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Potential Applications of A Sequential Construction Analyzer

Larry W. Masters

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Gaithersburg, MD 20899

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Prepared for:

U.S. Army Construction Engineering Research Laboratory
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U.S. DEPARTMENT OF COMMERCE, C. William Verity, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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ABSTRACT

The need exists in construction applications for improved methods by which (1) quality can be assured throughout the construction process, (2) the degree of construction progress can be assessed and documented and (3) the performance of systems and materials can be assessed over time to aid in maintenance decision-making. Although these aspects of construction processes have traditionally been addressed empirically, recent advances in computer technology have provided new opportunities for improving upon the traditional methods. The Construction Engineering Research Laboratory (CERL) of the U.S. Army's Corps of Engineers, for example, is exploring the use of a sequential construction analyzer to aid in quality assurance, tracking construction progress, and obtaining data for maintenance decision-making.

This study was carried out to identify potential applications of the sequential construction analyzer in three areas of construction: buildings, construction sites and paving.

Key words: computer image processing; condition assessment; construction processes; quality assurance; sequential construction analyzer

LIST OF TABLES

1. INTRODUCTION

1.1 Background

The U.S. Army's Corps of Engineers (CoE) is responsible for carrying out and overseeing a wide range of construction functions, including, for example, buildings, dams, waterways, and aircraft runways. In each type of construction, the need exists for improved methods by which (1) quality can be assured throughout the construction process, (2) the degree of construction progress can be assessed and documented, and (3) the performance of systems and materials can be assessed over time to aid in maintenance decision-making. Traditionally, the above aspects of construction processes have been addressed empirically, largely through visual assessments and a wide range of reporting formats.

With recent advances in computer technology, new opportunities have arisen for improving upon the traditional methods. The CoE's Construction Engineering Research Laboratory (CERL), for example, is exploring the use of a sequential construction analyzer (SCA) to aid in quality assurance, tracking construction progress, and obtaining data for maintenance decision-making. The SCA is a computer-based system which quantifies and stores images, such as those obtained photographically using either visible or thermal emanations. The intent of the SCA is to provide a means of documenting and tracking construction processes. Although initial applications of the system are intended to focus upon quality assurance during construction, other applications of the system are likely in the future.

1.2 Objectives of Study

The objectives of this study are to identify potential applications of the SCA in construction applications which are of primary interest to the Construction Engineering Research Laboratory (CERL), with a particular emphasis on quality assurance activities and to illustrate an approach by which other potential applications can be identified.

1.3 Scope

This study focuses upon SCA applications in three primary areas of construction: (1) buildings, (2) construction sites, and (3) paving. It emphasizes SCA applications for assuring quality during the construction process but cites other applications, such as tracking the performance of materials and systems over time to aid maintenance decision-making.

2. IDENTIFICATION OF APPLICATIONS OF A SEQUENTIAL CONSTRUCTION ANALYZER (SCA)

In order to survey potential SCA applications, this chapter will systematically address three major types of construction of interest to CERL: buildings, construction sites and paving. Potential applications will be considered through the use of tables which (1) divide each construction process into its major elements, subelements and materials, and (2) identify major properties or attributes of interest.

It is assumed in identifying potential SCA applications, that photographic documentation of the elements, subelements, or materials would be available. Photographic documentation may be obtained , for example, using either a video camera or a thermographic camera. While photographic documentation has long been used to provide qualitative data, recent advances by researchers in the Center for Building Technology (CBT) of the National Bureau of Standards (NBS) have led to methods for quantitatively documenting properties of a number of building materials and systems (1-7). A key advance in the CBT research has been the development and application of a computer image processing system which quantifies properties or defects, evident from either video or thermographically generated photographic images. The research, which has addressed delamination of adhesively-bonded seams of single-ply roofing membranes, moisture in roofing, corrosion and blistering at the interface of organic coatings on steel, roughness measures of sandblasted metallic substrates, and porosity of hardened cement paste, has provided a basis for nondestructive and quantitative assessment of numerous elements, subelements and materials of construction.

Within each table to be presented, a numbering code is used to identify a potential SCA application and to identify the most likely method by which an image portraying the application can be generated. For example, the number code "1" denotes the use of a video camera and the number code "2" denotes the use of a thermographic camera.

2.1 Buildings

A building can be divided into five major elements or subsystems: (1) exterior envelope, (2) interior space divider, (3) electrical subsystem, (4) plumbing subsystem, and (5) space heating and cooling subsystem. Each of these elements can be further divided into subelements and materials. For example, subelements of the exterior envelope are roof, wall, doors and windows, foundation and floor.

2.1.1 Exterior Envelope

Table 1 contains, on the vertical axis, a listing of the subelements and materials for the exterior envelope of a building and, on the horizontal axis, a listing of key system and material properties or attributes. Major subelements of the exterior envelope include roof, wall, doors and windows, foundation, and floor. Properties or attributes are divided into system and material properties. System properties would be assessed on the completed subelement and include skew, documentation of presence, thermal performance and presence of moisture.

To illustrate the use of the table, the following examples from the first four vertical columns of Table 1 are cited. Video camera photographs (Code Number 1) can be used to document or assess skew of all completed exterior envelope subelements (listed as "system" under each subelement) and components of some subelements (for example, decking and structural member of the roof). Video camera photographs can also be used to document the presence of all subelements and other components or materials. Such use of photographs may be helpful to inspectors in ensuring compliance with specifications throughout the construction process. Thermographic photographs are likely to be useful in assessing thermal performance of completed exterior envelope subelements, such as the roof, wall and doors and windows. In the fourth column, titled "presence of moisture," both video and thermographic photographs may be useful in documenting the presence of moisture. For example, moisture on or in the completed roof could be detected photographically by video camera if water is ponded on a flat roof or by aerial thermographic photographs if the presence of water is not so obvious. The presence of excessive moisture in insulation of roofs and exterior walls might best be detected by exposing the insulation and documenting the moisture with a video camera.

2.1.2 Interior Space Dividers

Table 2 illustrates potential quality assurance applications of the SCA for subelements and components or materials of interior space dividers. Major subelements of interior space dividers are ceiling, wall, floor and stairs.

As for the subelements and materials of the exterior envelope, video camera photographs can be used to (1) document the presence and (2) document the type or composition (e.g., gypsum board, tile or wood ceiling; clear or pigmented coating) of all subelements, components and materials of interior space dividers, assuming photographs are taken while items of interest are visible. Numerous other potential applications are illustrated in Table 2.

2.1.3 Electrical Subsystem

Potential SCA applications for the electrical subsystem of buildings are shown in Table 3. Major subelements of the electrical subsystem include (1) service entrance, (2) branch circuits, and (3) other.

Video camera photographs can be used to document the presence of and the type or composition of all components or materials. For example, a single photograph of the service entrance cable, including its label, could perhaps be used to document its presence, document the type of cable (aluminum, copper), document its size and document that it has been terminated in compliance with specifications (safety) to the main power breaker.

Under the property "conduct of electricity," photography is not identitied as a direct measurement tool. It could, however, be used indirectly to document the conduct of electricity by photographing an operable fixture, such as a light bulb.

2.1.4 Plumbing Subsystem

Table 4 presents potential SCA applications for the plumbing subsystem of buildings. Major subelements of the plumbing subsystem include transport, storage, heating and functional. Video camera photographs can be used to document the presence, type or composition and size of all components or materials. For components of the Transport Subelement, video camera photographs are shown on Table 4 to illustrate skew or slope of piping and spigots. Skew or slope of valves, restraints and fasteners is unlikely to be of interest and, therefore, is not shown as a potential application.

2.1.5 Space Heating and Cooling Subsystem

Potential SCA applications for the space heating and cooling subsystem are shown in Table 5. Major subelements of the space heating and cooling subsystem include (1) generation source, (2) transport, (3) storage, and (4) other. System properties are listed as skew or slope, documentation of presence, leaks and safety. Safety concerns of generation sources which, for example, could be addressed using video camera photographs are distance from flammable materials, venting facilities and restraints or fasteners.

2.2 Construction Sites

Table 6 illustrates potential SCA applications in construction sites. Elements associated with construction sites are divided into three categories: below grade, ground level, and above grade. Properties or attributes are divided into two main categories: (1) topographical and

(2) other. The SCA, for example, could be used at construction sites to document changes in terrain as a result of the construction, changes in vegetation patterns, and slope of terrain.

2.3 Paving

Table 7 illustrates potential SCA applications in paving. Paving elements are listed as: (1) construction base, (2) pavement, (3) drainage system and (4) safety-related system. Video camera photographs can be used, for example, to document or assess skew or slope of completed construction bases, pavements, drainage systems and safety-related subelements, such as surface markings, signs or markers, edge grading and guard rails. Likewise video camera photographs can be used to document the presence of all subelements, as shown in the table.

3. CONCLUSIONS AND RECOMMENDATIONS

It is clear that many potential applications of a sequential construction analyzer exist in the three major types of construction considered in this report. Recent advances in the use of computers for image processing have opened the door for major advances which can aid quality assurance, tracking construction progress, and obtaining data for maintenance decision-making.

While this report is limited to SCA applications in buildings, construction sites and paving, opportunities for the use of SCA are probably equally as great in construction areas such as dams, irrigation, bridge construction, and other areas of interest to the Corps of

Engineers. The tables used in this report illustrate an approach by which other opportunities can be identified.

It is recommended that:

1. Guidelines and criteria be developed for the use of SCA in construction applications,

2. Studies be carried out to demonstrate the use of the SCA in selected construction applications, and

3. Additional opportunities for use of SCA in construction applications not addressed in this report be identified for subsequent use by the Corps of Engineers.

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Table 1. Quality Assurance Applications of the Sequential Construction Analyzer in the Exterior Envelope of Buildings

BUILDING ELEMENT	PROPERTIES OR ATTRIBUTES[1]												
	SYSTEM PROPERTIES				MATERIAL PROPERTIES								
EXTERIOR ENVELOPE	Skew	Documentation of presence	Thermal Performance	Presence of Moisture	Voids	Cracks	Cleanliness	Topography (roughness)	Color	Thickness	Type or Composition	Delamination	Corrosion
ROOF													
- System	1	1	2	1,2	-	-	-	-	-	-	1	-	-
- Exterior coating	-	1	-	-	1,2	1,2	1,2	-	1	-	1	1,2	1,2
- Membrane	-	1	-	1,2	1	1	1,2	-	1	1	1	1,2	-
- Membrane joints	-	1	-	2	2	1,2	2	-	-	-	1	1,2	-
- Decking	1	1	-	-	-	-	-	-	-	1	1	-	1,2
- Structural member	1	1	-	-	-	-	-	-	-	1	1	-	1,2
- Insulation	-	1	-	1	1	1	-	-	-	1	1	-	-
- Vapor barrier	-	1	-	1	1	1	-	-	-	-	1	-	-
- Interior substrate	-	1	-	1	1	1	1	-	1	1	1	1	1,2
- Fasteners	-	1	-	-	-	-	-	-	-	-	1	-	1,2
- Seals/flashing	-	1	-	1	1	1	-	-	-	-	1	1	1,2
WALL													
- System	1	1	2	1,2	-	-	-	-	-	-	1	-	-
- Exterior coating	-	1	-	-	1	1	1	-	1	-	1	1,2	1,2
- Exterior substrate or siding (cladding)	1	1	-	-	1	1	1	2	1	1	1	1	1,2
- Sheathing or Waterproofing	1	1	-	-	1	1	-	-	-	1	1	1	-
- Structural member	1	1	-	-	-	-	-	-	-	1	1	-	1,2
- Insulation	-	1	-	1	1	1	-	-	-	1	1	-	-
- Vapor barrier	-	1	-	1	1	1	-	-	-	-	1	-	-
- Interior substrate	1	1	-	1	1	1	1	-	1	1	1	1	1,2
- Interior coating/ covering	-	1	-	1	1	1	1	-	1	-	1	1,2	1,2
- Fasteners	-	1	-	-	-	-	-	-	-	-	1	-	1,2
- Seals/flashing	-	1	-	1	1	1	-	-	-	-	1	1	1,2
DOORS/WINDOWS													
- System	1	1	2	1	-	-	-	-	-	-	1	-	-
- Exterior coating	-	1	-	-	1	1	1	-	1	-	1	1,2	1,2
- Base material (glazing)	-	1	-	-	-	1	1	-	-	-	1	-	-
- Frame	1	1	-	-	1	1	-	-	-	1	1	-	1,2
- Interior coating	-	1	-	-	1	1	1	-	1	-	1	1,2	1,2
- Hardware	1	1	-	-	1	1	-	-	-	-	1	-	1,2
- Fasteners	-	1	-	-	-	-	-	-	-	-	1	-	1,2
- Seals/flashing	-	1	-	-	1	1	-	-	-	-	1	-	1,2
FOUNDATION													
- Footing	1	1	-	1	1	1	-	-	-	1	1	-	-
- Mat	1	1	-	1	1	1	-	-	-	1	1	-	-
- Pile	1	1	-	1	-	-	-	-	-	1	1	-	1,2
- Tie beam	1	1	-	1	-	-	-	-	-	1	1	1	1,2
FLOOR													
- System	1	1	-	1,2	-	-	-	-	-	-	1	-	-
- Structural member	1	1	-	-	-	-	-	-	-	1	1	-	1,2
- Sub floor	1	1	-	-	1	1	-	1	-	1	1	1	1,2
- Finish flooring	1	1	-	-	1	1	1	1	1	1	1	1	-
- Floor coating/ covering	-	1	-	-	1	1	1	-	1	1	1	1	-
- Fasteners	-	1	-	-	-	-	-	-	-	-	1	-	1,2
- Seals/flashing	-	1	-	-	1	1	-	-	-	-	1	1	1,2

[1] Numbers refer to the most likely method for generating the image to be analyzed by the SCA; 1-video camera; 2-thermographic camera

Table 2. Quality Assurance Applications of the Sequential Construction Analyzer in the Interior Space Dividers of Buildings

PROPERTIES OR ATTRIBUTES[1]

BUILDING ELEMENT	SYSTEM PROPERTIES				MATERIAL PROPERTIES								
Interior Space Divider	Skew	Documentation of presence	Thermal Performance	Presence of Moisture	Voids	Cracks	Cleanliness	Topography (roughness)	Color	Thickness	Type or Composition	Delamination	Corrosion
CEILING													
- System	1	1		1,2	-	-	-	-	-	-	1	-	-
- Coating/covering	-	1		-	1,2	1,2	1	-	1	-	1	1,2	1,2
- Substrate 1 (outer-most)	1	1		1	1	1	1	2	1	1	1	1	1,2
- Structural member	1	1		-	-	-	-	-	-	1	1	-	1,2
- Insulation	-	1		1	1	1	-	-	-	1	1	-	-
- Substrate 2 (inner-most)	1	1		1	1	1	1	2	1	1	1	1	1,2
- Fasteners	-	1		-	-	-	-	-	-	-	1	-	1,2
- Openings	1	1		-	-	-	-	-	-	-	-	-	-
WALL													
- System	1	1		1,2	-	-	-	-	-	-	1	-	-
- Coating/covering	-	1		-	1,2	1,2	1	-	1	-	1	1,2	1,2
- Substrate	1	1		1	1	1	1	2	1	1	1	1	1,2
- Structural member	1	1		-	-	-	-	-	-	1	1	-	1,2
- Insulation	-	1		1	1	1	-	-	-	1	1	-	-
- Fasteners	-	1		-	-	-	-	-	-	-	1	-	1,2
- Openings	1	1		-	-	-	-	-	-	-	1	-	-
- Trim work	1	1		1	1	1	1	-	1	1	1	1	1,2
FLOOR													
- System	1	1		1,2	-	-	-	-	-	-	1	-	-
- Coating/covering	-	1		-	1,2	1,2	1	-	1	-	1	1,2	1,2
- Finish flooring	1	1		1	1	1	1	1	1	1	1	1	-
- Subflooring	1	1		1	1	1	-	1	-	1	1	1	1,2
- Structural member	1	1		-	-	-	-	-	-	1	1	-	1,2
- Fasteners	-	1		-	-	-	-	-	-	-	1	-	1,2
- Openings	1	1		-	-	-	-	-	-	-	1	-	-
- Trim work	1	1		1	1	1	1	-	1	1	1	1	1,2
STAIRS													
- System	1	1		1	-	-	-	-	-	-	1	-	-
- Coating/covering	-	1		-	1,2	1,2	1	-	1	-	1	1,2	1,2
- Finish flooring	1	1		1	1	1	1	1	1	1	1	1	-
- Structural member	1	1		-	-	-	-	-	-	1	1	-	-
- Fasteners	-	1		-	-	-	-	-	-	-	1	-	1,2
- Trim work	1	1		1	1	1	1	-	1	1	1	1	1,2

[1]Numbers refer to the most likely method for generating the image to be analyzed by the SCA: 1-video camera; 2-thermographic camera

Table 3. Quality Assurance Applications of the Sequential Construction Analyzer in the Electrical Subsystems of Buildings

BUILDING ELEMENT	PROPERTIES OR ATTRIBUTES[1]					
	SYSTEM PROPERTIES			MATERIAL PROPERTIES		
ELECTRICAL SUBSYSTEM	Documentation of presence	Conduct of Electricity	Safety	Terminal Overheating	Type or Composition	Size
SERVICE ENTRANCE						
- Entrance cable	1	-	1	2	1	1
- Breaker/fuse box	1	-	-	-	1	1
- Breaker/fuses	1	-	-	-	1	1
- Fasteners	1	-	-	-	1	1
- Terminations	1	-	1	2	1	-
BRANCH CIRCUITS						
- Cable	1	-	1	-	1	1
- Receptacles	1	-	1	2	1	-
- Switches	1	-	1	2	1	-
- Other terminations	1	-	1	2	1	-
- Enclosures	1	-	1	-	1	1
OTHER						
- Electrical fixtures	1	-	1	2	1	-
- Electrical appliances	1	-	1	2	1	1

[1]Numbers refer to the most likely method for generating the image to be analyzed by the SCA: 1-video camera; 2-thermographic camera

Table 4. Quality Assurance Applications of the Sequential Construction Analyzer in the Plumbing Subsystem of Buildings

PROPERTIES OR ATTRIBUTES[1]

BUILDING ELEMENT	SYSTEM PROPERTIES					
PLUMBING SUBSYSTEM	Skew or Slope	Documentation of presence	Leaks	Corrosion	Type or Composition	Size
TRANSPORT						
- Piping	1	1	1	1,2	1	1
- Valves	-	1	1	1,2	1	1
- Spigots	1	1	1	1,2	1	1
- Restraints	-	1	-	1,2	1	1
- Fasteners	-	1	-	1,2	1	1
STORAGE						
- Tank (interior)	1	1	1	-	1	1
- Sink	1	1	1	1,2	1	1
HEATING						
- Water heater	1	1	1	-	1	1
- Solar collector(s)	1	1	1	1,2[2]	1	1
FUNCTIONAL						
- Tub	1	1	1	1,2	1	1
- Shower	1	1	1			
- Sink	1	1	1	1,2	1	1
- Toilet	1	1	1	1,2	1	1
- Laundry	1	1	1	1,2	1	1
- Dishwasher	1	1	1	1,2	1	1

[1]Numbers refer to the most likely method for generating the image to be analyzed by the SCA: 1-video camera; 2-thermographic camera

[2]Assuming conduits for heat transport fluid are visible from the front surface

Table 5. Quality Assurance Applications of the Sequential Construction Analyzer in the Space Heating and Cooling Subsystem of Buildings

BUILDING ELEMENT	PROPERTIES OR ATTRIBUTES			
	SYSTEM PROPERTIES			
SPACE HEATING AND COOLING SUBSYSTEM.	Skew	Documentation of presence	Leaks	Safety
GENERATION SOURCE				
- Furnace/burner	1	1	-	1
- Stove	1	1	-	1
- Heat pump	1	1	-	1
- Electrical heaters	1	1	-	1
- Air conditioner	1	1	-	1
- Radiators	1	1	-	1
- Solar collector	1	1	-	1
- Fireplace	1	1	-	1
- Fasteners	-	1	-	1
TRANSPORT				
- Ductwork	1	1	2	-
- Piping	1	1	2	-
- Restraints	-	1	-	1
- Fasteners	-	1	-	1
- Conduction/convection	-	-	-	-
STORAGE				
- Tank	1	1	2	-
- Wall	1	1	-	-
- Rockbed	1	1	2	-
- Other	-	1	-	-
OTHER				
- Chimney	1	1	-	1
- Chimney liners	1	1	-	1

Table 6. Applications of the Sequential Construction Analyzer in Construction Sites

	PROPERTIES OR ATTRIBUTES[1]					
SITE ELEMENTS	TOPOGRAPHICAL PROPERTIES				OTHER PROPERTIES	
	Slope	Depth	Height	Width	Vegetation	Area
BELOW GRADE	1	1	-	1	1	1
GROUND LEVEL	1	-	1	1	1	1
ABOVE GRADE	1	-	1	1	1	1

[1] Numbers refer to the most likely method for generating the image to be analyzed by the SCA: 1-video camera; 2-thermographic camera

Table 7. Quality Assurance Applications of the Sequential Construction Analyzer in Paving

PROPERTIES OR ATTRIBUTES[1]

PAVING ELEMENTS	Skew or Slope	Documentation of Presence	Depth or Thickness	Presence of Moisture	Voids	Cracks	Topography (roughness)	Color	Composition	Delamination	Corrosion
CONSTRUCTION BASE											
- System	1	1	1		1	1	1	-	-	-	-
- Base material(s)	-	1	1		1	1	-	-	1	-	-
PAVEMENT											
- System	1	1	1		1	1	1	1	1	-	-
- Matrix	-	1	1		1	1	1	1	1	1	-
- Reinforcement	-	1	1		1	-	-	-	1	-	1[2]
DRAINAGE SYSTEM	1	1	1		1	1	-	-	1	-	-
SAFETY-RELATED SYSTEM											
- Surface markings	1	1	-		-	-	-	1	-	1	-
- Signs or markers	1	1	1		-	-	-	1	1	-	1,2
- Edge grading	1	1	1		1	1	1	-	1	-	-
- Guard rails	1	1	1		1	1	-	-	1	1	1,2

[1] Numbers refer to the most likely method for generating the image to be analyzed by the SCA: 1-video camera; 2-thermographic camera

[2] Assuming visibility of reinforcement

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The need exists in construction applications for improved methods by which 1) quality can be assured throughout the construction process, 2) the degree of construction progress can be assessed and documented and 3) the performance of systems and materials can be assessed over time to aid in maintenance decision-making. Although these aspects of construction processes have traditionally been addressed empirically, recent advances in computer technology have provided new opportunities for improving upon the traditional methods. The Construction Engineering Research Laboratory (CERL) of the U.S. Army's Corps of Engineers, for example, is exploring the use of a sequential construction analyzer to aid in quality assurance, tracking construction progress, and obtaining data for maintenance decision-making.

This study was carried out to identify potential applications of the sequential construction analyzer in three areas of construction; buildings, construction sites and paving.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

computer image processing; condition assessment; construction processes; quality assurance; sequential construction analyzer

13. AVAILABILITY

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