Passive and active infrared thermography: An overview of applications for the inspection of mosaic structures.

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Abstract. Infrared Thermography is a non destructive testing and evaluation (NDT&E) technique, which has been widely used for the investigation of cultural heritage and art objects. The main purpose of this study is to present the capabilities of both passive and active thermography for the inspection of mosaic structures, evaluating the performance of each testing approach through its application in representative mosaic structures. In situ passive thermography was applied on mosaic pavements in an attempt to acquire knowledge about their preservation state, while the active approach was used in order to study plastered mosaics and characterise the tesserae layer beneath the plaster. The results from this study revealed that passive approach can be efficiently applied as a moisture detection tool and a rapid monitoring technique of the mosaic condition, while the active thermographic investigation showed much more potentiality as quantitative information for the detected feature was further retrieved.

1. Introduction
Among the different NDT&E techniques, thermal imaging can accurately obtain subsurface features information without compromising the structural integrity of the inspected target. The above along with the non contact nature of this technique have resulted to its wide use in the cultural heritage conservation field [1,2]. The two basic configurations for implementing an infrared thermographic survey are passive and active approach respectively. In passive thermography, the monitoring of the thermal radiation, emitted by the surface of the test body under natural conditions, is used and it is widely applied as a standard quality control technique of historic structures since many years ago [3,4].

The active configuration is deployed through the generation of a heat flow such that the thermophysical properties of the test object can be made to enhance or impede this flow. The thermographic investigation during and/or after a heating process, has been proven to present much more potentiality than the conventional passive approach [5], while recent advances in thermographic signal processing and the development of efficient numerical algorithms have made it practical to implement active thermal imaging for quantitative purposes as well [6,7].

The main objective of this study was to evaluate the performance of both passive and active thermography as inspection methods and monitoring techniques of mosaic artefacts. In particular, passive thermography was applied in order to test three mosaic pavements having received different conservation interventions, while the active approach was used to test a plastered mosaic in order to
reveal the hidden artefact and gain information regarding its location, its thickness and its characterisation based on the estimation of its thermal properties.

2. In situ passive thermography for the inspection of mosaic pavements

2.1. Early Christian mosaic floor at Delphi Museum
The first mosaic tested was a stone-glass tesserae consisted pavement, discovered at the archaeological site of Delphi and transferred on the roof of the Delphi Museum, in Greece. Its origin is dated back to the Early Byzantine Period (5th century A.D) and as can be seen from Figure 1, its decoration schematises a tress as a framework and the main scene by geometrical motives and by human and animal representations. Initially, the mosaic was conserved in 1962, where the tessellatum layer was detached and placed on reinforced cement mortar, while in 2006 the mosaic was transferred in pieces and reattached on the roof of the Museum. In the latter conservation procedure, the infrastructure was built from bricks arranged in a square formation, within which polystyrene foam covered by metal armatures and cement was fitted. The sections were placed on the infrastructure and the gaps were filled with mortar. The thickness of the overall construction is about 25cm, while some parts of the mosaic carry inner tubes for drainage of water around the base.

![Figure 1. a) Panoramic view of the Delphi floor mosaic’s eastern area and (b) mosaic area of animal representations on the tessellatum layer.](image)

The main purpose of this survey was to apply thermographic testing in order to investigate for moisture accumulation on the mosaic pavement. Visual observations revealed local regions with detached tesserae, while the climate conditions where the mosaic is located, are also harsh during the winter time. Here, it shall be mentioned that the above mosaic’s thermographic investigation was performed during the noon when the solar energy was directly heating up the inspected structure, producing a transient in a manner thermal regime. Representative thermal images from the inspection of the Delphi mosaic are illustrated in Figure 2, where temperature variations were observed on the surface decorative layer.

![Figure 2. Thermal image from (a) the mosaic region without drainage system and (b) with drainage system.](image)
More specifically, Figure 2a presents the surface temperature map from an area without drainage system and Figure 2b presents the respective thermal image from a region having the drainage system discussed above. Comparing the two images and considering that the testing scenario was applied in a “naturally active” mode, temperature uniformity was observed in the latter case, indicating the better preserved state of the mosaic part with the drainage system. In other words, deterioration phenomena are more aggressive along the eastern area of the mosaic, where the water accumulation occurred due to the lack of the drainage system.

2.2. Mosaic pavement at the Ancient Agora of Athens

The second mosaic inspected is ruins of an ancient house, revealed during the excavation of Dörpfeld at the Ancient Agora of Athens. The mosaic floor dates back to the 2nd century B.C. and it is decorated with geometric patterns. In 1960, the mosaic was conserved using cement mortar, while in 2002, a second conservation procedure was applied during which a lower level of pebble floor was appeared (dated possibly at the Hellenistic period), that was covered with geotextile and sand. Photographs from the current state of the mosaic are presented in Figure 3, where visual observations revealed local tiles detachments, few biological deposits and surface cracks on the mosaic surface.

![Figure 3](image3.png)

**Figure 3.** Mosaic pavement from the ruins of an ancient house located at the Ancient Agora of Athens with (a) the state of the structure after the 2002 conservation intervention, (b) the preservation state during the survey in 2014 and (c) a region with surface cracks obvious through visual inspection.

![Figure 4](image4.png)

**Figure 4.** Thermal images revealing surface cracks with (a), (b) being invisible and (c), (d) being partially visible from visual inspection.
Apart from the above mentioned deterioration phenomena, thermographic inspection revealed some further surface cracks, which were either difficult to be detected through visual testing or undetectable in some instances. Nevertheless, through infrared vision it was very easy to detect and map the cracking as presented on the indicative thermal images of Figure 4, acquired at different parts on the mosaic surface. As the cracks were randomly detected at several areas, this phenomenon can be possibly attributed to the conservation procedure performed by placing cement mortar as a substrate layer, enhancing the incompatibility of the structure in terms of materials lay-up and mechanical behaviour. In this point, it is interesting to note that cracks propagation obvious to the naked eye was mainly detected on regions made of glass tesserae (such that in Fig. 3c), while cracks of smaller thickness and not easily detected though visual testing were mainly observed on the stone tesserae constructed regions.

2.3. Mosaic pavement at the Sanctuary of Pan

The third in situ passive thermographic inspection was performed on a mosaic consisted of lime mortar substrate and a coloured stone tesserae decorative layer, dated between the 2nd century B.C. and 1st century A.D. The Sanctuary of Pan was discovered in 2001, where outside the caved chamber a rectangular room with a floor mosaic of geometric patterns was found (Figure 5a).

![Mosaic pavement at the Sanctuary of Pan](image)

**Figure 5.** (a) Mosaic pavement at the Sanctuary of Pan and (b) thermal image confirming the good preservation state of the mosaic.

The room into which the mosaic was found should be a villa of the early Imperial period and its relationship with the adjacent "Sanctuary of Pan" has not been fully elucidated. Between 2001 and 2004, a complex program of restoration works was implemented by the Ministry of Culture of Greece. The conservation interventions focused on the reattachment of two scattered mosaic pieces on new mortar (areas A and B in Figure 5a), while cleaning and consolidation procedures were also applied on the structure. Moreover, a shelter was built in order to protect the artefact from its direct exposure to rain and solar radiation. Visual inspection verified that the mosaic structure was in a good preservation state, something that was also confirmed through the aid of thermographic testing. In particular, as presented on Figure 5b, surface temperature uniformity was detected on the decorative layer of the mosaic. Nevertheless, humidity was detected at the consolidated edges mainly next to the lateral cave wall even if a tent that was placed vertically on the cave wall.

3. Active thermographic investigation of plastered mosaics

3.1. Samples preparation and testing methodology description

The aim of this study was to experimentally and numerically demonstrate the potential of active thermography on revealing and quantitatively characterising a hidden mosaic. Images seeing-through the mortar on a plastered mosaic surface were obtained using the principles of cooling down thermography, while quantitative information regarding the hidden artefact was retrieved through the simultaneous monitoring of the surface temperature decay over a reference (just plaster) and a mosaic-consisted area, and through the conduction of numerical parametric studies for the evaluation of...
specific parameters alterations (i.e. covering thickness, mosaic layer thickness, mosaic thermophysical properties) on the thermal response of the structure. For this study, two (2) panels -one mosaic sample consisted of marble tesserae and covered with two different layers of plaster and one blank sample with just plaster and no tiles underneath it- were prepared in the laboratory. The cross section of the investigated panel is shown in Figure 6b, while the description of the tested panels is presented in Table 1.

For the cooling down thermographic approach, the inspected specimens were heated with the use of an external 1500 W heat source (infrared lamp of INFRATECH type), placed at the distance of 40 cm from the inspected surfaces. The thermal excitation process was performed for 90 min, while the recording of the transient cooling phase was performed for 60 min, through the aid of an infrared camera placed always vertically to the surface of the panels. The thermographic system used for this study (TheraCAM SC640) was operating at the wavelength region from 7.5 to 13.5 μm and it was a focal plane array device with an image resolution of 640 x 480 pixels. For the monitoring of the cooling down process, thermal images were recorded sequentially with a time step of 30 s. The concept of the measurements performed in the present study, was based on the assumption that infrared thermography will be able to detect the hidden mosaic, presented with temperature variations on the surface, due to the dissimilar thermal diffusion that each layer renders. Thus, the measurement was performed by comparing the thermal behaviour of the covered mosaic with respect to the behaviour of the corresponding in terms of plastering reference sample. For quantitative analysis, the monitoring of surface temperature variation as a function of time from areas above the plastered mosaic and above the blank sample were compared and the produced temperature differences were further plotted as a function of time.

### Table 1. Test samples description

| Sample No. | Tesserae material | Lay-up description (starting from the top surface layer) | Lateral dimensions |
|------------|-------------------|----------------------------------------------------------|-------------------|
| M2         | Marble            | 1cm lime mortar + 1 cm of cement mortar + 0.5 cm tesserae layer + 2cm lime mortar | 20 cm x 33cm      |
| M5         | No tesserae       | 1cm lime mortar + 1 cm of cement mortar + 2cm lime mortar | 20 cm x 33cm      |

The purpose of $\Delta T$ vs. time plotting was to monitor how this quantity changes as a function of time and to identify the maximum $\Delta T_{\text{max}}$ and the distinct time of this occurrence $t_{\text{max}}$. In order to compute the above quantity, two different options were investigated in the sequential analysis of the cooling down process, selecting initially a single pixel above the plastered mosaic and a single pixel above the mosaic-free surface. Additionally, the same analysis was repeated after computing the average temperature values on the two aforementioned areas. As the first option raises the crucial issue of how
the control points should be selected (the feature of interest occupies a large volume of pixels in the thermal image), four different points were selected – two on each sample surface- accommodated in diametrically opposed positions between them (pixels T1 and T4 were selected at the centre of each panel, while pixels T2 and T3 were selected near the bottom edges, Figure 6a).

Along with the experimental testing, parametric studies were conducted in a simulation environment, modelling transient thermal regimes. Through numerical simulations, the aim was to evaluate the mosaic detectability by altering parameters such as the covering intervention thickness, the mosaic layer thickness and the thermophysical properties of the hidden mosaic. The above parametric studies were implemented through the aid of ThermoCalc-3D™ heat transfer model [8], calculating the thermal response of the covered mosaics after the application of a heat flux. The dimensions of the physical models were 40 cm x 33 cm x 4 cm with the half area referring to the blank panel (20 cm x 33 cm), whilst the other half was designed to consist of a simulated subsurface mosaic area (20 cm x 33 cm). For the creation of the physical models, the materials properties were obtained by the literature [8,9] and the complete description of the layers specifications and the simulated testing parameters are summarised in Table 2. For numerical analysis and data interpretation, transient curves were calculated in a similar manner as in the case of experimental testing. Nevertheless, in order to measure the temperature decay and the thermal contrast evolution curves above the mosaic-free and covered mosaic regions, only two points accommodated in diametrically opposed positions and placed at the centres of each respective area, were selected due to the thermal stimulation uniformity that the simulation regime provided.

### Table 2. Input parameters for the description of the simulated samples’ layers and testing procedure

| Layer                               | Thermal conductivity (Wm⁻¹K⁻¹) | Specific heat (Jkg⁻¹K⁻¹) | Density (kgm⁻³) | Thermal diffusivity (x10⁻⁷m²s⁻¹) |
|-------------------------------------|-------------------------------|--------------------------|-----------------|----------------------------------|
| Lime plaster                        | 0.87                          | 800                      | 1440            | 1001                             | 7.55                             |
| Concrete plaster                    | 1.4                           | 1100                     | 2000            | 1755                             | 6.36                             |
| Marble tesserae layer               | 3.14                          | 870                      | 2700            | 2715                             | 13.4                             |

**Geometrical characteristics**

| Layer                               | length (cm) | width (cm) | thickness (cm) |
|-------------------------------------|--------------|------------|----------------|
| Concrete cover                      | 40           | 33         | 1              |
| Lime cover                          | 40           | 33         | 1              |
| Subsurface lime layer               | 40           | 33         | 2              |
| Marble mosaic layer                 | 20           | 33         | 0.5            |

**Simulation testing parameters**

| Power input (W/m²) | Duration of energy input (min) | Duration of observation in min (including heating) | Time interval (s) |
|-------------------|-------------------------------|--------------------------------------------------|------------------|
| 1500              | 90                            | 150                                              | 30               |

3.2. Experimental and numerical results

The figure of Table 3 presents an indicative thermal image from the inspected set, after thermally exciting simultaneously the reference panel and the covered mosaic. As can be seen from the thermogram, increased thermal energy was deposited on the right surface (plastered mosaic) with respect to the thermal energy deposited on the left surface (blank sample), revealing the presence of the hidden mosaic layer beneath the coating. In other words, the different type of material embedded into the structure is altering the cooling down behaviour on the respective area. Additionally, the thermal contrast levels measured using the different control points are also summarised in Table 3, providing the temperature difference values at the beginning, at the time point of maximum thermal contrast occurrence and at the end of the cooling down process. In particular, from the ΔT values monitored through the T4-T1 spots analysis, it was observed that a local negative ΔT value of -5.7 °C was initially detected, having an upward trend, until reaching its maximum value ΔT_{max} of 12.4 °C at t_{max} = 31 min. The signal after that slowly decays to a ΔT value of 8.8 °C at the end of the cooling
down recording. The thermal characterisation obtained from the second spot testing (T3/T2) and the measurement of the average temperature over the investigated areas, produced similar results as in the case of T4/T1 analysis. However, some small variations in terms of $\Delta T$ and $t_{\text{max}}$ values were observed, indicating that the quantity of heat delivered to the sample surface was not uniform directly influencing their temperature decays and thus the resulting thermal contrast evolutions. This can be further confirmed if consider that the surface emissivity was constant on the two panels due to the same covering intervention that they received.

### Table 3. Summary of experimental results

| Set of samples | Indicative thermal image at t=30 min after the beginning of the cooling down process | Temperature differences (°C) |
|----------------|--------------------------------------------------------------------------------------|-------------------------------|
| M2-M5         | ![Indicative thermal image](image)                                                                 | $\Delta T_{4,1}$ min $\Delta T_{4,1}$ t=60 (min) |
|               | $t=0$ (min) max $t=60$ (min)                                                        | $\Delta T_{3,2}$ t=0 (min) max $t=60$ (min) |
| marble/cement, lime |                                                                                   | $\Delta T_{\text{avg}}$ t=0 (min) max $t=60$ (min) |
|                | -5.7 12.4/ t= 31 8.8                                                            | -2.3 8.8/ t=30.5 5.8 |
|                | -4.4 10.9/ t=32 7.7                                                            |  |

In order to conduct the parametric studies discussed above and to extract results regarding the influence of specific parameters variations on the hidden mosaic identification, a series of simulations were also carried out. Particularly, in order to study the influence of covering layer thickness on hidden mosaic detectability, simulations were performed for a mosaic layer of stable thickness (5mm) covered with plaster varying from 0.5 to 3.5 cm. The thickness step increase was of 0.5 cm and each layer was increased equally from 0.25 to 1.75 cm. The numerical investigation was fitted to simulate the experimental testing conditions and in each individual model setup, the characteristic $\Delta T_{\text{max}}$ and the respective $t_{\text{max}}$ were calculated. The above procedure aimed to correlate the variation of these physical quantities with respect to the covering thickness increase, as illustrated in Figure 7a. As can be seen from the plot, for thicker covering interventions the hidden mosaic layer can be still identified, despite the reduced thermal contrasts produced on the modeled surfaces, while the simulated thermographic monitoring of thinner interventions produced a faster seeing-through condition of the hidden feature.

![Figure 7.](image)  
(a) Variation of $\Delta T_{\text{max}}$ and of the correspondent $t_{\text{max}}$ with respect to (a) the plaster cover thickness increase and (b) the mosaic layer thickness increase.

Along with the covering influence, the thickness of the tesserae layer is another parameter affecting the identification of the covered features. In a similar manner, the influence of mosaic layer thickness on the thermal response of the structure was studied in a 2 cm covering model with tiles thickness
varying from 2 to 14 mm. The mosaic thickness was increased by a 2 mm step and Figure 7b presents the variations of the peak thermal contrast values and of the correspondent maximum times associated with the mosaic thickness increase. The numerical results from this parametric study indicate that an enhanced visibility can be achieved for more resistive subsurface features. In other words, as higher was the thickness of the hidden tiles the more enhanced was its visibility under the plastering regimes, as hidden mosaics react better in heat accumulation.

Finally, the thermal response of the covered mosaic was evaluated in terms of its thermophysical properties, taking into consideration the material properties of thermal effusivity and thermal diffusivity, respectively. In a model having the physical dimensions of the real samples, the influence of the mosaic thermophysical characteristics was investigated by varying simultaneously the thermal conductivity of the mosaic surface from 1 to 4.5 W/(mK), the mass density from 1500 to 3000 kg/m$^3$ and the specific heat from 700 to 1300 Jkg$^{-1}$K$^{-1}$. The above variations produced 7 models, where the thermal effusivity of the investigated feature was varied from 1024 to 4189 Ws$^{1/2}$m$^{-2}$K$^{-1}$ and its respective thermal diffusivity from 9.5 to 11.5 x10$^{-7}$ m$^2$s$^{-1}$. Figure 8 illustrates the variations of the informative parameters $\Delta T_{\text{max}}$ and $t_{\text{max}}$ as a function of the mosaic thermal effusivity (a similar behaviour would be exhibited if the x-axis had the values of thermal diffusivity), where as can be seen as the effusivity of the covering layer remained constant, as greater was the thermal effusivity of the hidden feature the lower was its reaction in the conductive heat transfer back to the surface due to the produced temperature difference.

3.3. Quantitative analysis of plastered mosaic

Along with the qualitative characterisation of the plastered mosaic structures, quantitative information were retrieved correlating numerical and experimental results and solving the inverse problem through the parameter estimation approach. As a result, three different inverse problems were produced, where in the first one the location of the mosaic layer was estimated considering mosaic’s thermophysical properties and thickness known, the second one was conducted for the estimation of mosaic thickness being known its location and its thermophysical properties and the last one predicted the thermophysical properties of the hidden mosaic being known the geometrical characteristics of the structure. As a result, least square fitting was used in order to find the best fitting function describing the evolution of the dependent variable of $t_{\text{max}}$ with respect to the parameter estimated (independent variable) in each individual inverse problem. An example of this analysis is presented in Figure 9, where the fit function of $t_{\text{max}}$ related to the depth at which the mosaic is located to, is presented. On the aforesaid plot, the experimental values of maximum times from the three different analysis procedures can be connected to particular mosaic depths.

The results obtained by solving the inverse problem for mosaic depth and tiles thickness prediction are summarised in Table 4. The measured depths determined by the inverse solution differ from 0.11 mm to 0.17 mm to the nominal depth, which in terms of error estimation can be deduced to a range from 5.5% to 10%. These deviations can be characterised as relatively short, as their production can be possible attributed to a non uniform plastering during the sample manufacturing. As regards the
comparison of depth information retrieval through the different analysis procedures, variations were detected when using the experimental data derived from the correspondent pixels’ analyses, which was fixed using the average surface temperature.

![Figure 9](image)

**Figure 9.** Time of maximum temperature difference as a function of mosaic depth, with the curve following a fitting function of a second order polynomial.

The second inverse problem investigated the correlation of numerical and experimental data in order to acquire quantitative information regarding the thickness of the hidden mosaic layer. In general, the acquired results were able to provide estimations regarding the tesserae thickness, however larger prediction errors were produced in this case with respect to the accuracy produced in the former one. Nevertheless, a comparison of the produced results through the different data analysis procedures confirmed as well that the temporal monitoring of the average surface temperature produces more accurate results with respect to these derived from the pixel analyses.

| Table 4. Determination of mosaic depth and thickness through the inverse solution |
|-----------------------------------|-----------------|-----------------|-------------------|-----------------|-----------------|
| Actual depth (cm) | Estimated depth (cm) | Error (%) | Actual thickness (mm) | Estimated thickness (mm) | Error (%) |
|-----------------|-----------------|-------------------|-------------------|-----------------|-----------------|
| Centre          | 1.83            | -8.5              | Centre            | 2.55            | -49            |
| Edge            | 1.80            | -10               | Edge              | 2.06            | -58.8          |
| Average         | 1.89            | -5.5              | Average           | 3.54            | -29.2          |

Finally, the third inverse problem was created in order to fit the maximum temporal characteristic with respect to the mosaic’s thermal effusivity and thermal diffusivity changes. The classical thermophysical properties of a material that are characterising its response to a heat flux are the thermal conductivity \( k \), the specific heat \( c_p \) and its mass density \( \rho \). The latter two can be combined to the heat capacity which is a material property, derived from the product of specific heat and density \( c_p \cdot \rho \). These thermophysical properties in a transient thermal regime can be considered in two other material properties, the thermal effusivity \( \varepsilon = \sqrt{k / \rho c_p} \) and the thermal diffusivity \( \alpha = k / \rho c_p \) respectively. Thus, by determining the aforementioned thermal properties, estimations regarding the thermal conductivity and the heat capacity of the investigated feature can be obtained [10], according to \( k = \sqrt{\varepsilon \alpha} \) and \( \rho c_p = \varepsilon / \sqrt{\alpha} \). In this point, it should be mentioned that the indirect characterisation of the mosaic material though the estimation of its thermophysical properties was performed taking into consideration the temporal information derived from the average temperature data and the results produced are summarised in Table 5.

From the results produced, it can be observed that a rough characterisation of the hidden mosaic layer can be performed. By defining the properties of thermal conductivity and heat capacity, these can be combined searching in the literature to match both values with a specific material. In this point it should be mentioned that the nominal values of the thermal properties, are actually the values that have been used in order to create the numerical simulations and as stated above these have been retrieved from the literature. However a bibliographic search exhibited that the several types of marble existed have different thermophysical properties. For instance according to the type of marble used its thermal conductivity can vary from 2.08 to 3.34 [11].
Table 5. Determination of mosaic thermophysical properties

| Nominal $e$ ($W \cdot s^{1/2} \cdot m^{-2} \cdot K^{-1}$) | Estimated $e$ ($W \cdot s^{1/2} \cdot m^{-2} \cdot K^{-1}$) | Nominal $\alpha$ ($10^{-7} \cdot m^{2} \cdot s^{-1}$) | Estimated $\alpha$ ($10^{-7} \cdot m^{2} \cdot s^{-1}$) |
|---|---|---|---|
| 2715 | 2616 | 13.4 | 10.97 |

| Nominal $k$ ($W \cdot m^{-1} \cdot K^{-1}$) | Estimated $k$ ($W \cdot m^{-1} \cdot K^{-1}$) | Nominal $c_p$ ($K \cdot J \cdot m^{-2} \cdot K^{-1}$) | Estimated $c_p$ ($K \cdot J \cdot m^{-2} \cdot K^{-1}$) |
|---|---|---|---|
| 3.14 | 2.74 (-12.7%) | 2349 | 2515 (7%) |

4. Conclusions

From the results produced through this study, it can be concluded that infrared thermography either through the passive configuration or through the active one can act as a useful tool for the evaluation of mosaic structures. In particular, through the aid of passive thermography, results concerning the condition of the structure can be extracted in real time, while the surface temperature readings can be correlated with physical and chemical phenomena, such as the influence of humidity in the structure and the evaluation of incompatible conservation interventions to the structure’s reaming life. On the other hand, the thermal excitation in active thermography and the sequential monitoring of the surface transient cooling can produce a complete set of qualitative and quantitative information. A limitation characterising the active approach could be the fact that it can be applied in cases where only an unknown parameter is missed. In other words, in order to create the relevant models and follow the above described methodology, only one parameter each time can be altered and can be defined by the inverse problem (i.e. in order to estimate the mosaic depth, its thermophysical properties and its thickness have to be known and so on). However, this approach can be efficiently applied in cases of cultural heritage investigations, where a detail is missing from the archives documenting the artefact, or can be overcome by using experimental procedures to gain missing quantitative information, so that these can be inputted into the model.

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