Effective 3D Imaging Framework for Building Inspection

same workflow is applied to the serviceability analysis of any structure

SCDS
BEYOND THE SCAN WORLD

Adaptive Digitization + Façade Deformation Analysis + Thermal Orthoimaging + HF GPR + HD Documentation + Data/Configuration Mgmt via metadataX™ + Concrete Lab Test + Certification

Engineering Audit

OVERVIEW

This document describes a complete package of products, tools, solutions and services, which have been developed, validated and implemented by SCDS Corp., into a wide-ranging workflow for inspection of buildings and other large industrial structures. Although the framework detailed here is essential to a multitude of applications such as ensuring the serviceability and safety of coastal structures and navigation waterways, and performing bridge and dam inspections, the scope of this paper will be limited to building inspection only. Our main objective here is to illustrate and explain how the proposed workflow can augment the building inspection capabilities, facilitate the creation of HD documentation in any stage of a building life cycle, promote an improved safety, and support the full-scale serviceability analyses.

1

In "Effective Response to New Regulatory Provisions" we explain what motivated us to develop the building inspection package and we emphasize important regulatory aspects that inspired our developments.

2

In "Generic Workflow" we show a typical wide-ranging workflow for building evaluation projects.

3

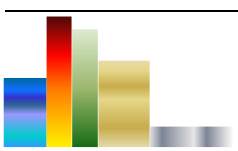
In "Multichannel-Integrated Imaging Technologies" we describe various technological channels associated with the workflow steps.

4

In "Data and Configuration Management via metadataX™" we briefly discuss the role, technological features and competing advantages of metadataX™.

5

In "Conclusion" we emphasize the problem solving scope of the framework presented in this paper.



1 EFFECTIVE RESPONSE TO NEW REGULATORY PROVISIONS

There was a considerable motivation to develop an integrated methodology for highly accurate, rapid, and inexpensive documenting and analyses of building structures and services. Actually, the motivating factor was the Buildings Chapter of the RBQ[1] Safety Code that came into force on March 18, 2013, to improve many regulatory provisions that no longer met building safety requirements. As part of Quality and Safety requirements, RBQ established a set of principles regarding the Building Façade Maintenance and Inspection, which include[2]:

Preventive Maintenance

Buildings require of their owners the application of a thorough and consistent program of preventive maintenance. This is why the façades of all buildings of 5 storeys and more coming under the Regulation must now be subject to a program of periodic verification and maintenance. It is mandatory that they be maintained so as to be free from any defect which could jeopardize safety or contribute to the development of dangerous conditions.

Keeping of a Register

For the lifetime of the building, the following information or documents must be consigned in a register, kept on the premises:

- if available, the copy of the as-built drawings of the construction work of the façades, any photography and any other document or information in connection with the alterations performed;
- the verification reports of the façades.

Verification by a Professional

The owner must obtain from an architect or an engineer a verification report certifying that the façades of the owner's building do not show signs of any dangerous condition. An examination of each façade of the building must be carried out no earlier than 6 months before the date of production of the verification report, which must contain:

- a description of the mandate, observation methods used and scope of verification;
- the location and description of the defects and their causes, which can contribute to the development of dangerous conditions (infiltrations, rust, efflorescence, scaling, cracks, etc.) as well as all problems with connectors or ties noted on components attached to any one of the façades;
- the description of the work remedial actions called for as well as the schedule recommended for performing these, if applicable;

[1] RBQ (La Régie du bâtiment du Québec - Building Agency) has been created in 1992 to ensure, among others, the quality of the work and safety of the buildings and facilities.
[2] https://www.rbq.gouv.qc.ca

- a summary of the report confirming that the façades of the building do not show signs of any dangerous condition, and if applicable, that recommendations have been issued to the owner in view of rectifying the defects reported;
- appendices for the photos, drawings and all other relevant data which may complement the report.

Reporting of Dangerous Conditions

When the presence of a dangerous condition is noted by the professional, he/she must advise immediately both the owner and the RBQ about it and make recommendations in this regard. As for the owner:

- he/she must obtain, at the end of the work, a verification report confirming the safeness of the façades;
- forward to the RBQ a letter signed by the engineer or architect, confirming that all of the remedial action work called for has been performed and that there no longer exist dangerous conditions.

Frequency of the Verification Reports

The owner of a building must obtain a verification report at the latest on the day of the 10th anniversary of its construction.
The owner shall obtain a verification report of the façades every 5 years.

Signs of Deterioration

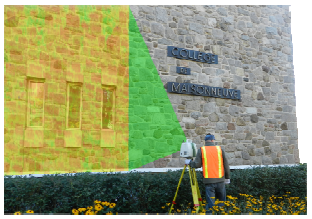
Some signs of the deterioration of façades may be detected by the building owner. Such signs should alert him/her that a more thorough, in-depth inspection is called for.
Here are a few examples of these: cracks, rust stains, signs of physical deterioration at balconies, signs of a displacement of stone or concrete blocks or bricks, problems with integrity of joints on the exterior cladding.

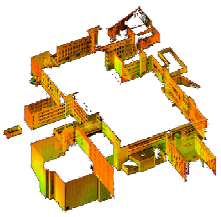
The requirements presented hereinbefore have been addressed and effectively met within several building inspection projects that SCDS Corp. executed and delivered in the last years, through adaptive applications of the following WORKFLOW[3].

[3] Unless otherwise noted, this paper is illustrated with snapshots from the building inspection projects performed by SCDS.

2 GENERIC WORKFLOW

0. Process Initiation, Planning and Site Preparation

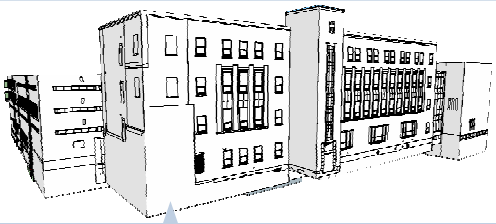




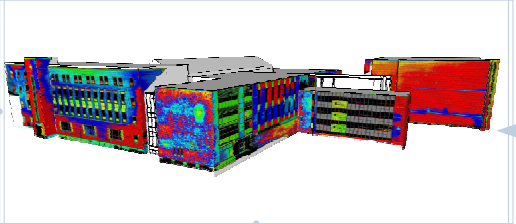
1. Adaptive Digitization via HD Laser Scanning

3. Structural Health Evaluation, Thermal Orthoimaging

2. Subsurface Imaging via High Frequency GPR Scanning

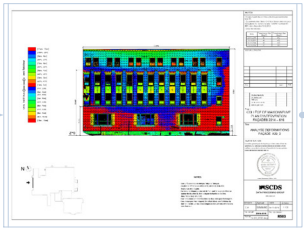


4. Processing, 3D Modeling, Analysis, HD Documentation/CAD, As-Builts



5. Façade Inspection and Deformation Analysis via Spatial Parameter Imaging - SPI™

6. Concrete Sampling, Laboratory Testing



7. Certification, Studies, Assessments, Intervention Proposal, Reporting

8. Data/Configuration Management via metadataX™

3 MULTICHANNEL-INTEGRATED IMAGING TECHNOLOGIES

Although commonly regarded as trivial, the HD Laser Scanning (Step 1) offers spatial data collection and input data opportunities for the development of other digital imaging and analysis tools, such as discrete/combinatorial computational and numerical computational geometry used in SPI™ (Step 5), Thermal Orthoimaging for Structural Health Evaluation (Step 3), and Subsurface Imaging via HF GPR (Step 2).

This paper particularly emphasizes the technological aspects beyond the traditional laser scanning, regardless any laser scanner marque, which is an issue of very little importance.

Spatial Parameter Imaging[4] – SPI™ provides the algorithms for mapping the façade deteriorations, deformations and displacements, which trigger the in-depth and local inspections.

SPI™ creates the ability to form visual representations of spatial parameters, i.e. non-physical entities, for the purpose of structural/physical characterization, health diagnosis and monitoring, by means of HD data collection, data mining, data processing, modeling/CAD, and (meta)data graphical management. SPI™ is quite dissimilar from direct imaging of physical objects, structures and sites, since it generates images through computer simulation of specific spatial parameters, which do not physically exist but are made to appear by specialized algorithms of "parameter embodying".

SPI™ also provides the tool for façade deformation monitoring over a building's life span.

Thermal Orthoimaging uses thermal scanning to "see" beyond the façades by detecting the presence of moisture and energy loss - two major implications for structural damages. Infrared Thermal Scanning is a fast and effective way to locate damages, even when the damage is not visible, and to instantly show the energetic gradient. The novelty proposed here is to perform comprehensive (drone-driven) Thermal Imaging of the façades, and to export and reference the results in the orthogonal mode, to CAD models, potentially in any format, either 2D mapping or tridimensional.

Subsurface Imaging via High Frequency GPR Scanning

Amongst the non-destructive technologies for imaging and assessing the interior of concrete structures, High Frequency Ground Penetrating Radar (HF GPR) has emerged in recent years as a leading tool. Unlike traditional X-raying, HF GPR is safe, requires access to only one side of a slab or wall, can produce results in real time and can be performed with minimal disruption to building operations.

There are numerous advantages and benefits in scanning concrete with HF GPR[5]:

- **Accurate Imaging:** HF GPR provides accurate images and, the ability to analyze slices at varying depths, provides the depth and orientation of embedded objects; the

[4] A more detailed description of the SPI™ concept and its application to a serviceability analysis case are provided in "Hindié, F., Busuioc, S., Effective Spatial Parameter Imaging Methodology for Assessing the Current Condition and Serviceability of Monolith Structures of St. Lawrence Seaway Locks. CSCE 2013 Int'l Conference".

[5] extract from sensoft.ca, Copyright © 2015 Sensors & Software Inc.

dual-technology system we use goes a step further and indicates which conduits hold hazardous current carrying power lines.

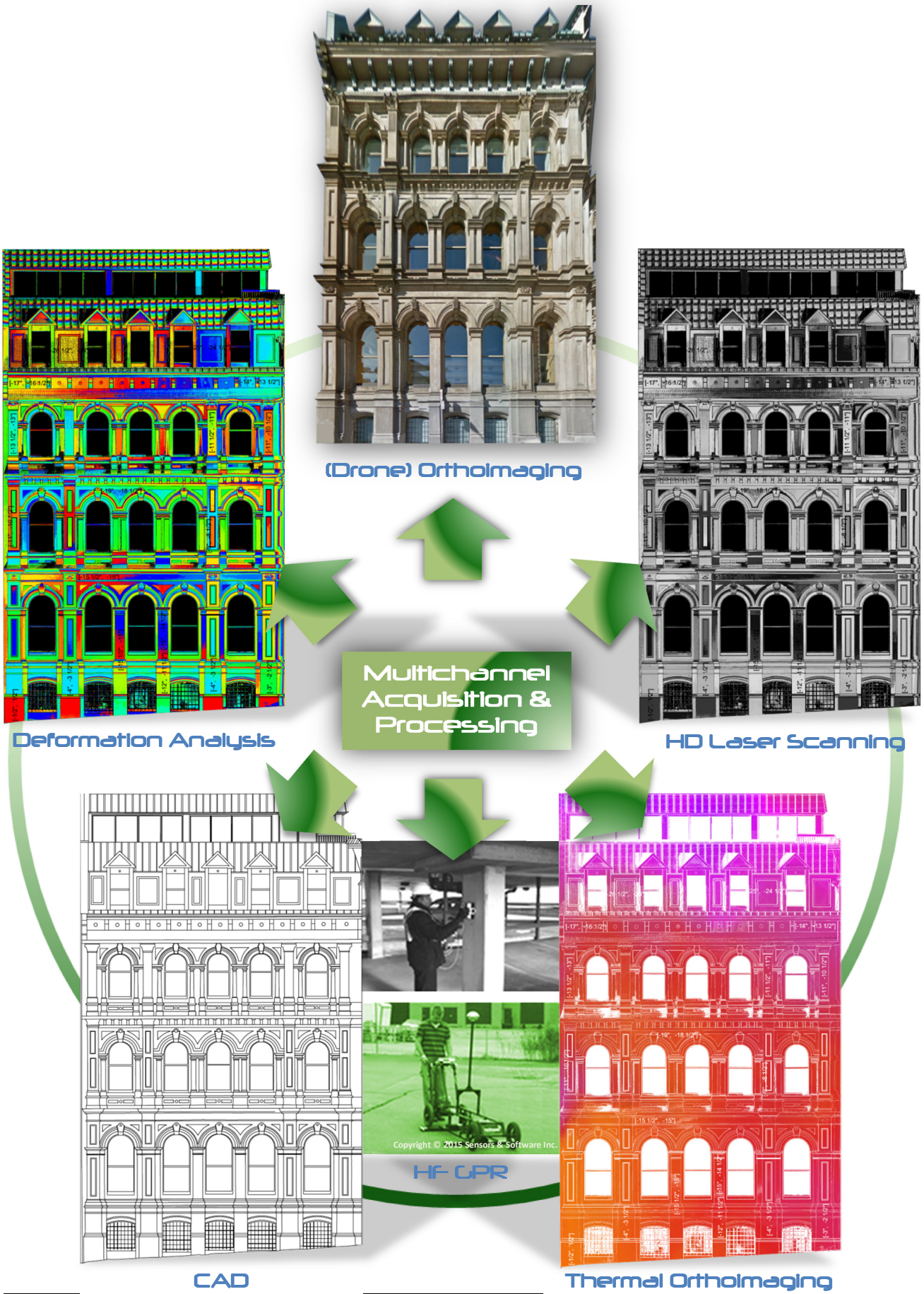
- **Non-Invasive:** Assessment and testing without expensive and harmful destructive testing is always preferable.
- **Difficult Sites:** the sensors we use are small and can be operated in tight spaces and in any orientation on floors, walls, columns and ceilings. Critically, HF GPR is applied from the exposed surface and is able to find features in slab-on-grade. It can even identify voids in surrounding materials. Large areas can be mapped efficiently by deploying the sensor on a cart or vehicle-towed platform (Generic Workflow, Step 2).
- **Flexibility:** HF GPR can be thought of as many tools in one. From investigating structural components such as foundations and ground beams/slabs, locating existing underground services, providing due-diligence records, studies, assessments and intervention proposals, to assessing the deterioration of rebar, a good HF GPR system can do it all.
- **Health and Safety:** Not only is HF GPR harmless to the infrastructure, it also poses no risk to the operators or the general public. We can safely use HF GPR in a crowded public setting without any risk to the people around.
- **Ownership:** Our workflow-integrated tools have the ability to transform data into 3D volume images which can be displayed as volume renderings, collated onto 3D models that are readily available via HD Laser Scanning (as illustrated in Generic Workflow, Steps 4 and 5), or as plan or elevation maps at specified depths (Step 7).
- **Workflow Integration:** Subsurface Imaging via HF GPR can fit seamlessly into any project, regardless its size. Our Generic Workflow is regularly tailored and customized to any project case. Subsurface Imaging can be used jointly with HD Laser Scanning for documenting the sub-structures and services, for foundations, ground beams/slabs, and services (electrical, electro-mechanical, sanitary and water lines) or entirely standalone, for documenting the existing underground services (going to and coming from the building). In general, HD Laser Scanning is still performed on those terrestrial areas corresponding to the underground services, for the purpose of accurate spatial integration (localization and referencing).

Concrete Sampling and Laboratory Testing

Owners of concrete structures are responsible for the safety of their assets. Many concrete structures are more than 50 years old and have been exposed to adverse environment conditions. Material properties of their key structural components could have changed over the past decades. We utilize concrete sampling, laboratory testing, and destructive and non-destructive testing to determine representative parameters of existing structural conditions.

The building inspection framework is built on **Multi-channel Data Acquisition and Processing**. In addition to the active imaging channels ("HD Laser Scanning" and "HF GPR"), four other channels have been considered for a quasi-complete building description. Two of them are inherently passive ("Drone Orthoimaging" and "Thermal Orthoimaging"), and the other two are of derivative nature ("CAD" and "Deformation Analysis - SPI™").

Besides the model-based capabilities, this 6-channel process provides an effective way to correlate, confirm, display and locate different types of structural damages.



4 DATA AND CONFIGURATION MANAGEMENT VIA metadataX™

As shown in "Generic Workflow", metadataX™ (Step 8) collects data and information from all the other steps and plays a central role in the establishment of the general concept of Engineering Audit and its and capabilities-based methodology for building inspection.

metadataX™ has been initially developed by SCDS Corp. as an in-house software, which was intended to support the spatial data/configuration management and specific deliverables of company's 3D imaging projects. Afterwards, in the last years, the system evolved into an advanced, secure, reliable, affordable and universal tool for (meta)data management and project deliverables standardized packaging and deployment to customers.
metadataX™ considers data management as a process, rather than an event, and makes its embedded features available to end users requiring a passable level of skills.
metadataX™ is a highly visual/graphical system for (meta)data management and data configuration management and a specialized open source solution set for data configuration management applicable through any project lifecycle. metadataX™ uniqueness consists primarily of its graphical attributes and features implemented via various types of repository viewers.

The overall data management market is dominated by few major players, such as IBM, Oracle and SAP. However, the market continues to favor the specialized solutions over 'generic' offerings. The data management tools developed by the dominant players can be effectively operated only by specialized users requiring a higher-level of skills than the average user has. Our system provides enhanced visualization and user friendliness and can be operated by any users, regardless their skills in database administration and management.
More and more small and midsize organizations will adopt data management systems in the coming years. This will probably determine lower prices and more flexibility from vendors. As a result, many new data management vendors and offerings will be focused on cost-effective areas such as open source. For many companies, metadataX™ may be the instrumental system in place to execute the kind of process they have always wanted to, without the expense and pain of acquiring and implementing a new data management system, which could cost them several hundred thousand dollars.
metadataX™ competing advantages reside in:

- unique highly visual/graphical repositories;
- wide operational scope; being effectively operated by non-specialized users;
- reduced costs of adoption/implementation.

Being developed onto an open source foundation, metadataX™ also provides a simple and effective mechanism of data versioning control, a high degree of customization, a steep learning curve, i.e. the user becomes quite proficient with a minimum amount of effort/time, and a quick and almost effortless adoption and integration within the processes and workflows of any organization.

5 CONCLUSION

All technological capabilities and capacities highlighted hereinbefore, and integrated into the "Generic Workflow", are utilized to concurrently develop and deploy a structural evaluation-based processing system that serves and supports:

- structural and service inspection;
- preventive maintenance;
- documenting and certifying the dangerous conditions, signs of deterioration, defects, displacements and deformations;
- monitoring of structural deterioration/deformations/damages;
- consigning and registering the professional verifications and documentation over the building life cycle;
- decision making process for the rehabilitation work to be undertaken;
- remedial work designs and planning.

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ABOUT SCDS CORP.:

Actively engaged internationally in 3D imaging technologies since 2002, SCDS Corp. offers successful product solutions for a broad range of applications including Digitization via HD Laser Scanning, Thermal and Subsurface Imaging, Spatial Parameter Imaging - SPI™, reverse engineering, large structure serviceability and performance analyses. Beyond the quality services provided so far to reputable clients in North America, EU and Middle East, over the past decade, within more than 100 digital imaging projects, across multiple industrial and non-industrial domains, SCDS has received well-earned recognition as a leading innovator in SPI™. SCDS currently operates as a group of turnkey service providers, application system developers and integrators, capacity builders, and technology promoters. SCDS offers a complete package of solutions, which are implemented on a perfectly reliable and coherent digital imaging, data processing, (meta)data management and data configuration management platform.

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