Applying Infrared Thermography (IRT) to Detect Deterioration and Anomalies in Adobe Masonry

Field Manual, Equipment List, and Case Study Results

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TABLE OF CONTENTS

SUMMARY

This project proposed to test the application of infrared thermography (IRT) to detect conditions through a case study adobe structure, which exhibits a range of deterioration conditions after a moderate seismic event. The primary research objective is to test various IR field methods for their accuracy, ease of use, and feasibility in backcountry applications. Based on that experience, this infrared thermography field manual, equipment list, and image processing guide was drafted to demonstrate a comprehensive IRT methodology for historic adobe resources in remote settings. Ultimately, the goal of this manual is to clarify the IRT process and to promote integrating the use of IRT into building investigation and conditions assessments for adobe structures and features. The circulation of this field manual and case study conclusions will contribute to the development of successful common methodologies for using nondestructive tools to evaluate culturally significant adobe masonry.

Goals:
- Draft a field methodology and tool list for infrared thermography.
- Establish IRT calibrations, parameters and protocol tailored to adobe masonry systems.
- Identify subsurface abnormalities within the plaster and adobe/stone masonry wall system at the case study site.

INTRODUCTION: INFRARED THERMOGRAPHY

Infrared thermography (IRT) investigation is a remote measuring technique which maps the distribution of radiation emitted from a surface. IRT investigation relies on the use of an infrared camera, which has sensors that can record infrared radiation emitted from an object surface and interprets that radiation into a thermal image. This operates based on the principles that 1) all objects above the temperature 0 degrees Kelvin emit infrared radiation and 2) the infrared radiation emitted from its surface is related to its temperature.

Surface temperature is based on several factors, including localized thermal properties of materials. The diffusion of heat from the surface through the materials inside the assembly can alter the surface temperature distribution, indicating details about the subsurface matrix. The resultant variation in temperature within a given area can indicate these possible defects in the materials examined. For historic structures and features, this includes the presence of heterogeneous materials,[1, 2] moisture,[3] or the presence of defects;[4,5] case studies have been published which prove the effectiveness of IR in detecting these phenomena for several building materials and construction types, including historic wooden and masonry structures.

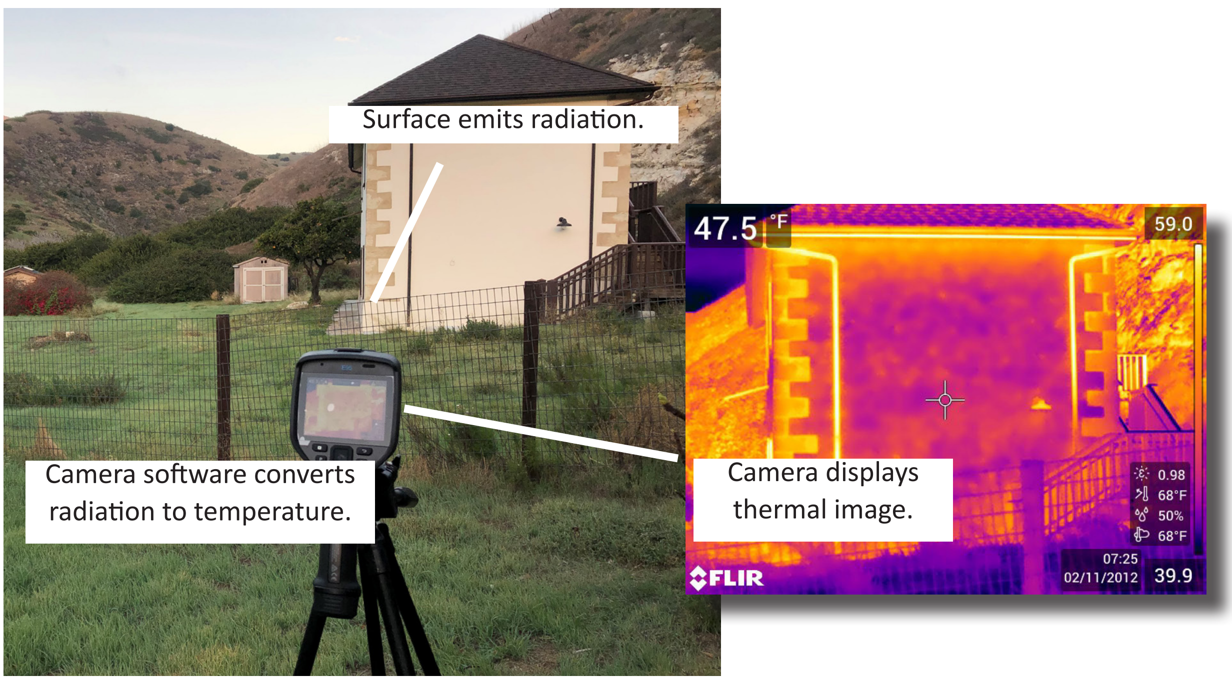

FIGURE 1. A simplified infographic to demonstrate how infrared cameras translate acquired data into thermal images.

[1] Elisabetta Rosina and Elwin C. Robison, "Applying Infrared Thermography to Historic Wood-Framed Buildings in North America," *APT Bulletin: The Journal of Preservation Technology* Vol. 33, No. 4 (2002): 39.

[2] S. Filippeschi and F. Leccese. 2005, "Infrared Thermography to Visualize the Texture of Historical Buildings in Tuscany," Paper presented at *8th International Conference on "Non Destructive Investigations and Conservation of the Cultural and Environmental Heritage," Lecce (Italy), May 15-19th, 2005*.

[3] Elisabetta Rosina and Johnathan Spodek, "Using Infrared Thermography to Detect Moisture in Historic Masonry: A Case Study in Indiana," *APT Bulletin: The Journal of Preservation Technology* Vol. 34, No .1 (2003): 11-16.

[4] Fulvio Mercuri, Ugo Zammit, Noemi Orazl, and S. Paoloni, "Active infrared thermography applied to the investigation of art and historic artefacts," *Journal of Thermal Analysis and Calorimetry* 104 (2011): 475-485.

[5] Milovanović, Bojan and Ivana Banjad Pečur. "Review of Active Thermography for Detection and Characterization of Defects in Reinforced Concrete." *Journal of Imaging*, 2, 11 (2016): 1-27. https://doi:10.3390/jimaging2020011.

Using IRT methods are particularly beneficial for evaluating cultural heritage resources for several reasons. With an IR camera, an investigator looking at a significant structure may:

- Evaluate large areas in a short amount of time.
- Scale the camera's field of view to a range of surface areas, from an entire building elevation to a small feature.
- Acquire information from a distance, meaning that buildings several stories tall can be studied without the use of scaffolding.
- Examine the resource without surface contact, an ideal tool for sensitive materials.
- Utilize the camera and its software without needing a high degree of experience, as more recent cameras and software tend to have comprehensible graphic user interfaces.

Methods of Infrared Thermographic Investigation

IRT investigation methodologies are broadly categorized into two distinct types, according to the inputs of heat flux: passive and active thermography.

Passive thermography describes methods in which the emitted radiation is monitored utilizing naturally occurring thermal phenomena, without employing or inducing any heating of the surface by artificial means. Heat introduced by sunlight, ambient air temperature, and other environmental conditions to the study surface area can expose potential anomalies with little to no preparation on the part of the investigator. This makes passive IRT an ideal candidate for building elevations because it allows for rapid investigation with low intervention or need for additional scaffolding, sensors, heat sources, and so on.

Passive IRT relies on utilizing natural changes in temperature conditions to produce thermal differences across the surface; this is most easily observed when heat changes at sunset or sunrise, and the thermal contrasts reveal anomalous areas in the materials where the temperature may differ from the surrounding material. The resulting patterns in temperature distribution may be interpreted qualitatively, i.e., looking for notable hot and cold spots in areas of concern.

Active thermography utilizes artificial heating of the surface to induce thermal diffusion and enhance differences in surface temperatures. This is particularly useful for traditional building materials, which have similar thermal properties. In most steady state conditions, differences in surface temperature can be hard to detect. Surface temperature patterns can be provoked with significant fluctuations in temperature, which can help to indicate subsurface anomalies.

Active thermography is more difficult than passive for several reasons. The size of the surface area under active IRT investigation is typically limited by the range of the external heat source, as it can be difficult to produce even, constant, and unidirectional heating over a large surface area. Active thermography also requires more inputs and time than passive thermography, such as positioning the heat source and camera or programming and placing thermocouples (if desired).

Active IRT can be further categorized by the positioning of the heat source with respect to the thermal camera and the method of thermal stimulation:

- *Reflected thermography* describes applying thermal excitation (i.e. a heat source) directly to the surface which is in the thermal camera's field of view (Figure 2). This is typically easier to complete in the field, as the opposite site of the surface is not always accessible.
- *Transmissive thermography* describes a method of active thermography in which the thermal excitation is applied to the surface opposite from the surface which is in the thermal camera's field of view (Figure 2). Ideally, the energy from the source on the opposite side of the feature from the camera will travel through the material. A common example of this concept is thermal cameras to

observe heat loss from the outside of a building; heat from the interior conducts through the materials and then registers on the exterior surface for the camera to observe heat loss around windows or lack of insulation.

- *Pulsed thermography* (PT) describes a method of heating in active IRT which consists of briefly heating a specimen and then recording the temperature decay as the heat propagates beneath the surface by diffusion. Once the heat reaches a subsurface defect, that defect modifies the diffusion rate so that the surface temperature over these locations will be different than the surrounding sound area. PT tends to be the most common method used among active IRT methods, owing to its quickness. For low conductivity materials, as most traditional building materials are, heat stimulation phases should last a few seconds. In studying highly conductive materials, such as metals, researchers typically pulses which last a few milliseconds. Due to the pulse length, PT is typically better for examining areas close to the surface. For example, this can mean setting heaters to turn on for 10 seconds, and then off for 10 seconds. This can be adjusted to longer or shorter intervals.
- *Long pulse* (also called step heating pulse) is similar to pulsed thermography in that an external heat source is used to heat the study area surface, and the surface temperature is monitored for anomalies. Rather than introducing heat in short periodic pulses, the object is continually heated in long pulse thermography; for example, this could mean constantly heating a surface for 1 hour. Long pulse is typically better for composite assemblies, and is used to evaluate the thickness, discontinuities, and debonding of layers or coatings.

Selecting an IRT method depends on several factors. The environment and resources within a project can limit the level of investigation, due to the requirements or constraints of each type of investigation. Materials within the assembly, if known, also dictate which may be a more successful method. For building assemblies in which the materials have dissimilar thermal properties, the passive approach may yield sufficient results. Active methods, which utilize artificial heat flux, tend to be more useful in instances where the materials have similar thermal properties.[6]

Generally, an optimal IR field examination approaches tend to use the passive methodology to ascertain general conditions information across a large surface area and then active thermography to capture refined information about conditions in limited areas. Ideally, passive thermography is used to complete an initial survey from which smaller anomalous areas are identified and active thermography may be employed to gain more information.

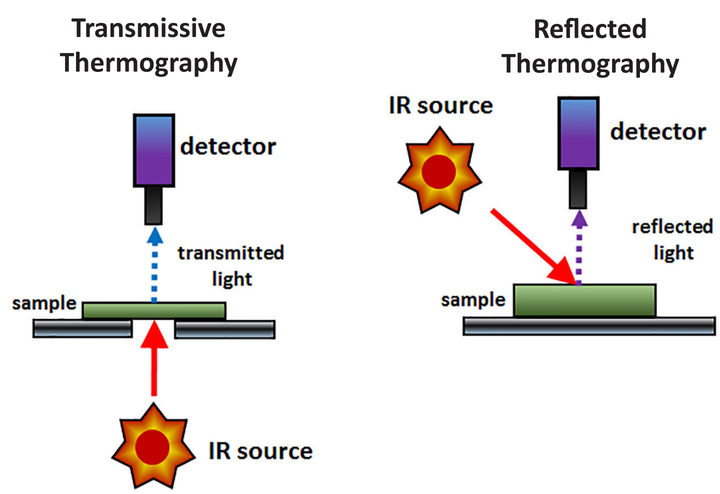

FIGURE 2. The two methods of positioning the camera and external heat source for Active Thermography.

[6] Elisabetta Rosina and Elwin C. Robison, "Applying Infrared Thermography," 38.

Calibrating Thermal Images

When imaging a surface, however, the camera senses radiation from multiple sources-- not just the surface in question. Radiation from the object itself depends on the temperature of the object as a function of its emissivity. The surroundings also reflect radiation onto the surface in question. Both the radiation from the object and the reflected radiation are influenced by absorption of the atmosphere. In all, to measure the surface temperature accurately, it is necessary to compensate for these multiple radiation sources. More recent infrared cameras give the user the option to calibrate these values and the camera software adjusts the image.

Emissivity (ε) is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody of the same temperature. Normally surfaces exhibit emissivity between 0.1 and 0.95. A highly polished mirror falls below 0.1, whereas an oxidized or painted surface, regardless of color, has an emissivity over 0.9. For non-metals, emissivity tends to be high, and decreases with temperature.

Reflected temperature is any thermal radiation reflected off the target surface which originates from other objects; this is conveyed in degrees much like the ambient temperature. For objects with lower emissivity, the infrared radiation detected by the camera is coming from the surrounding environment. By calculating and inputting the reflected temperature into the camera's object parameters, the camera software calibrates the thermal image to show the temperature of that object's surface (rather than the ambient temperature).

Material	_Standard Emissivity Value_
Brick, common red	0.93
Clay, fired	0.91
Copper, polished	0.05
Copper, oxidized	0.65
Hardwood, across grain	0.82
Hardwood, along grain	0.68-0.73
Limestone	0.96
Mortar, dry	0.94
Plaster	0.86-0.90

TABLE 1: Emissivity values for some common building materials. (source: https://www.thermoworks.com/emissivity-table)

FIELD EQUIPMENT LIST

This section discusses the equipment necessary to carry out infrared thermography (IRT) for adobe structures with a focus on applications in backcountry settings with no power infrastructure and low accessibility. The following sections contain: a table which lists the tools required, and whether they require a power source (Table 2); descriptions of these tools and some recommendations for selecting particular models; and a table with anticipated prices as well as links to specific products (Table 3).

TOOL	*POWER SOURCE NEEDED (YES/NO)*
Infrared Camera	Yes, battery life is about 2 hours
Tripod	No
Temperature/RH Monitoring Unit	No
Heating Apparatus	Yes
Portable Photo-voltaic Lamp	No

TABLE 2: List of tools for field IRT, and whether these tools individually require an external power source.

<u>Infrared Camera</u>
For IRT applications on historic structures, a thermal camera should have relatively high resolution, be highly portable, and have time lapse image capture functions to use the recommended methodology (see the Field Methodology section). The time lapse feature tends to be an option in only the pricier cameras; this can be offset by renting a camera or purchasing a refurbished camera.

A FLIR E-95 camera meets these requirements. The FLIR E95 is a pistol-grip hand-held camera with time lapse, video, and single image capture functions. The camera has a 4” touch-screen display shows a graphic interface has a folder and naming structure which makes it easy to find and organize images. The camera includes a laser which can provide distance measurements and auto focuses images. The thermal images can be opened and viewed without proprietary software but require the accompanying FLIR Tools software to edit thermal images.

<u>Tripod</u>
A tripod is needed to hold the IR camera in place while collecting time lapse imagery; this allows for the camera to maintain the same field of view, which makes the images easier to compare. A collapsible, lightweight tripod is ideal for its portability. The height of the tripod depends on the resource, but a 4’ tripod should be suitable for most applications; for taller resources (such as a multistory structure) a taller tripod or standing ladder could be employed. Sandbags or other weights may be needed to secure the tripod legs in moderate winds.

<u>Temperature/RH Monitoring Units</u>
Capturing ambient weather conditions (temperature and relative humidity, or RH) during image capturing is needed to calibrate the thermal images. HOBO Temperature/RH Data Logger (MX2300) is an ideal data logger with built-in temperature and relative humidity sensors. Recording periods and intervals can be setup via Bluetooth connection to a mobile device (iOS, Windows) or Windows computer using HOBOConnect, a free application. The Bluetooth connection enables faster programming and can control several units within a 100 foot range. The HOBO Loggers can be set to record at specific times and intervals. Files with the recorded data may be accessed within the application. The data can be viewed in the application interface and downloaded; live data can also be viewed as its recorded. The MX2300 Temp/RH Logger will record ambient temperature and relative humidity with an accuracy of ±0.2˚C and ±2.5% RH.

Heating apparatus

An ideal heat source projects heat evenly across the subject surface, heats to moderate temperatures (<300˚F) to avoid damaging or burning historic materials and are easy to transport for flexibility in use. Heating pads, lamps, and lights can all be used to this end, but the attributes of the heat source chosen should reflect the needs of the investigation.

To ensure that the thermal images acquired during active thermography represent the anomalies as accurately as possible, it is crucial that the heating apparatus must evenly disperse and provide enough energy to cause a distinguishable heat flux among the concealed materials. Heaters which project heat, such as halogen, IR and quartz lamps, are useful in that they can provide the necessary quantities of energy, but they cannot evenly disperse heat flux across the area of study. Heat sources which apply energy directly to the surface (silicone rubber heaters, electric blankets, warming pads) have some advantages over heat lamps. Surface-applied heat sources are typically better at evenly applying heat, offer greater control at directing heat to a particular area, and diminish the effect of some environmental factors. However, utilizing applied heat sources limits the method of thermography to transmissive methods only, as it is impossible to both heat the surface and not obstruct the camera's field of view in a reflected mode.

For a smaller area of investigation, a small infrared heater is suitable. An infrared paint remover like the Speedheater™ Cobra can heat surfaces up to 400-600˚F using a concentrated heating element. This model is ideal for two characteristics which increase the lamp's flexibilityin use: 1) this model has an adjustable head to focus the heat and 2) the model's long handle provides an optimal surface for securing the heater to a tripod for long periods of time. This flexibility is critical when study areas can be difficult to reach, or decisions are made to investigate an area with little pre-planning. Additionally, the Speedheater is ideal because it does not have an automatic heat trip, which ensures that the lamp will continue to throw heat so long as it has power and thus can be left alone if needed.

The Cobra requires a power source; for the field application and laboratory testing, a standard household 15 amps/120 V outlet was used. The Cobra was useful for its ability to throw consistent, even heat across a small area (< 3 sq ft), thus adequate for a small feature or small area of concern. In areas where a power source is not available, a gasoline-powered generator or portable solar power generator will be needed.

For larger study areas heated blankets are typically recommended, but these can create false hotspots imparted by heating coils within the blanket. Utilizing generators or other heat sources for a larger study area will likely require access to greater power sources or general site accessibility to transport tools.

Photo-voltaic (PV) panel, USB-C cord, external storage (optional)

In future field projects, researchers should test the use of a portable photo-voltaic (solar panel) with external power storage. In backcountry applications where standard power sources are not available, the most serious need is a power source for the IR camera. If active thermography is to be employed, then a power source may be needed depending on the heat source used. Portable solar panels and external power storage are capable of powering small to medium tools and appliances. For example, Goal Zero makes light weight solar panels for outdoor recreation, and there are several models to meet the volts and amps required to charge camera. Ensure that the selected panels and external battery will be sufficient to power the camera through the night for passive thermography, or power the camera and heater simultaneously during active thermography.

Thermocouples, Data Aquisition Unit for Thermocouples

Thermocouples are useful for determining surface temperature when applying heat to a surface in active IRT. These are a useful for establishing test parameters but not critical to completing IRT; see Appendix B.

TOOL	*COST PER UNIT*	*LINK*
Infrared Camera	$7,000 to $12,000	Used or refurbished units of recently discontinued models are in the low part of the listed price range and will have the same capabilities as a newer camera; just ensure that it has time lapse capabilities. Renting a camera can also help to cut costs, and is an ideal option where a camera will only be used once for diagnostics.
Tripod	$20 to $50	Look for a collapsible, light weight tripod which is designed for portability.
Temperature/RH Monitoring Units	$170	https://www.onsetcomp.com/products/data-loggers/mx2301a/
Heating Apparatus (IR Lamp)	$500	https://eco-strip.com/product/speedheater-cobra/?gclid=C-jwKCAjw-e2EBhAhEiwAJI5jg9gqm9crIF8rnhbmXkf6Puo_LkQWms_Xzxj7QpJqEDWufEnZsrGRERoCxNgQAvD_BwE
Photo-voltaic Panel	About $150	https://www.rei.com/product/180607/goal-zero-nomad-20-solar-panel
Additional Tools (not essential, but helpful)		
Programmable Cycle Outlets	$16	https://www.amazon.com/gp/product/B01G6O28NA/ref=p-px_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1
Thermocouples	$28-$140	https://www.omega.com/en-us/temperature-measurement/temperature-surface-sensors/sa3/p/SA3-T-SRTC
Thermocouple Logger	$275	https://www.onsetcomp.com/products/data-loggers/ux120-014m/

TABLE 3: Tool list, prices, and links to these products or comments about selecting models.

FIELD METHODOLOGY

Pretesting Guidance

i. Environmental Conditions

In field settings, it is difficult to regulate the environmental conditions (such as temperature, air flow, and relative humidity) to precondition the study surface area before conducting IRT. This would be possible for laboratory testing, where the ambient temperature, humidity, exposure to sunlight, and wind speed can be regulated to some extent and kept at a constant throughout testing. For field testing, the best this can be managed is to watch environmental conditions in the days preceding testing to ensure relatively constant or consistent conditions. If possible, install environmental monitors to monitor temperature and relative humidity at the site.

To ensure accurate data, it is crucial to set and adhere to consistent environmental parameters for testing. Variables which can affect the results of thermographic investigation (whether passive or active) in a field setting include atmospheric temperature, thermal bodies (the presence of people or other energy emitting bodies), solar radiation, and air speed. Optimal testing conditions reduce the potential of these variables to skew or obscure temperature readings but also take into consideration that field environmental conditions can be highly variable, particularly for longer testing period (<24 hours). An operable field methodology acknowledges the inherent variability and takes steps to reduce this where possible.

Temperature: The sensors on the camera make it better at detecting temperatures within a specified thermal range. Cameras are typically most accurate when material temperatures are above 40˚ F; below freezing (3˚ F/0 C), there is a greater chance of ice crystallization, which can result in false readings.

Thermal Bodies: Testing participants and observers should be kept to a minimum and at a constant number to avoid fluctuations in temperature due to thermal bodies. Though likely rare in earthen structures, services such as HVAC should be turned off during the passive thermography testing period but may be used to aid in active thermography if applicable.

Solar radiation: Solar radiation matters for both active and passive IRT investigations, and the numerous factors which influence how a structure receives solar radiation can greatly impact the results of investigations. These factors include latitude, orientation of the structure, season, time of day, weather, and surroundings (whether the structure is in an urban setting with adjacent tall buildings, or in an open field).

Winds: Convective effects from wind can cause variations in ambient air temperatures, which can alter the thermal images. This is critical to consider for field applications. Testing methodologies should strive to reduce these variables as much as possible. The degree to which control measures should be taken differ from resource to resource. Air flow around a free-standing wall (as condition would be for a ruined wall) will be different than for a complete structural system with an enclosed, semi-controlled environment.

ii. Environmental Monitoring

Throughout each IRT testing session, keep the environmental monitors recording the temperature and relative humidity to ensure that the conditions during testing remain within the parameters set. Tracking conditions during testing also helps later to determine optimal conditions with which to view particular anomalies and may be used to optimize future investigations.

iii. Guidance for Calibrating Images

As previously mentioned, inputting the reflected temperature and emissivity values are important to calibrating thermal images. In the appendix, there is a field methodology for calculating the emissivity and reflected temperature using the materials on site. However, for the ease of the user, there are ways to approximate these values which will simplify the calibration process and provide enough calibration for qualitative purposes.

1. Use a standard value for emissivity value, if one can be found. There are published tables which have standard values for a variety of standard building materials and surface treatments, and the difference between the standard value and actual value are likely insignificant when processing thermal images.
2. Use the ambient temperature value for the reflected temperature. Generally, for materials with emissivity values greater than 0.5, the ambient temperature may be used. Most earthen materials, and most traditional building materials for that matter, have high emissivity values.

For the duration of testing, the emissivity value should remain constant so long as there is one subject material being tested. This should be set in the parameters before testing, so that the several images (between tens and hundreds) produced during the testing period are already calibrated. However, because the reflected temperature value will vary based because it is related to the ambient conditions, which are likely to shift over the course of the testing period which can last up to 24 hours. This should be edited after testing has been completed in the desktop editing software utilizing the ambient conditions data.

Field Methodologies for IRT

Below are field methodologies for Passive IRT, Active Transmissive IRT, and Active Reflected IRT. These recommended methodologies consist of the crucial steps needed to complete IRT, but some specifics such as recommended ambient conditions, duration of heating for active thermography, and frequency of image capture are flexible and ultimately depend on the case.

Passive IRT Field Methodology	
Procedure	*Description*
Testing Conditions for Passive Thermography.	Tests should be conducted where the temperatures are greater than 32˚F, wind speeds are less than 15 mph. Relative humidity should be less than 50%. Monitor temperature and relative humidity for the days leading up to thermal imaging, if possible.
Set up the camera to optimize a wide surface area for initial passive testing.	Depending on the camera's field of view, select as large a section of the wall as possible while retaining focus. Set the camera on a tripod at this distance with the camera perpendicular to the wall. The camera should be raised to a height about midway between the floor and the ceiling, if possible.
Set environmental monitors to begin recording.	Set monitors to record values every minute to coincide with thermal image capture.
Set up control functions for the IR camera to capture images.	IR camera should be set up to take images every minute for 24 hours. Set the emissivity value before beginning testing.
Begin testing.	Initiate time lapse image recording.
Turn off camera after 24 hours.	

NOTE: Where power sources are inaccessible, the ability to recharge batteries becomes an impediment to running time lapse image capture for more than a few hours. Consider strategizing testing periods to occur around radiation fluxes such as when sunlight first hits the elevation and when the elevation passes into shadow. For example, set up the camera and begin capturing imagery the hour before the sun rises and then leave to capture imagery for four hours. One lithium battery lasts at least 2 hours when the camera is set to record time lapse images; make sure to change out the batteries midway through testing.

Active Transmissive IRT Field Methodology	
Procedure	*Description*
Testing Conditions for Active Transmissive Thermography.	Tests should be conducted where the temperatures are greater than 32˚F and wind speeds are less than 15 mph. Solar radiation should be at a minimum, which makes early morning an ideal testing time for south, east and west facing exterior elevations. Relative humidity should be less than 50%. At the initiation of testing, the temperature and ambient conditions should be relatively similar on the interior and exterior of the structure. Opening windows and doors and turning off HVAC units will help to equalize the ambient conditions, if applicable to the site.
Place heaters on the surface opposite the IR camera.	Place the heater and the camera on opposite sides of the feature. Measure off features (openings, wall junctures, floor, etc.) to ensure that the camera and heater are roughly in line with one another. Remember, test the heater beforehand and monitor the surface temperature to ensure that temperatures do not exceed 300˚F; extreme temperatures can damage historic finishes and materials. Surface temperature can be monitored with thermocouples, or tested in an inconspicuous area.
Set up control functions for all the tools (IR camera, data acquisition units, heating apparatus, environmental monitors) to capture images and data.	Set IR camera to capture 1 image every 30 seconds for 2 hours (120 minutes). Set the environmental monitoring unites to acquire data at the same interval, every 30 seconds. Set heat apparatus to begin heating at 00:00 and end heating at 1:00, or one hour into the testing period. Programmable outlets are useful to start the heater at a designated time.
Begin testing. All equipment should be started simultaneously.	The IR camera may need to be manually started. Environmental monitors are programmed to start remotely.
Turn off test at end of 120 minutes (2 hours).	Allow area to equilibrate back to ambient conditions for 24 hours before conducting further testing in the same area.

NOTE for Transmissive Active Thermography: Adobe walls tend to be very thick (12” to 10’, in some extreme cases) and have generally low thermal conductivity. Due to these characteristics, transmissive thermography will require significant amounts of energy over a long period of time, which means that achieving results may be difficult. For sites which are located in colder climates, cool ambient conditions can be used to encourage heat transfer through the wall.

Active Reflected IRT Field Methodology	
Procedure	*Description*
Testing Conditions for Active Reflected Thermography.	Tests should be conducted where the temperatures are greater than 32˚F and wind speeds are less than 15 mph. Solar radiation should be at a minimum, which makes early morning an ideal testing time for south, east and west facing exterior elevations. Relative humidity should be less than 50%. At the initiation of testing, the temperature and ambient conditions should be relatively similar on the interior and exterior of the structure. Opening windows and doors and turning off HVAC units will help to equalize the ambient conditions, if applicable to the site.
Place heaters on the exterior of the wall assembly where they won't obstruct the camera's field of vision.	To ensure good image resolution, the IR camera should be placed so that it is perpendicular to the wall surface. Heating sources should be placed so that the heat hits the surface perpendicularly and evenly. It is difficult to achieve both without obscuring the camera's field of vision, but position these elements should be as close to ideal as is realistic. Remember, test the heater beforehand and monitor the surface temperature to ensure that temperatures do not exceed 300˚F; extreme temperatures can damage historic finishes and materials. Surface temperature can be monitored with thermocouples, or tested in an inconspicuous area.
Set up control functions for all the tools (IR camera, data acquisition units, heating apparatus, environmental monitors) to capture images and data.	Set IR camera to capture 1 image every 30 seconds for 2 hours (120 minutes). Set the environmental monitoring unites to acquire data at the same interval, every 30 seconds. Set heat apparatus to begin heating at 00:00 and end heating at 1:00, or one hour into the testing period. Programmable outlets are useful to start the heater at a designated time.
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Turn off test at end of 120 minutes (2 hours).	Allow area to equilibrate back to ambient conditions for 24 hours before conducting further testing in the same area.

RECOMMENDATIONS FOR THERMAL IMAGE PROCESSING

Many of the suggestions listed below do no use quantitative methods to determine patterns or information from the thermal image. Instead, these tips focus on the ways that a thermal image can be manipulated using visual attributes to highlight thermal anomalies, particularly when the temperature variability across a single surface like earth or plaster is small. Temperature differences with a ΔT value of > 4˚F should be investigated further. This value is based on observations during the case study accompanying this guide. Generally, this value is typically higher (>9 ˚F) when investigating other types of materials, but the low thermal conductivity of plaster lowers this value. It is critical to use this threshold wisely, however, so as not to misconstrue minute changes in temperature as a signal of serious deterioration or other problems; as a reminder, anomalies which are detected in the thermal image should be confirmed in the field before planning preservation interventions.

Below are a few tips to image processing which can help to highlight thermal anomalies utilizing desktop thermal image processing software:

Adjust the minimum and maximum temperatures: When a thermal image is taken, often times the image will use the extreme temperatures detected to set the temperature scale of the photo. The problem with this is that when using these factory settings, the extremes used can be too divergent and therefore diminish the thermal variability present in the photo. In situations where a remote or rural earthen structure is being investigated, and there are no services or extraneous thermal bodies, the high temperature in the image may be as high as 100 ˚F which may be a realistic surface temperature for an adobe surface in some parts of the American Southwest. However, if there is window glass or parts of the sky in the camera's field of view, that image's minimum temperature could be sub-zero—even during the middle of the day. This wide range in represented temperatures (-20 ˚F to 100 ˚F will diminish the visible contrast of the temperature variability across a plastered surface, where the ΔT value might only reach as high as 4-10˚F. The desktop thermal imaging software allows for the user to set a new temperature range. One can easily adjust these values manually to bring more contrast to the surface in question. Additionally, FLIRTools has a tool called "Set Auto Adjust Region," which allows the user to select an area and the software will adjust the min/max temperature range of the image based on the min/max temperature detected within the area selected.

Adjust the color palettes: The colors used to represent the range of temperatures can be used to highlight patterns and clarify temperature anomalies. Thermal cameras and image editing software have several options to this end, ranging from black/gray/white to multicolor. A color palette with more variation in hues can better highlight the variation in surface temperature across areas, particularly those with a smaller range of temperature variation such as the plaster in this case study.

Use Line/Box/Ellipse Measurement Tools to observe high and low temperatures: The measurement tools may be used to select an area and denote the pixels along that line (or within that area) which represent the highest and lowest temperature; the pixels will be identified with symbology, and the values listed in the sidebar. During image processing, this was used to better understand the actual variation in values across the surface of the plaster; altering the color ramp and min/max temperature can increase the visual variation across a surface in question, but it is wise to be aware of the temperature range in order to establish typical (and abnormal) ranges of temperatures.

Use Spot Measurement Tool: The Spot Measurement tool allows the user to select a pixel on a thermal image and read the temperature value. This tool could be used in an area with both voids and known attachment of the plaster to the adobe. Spot measurements can be used to compare the temperatures associated with those conditions and help to interpret temperature variation.

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Spodek, Jonathan and Elisabetta Rosina. "Application of Infrared Thermography to Historic Building Investigation." *Journal of Architectural Conservation* vol. 15, no. 3 (2009): 65-81. https:// DOI:10.1080/13556207.2009.10785040.

<ins>Helpful IR Manuals:</ins>

Basic Principles of Non-Contact Temperature Measurement. Berlin: Optris Infrared Thermometers. Accessed January 15, 2021. https://www.optris.global/basic-principles-of-non-contact-temperature-measurement?file=tl_files/pdf/Downloads/Zubehoer/IR%20Basics.pdf

Thermography Pocket Guide. Titisee-Neustadt: Testo, 2017. Accessed January 17, 2021. https://static-int.testo.com/media/1d/b7/21fc65abbea1/Pocket-Guide-Thermography-EN.pdf

APPENDIX A

IRT Case Study: Smugglers Adobe, Channel Islands National Park, CA

i. Resource Description

The Smugglers Adobe Ranch House was built in the late nineteenth century to support sheep ranching and farming on Santa Cruz Island off the coast of Southern California (Figure 3-4). The house, which is colloquially called Smugglers Adobe, is built of local stone and adobe with thick walls (15-20”) on a stone foundation. The structure measures 21 by 40 feet and is two-stories. The exterior of the structure is stuccoed with lime plaster and lime washed, and the builders incised a sundial in the stucco above the central doorway (Figure 5). In 2011, the National Park Service completed a rehabilitation project, which included restoring exterior finishes and installing a concrete bond beam for seismic safety compliance. In 2018, the structure suffered minor damage due to a nearby earthquake, and this damage has not been subsequently repaired.

ii. Conditions Assessment

The exterior envelope at the Smugglers Adobe exhibits conditions which indicate the present of hidden voids underneath plaster surface. Each exterior elevation is stuccoed with a coarse plaster coat—comprising of historic and repair materials-- and finished with a skim plaster coat to protect the historic plasters and for aesthetic unity.

Based on a conditions assessment completed in 2020, the deterioration conditions present on the structure’s exterior consist of:

- Detachment of exterior coarse plaster from the underlying adobe and/or stone masonry.
- Detachment of the exterior skim coat (from the 2011 rehabilitation campaign) from the underlying coarse plaster.
- Cracking of the plaster system (both superficial cracking of the skim coat and cracks through the plaster).
- Loss of the exterior skim coat.
- Basal damage due to moisture on the west elevation (See Table 4 for conditions definitions and the following conditions drawings on pages 20-22).

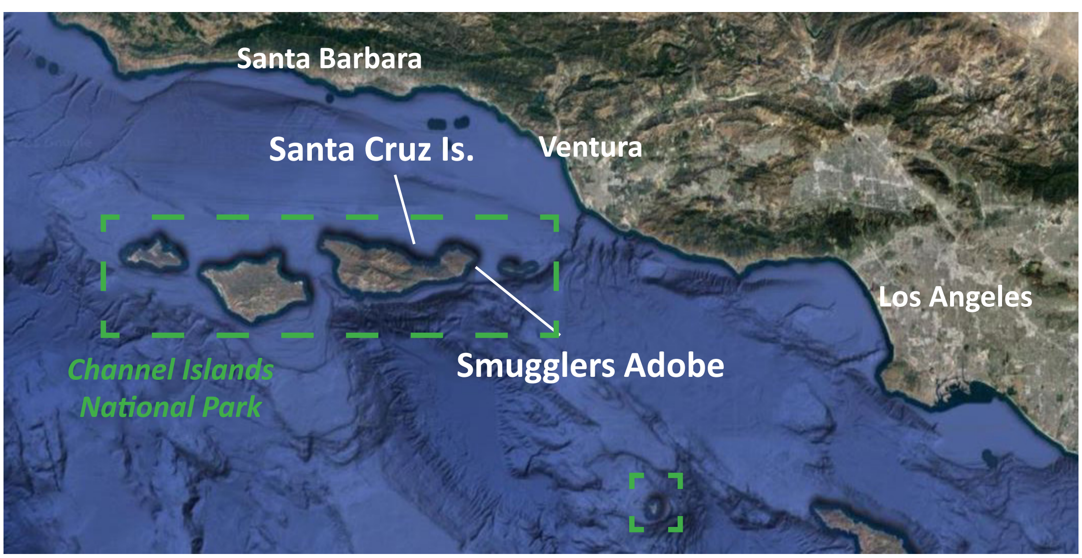


FIGURE 3. Map indicating the approximate location of Smugglers Adobe and Santa Cruz Island.

FIGURE 4. South elevation and principle façade of the Smugglers Adobe.

FIGURE 5. Above the principle doorway, the builders incised a sundial in the plaster. Based on historic photos, this detail is assumed to be original to the structure.

TABLE 4: Observed conditions, conditions definitions, and photo examples.

Condition and Description	Photo Example
Detachment of Exterior Plaster from Adobe/Stone Masonry *Debonding or detachment of the coarse coat (not historic) from the masonry. At present, this condition is a "blind condition," or not visible to the naked eye.*	
Detachment of Skim Coat from Coarse Plaster *Debonding or detachment of the skim coat (not historic) from the underlying plaster. This condition either coincides with some cracking or a blind condition (not visible)*	

Cracking _Discontinuities in historic plaster, non-historic coarse plaster coat or skim coat rendering (also not historic). Cracks are the result of movement during the 2018 seismic event, although some cracks may have been previously existant and repaired during the 2011 rehabilitation project._	
Loss of Skim Coat _Loss of the exterior skim coat rendering (not historic); largely the result of movement during the 2018 seismic event._	
Basal Damage due to Moisture Infiltration _Moisture rises up through the base of the wall due to capillary action. Evaporation of the moisture causes the materials to disintegrate._	

TITLE OF SHEET:
CONDITIONS DRAWINGS
South Elevation

STRUCTURE:
SMUGGLERS ADOBE
LOCATION:
EASTERN SANTA CRUZ ISLAND (ESCI)
PARK UNIT:
CHANNEL ISLANDS NATIONAL PARK

VENTURA, CALIFORNIA
PACIFIC WEST REGION

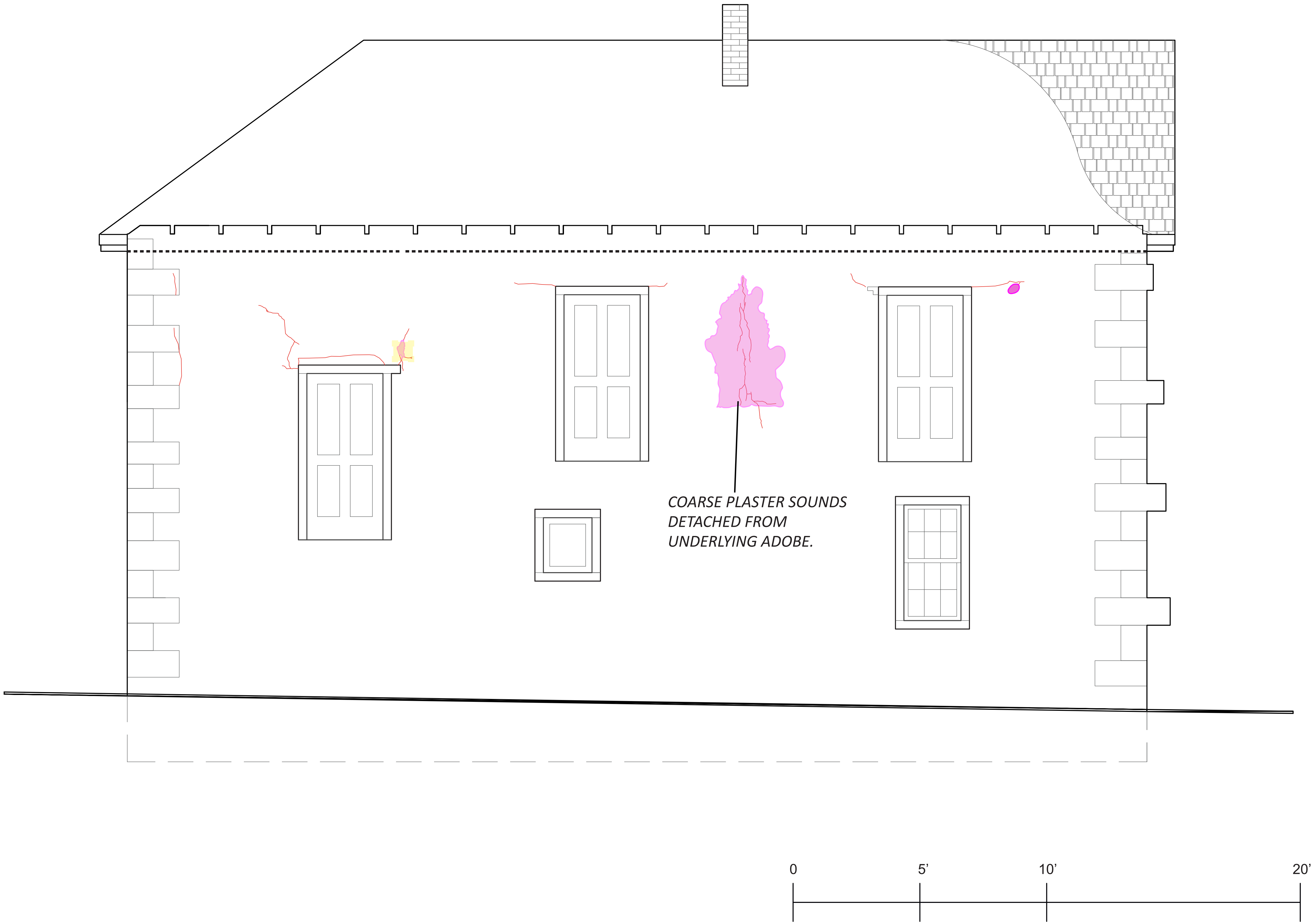
AUTHOR:
S. STRATTE
DATE:
MAY 2021

SCALE: 1/4" = 1'-0"

KEY:

- SKIM COAT LOSS
- CRACK
- MOISTURE DAMAGE
- DETACHMENT

CONDITIONS DENOTED IN THESE DRAWINGS ARE BASED ON VISUAL SURVEY ONLY.



TITLE OF SHEET:
CONDITIONS DRAWINGS
North Elevation

STRUCTURE:
SMUGGLERS ADOBE
LOCATION:
EASTERN SANTA CRUZ ISLAND (ESCI)
PARK UNIT:
CHANNEL ISLANDS NATIONAL PARK

VENTURA, CALIFORNIA
PACIFIC WEST REGION

AUTHOR:
S. STRATTE
DATE:
MAY 2021

SCALE: 1/4" = 1'-0"

KEY:

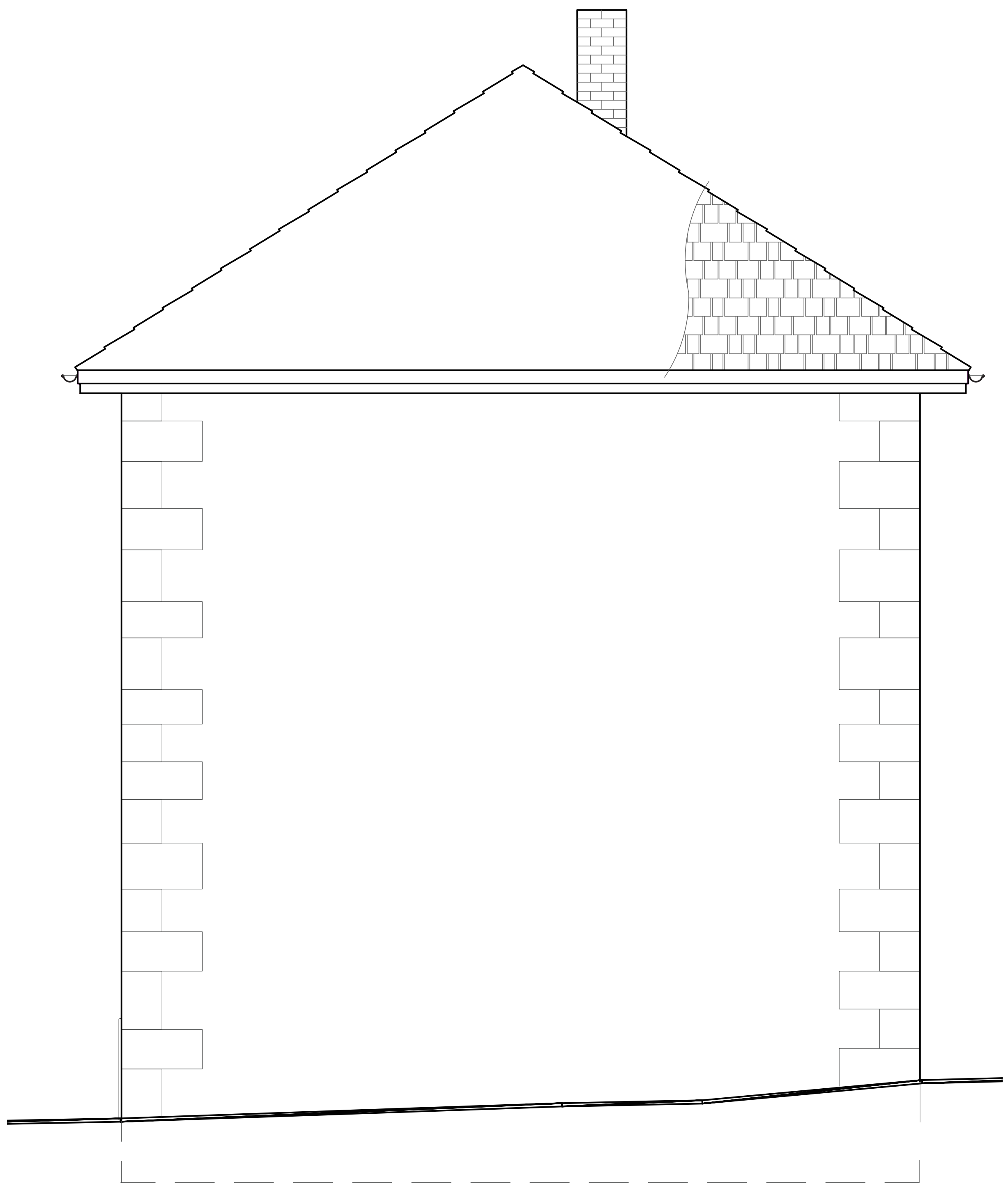
SKIM COAT LOSS

CRACK

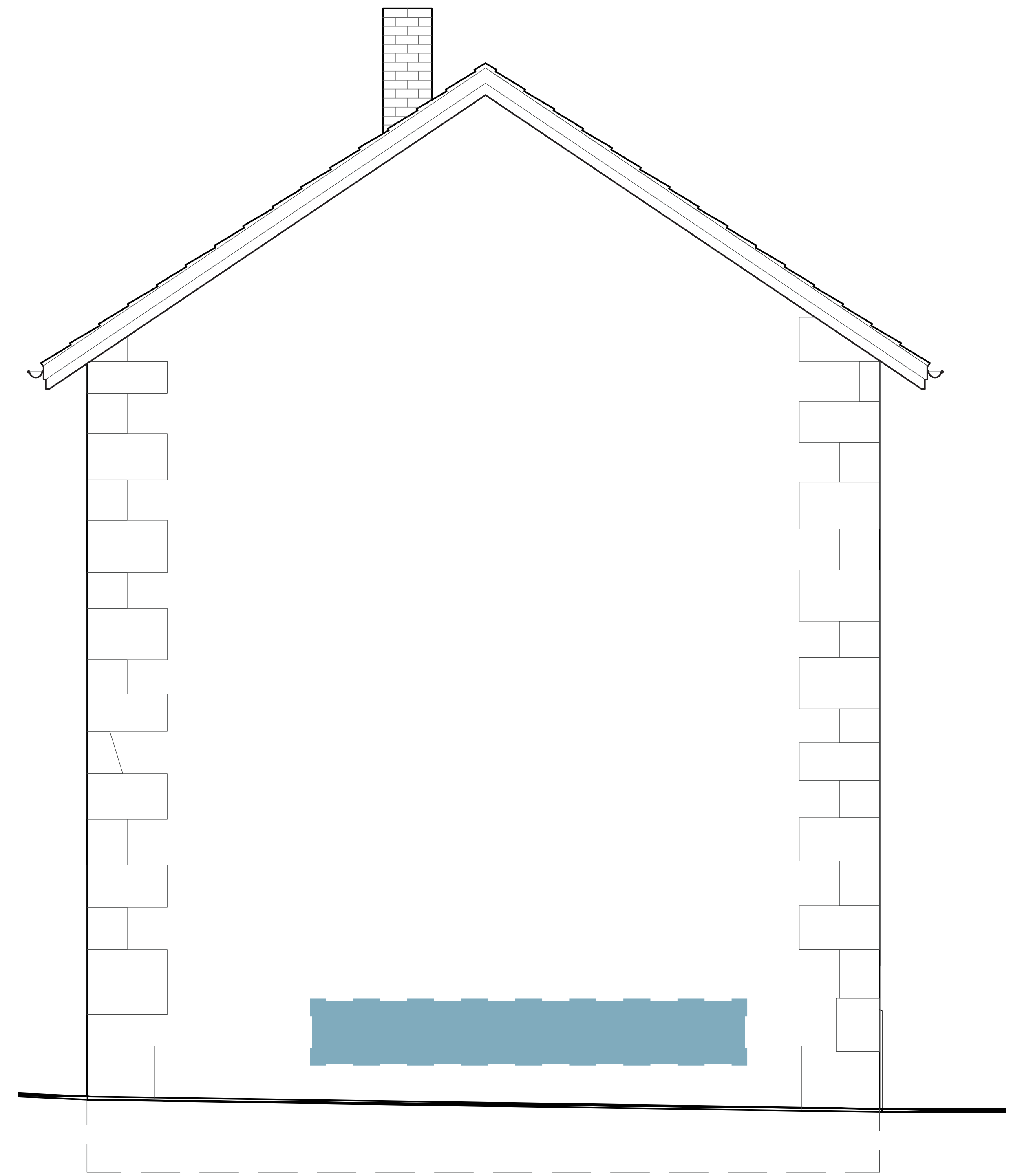
MOISTURE DAMAGE

DETACHMENT

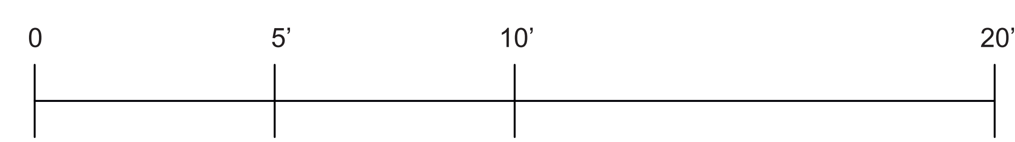
CONDITIONS DENOTED IN THESE DRAWINGS ARE BASED ON VISUAL SURVEY ONLY.



EAST ELEVATION



WEST ELEVATION



TITLE OF SHEET:
CONDITIONS DRAWINGS
East and West Elevations

STRUCTURE:
SMUGGLERS ADOBE
LOCATION:
EASTERN SANTA CRUZ ISLAND (ESCI)
PARK UNIT:
CHANNEL ISLANDS NATIONAL PARK

VENTURA, CALIFORNIA
PACIFIC WEST REGION

AUTHOR:
S. STRATTE
DATE:
MAY 2021

SCALE: 1/4" = 1'-0"

KEY:

SKIM COAT LOSS

CRACK

MOISTURE DAMAGE

DETACHMENT

CONDITIONS DENOTED IN THESE DRAWINGS ARE BASED ON VISUAL SURVEY ONLY.

iii. Results from IRT Investigations on Case Study

A. Heterogeneous materials: Detecting stone and adobe masonry

During the 2011 rehabilitation, preservation construction crews mapped the extents of stone and adobe masonry for each of exterior elevations. The first story on the south elevation of the Smuggler's Adobe was constructed with limestone masonry, the second with adobe. The extents of these materials is evident in thermal images taken before sunrise using passive thermography (A1-2). After the plaster and masonry cooled through the night, the two sections of the elevation have differing temperatures. This example shows that the diffusion of heat through the differing materials can be detected, even as it transfers through the plaster.

Image **A1** is from shortly after sunrise, although images from preceding hour registers this contrast and the temperature difference remains roughly the same (about 0.5˚F). Contrastingly, similar imagery was taken at the end of the day using the passive method, after the surface had received sunlight for roughly 12 hours (**A2**). The thermal images show that heat is evenly been distributed across the surface of the plaster, the distinctions between the two material substrates is less apparent.

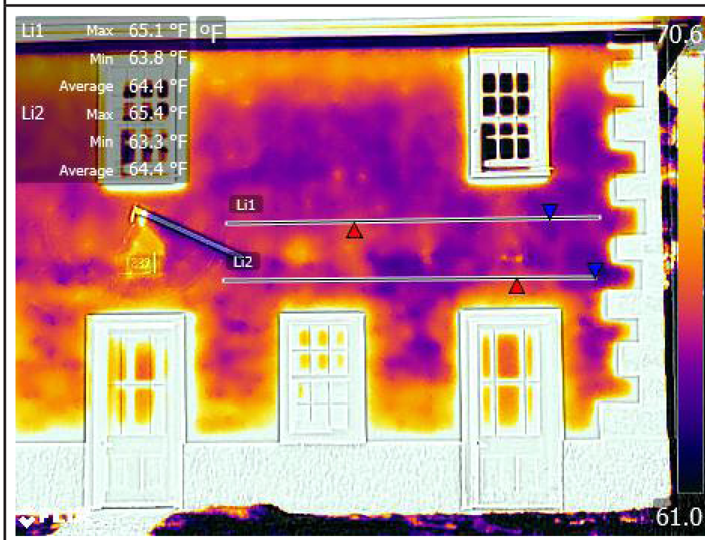
This example and its counterpart demonstrate the usefulness of completing a general time lapse series to help identify times of day and conditions which are suited for capturing the condition or feature in question. While the same materials (and deterioration conditions) are present, the ambient conditions can significantly alter the thermal images.

Testing Conditions:	
Testing Methodology	Passive Thermography, Sunrise (Test period was 5:45 am to 7:45am, sunrise at 6:44 am)
Ambient Conditions	Exterior: 55˚F to 65˚F , 60-74% RH Interior: 61˚F to 70˚F , 49-56% RH
Surface Temperature Variation	ΔT= 0.5 ˚F

Detecting Heterogeneous Materials: Thermal Imaging Results

(A1)
6:56 am

Line 1 (Ln1) shows the temperature extremes along the line drawn over the adobe portions of the elevation. The average temperature along this line is 51.7˚F, as compared to the average 52.5˚F along Line 2 (Ln2) on the stone masonry.



(A2)
4:36 pm

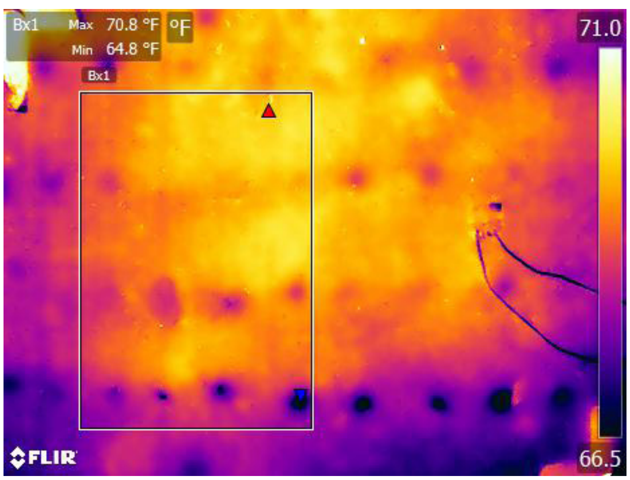
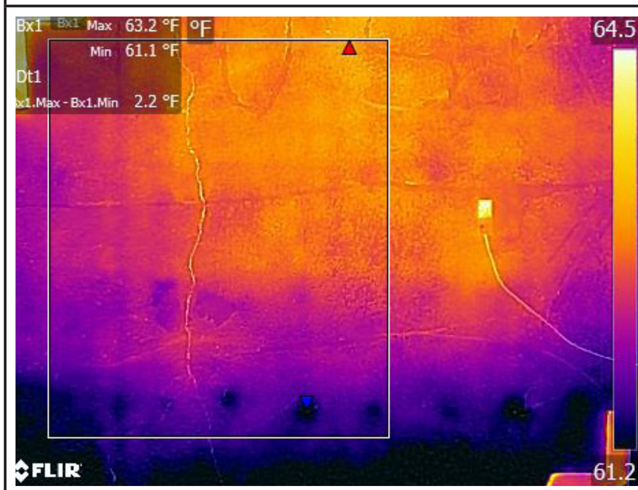
The contrast between the stone and adobe masonry is not as evident in thermal imaging taken at the end of the day; the average temperature along Ln1 and Ln2 are equal.

B. Heterogeneous materials: Detecting embedded nails in plaster

While testing the use of reflected active thermography to detect voids, regular anomalies were observed in an area of plaster over adobe masonry. Based on literature from the 2011 rehabilitation project, nails were found at regular intervals in the adobe masonry. Perhaps these nails were used to key the lime plaster to the building surface, but the exact purpose is unknown.

Due to their differing conductivity values, the metal was evident to some extent through the plaster under ambient conditions (**B2**). By applying heat, the full extents of the nails were evident at the outset of the testing period (**B1**). It may be possible to get images like this just by using sunlight/passive warmth on an elevation which receives sufficient solar radiation as a means to determine areas of original plaster on the Smugglers Adobe, although the addition of some heat flux was necessary to see the full extents.

Testing Conditions:	
Testing Methodology	Active Thermography, reflected heat (30 second intervals, 1 hour testing period).
Ambient Conditions	Exterior: 58˚F to 62˚F , 44-58% RH
Surface Temperatures	Exterior (heated surface): 100.77˚F Interior: 59.2˚F
Surface Temperature Variation	ΔT= 5-10 ˚F

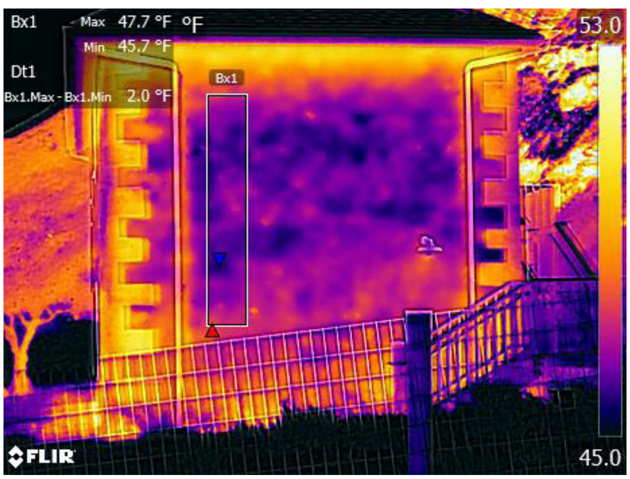
Detecting Heterogeneous Materials: Thermal Imaging Results	
	**(B1)** 11 minutes after the initiation of heat. The box measurement tools shows that the plaster is nearly 6˚F warmer than some of the plaster areas over nail heads. Box Measurement Max: 70.8˚F Min: 64.8˚F
	**(B2)** 4 minutes prior to the initiation of heat. Under ambient conditions, some of the embedded nails are evident in thermal images but the application of heat to the surface improves the temperature contrast and shows the full extents of the nails within the plaster. Box Measurement Max: 63.2˚F Min: 61.1˚F Difference (Bx1Max-Bx1Min): 2.2˚F

C. Voids

Heat moves differently through areas in which the plaster is attached to the stone or adobe substrate than areas in which there is a void between the two materials; this means that resultant surface temperature in these cases should differ from each other under the right environmental conditions. On the east elevation of the Smugglers Adobe, thermal images captured using passive thermography revealed a consistently warmer area at the south side of the elevation, reaching ~5 feet above grade (**C1-2**). After IR imagery, this area was investigated using tap-testing to determine whether the plaster was debonded or soundly fixed to the underlying stone masonry. By contrast to the other elevations, the plaster on the east elevation is almost entirely historic and was only painted in the 2011 rehabilitation campaign rather than coated with a render. Thus, we can say with confidence that this void exists at the interface between the stone masonry and historic plaster, at a depth greater tahn 1” from the plaster surface.

Testing Conditions:	
Testing Methodology	Passive Thermography, Sunrise (Test period was 5:45 am to 7:45am, sunrise at 6:48 am; direct sunlight was delayed by fog layer)
Ambient Conditions	Exterior: 48˚F to 60˚F , 70-90% RH Interior: 58˚F to 63˚F , 52-56% RH
Surface Temperature Variation	ΔT= >3 ˚F

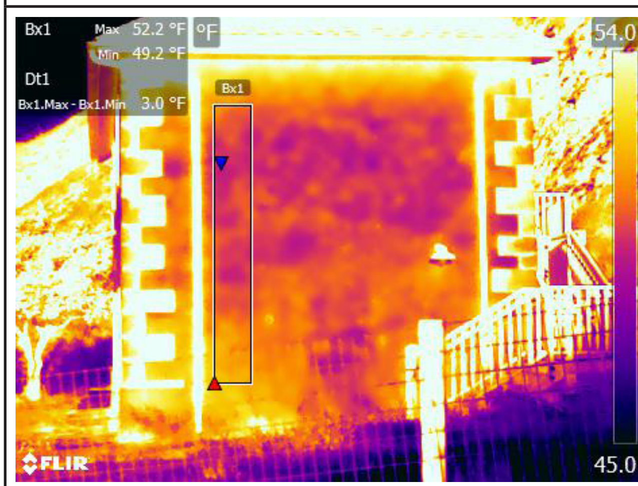
Detecting Voids: Thermal Imaging Results



(C1)
7:18 am (before sunlight)

Temperature variance on the south side of the elevation is 3.0˚F preceding sunlight.

Box Measurement
Max: 47.7˚F
Min: 45.7˚F
Difference (Bx1Max-Bx1Min): 3.0˚F



(C2)
7:32 am (after sunlight)

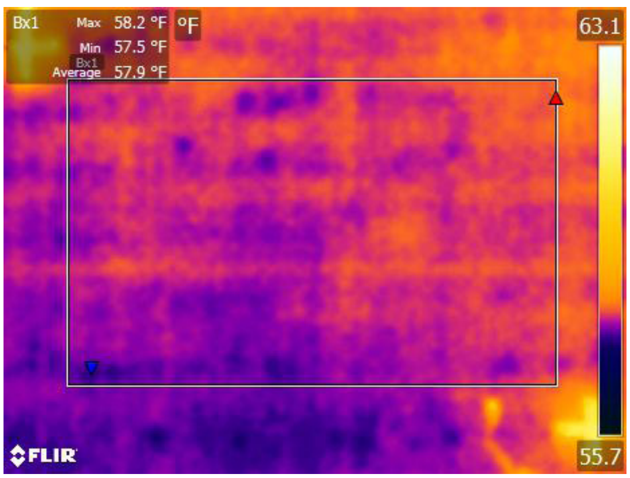
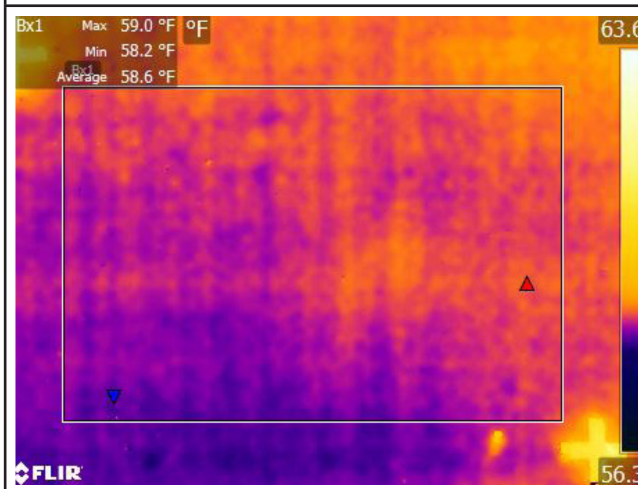
Temperature variance on the south side of the elevation is 4.0˚F; after sunlight has been directly on the elevation for 10 minutes.

Box Measurement
Max: 52.2˚F
Min: 49.2˚F
Difference (Bx1Max-Bx1Min): 4.0˚F

D. Transmissive Active Thermography

Transmissive active thermography was tested on both the stone and adobe masonry sections of the north elevation to test the usefulness of this methodology in detecting voids. Ultimately, neither test was successful on site due to the thickness of the stone and adobe masonry. In tests conducted, heat was applied to the wall for 4 hours with no compelling temperature changes perceived in the field of view (**D1-2**). This method may be more successful where cooler ambient conditions (32- 60˚F) could help draw the heat front through the wall.

Successful Testing Conditions:	
Testing Methodology	Active Transmissive Thermography (Test periods lasted 4 hours with constant heat applied)
Ambient Conditions	Exterior: 58˚F to 62˚F , 44-58% RH
Surface Temperatures	Interior (heated surface): 106.68˚F Exteiror: 60.39˚F
Surface Temperature Variation	ΔT= Null

Detecting Voids: Thermal Imaging Results	
	**(D1)** 5 minutes after initiation of testing Box Measurement Max: 58.2˚F Min: 57.5˚F Average: 57.9˚F
	**(D2)** 248 minutes after initiation of testing. Box Measurement Max: 59.0˚F Min: 58.2˚F Average: 58.6˚F

iv. General Findings

Based on the results from the case study, the applied IRT methodologies proved to be successful in identifying heterogeneous materials on broad (stone vs. adobe sections) and detailed (embedded nails) scales. There was moderate success in detecting voids between the plaster and masonry, perhaps owing to the similarity of the adobe and plaster in terms of thermal characteristics. The testing parameters and environmental conditions are listed in **Table 5**.

While analyzing the results from passive thermography tests, the variation in temperature across plaster surfaces was generally low, despite the presence of known voids. Whereas the suggested threshold for examination is ΔT= 5˚C,[1] the observed thermal contrast in this case study was much lower- about ΔT= 4˚F. This could be related to the thermal properties, perhaps low conductivity, of the plaster itself. Additionally, this observation comes from an instance where the underlying material was limestone masonry rather than adobe. The thermal characteristics of the stone make detecting voids through passive thermography more successful than with adobe masonry. Assemblies which contain materials with differing thermal properties are typically more successful at demonstrating thermal variation in IR images with passive thermography. Contrastingly, for those with similar thermal properties, active thermography could be more successful.[2] The limestone likely has higher thermal conductivity than the adobe masonry, and will heat more rapidly in response to heat (whether passive solar radiation or applied heat).[3] Future testing should focus on using active thermogrpahy in broad applications to detect subsurface voids.

IRT Testing Parameters and Environmental Conditions for Adobe/Stone Masonry		
Condition	*IRT Method*	*Environmental Parameters*
Differential Materials *(>1" below plaster sur-face; detecting different masonry materials)*	Passive Thermography	*Ambient Conditions* Exterior: 55°F to 65°F , 60-74% RH Interior: 61°F to 70°F , 49-56% RH
Differential Materials *(1" > below plaster surface; detecting metal within plaster)*	Active Thermography, Reflected/Long Pulse	*Ambient Conditions* Exterior: 58°F to 62°F , 44-58% RH *Surface Temperatures* Exterior (heated surface): 100.77°F Interior: 59.2°F
Voids *(>1" below plaster surface on limestone masonry)*	Passive Thermography	*Ambient Conditions* Exterior: 48°F to 60°F , 70-90% RH Interior: 58°F to 63°F , 52-56% RH
Voids*** *(>1" below plaster surface on adobe masonry)*	Active Thermography, Transmissive/Long Pulse***	*Ambient Conditions**** Exterior: 58°F to 62°F , 44-58% RH *Surface Temperatures* Interior (heated surface): 106.68°F Exteiror: 60.39°F
**** Indicates unsuccessful testing conditions*		

TABLE 5: IRT testing parameters and protocol based on the Smugglers Adobe case study.

1 Xavier P. V. Maldague, Theory and practice of Infrared Technology for Nondestructive Testing, 1-2.
2 Elisabetta Rosina and Elwin C. Robison, "Applying Infrared Thermography," 38.
3 Filippeschi, S., and F. Leccese. 2005. "Infrared Thermography to Visualize the Texture of Historical Buildings in Tuscany." Paper presented at 8th International Conference on "Non Destructive Investigations and Conservation of the Cultural and Environmental Heritage," Lecce (Italy), May 15-19th, 2005: 8.

APPENDIX B

Monitoring Suface Temperature with Thermocouples

Thermocouples

Thermocouples are temperature sensors which rely on the resistance measured by electrical conductors infer temperature. In this project, we are concerned with measuring the surface temperature, thus the self-adhered thermocouples which can be applied directly to surface of material were an optimal choice. Thermocouples are calibrated to record particular ranges of temperatures, and these are denoted by type codes, signified by a letter; this is related to the types of metals used in the thermocouple, and there are pros and cons to using each in different environments. For example, Type T thermocouples can measure temperatures between 32˚F and 62˚F (0˚C and 350˚C). In this instance, Type T thermocouples were selected because the process temperature range matched that expected for most traditional architectural materials (wood, stone, earth, concrete, plaster) surfaces heated by insolation and being artificially heated by infrared heaters. While it may seem beneficial to have a larger process temperature range, the greater ranges can have higher absolute tolerances; Type N Thermocouples, which have a temperature range of 32-2372˚F have a tolerance of 4.0˚F, while tolerance values for Type T is 1.8˚F.

Other characteristics of note in selecting thermocouples include wire length, wire insulation, and connector end compatibility. The length of the wire needs to be suitable for the situation, ensuring adequate length to span the distance from surface measured to data logger. The wire insulation is critical to avoiding unintended electrical contact between the wires other than at the desired sensing point. Plastic insulation is suitable for the temperatures in this instance, but other more resilient insulation types may be more helpful in rugged back-country situations or if the thermocouples are left in place for long durations. Finally, thermocouples can be purchased with miniature connectors (which attach to the datalogger ports) or with stripped leads for a reduced cost.

Type	*Range*	*Length*	*Link*	*Optimal Use*
Type T	-40 to 302°F	40 inches	https://www.omega.com/en-us/temperature-measurement/temperature-surface-sensors/sa3/p/SA3-T-SRTC	Field, Lab
Type T	32 to 305°F	80 Inches	https://www.omega.com/en-us/temperature-measurement/temperature-surface-sensors/sa1xl/p/SA1XL-T-72-SRTC	Field; improved durability of cables.

Data acquisition unit

The data acquisition unit is used to log information gathered by the thermocouples. For this project, a HOBO 4-Channel Thermocouple Data Logger (UX120-014M) was selected. The four subminiature connector channels enables the user to capture data from several sensors simultaneously, which was necessary to capture surface temperature data from the interior and exterior faces of walls. In order to program data recording intervals, the Thermocouple Data Logger requires a USB cable to connect to a computer. Utilizing the HOBOware, a user can program the time and interval parameters for recording data.

APPENDIX C

Method to Calculate Reflected Apparent Temperature

To calculate the emissivity of a surface in question, first determine the reflected apparent temperature or background temperature. This method relies on the use of foil because it is considered to be a perfect reflector. Therefore, its apparent temperature equals the reflected apparent temperature from the surroundings.

Method to Calculate Reflected Apparent Temperature	
Procedure	*Description*
Set parameters on the camera: distance to object, relative humidity, atmospheric temperature.	
Attach a piece of aluminum foil to a firm backing of the same size; this can be cardboard, foam board, etc.	Before attaching the foil to the board, crumple and then un-crumple the foil.
Place the foil in front of the surface under investigation with the foil facing the camera. Set the emissivity value to 1.0.	
Take a thermal reading of the foil using the box analysis tool on the FLIR interface.	This provides an average temperature rather than a single spot reading, which is helpful if there is any temperature variation.
This value is the reflected apparent temperature.	

NOTE: The reflected temperature can vary substantially with atmospheric temperature; thus, if the atmospheric temperature changes throughout the day during field testing, it is important to periodically determine the reflected temperature and emissivity to ensure accurate data.

APPENDIX D

Method to Calculate Emissivity

Once the reflected temperature has been calculated, one can calculate the emissivity of the surface.

Method to Calculate Reflected Apparent Temperature	
Procedure	*Description*
Set the reflected temperature on the camera.	Use procedure in "Calculate Reflected Apparent Temperature."
Put a piece of electrical tape on the surface.	Electrical tape has a known high emissivity, usually about 0.97.
Heat the surface area evenly at least 36 deg F above ambient temperature.	Make sure that heating is reasonably even.
Take a still IR image of the object, making sure to including the electrical tape in the photo.	Make sure to focus the camera.
Adjust the level and span of the image to provide the best contrast in order to locate the electrical tape.	
Set the emissivity to 0.97.	
Measure the temperature of the tape using the box avg tool; remember to record this temperature.	Again, using the averaging tool provides an average temperature rather than a single spot reading, which is helpful if there is any temperature variation.
Use the box analysis tool to measure the adjacent surface under investigation.	
Change the emissivity setting on the camera so that the temperature being measured on the surface matches the temperature of the electrical tape.	
The final value is the object's emissivity at that atmospheric temperature.	