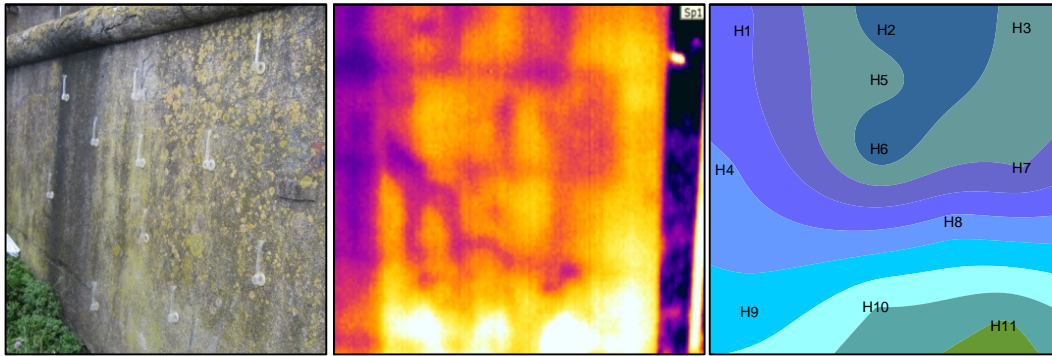




INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa



IN-SITU ANALYSIS OF THE PHYSICAL PERFORMANCE OF RENDERING FACADES

Alexandre Canteau de Menezes Serafim

(IST)

JULY 2012

1. Introduction

Buildings habitability is directly related to the elements used in its construction. The facades are integral components of the outer system building and, as such, they play a major role in the design and architectural value of surrounding areas (Silva, 2003). Besides that, they contribute to a good in-service performance of the buildings. Thus, the façades are critical to the durability of the constructions, influencing decisively the health and comfort of the places where people live and work (Veiga, 2003). In fact, façade claddings are the first elements subjected to degradation agents and, as such, they are essential in construction durability. Throughout their lifetime, in-service performance of claddings deteriorates and ceases to fulfill its requirements. As a result, they require periodic maintenance operations to ensure a good overall performance of buildings during their life cycle. The periodicity of those operations depends largely on the intensity and the severity of degradation agents.

The use of in-situ diagnostic techniques can lead to a more accurately evaluation of the performance level of façade claddings. It allows gathering knowledge of the performance characteristics of applied claddings and assessing their state of degradation as well as the degradation mechanisms by which they are affected.

This research aims at contributing to a deeper study of the physical performance of renders. Thus, the main objective is to propose a methodology for in-situ inspections with a low degree of intrusion for the evaluation of physical in-service performance of renders applied on external walls. In this work, non-intrusive inspection techniques such as thermography, Karsten tube and moisture meter were used to evaluate in-situ physical performance of renders. The information gathered will help to develop a sensitivity analysis of the used techniques, to the anomalies identified and to propose a methodology for in-situ inspection to assess the in-service performance of rendering walls.

2. Evaluation of the in-situ physical behavior of renders

2.1 Physical performance characteristics of renders

Façade renders degradation begins when they are applied, with the appearance of anomalies (cracking and moisture) caused by the processes of curing and drying. Beyond its natural aging, the service conditions and degradation agents that they are subjected can accelerate the degradation. These agents include solar radiation, the action of water, temperature variations, the colonization of microorganisms, the exposure to pollutants and the wind, and should be considered in the design phase for the performance characteristics the specification.

Among the various degradation processes that affect the exterior walls, water in its various forms is the main cause of the appearance of anomalies. In fact, water, gives rise to the appearance of spots of moisture, biological colonization stains and runoff of soluble salts which accelerates the degradation processes. Therefore, the knowledge of in-service physical performance of wall renderings is fundamental, including its resistance to water penetration, its resistance to rising damp and hygroscopic moisture. These characteristics will be a function of render performance properties, such as porosity, permeability to liquid water and water vapor, the coefficient of capillarity, the rate of drying or the presence of soluble salts in the composition. These characteristics should be taken into account in mortar formulation and in the evaluation of its in-service performance through in-situ testing techniques.

2.2 In-situ techniques for the evaluation of the in-service physical performance

The importance of knowing the in-service performance of exterior renders requires the implementation of in-situ inspections. These inspections are based on a visual inspection and, when possible, require the use of technical aids and complementary test techniques. These techniques should be low-intrusive in order to not compromise the aesthetic and performance of the renders. In this work the used techniques for the in-situ inspections were the thermography, the Karsten tube and the moisture meter.

2.2.1 THERMOGRAPHY

Thermal imaging is a technique for measuring infrared radiation that allows obtaining the surface temperature distribution of objects. Wirahadikusumah et al. (1998) explains the principles of infrared thermography relying on the theory of energy transfer, which occurs from hot areas to cold areas. The energy in the form of heat can be transferred by phenomena such as conduction, convection and radiation. The thermal imaging technique is based on the mechanism of heat transfer by infrared radiation and in the fact that all bodies at a temperature upper 0K emit thermal radiation. The higher the temperature of a surface, the greater will be the energy of the emitted radiation.

Any variation in the thermal properties of the elements, such as thermal bridges, defects in isolating or blisters, cause variation in surface temperature that can be easily detected in the thermograms. However, for these defects being visible on the thermograms a temperature gradient is necessary (Barreira, 2004).

In active thermography, the studied surface is artificially heated or cooled in order to produce thermal contrast areas. The thermography image is captured during the return to the state of thermal equilibrium. The thermal contrast can be induced using various energy sources that interfere in different ways with the surface under study. Ibarra-Castanedo et al. (2007) classifies the energy sources as external, when the energy hits the surface propagating through the material until the anomaly is found, or as internal, when energy is injected directly into the specimen so as to enhance existing defects. In this case, an ultrasonic system is used in order to cause the vibration of the particles without the need to heat the surface.

In the case of passive thermal imaging, the study takes place without interference from any artificial source of external heating (or cooling). The irradiation sunlight or the temperature gradient between the interior and exterior environments are considered as natural sources of heat. The main advantage of this approach is that the only necessary equipment is the infrared camera.

The Stefan-Boltzmann law allows relating the surface temperature (T) and the flux of radiation emitted by the object (E) with the introduction of a constant σ (Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8} W \cdot m^{-2} \cdot K^4$). This law is valid for perfect blackbody defined as bodies which absorb all the incident radiation, irrespective of the direction and wavelength. In real bodies, not all the incident energy is absorbed. To this end, a coefficient of emissivity (ϵ) of the object is introduced into the equation 1:

$$E = \epsilon \sigma T^4 [W/m^2] \quad (\text{Eq. 1})$$

The emissivity is a surface property whose value is influenced by several factors such as the orientation and the surface condition, temperature, radiation wavelength and the type of material (Maldague, 2000; Hellier, 2003).

Thermography is useful in various stages of construction processes and can assist in the project design phase and in facilitating the investigation research of new materials and technologies. This technique allows performing rapid tests which detects heat loss through building envelope, resulting in poor thermal insulation (thermal bridges) or infiltration air, cracked areas in the opaque building elements and points of water leakage. The main advantage for users resides in the fact that the technique is quite non-destructive and non-invasive (Barreira, 2004; Dinis, 2009).

The results of this technique depends on various factors such as: the surface emissivity, which vary depending on the materials; reflectivity, resulting from reflection of the radiation emitted by near objects; the atmospheric attenuation, resulting from absorption of radiation by the elements diffuse into the atmosphere (gas and particles); the angle of observation.

In addition to these factors there is the incidence of solar radiation, the occurrence of shading, the existence of localized hot spots or the wind speed in direct contact with the analyzed surface (Gomes, 2006). The experience of the surveyor and the quality of the equipment used can also limit the quality of results (Dinis, 2009).

While some thermographic tests, such as detection of thermal bridges, require stable environmental conditions other are favored by varying environmental conditions, such as detecting the presence of moisture and delamination. In fact, in the latter case the rapidly varying environmental conditions (sunset, sun, sudden appearance of clouds) is rapidly changing the temperature in areas with lower thermal inertia (with peel), while other areas will take longer to change their thermal state. For this reason, often chooses to put the hours of sunset to carry out this type of test, in addition to reduce the phenomena of reflection and shading surfaces.

Most of these factors can be detected prior to testing in order to be registered or, if possible, eliminated (Barrier, 2004).

2.2.2 KARSTEN TUBE

The Karsten tube method allows the evaluation of liquid water permeability of wall claddings in a simple, very fast and non-destructive. This property, which relates to the ability of sealing the plaster against the combined action of rain and wind, is evaluated in non-cracked and vertical surfaces (Flores-Colen, 2009).

The methodology employed, follows the recommendation of RILEM (1980) and LNEC FE 39.1 Pa - LNEC (2002b).

The obtained results using this technique correspond to the volume of water absorbed by a particular cladding, in cm³, during a specific period of time. The absorption coefficient gives a value for water absorption of the render under the action of rain and wind during a time interval determined by the equation 2 (Kunzel et al., 2004 cited by Flores-Colen, 2009):

$$A_{façade} = C_{absorption} \times \sqrt{t_{rain}} \quad (\text{Eq. 2})$$

with, $A_{façade}$ – water absorption in kg/m²; $C_{absorption}$ - water absorption coefficient in kg/m².s and t_{rain} - testing time in min.

The results obtained by Karsten tube method are very sensitive to the conditions under which the test is performed. Factors such as the characteristics of the claddings and its finish, weather

conditions, the degradation of the cladding and the execution mode are crucial to obtaining good results. Referring to cladding and its finish, characteristics such as the type of material used, the type of plastering, the number and thickness of layers constituting the surface roughness and age influence the results obtained (Apps, 2010). The ambient temperature as well as relative humidity and time of day, also affect the results, so they should be taken into account when interpreting the results.

Finally, it should be noted that the human factor may affect the validity of the results. The placement of silicone or mass in excess lowers the contact area and the variations in the intervals of measurement or changes in the number of assays are also critical to the results (Duarte, 2009).

2.2.3 MOISTURE METER

The moisture meter is a measuring instrument that allows obtaining readings of the surface moisture content of several materials. It is a fast and nondestructive in-situ technique; however the obtained values can only be used in a comparative analysis (Magalhães et al. 2005). This equipment when used with accuracy is a very useful tool for the detection of areas of high moisture content. Upon performing various measurements at the surface of a wall it is possible to map the distribution surface moisture content.

This test method is based on the fact that the electrical impedance of a porous medium varies with the amount of water present in the pores by settling a relationship between these quantities, which are inversely proportional the water content is estimated. Thus, it does not directly measure the moisture but changes of the electrical resistance on the substrate. This device is very sensitive to the presence of hygroscopic salts. A computer program (Surfer) was used for processing the obtained values in order to obtain surface moisture maps of the analyzed walls.

This technique allows low accuracy of results which can only be used in comparison. The measurements obtained may have errors due to the capacitance and conductance which depends not only on the water content but also the type of material and the presence of hygroscopic salts.

According to Coleman (1999), the hygroscopic salts cause an increase in the readings obtained. The weather conditions also greatly affect the results. The measurements made on outer garments after rain present results higher than in ordinary weather conditions (Magalhaes et al. 2003). The temperature of the surface to be tested has also influence readings. The degradation of the ornament, such as the presence of cracks, damp stains and biological colonization are also factors which affect the results obtained (Duarte, 2009).

3. Experimental work and results analyses

The main objective of this work is to characterize the physical performance of external renders using different in-situ techniques in addition to visual inspection. For that, the different rendering walls were analyzed using thermography, moisture meter and Karsten tube.

The experimental campaign was conducted in three different case studies and under different climatic conditions. The first campaign took place at the natural aging station for wall claddings (EENRevPa) in the National Laboratory of Civil Engineering (LNEC), in which walls with different characteristics were analyzed. The second campaign was held at the Retaining wall of the Road Platform EN 6 at the Gibalta zone, and the third took place at the surrounding wall of the Instituto Superior Técnico (IST) at the Alameda Campus.

The three campaigns were carried out following the same methodology which is based on visual inspection techniques complemented by IR thermography, Karsten tube tests and moisture meter, in order to assess the physical performance of claddings. The correlation of the results between the three technics and there suitability for each case were assessed in order to develop a consistent methodology for the analysis of in-service physical performance of external renders.

The experimental work allowed the analysis of 21 zones, in which 40 measurements were made by Karsten tube technique and 111 measurements by using the moisture meter. Although it was captured 2 to 4 thermograms for each examined area, only the ones considered useful for diagnosis were used in results analysis.

In order to prepare the field work and to allow collecting all the information and results obtained, inspection sheets were prepared and have been completed during the course of inspections. One inspection sheet with individual records was associated for each inspected area.

This document presents the study of Zone 2 in order to illustrate all the analytical study performed in this dissertation.

Zone 2

The thermography image (Figure 1, right) allows seeing clearly an increase in surface temperature in stained areas. The results of the Karsten tube (Table 1) lead to the conclusion that this render has relatively high permeability to liquid water, which explains the presence of surface moisture measured with the moisture meter. However, temperature rises due to the presence of biological colonization and dirt which changes the emissivity of the surface (dark coloring).

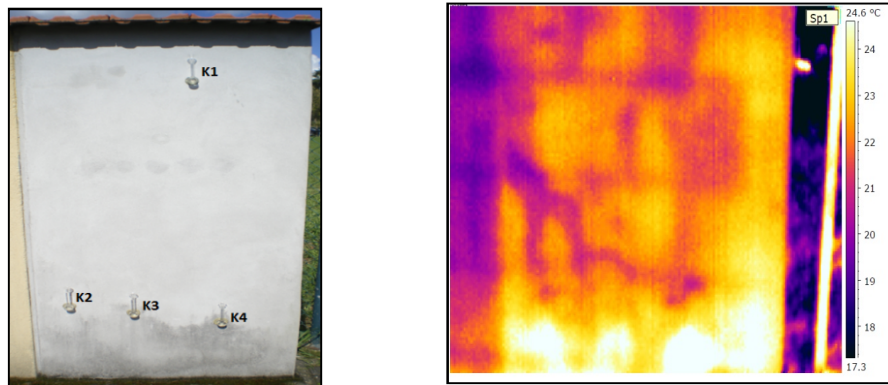


Figure 1 – Tested spots by Karsten tube technique (left) and thermogram (right) for Zone 2.

As expected, the K1 test has lower water absorption (0.50 cm^3) than the other locations. The difference is about 1 cm^3 . This result, coupled with the fact that this it is an area in better condition (visual inspection) suggests that the upper portion of the wall have lower permeability to liquid water than the bottom. This indicates that the upper region appears to be in a better physical performance, as suggested by visual inspection.

Table 1 – Results and statistical analysis for the Karsten tube test in Zone 2.

Zone	Average result (cm^3)	Maximum result (cm^3)	Minimum result (cm^3)	Standard deviation (cm^3)	Coefficient of variation (%)	Average Cab at 60 min ($\text{kg}/[\text{m}^2 \cdot \text{min}]$)
2	1,30	2,30	0,50	0,75	58	0,32
Cab – Water absorption coefficient						

For the tests in the bottom of the walls it can be observed in Figure 1 (left), that the K2 test was carried out in a zone with less indications of moisture than other zones. In fact, the measured values of absorption increases with proximity to the base side walls. Value obtained was 1.10 cm³ for K2 test and 2.30 cm³ for K4 test. The results show that in this wall there is a high variation in moisture distribution on the surface, with the minimum value as 0% and maximum 69%, which reflects into a higher coefficient of variation (141%). The maximum, minimum and average surface moisture are presented in Table 2, as the standard deviation and coefficient of variation.

Using the moisture meter, an increase in moisture of 46% was detected at the point H7 to 69% at the point H9 on the right side of the wall where there is more moisture stains. The increase in moisture stained areas represents 78% of the average of the surface.

Tabela 2 - Results and statistical analysis for the moisture meter test in Zone 2.

Zone	Average result (cm ³)	Maximum result (cm ³)	Minimum result (cm ³)	Standard deviation (cm ³)	Coefficient of variation (%)
2	18,36	69,00	0,00	25,89	141,00

Therefore the use of the moisture meter allowed the detection of an area with increased presence of surface moisture, located in the lower half of the walls in its right side (Figure 2, left and right).

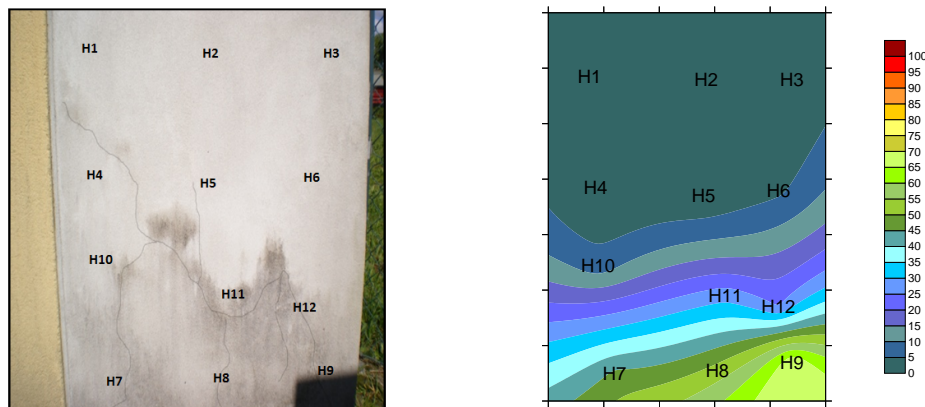


Figure 2 - Tested spots by moisture meter technique (left) and moisture map (right) for Zone 2.

In the thermogram (Figure 1, right) it is possible to identify an area which has a cooler temperature (2 ° to 3 ° C lower). This area corresponds to the area surrounding the crack (≤ 1 mm average width) which is characterized by a decrease in temperature for this wall. This is explained by the fact that the cracks are wet. This type of anomalies allows the penetration of water, which has a higher thermal conductivity but, when evaporate, creates a cooler environment around it (Gomes, 2006). In addition to cracking, it is also possible to observe that there is an increase in temperature in the areas stained with moisture and biological colonization. This difference is about 5 ° C to 8 ° C, and is explained by the color change caused by moisture and biological colonization (darker) which increases the value of the emissivity of the surface in these areas, thereby obtaining a higher reading of the surface temperature thermogram.

4. Conclusions

In this study non-intrusive techniques such as Karsten tube, moisture meter and thermography were used as complement to visual inspection for the physical performance evaluation of rendering walls. In order to increase the speed and ease of the inspection, visual inspection

should be the starting point in any in-situ inspection to assess the physical performance of renders.

In this first phase it is possible to identify many of the defects existing on renders, even in conditions of difficult accessibility. Some limitations have been identified, such as the difficulty in detecting cracks, in distinguishing dirt stains, moisture stains and biological colonization stains specially when located in limited access areas where it is not possible to use auxiliary techniques (test with sodium hypochlorite at 5% or optical microscopy). The importance of making a photographic record of the areas inspected for later evaluation was mentioned. This method is also limited by relying heavily on the level of experience and knowledge of the inspector as well as its subjectivity. The use of predefined methodologies allows a better monitoring and control of this step, which is the object of the present study.

The accuracy of the results obtained by Karsten tube technique depends on many external factors such as weather, the experience of the inspector, the characteristics of the cladding and the accessibility conditions, which strongly influence their results. The choice of sealing material, putty in this case, confers the non-destructive character of this technique but on the other hand can influence the obtained results. Note that in the experimental campaigns of this study some tubes detached and some leaks were also detected. In the studied cases some tests were affected by high cladding surface roughness, and that condition should be taken into account when choosing the correct placement of the Karsten tubes.

Regarding the use of moisture meter, it was observed that the shading element meet or less exposed to weather conditions do vary the values of surface moisture, this variation may be of the order of 10% to 20%. It is noted the fact that this technique enables the detection of wetlands not manifested by the appearance of stains which aren't visually perceptible. Besides that, it should be noted that the use of portable moisture meter help to distinguish damp stains and biological possible colonization from dirt and color changes because, the visual inspection times do not allow it accurately.

Thus, this technique allows obtaining information on the qualitative level of moisture on the surface of the elements tested proving to be very useful in addition to a visual inspection.

Thermography is a non-destructive technique that can identify anomalies related to the presence of excessive moisture such as biological colonization, stains and dirt runoff. This is because all of them are reflected by a color change which, in turn, changes the emissivity of the affected surface, thereby giving rise to a variation of its surface temperature. This variation can be positive or negative, depending on the surface is not exposed to direct sunlight or from solar radiation. The damp stains, when characterized by a color change, react in a different way to the direct sunlight and the result will be a change in surface temperature. The absorption of heat by the dark surface is softened by water that has high thermal conductivity and the endothermic nature of the reaction by evaporation. The cracking is also visible by thermography and the fact that associated with other anomalies (damp patches, biological colonization) facilitates their detection. The loss of adhesion zones are visible if the surface has been exposed to the direct effect of solar radiation for a time.

During the use of this technique some constrains were detected such as weather conditions, surface emissivity (which varies with the color and type of material) or even the distance and angle to the wall. These constrains can complicate the interpretation of thermograms and even lead to wrong conclusions.

It follows that for all the techniques, the inspector knowledge and experience coupled with complementary techniques and the subsequent crossing of results are extremely important to

validate the diagnoses obtained by visual inspection. In some cases it is essential because it allows the distinction of anomalies with identical symptoms.

Based on this study and in the comparison and extrapolation of results obtained in areas where analysis was carried out using all the techniques it was possible to measure temperature variations for each type of anomalies (Table 3). These results can be used in order to help the interpretation of thermographic results in non-accessible areas of the same wall.

Table 3 – Quantification of surface temperature variations for each type of anomalies in thermographic inspections depending of the renders characteristics and conditions inspections.

Anomalies type	ΔT (°C)	ΔT (%)
Moisture stains	[2,5 - 3]	[9 - 11]
Biological colonization	[2,5 - 3,5]	[11 - 21]
Water runoff	[1,3 - 2]	[4 - 9]
Durt satins / Chromatic changes	2,5	7
Cracking	[2 - 3]	[9 - 12]
Adhesion lost	2,5	10

The work has reached the proposed objectives, as evidenced by the influence of various factors in evaluating the physical performance of renders in real conditions by in-situ testing techniques in situ. It also allowed concluding about the feasibility and potential sensitivity of the test techniques used in the in-situ evaluation of the physical behavior and state of degradation of renders. The sensivity analisys allowed the proposal of an in-situ inspection methodology which includes the use of low intrusion and low cost techniques that can be used in low access areas.

Acknowledgments

To my supervisors Prof. Maria da Glória Gomes and Prof Inês Flores-Colen. To Eng.^a Maria Rosário Veiga and Dr. Luís Matias (LNEC), to Eng.^o Nuno Cerqueira (H-Tecnic Construções) and to Laboratório de Construção of IST.

References

- Barreira, E. (2004) – *Application of thermography to the study of the hygrothermal behavior of buildings*. Dissertation in Building Construction. Porto: Faculty of Engineering, University of Porto, 196 p.
- Dinis, B. (2009) – Thermography applied to physical study of constructions. Paper presented at Fernando Pessoa University as part of the requirements for the degree of BA in Civil Engineering, 87 p.
- Gomes, M. (2006) – *Inspection of buildings - Thermography*. Rehabilitation of Contemporary Buildings curse study elements, Association for Training and Development in Civil Engineering and Architecture (FUNDEC), 36p.
- Flores-Colen, I. (2009) - *Methodology for assessing in service performance of building facades towed from the perspective of predictive maintenance*. Doctoral Dissertation in Civil Engineering, Lisbon, Instituto Superior Técnico, 487 p.

Hellier, C. (2003) – Handbook for Nondestructive Evaluation, 594 p.

Ibarra-Castanedo, C. (2007) – Active infrared thermography techniques for the nondestructive testing of materials, 25p.

Magalhães, A., Veiga, M. (2002b) - Tests on in-situ wall coverings for historic buildings. Preliminary tests with tubes Carsten. Report no. 238/02 - NCCT, National Laboratory of Civil Engineering, 40 p.

Magalhães, A., Veiga, M., Costa, D. (2005) - Characterization of the state of conservation of wall coverings using old tests "in-situ". Two case studies. VI Brazilian Symposium on Technology mortars. Florianópolis: ANTAC, May 2005, p. 701-711.

Maldague, X. (2000) - Applications of infrared thermography in non-destructive evaluation, 23p.

Silva, J., Abrantes, V. (2003) - Observation, Recording, Monitoring and Diagnosis of Nonstructural Walls Cracking in Masonry, a National Meeting on Pathology and Rehabilitation of Buildings. Porto, FEUP Editions.

Veiga, M. (2003) - The mortars in conservation. In Proceedings of the 1st s Conference on Civil Engineering, University of Aveiro. Assessment and Rehabilitation of Existing Buildings, 22p.

Wirahadikusumah R, Abraham DM, Iseley T, Prasath RK. (1998) - Assessment technologies for sewer system rehabilitation. Automation in Construction; 7; pp 259–70.