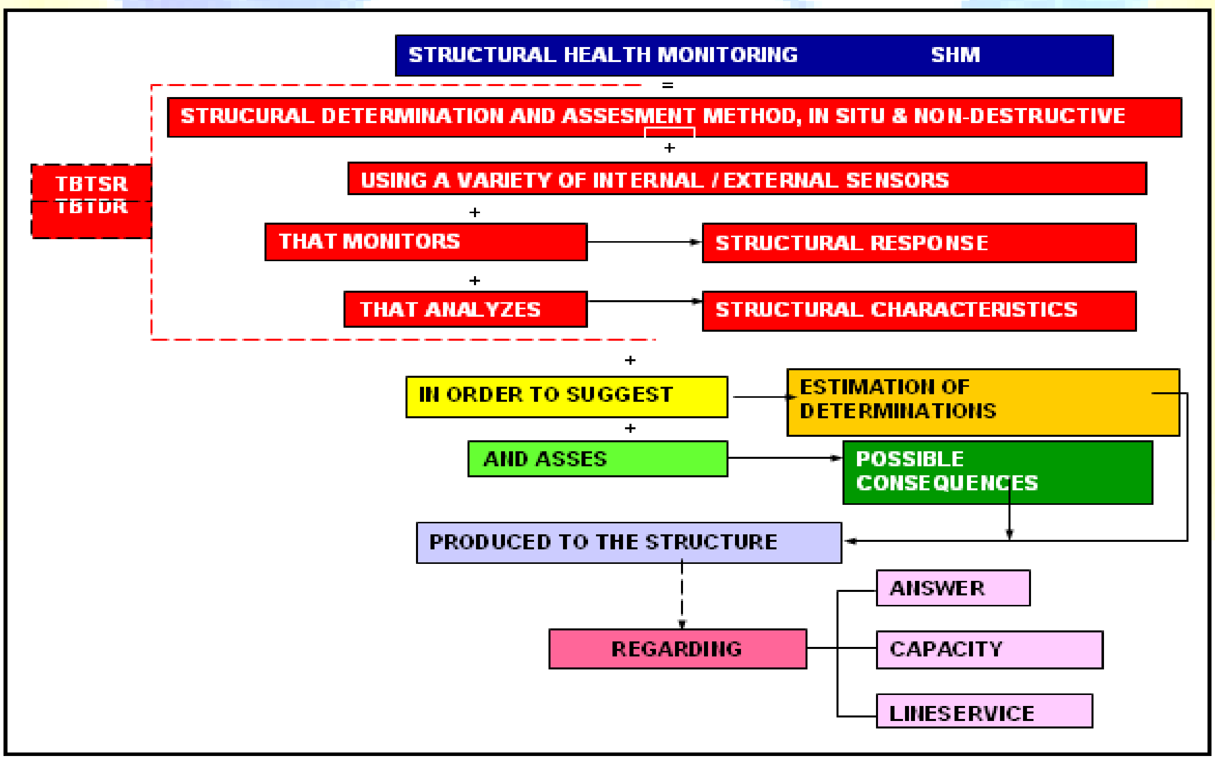

Figure 4. Flowchart for Structural Health Monitoring Defining

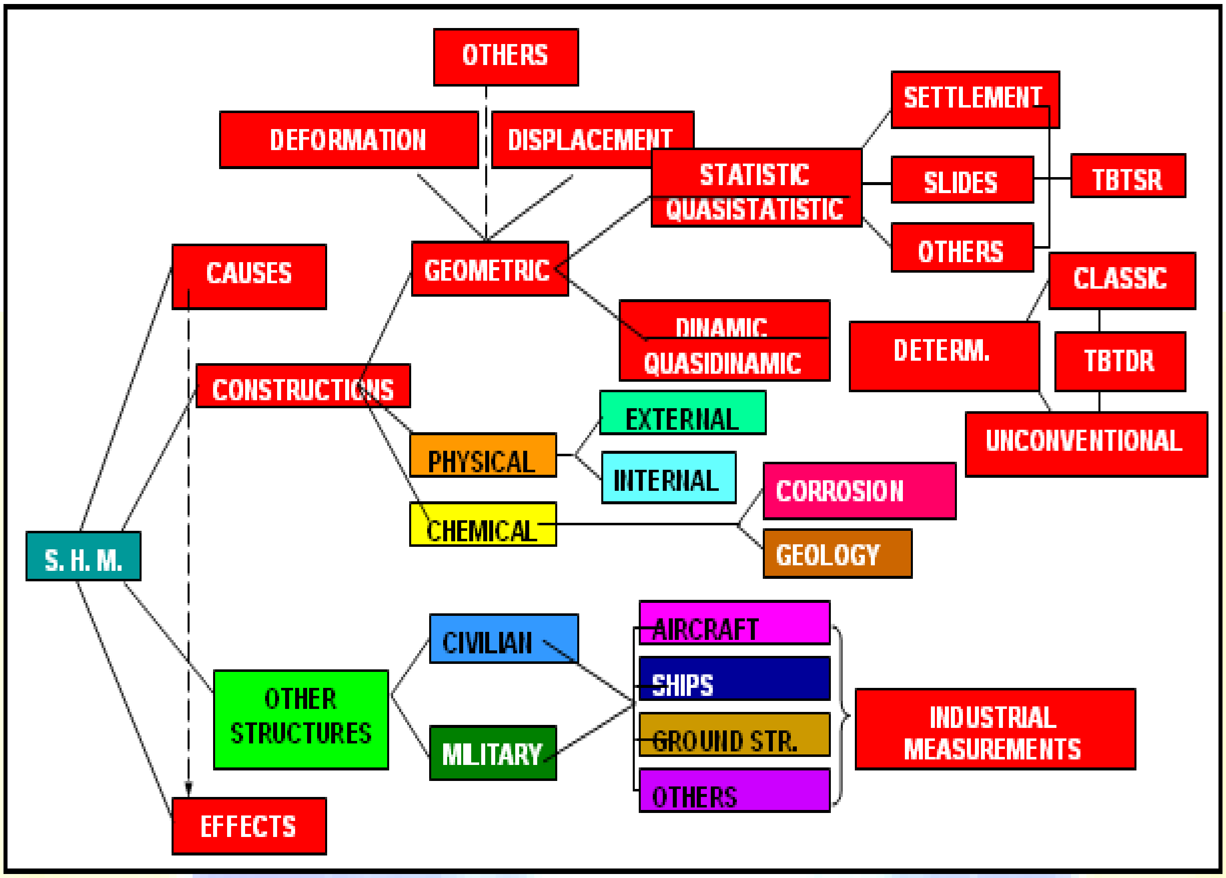

Figure 5. SHM fields resolved by Tracking behavior over time in differents regime

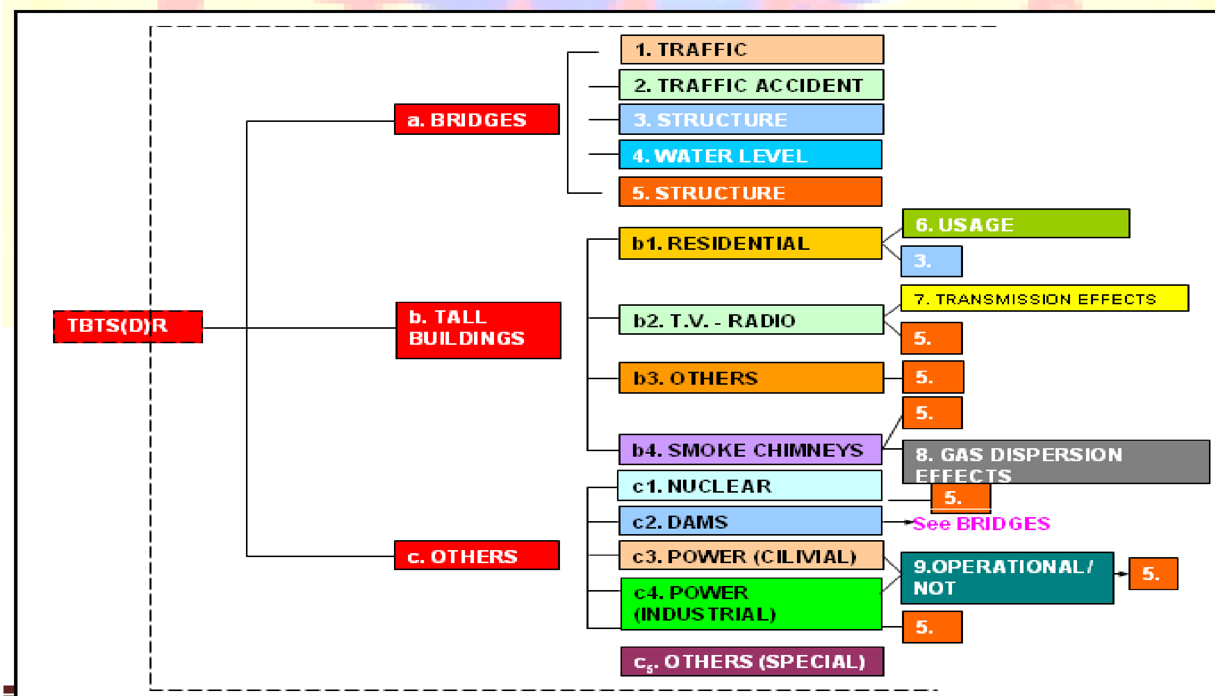

Figure 6. The main structures monitored and the main artificial effects measured

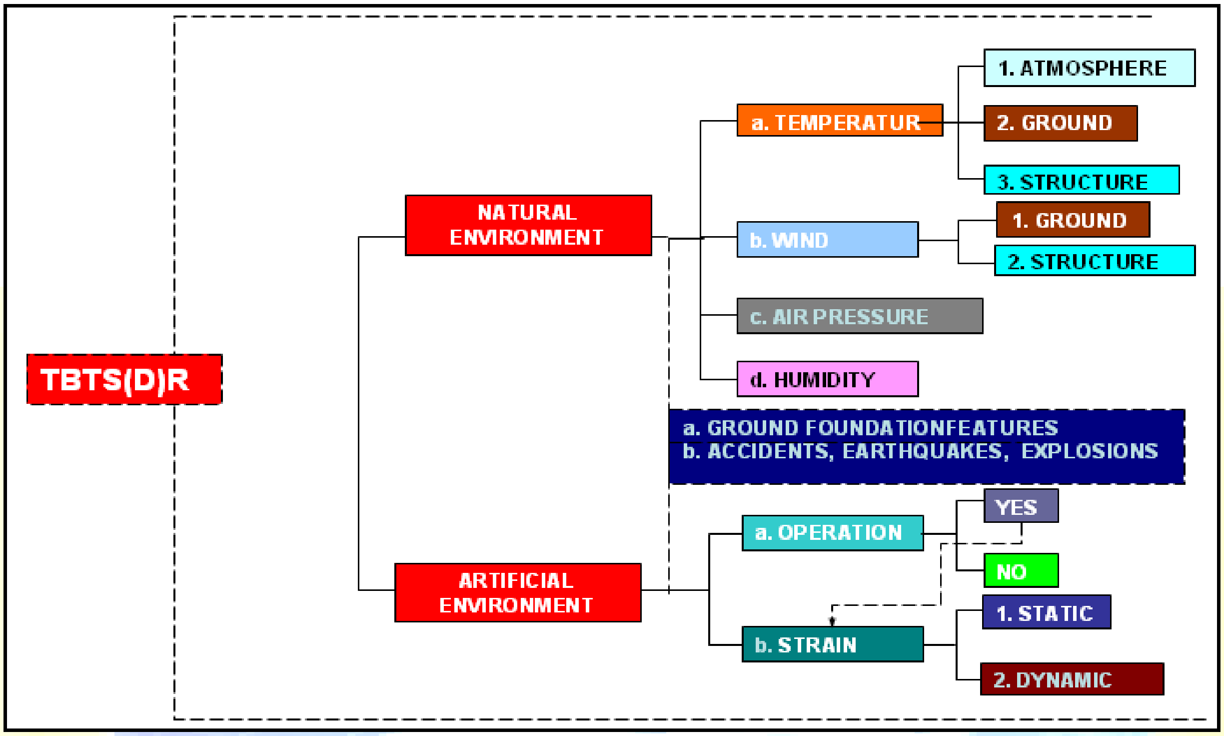

Figure 7. Monitored parameters (regarding the nature of the stress factors)

Operational assessments of Structural Health Monitoring

In the decision making process for the adoption of a SHM solutions, we must primarily clarify, through an operational evaluation, what are the main arguments underlying the substantiation of such a decision. We go through the four steps shown in Figure 9. starting from the main justifications underlying the decision and ending with the establishment of limitations that may condition the action. Operational evaluation of SHM will try to adapt the best monitoring techniques to detect those defects that may affect the structure(figure 9).

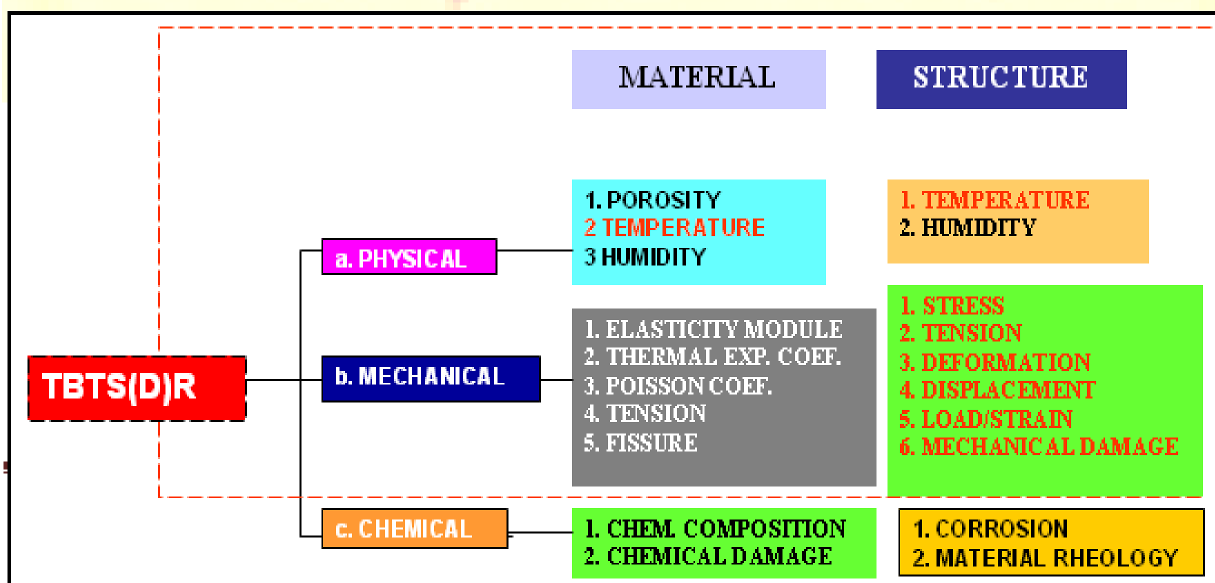

Figure 8. The most common SHM monitored parameters of the structure

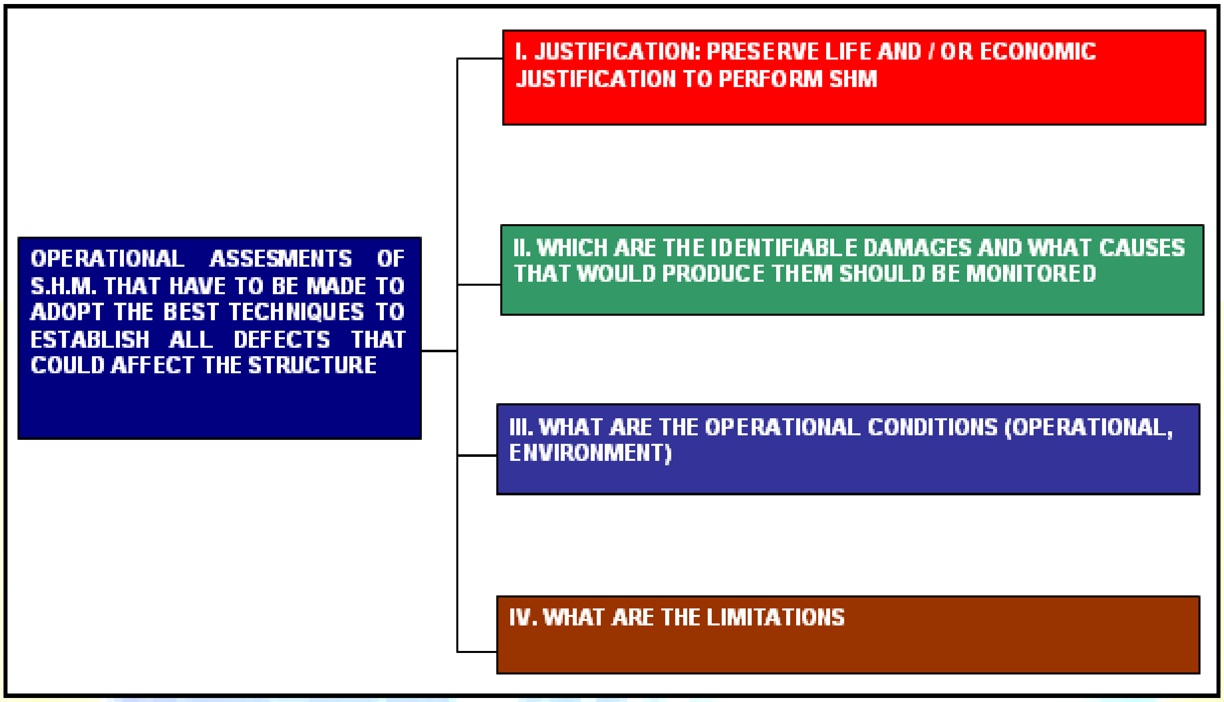

Figure 9. Operational assesments of Structural Health Monitoring

The structural geometric monitoring activity covered by topographic methods and tools is involved in all four stages of the decision to adopt a SHM solution. By solving them we are left with the most suitable monitoring method. The first stage, compared to similar cases, results in an estimated cost of the work that can justify and determine the appropriateness of adopting a SHM procedure. The second stage, only through collaboration between the designer and SHM specialist, we can establish the main coordinates of the SHM action, the causes and effects which will be analyzed, in relation to the existing situation. In the last two stages we can establish the existing operating conditions and limitations, thus finalizing the SHM method to be adopted for the analyzed structure.

The next step is to determine the level of activity. The SHM classification (figure 10.) can be done on four levels[9, 10, 11]:

Level I: At this level, SHM system is capable of detecting damage in a structure, but cannot provide any information on the nature, location, or severity of the damage. It cannot assess the safety of the structure. In fact is: **Detect presence of damage**

Level II: Slightly more sophisticated than Level I. Level II systems can detect the presence of damage and can also provide information on its location. In fact is: **Detect presence**

and location of damage

Level III: A Level III SHM system can detect and pinpoint damage, and quantify the damage to indicate the extent of its severity. In fact is: **Detect presence, location and severity of damage**

Level IV: This is the most sophisticated SHM systems. At this level, the system is capable of providing detailed information on the presence, location, and severity of damage. It is able to use this information to evaluate the safety of the structural system. In fact is: **Detect presence, location, severity and consequences of damage**

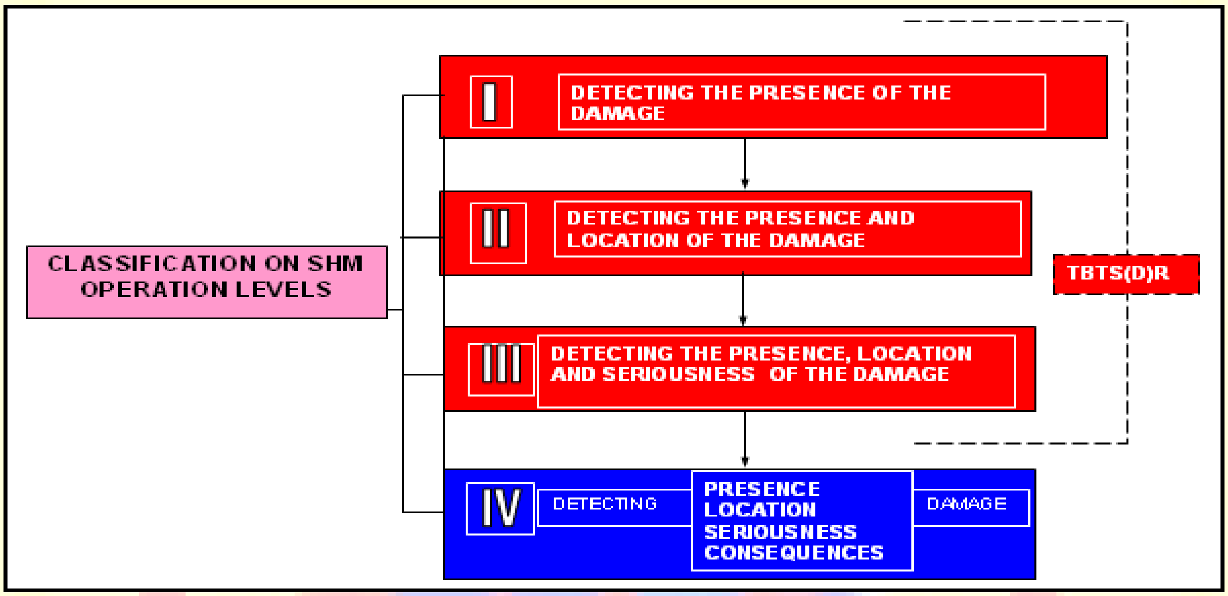

Figure 10. Structural Health Monitoring clasification

Considering the seven axioms launched in by Keith in 2007[12] on SHM, the author develops the topic (Figure 11.), adapting it to the need to identify the degree of involvement of terrestrial measurements sciences methodology in this respect. This resulted in ten axioms, shown in Figure 11. Starting from the first three axioms, which established that whatever the nature of the resistance structure of a monitored object there will be displacements and deformations that will change the status of a structure, up to its destruction, we were able to identify that the type of damage present and the damage severity can generally only be done in a supervised learning mode. According to axioms IV, V and VI, using the tracking the behavior over time in differents regimes methodology, we will adapt the most appropriate methods and tools to determine the exact cause and the cause-effect ratio of the main damages which can be detected from changes in system dynamics.

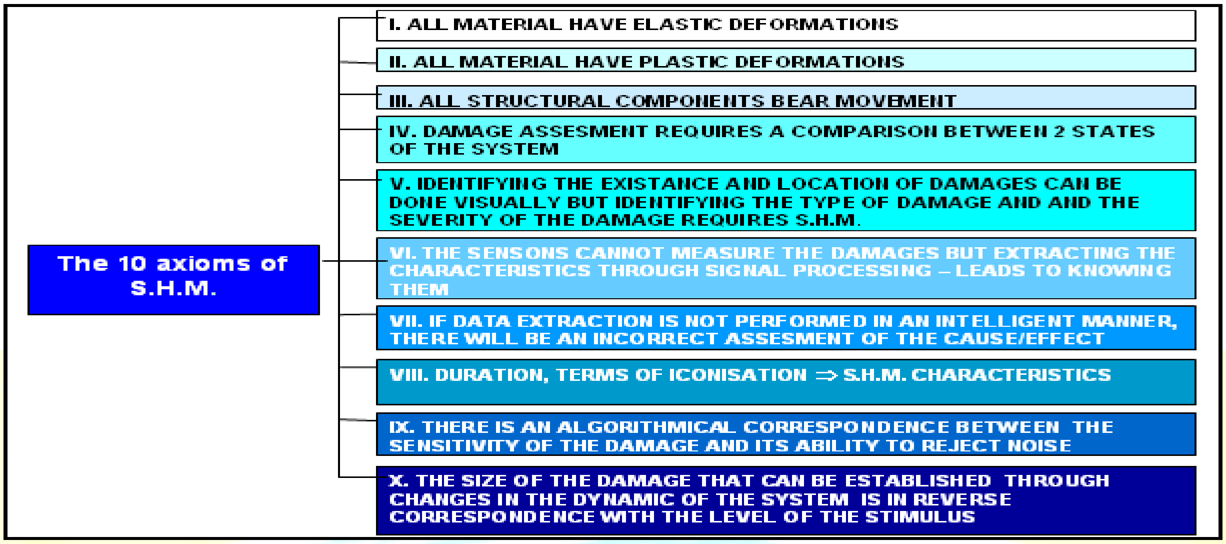

Figure 11. Structural Health Monitoring Axioms(Source: Author, adaptation after Keith, 2007)

The classification of SHM methods can be made from the point of view of nature and the complexity of the instruments used adapted to the objectives in view, but also depending on the nature and level of information provided[9, 10, 11]. In the first case, Bisby[10] classified SHM into four classes: static field testing, dynamic field testing, periodic monitoring and continuous monitoring (Figure 11).

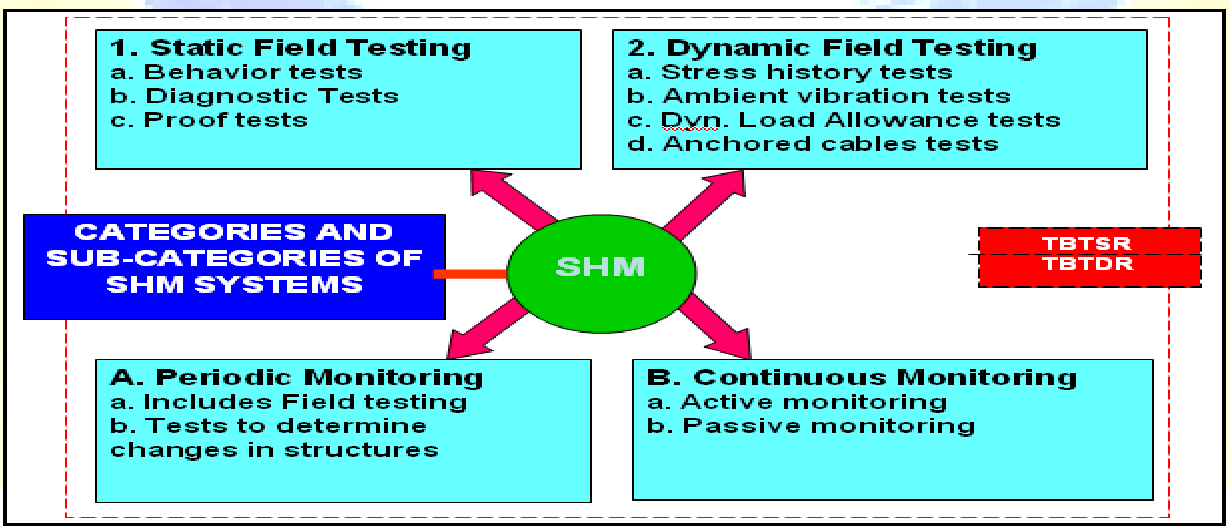

Figure 12.. Structural Health Monitoring categories and sub-categories

The advantages of monitoring the health of constructions (SHM) can be summarized as follows:

1. Observing the law, as all states require this activity through mandatory laws and regulations;
2. A better understanding of structural behavior in situ;

3. Early detection of degradation of the monitored building;
4. Ensuring that the structure can withstand loads, even in the most unfavorable combination thereof;
5. Reducing the so-called "down time", i.e. the time in which the functionality of the structure is disturbed by remedial or modernization activities;
6. Adopting improved strategies of maintenance and general management for the operation of the monitored structure for better resource allocation.

SHM must be designed so that with minimal cost we can obtain information that on the one hand can satisfy the needs for information used to protect the integrity of the structure, and on the other hand provide sufficient data about the in situ behavior of a structure so that the architect can validate the solution chosen. Some of the benefits/advantages of a properly designed SHM are[13]:

- Real time monitoring with alarms increase the safety for the end-uses,
- Down time reduction,
- To verify, control, assess, understand the actual behaviour of the structure,
- Calibration of FEM and calculations,
- Decreased maintenance costs.
- In general, the activity of SHM during execution differs from its period of service, but some sensors may remain, thus making the overall process less expensive.

Some disadvantages of the monitoring are mentioned as follows:

- Costly,
- Might disturb and delay the construction work,

Conclusions

Structural Health Monitoring is extremely important for maintaining the functionality of structures throughout their lifetime at their design parameters, checking in situ the reaction to various strains and comparing it with the project's design. For each issue addressed, when it comes to SHM, the components covered by terrestrial measurement methods and tools were emphasized. Figure 13.. summarizes the components of SHM with geometric content (red background), emphasizing those solved by terrestrial measurements' methods and tools. When organizing structural monitoring activities we must consider a number of factors which can be determined both in choosing the most useful methods for monitoring and the most economical solution. Structural Monitoring (SM) is an indirect way of detecting the level of damage that has been done to a structure via natural or human induced disturbances. Structural Monitoring[2] was done using wired systems that collected and monitored data from these structures. This was an expensive and inflexible approach because the system could not be easily redeployed if better data collection points were discovered on the structure. Wireless Sensor Networks became a good way to solve this problem, and thereby meet a major requirement for a viable SM system. Autonomous motes could now be deployed over a field of interest while data was collected at a base station[14]. The decision to use WSNs came with a significant tradeoff; bandwidth had to be sacrificed for flexibility and price.. Realtime data monitoring involves continuous data capture with a very small time margin between data sample blocks[15]. The marginal time is represented as a percentage of total execution time, and the acceptable threshold will be set by the system designer. This idea forms the basis for this thesis work where a single hop network will be observed and characterized for continuous data sampling and on chip computation.

For the quality of the construction, a very important function is hold by the geodetic measuring and tracing technologies. These must satisfy the necessary precision on construction's execution phases starting with the design-imposed precisions, then tracing, practically the lead of the phase construction process, carrying forward with the time behavior study both on execution process and during the exploitation.

In this context, the monitoring techniques and instruments, which nowadays are considered to be classical, have been partially replaced by new observation methods and sensors and more recently by fully operational monitoring and early-warning systems [16, 17], in fact, the need for structural monitoring has been attracted the interest and various ideas exposed by a great number of researchers – for instance, see [18, 19, 20]]. Also, at an early stage [1990-2010] a distinction between low and highly dynamic phenomena was made. The introduction of GPS for deformation monitoring in the nineties [21], the use of accelerometers [22], Fiber Optic Sensors [23, 24, 25, 26, 27], terrestrial laser scanners [19] and other systems have now changed the landscape in geodetic structural monitoring.

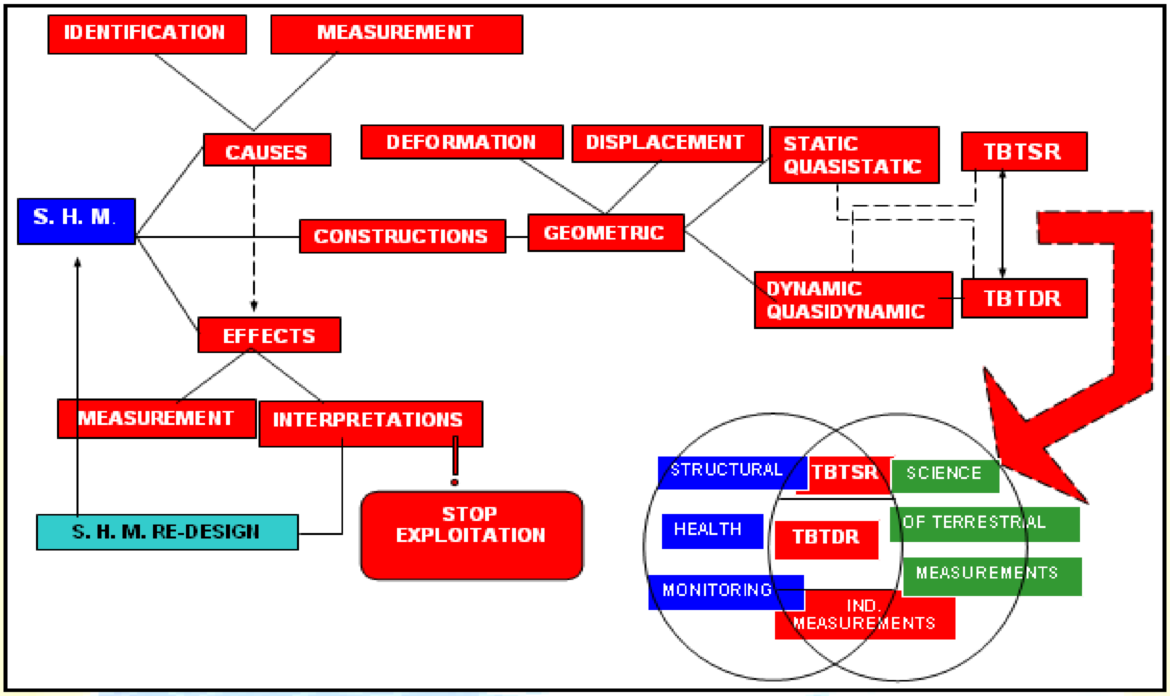

Figure 13.. Structural Health Monitoring categories and sub-categories covered by Terrestrial Measurements Components

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