Preventive Conservation in Historic Houses and Palace Museums: Assessment Methodologies and Applications

SilvanaEditoriale

Preventive Conservation in Historic Houses and Palace Museums: Assessment Methodologies and Applications

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and the Research Centre
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Multi-View-Monitoring of Dimensional Changes of Wooden Panels Due to Changes in the Microclimate at Linderhof Palace

Abstract

Every year 500,000 visitors come to see Linderhof palace, by King Ludwig II of Bavaria. The indoor climate in the small palace is highly affected by the high amount of visitors. Until recently, the only way to obtain fresh air was by opening the windows. Due to this, the original historic furnishings were exposed to high humidity levels which fluctuated widely. In February 2017 an innovative ventilation system was installed to solve this problem. The goal of the research project was to examine how the historic furnishings respond to both the former and current climate situation. A method to investigate the reaction of various surfaces to changes in the microclimate generated by the ventilation system was developed by a multi-view-monitoring (MVM). A combination of three different non-destructive optical methods: structured light scanning, 3D-microscopy and time-lapse photography has been applied to different object surfaces. The monitoring has been conducted in daily and seasonal cycles.

Keywords

Micro climate, monitoring, historic furnishing, ventilation system, preventive conservation, structured light scanner, 3D-microscope, time-lapse photography.

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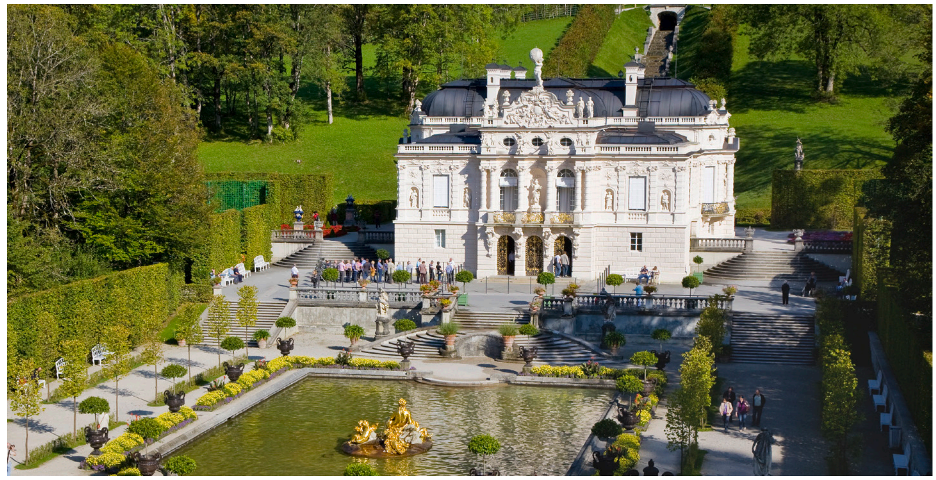
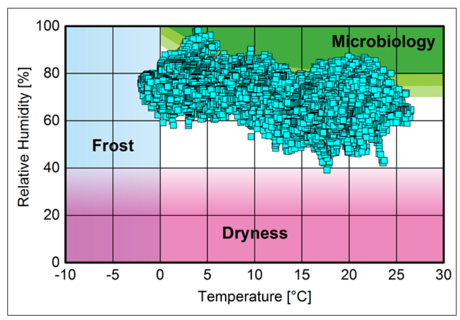
Previous Climatic and Conservation Situation in Linderhof Palace

Linderhof Palace was built in the 19th century (1870-1874) for King Ludwig II of Bavaria. The palace is situated in the heart of the Bavarian foothills of the Alps (ca. 950 a.s.l.). For more than 125 years the palace has attracted hundreds of thousands of visitors each year (fig. 1). This number of people has had a huge influence on the indoor climate and has contributed to the decay of the vulnerable original furnishings.

Since 2008 the impact of the indoor climate on the historic furnishing has been examined by two research projects in close cooperation with the Fraunhofer Institute for Building Physics (national project "Climate stability in historic buildings" 2008-2013 and European project "Climate for Culture," 2009-2014).

There are two main climatic problems in Linderhof. The first occurs





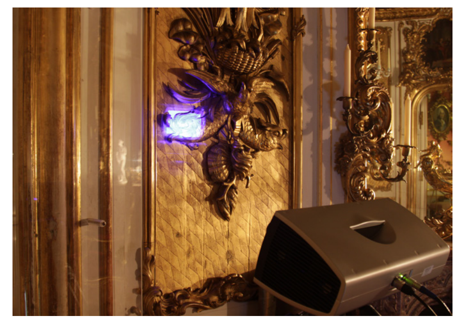


Fig. 1
Linderhof Palace built for King Ludwig II of Bavaria – exterior view of the southern façade. (Source: BSV)

Fig. 2
Scatter diagram of RH and T of the hourly data taken in the bedroom between February 1st 2008 and June 1st 2011. (Source: Fraunhofer IBP)

Fig. 3
Examination of a gilded wooden panel in the dining room using a structured light scanner. (Source: BSV)

mainly in the northern part of the palace where the relative humidity is much too high (fig. 2). The statistical analysis of temperature (T) and relative humidity (RH) in the bedroom, measured hourly for three years showed an annual average of 71% RH, reaching a maximum level of 96.8% RH. To minimise the risk of mould growth and other negative impacts on the historic furnishings, such as swelling of surfaces, a mean value of 60% RH is recommended. Secondly, the short term fluctuations are extreme. In summer, as soon as the first group of visitors enters the palace, the windows are opened to counter the damp atmosphere. Throughout the day, T and RH inside the palace rise steadily, and after closing time, decrease again. During a single day the fluctuations may exceed 20% RH [Bichlmair *et al.*, 2013]. Assessments of the state of preservation of the historic furnishings were conducted as well [Holl 2013, Holl 2016]. Climate-induced damage such as cracks in the wood, flaking gilt and paint layers as well as mould growth was found, especially on the painted and gilded wooden furnishings.

Innovative Airing Strategy in Linderhof Palace

For the long-term protection of the Palace a ventilation system was installed. The control system is based on the European standard 15757 "Conservation of Cultural Property – Specifications for T and RH to limit climate-induced mechanical damage in organic hygroscopic materials" [DIN EN 15757]. Based on that standard the Fraunhofer Institute for Building Physics devised the specifications for the indoor climate in the palace [Bichlmair *et al.*, 2013]. The aim of the specifications was two-fold: first, the RH in the bedroom should be reduced to the level of the adjacent rooms (the RH in the adjacent hall of mirrors averaged 62% RH over three years). A RH level of 62% was specified, allowing ± 6% RH fluctuations on a monthly average. The second aim was to limit the short term fluctuations so that most of the time an average monthly fluctuation of ± 8% RH is not exceeded. The T should follow the seasonal cycle with little interference. The upper limit is 20 °C, and at low temperatures the difference between the indoor T and that of the air supplied by the ventilation system must not exceed 6 Kelvin. However, the main aim is to control the RH, not the T, and the key criterion of the control of the air inlet is to not exceed 40% RH. The volume flow is adjustable by a frequency converter and can vary depending on the number of visitors [Holl *et al.*, 2015]. As well as the installation of the ventilation system, a research project was carried out to conduct a scientific and conservation assessment of the system. The project "Wissenschaftliche Begleitung einer Maßnahme zum präventiven Schutz vor Umwelteinflüssen in Schloss Linderhof" was funded by the DBU (German Federal Environmental Foundation) from 2013 till 2018.

Development of a Multi-View-Method for Monitoring Microclimate Changes on Wooden Panels

Climatic fluctuations may have a different impact on artworks depending on their material properties and thickness. An artwork such as a panel painting usually consists of different materials and layers (e.g., priming, several colour layers, coating) and each one reacts differently regarding swelling and shrinking. The divergent behaviour of each layer can cause stress inside the composite material. Both short and long term fluctuations have an impact on artworks: short term fluctuations which occur on an approximately daily cycle will affect the surface more, especially when there is already damage present. Fluctuations which occur over a longer period will also affect the inner layers and the support. Therefore, depending on the frequency and amplitude, climate fluctuations can cause a variety of damage, such as deformation or cracking of the support or loosening of the surface. Thus, it is complex to know which climate fluctuations are really damaging to the collections.

According to Michalski, the highest stress in objects is caused by fluctuations which last longer than the response time but are shorter than the relaxation time [Michalski 1993, Michalski 1996]. However, outside a laboratory environment the response and relaxation times

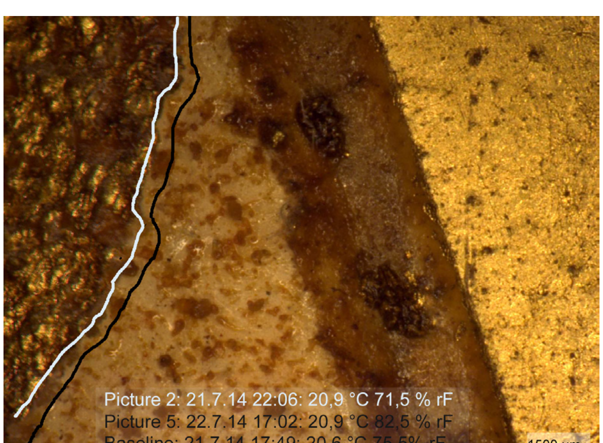
Fig. 4
Left: time-lapse pictures with a SLR-camera in the eastern tapestry room. Right: 3D-microscopy of the wall paintings in the bathroom. (Source: BSV)

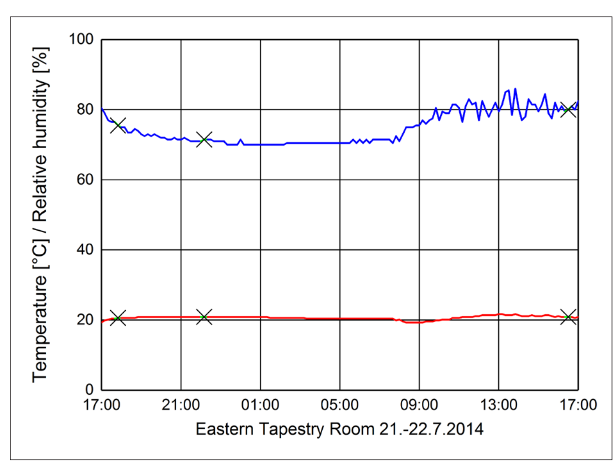
Fig. 5
Left: visualization of climate induced movement by matching the single pictures and marking the contours of the gilt layer (source: BSV). Right: T and RH during measurement (July 21^{st}-22^{nd}, 2014) with the 3D-microscope (marked with black crosses).

of different objects can only be estimated.

For the case of Linderhof Palace it was clear at the beginning of the research project that due to the ventilation system, both the pattern of atmospheric fluctuations and the average values of the indoor climate would change. Therefore, in order to judge the effect of the new system there was a need to document the reaction of the historic furnishings to the changes in climate. Climate-induced damages are not easily documented as they usually only occur over long periods, so for their detection a multi-view-monitoring (MVM) technique was developed. The idea was to combine three non-destructive-testing methods (NDTs) alongside detailed climate monitoring in order to investigate the effects of both short and long term climate fluctuations.

To evaluate the changes caused by the new climate, it was necessary to document the regular seasonal changes of the historic furnishings in advance. This was carried out with a structured light scanner (SLS) (fig. 3). For the examination of the effects of short term fluctuations on already damaged surfaces, areas such as loosened parts of a gilded wooden panel were chosen. The investigation of these surfaces





Climate analysis	Examination	Method
Short term fluctuations (daily – several days)	Examination of already damaged surfaces with regards to movement (swelling / shrinking)	SLR-Photography 3D-Microscopy Investigation of selected surfaces
	Comparison of the detail of a historic surface	Structured light scanner "1-shot-method"
Seasonal fluctuations	Comparison of the detail of a historic surface	Structured light scanner Investigation of selected surfaces

Table 1
Description of the different methods used to examine the reactions of the historic furnishings over varying periods. The selected surfaces were examined before and after the implementation of the ventilation system.

helped to define acceptable ranges for short term fluctuations. For this a 3D-microscope and SLR-photography were used (fig. 4). The structured light scanner was also used to examine the effects of short term fluctuations using the "1-shot-method." All examinations were conducted in different seasons and over the course of several days (see table 1).

Structured-Light-Scanning (SLS)

SLS is a combination of optical triangulation technology (optical distance measurement by angular measurement inside triangles) and interferometry (interaction of waves). The big advantage of this optical method is the fast recording of surfaces at a high resolution. For the measurements in Linderhof Palace the COMET L3D 5M structured light scanner by Steinbichler (now Carl Zeiss Optotechnik) was used (fig. 3). With this method it is possible to scan areas of varying sizes by changing the lenses. Using the 250 mm lens an area of 260 x 215 x 140 mm can be examined, and with the 75 mm lens the area is 74 x 62 x 45 mm. The distance between two measured points also depends on the lens: the smaller the image section the higher the resolution (250-mm-lens: 100 µm distance, 75-mm-lens: 30 µm). Using the Comet Plus 9.63 software, several scans are combined into a single data file. The scans were carried out in rows with a vertical and horizontal overlap of more than 50% between each single scan. This redundant data reduced the matching errors between the individual scans and guaranteed a higher geometrical accuracy for each monitoring area [Drewello *et al.*, 2011].

To examine the SLS data, two scans of the same surface are compared using the software Inspect Plus®. After a manual orientation using reference points, the software registers the scans to each other and calculates a "best fit orientation" (by specifying an error between 0.05 and 0.1 mm). Afterwards a comparison of the surfaces can be carried out. In order to demonstrate how much the two scans deviate from each other, the software creates a colour coded image illustrating the

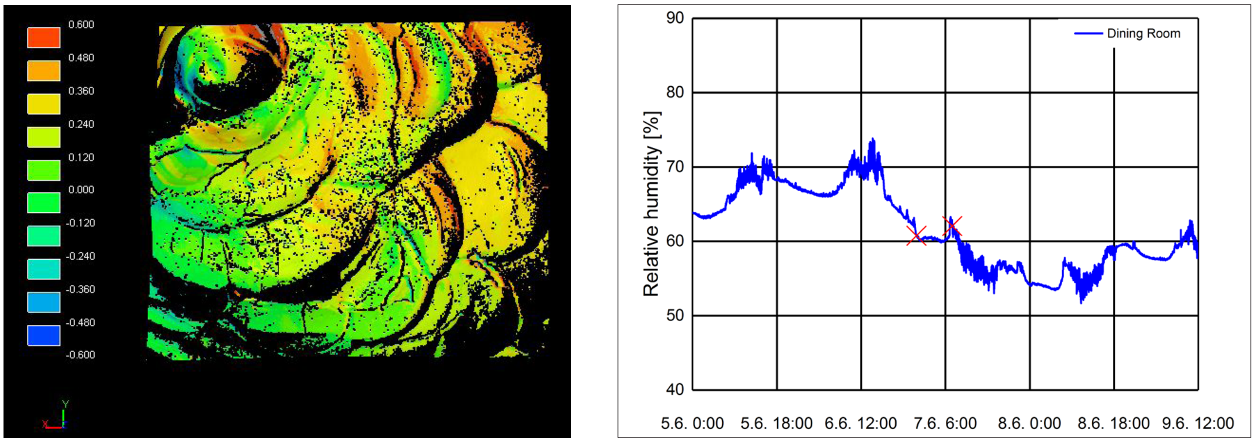


Fig. 6
Left: One-Shot Measurement: June 7th 2017, shows movements up to 1 mm (with ventilation system).
Right: RH during the whole measurement week. The time of the investigation with the SLS – 1shot-method (June 7th 2016) is marked with red crosses.

deviation. The scale of the false-colour illustration is manually selected. In this case, a dark green area means no change; areas which are coloured light green (minimum) to red (maximum) indicate a forward warping has taken place while colours from turquoise to dark blue indicate an increasing reverse warping (fig. 6).

The "1-shot-method" aims to minimise errors which can arise in the processing of the data. Two scans of the same area are taken at different times (last scan in the evening and first scan in the morning) without moving the measuring device. By this means it is possible to achieve a quantitative high resolution measure of the movement of the surface due to short-term climate fluctuations without the need to manually orient the scans via reference points (fig. 7).

3D-Microscopy and Time-Lapse Photography

For the examination of short-term fluctuations a single lens reflex camera (SLR) and a 3D-microscope were installed in front of the relevant area, focused on the damage, and left for the duration of the measurement campaign (fig. 5). The camera and microscope were programmed to take a picture every 20 minutes. Thus the impact of short term fluctuations could be examined micro- and macroscopically.

Unfortunately the analysis of the quantification of movement with the 3D-microscope didn't work on site as the motor used to focus on the object caused too many vibrations. Therefore, for both methods, an optical comparison was carried out by laying single images over each other using the graphical software Adobe Photoshop©. The change due to the mechanical response is made visible by tracing the contour of the flaking surface (fig. 5, left).

Results

As all recorded movements are caused by climate fluctuations it was necessary to correlate the results for all the deployed systems with the corresponding climate data. For that reason, a detailed record of climate data near the observed areas was carried out for the duration of the project.

Response of the Historic Furnishing to Short-Term Fluctuations

In the run-up to the implementation of the ventilation system, surfaces with existing damage (loosening of the surface or craquelure) were examined with the 3D microscope and SLR photography over several days during different seasons. As initially assumed, the movement of the loose parts was dependent on variations in the levels of moisture. In the summer months, for example, where daily fluctuations in RH could sometimes exceed 15%, the equipment showed a stronger movement than in winter when the room climate was more stable (see fig. 5). Figure 5, right, shows a graph of the T and RH next to the surface examined by 3D-microscopy. The green crosses mark the relevant climate at the time of examination. The evaluation of the investigation with the 3D-microscope is shown for the period of July 21st-22nd, 2014. The climate diagram indicates the most interesting times to be used for the graphical investigation. The method described here was also used for the evaluation of the data taken by the SLR-camera.

The investigations show that already loosened parts produced macroscopically visible movements caused by swelling / shrinking from a daily fluctuation of 10% RH. It was also seen that short term fluctuations do not affect the surface immediately, but occur after a short delay.

Compared to the results with the 3D-microscope, the loosened parts of the surface are seen less clearly with the SLR camera due to the reduced magnification. However, a mechanical response is still visible. Thus, examination with an SLR camera is sufficient for evaluating which short term fluctuations are acceptable.

With regard to the assessment of the reaction of the historical furniture to the changed indoor climate, the results of the "1-shot measurements" were particularly informative (fig. 6, left). The climate diagram (fig. 6, right) shows that the RH was very constant during the

Fig. 7
Combined illustration of photography and assessment of the structured light scanner (March-October 2015). The red lines mark the joints.

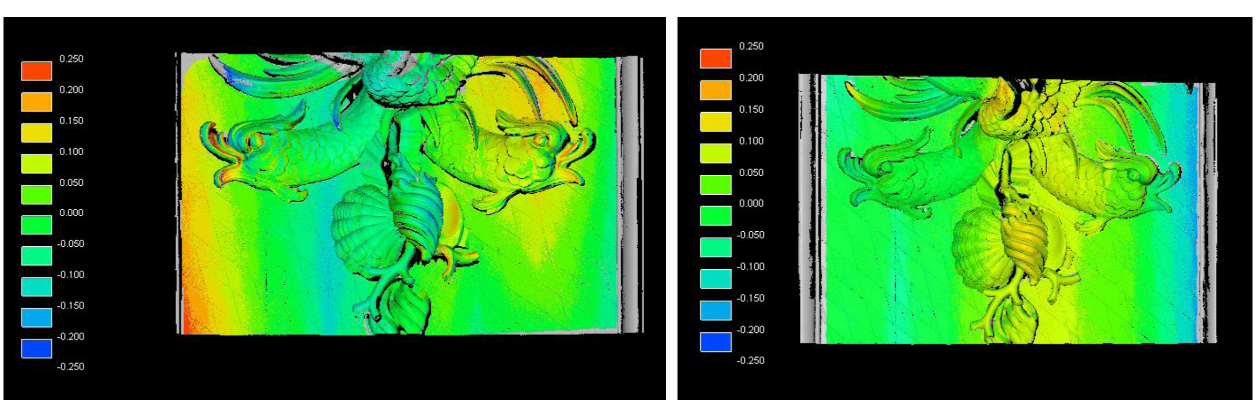
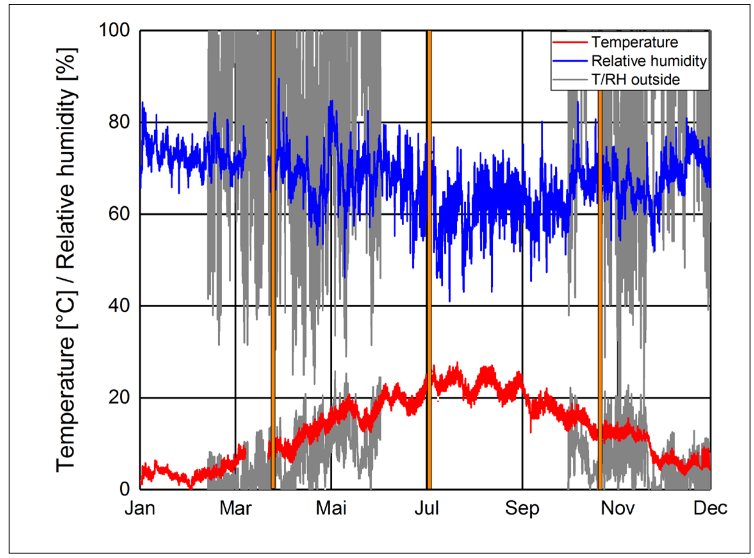


Fig. 8
Left: comparison March-July 2015. A clear shift of the panel is visible (blue: movement to the back, yellow/red: movement to the front). Right: comparison July-October 2015: the countermovement, although less distinctive, is visible. Both measurements were executed using the 250 mm lens. On both figures a movement of about ± 0.25 mm is visible.

Fig. 9
Line diagram of RH and T in the dining room (blue and red) compared to the outdoor climate (grey) for the year 2015. The orange parts mark the times when the measurement campaigns were conducted.



time when the measurements took place (red crosses, Δ 2.9% RH), but as there were quite high fluctuations in the days before the documentation, it is clear that the changes in the historic furnishings recorded by the 1-shot measurements are caused by those previous climatic changes. Also, the commissioning of the ventilation system began a long-term process of dehumidifying the furnishings, which might be visible here as well. An investigation over a monthly cycle could give a better answer here.

Response of the Historic Furnishing to Seasonal Fluctuations

The example described in this paper is a carved and gilded wooden panel dedicated to the art of fishing, situated in the dining room. Flaking and losses of gilt were found on the panel, especially on the left fish head (fig. 3). The joints have been partially repaired, which indicates large mechanical responses in the composite material (fig. 7). Before the installation of the ventilation system, the biggest and most frequent movement of the panel occurred between spring and autumn 2015 (fig. 8). During that period, various parts of the panel reacted differently. From March to July the left part of the surface warped to the front (fig. 8, left), whilst from July to October the right part warped to the back (fig. 8, right). The changes in T and RH over the course of 2015, as well as the times of data collection (marked in orange), are detailed in figure 9.

After the implementation of the ventilation system two measurement campaigns were conducted in June and July 2016. The results are shown in figure 10. The observed surface shows a movement of ± 0.2 mm, comparable to the previous measurements. We can see that the climate created by the ventilation system has so far not increased the movement in the historic furnishings. However, observations must

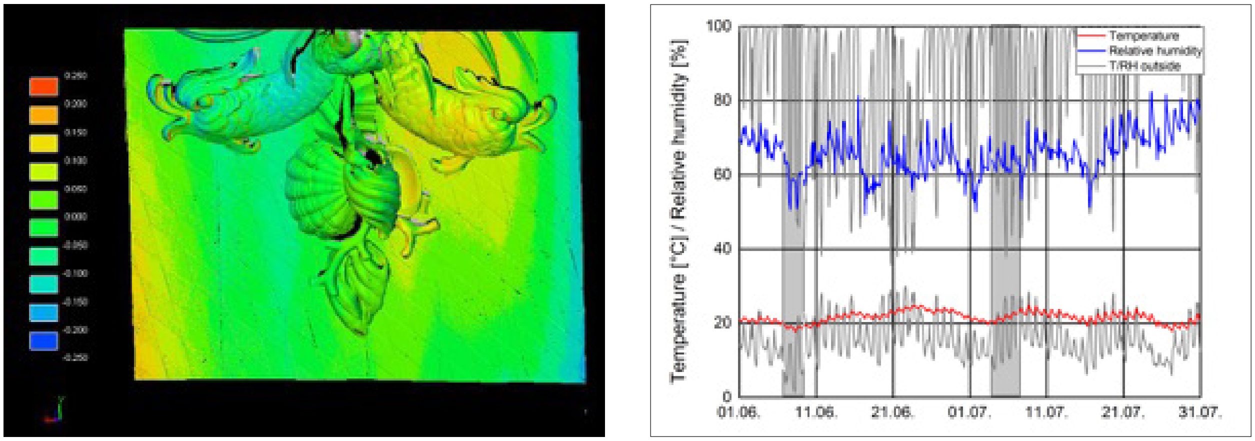


Fig. 10
Left: The comparison June-July 2017 with the 250 mm lens shows a movement of ± 0.2 mm.
Right: diagram of T and RH of the dining room (blue and red) compared to the outdoor climate (grey) from June 1st till July 31st. The time when the measurements where conducted are marked with grey areas.

be conducted over a longer time period before we can make a reliable statement.

In conclusion, the examined panels show a clear mechanical response to seasonal changes in the environment. Depending on the position of the objects in the palace, the response was most pronounced between either spring and summer or spring and autumn. The counter-movement, which correlates to the seasonal changes of climate, was noticeable between summer and autumn. The mechanical response in spring (fig. 8, left) and in autumn (fig. 8, right) clearly differed. This can be explained using the amplitude of two sine waves as an example: depending on the phase displacement the wave intensifies or decreases. In our case the mechanical response depends on the climate conditions. It should be pointed out that the measurements record just a single moment of the total environmental condition, therefore it is not surprising that the maximal mechanical response differs depending on the location and the equilibrium moisture content of the individual panels. Increasing the measurement intervals (for example, monthly) provides more detailed information on the movement and dimensional changes of the panels. In figure 10 the reaction of the surface to the “new climate” created by the ventilation system can be seen. The historic furnishings react to the decrease in average RH but the movement does not exceed the previous movement of ± 0.2 mm measured in June / July 2017.

Effects of the Ventilation System on the Indoor Climate – First Evaluation

As stated earlier, the indoor climate in Linderhof Palace is affected by strong daily fluctuations. These occur especially in the summer months due to the high number of visitors as an additional source of T and humidity. This forces the staff to open the windows for additional fresh air.

By implementing the ventilation system, the room climate is being gradually dehumidified as a fast change of the overall climate might stress and damage the historical surfaces. Therefore the RH will be reduced in small steps over several years. For the moment the value is around 67% RH, within the next few years it will be reduced to the target value of 62% RH.

Further monitoring campaigns will show how the ventilation system reduces short-term fluctuations, especially in the summer months.

Conclusion and Outlook

The comparison of the first measurements shows the great potential of MVM to answer questions of preventive conservation. Using this combination of techniques, the strengths and weaknesses of the individual technologies can be exploited optimally. Using SLS, three-dimensional measurement data of the historical surfaces are available in extremely high resolution. Here, even the smallest movements of the surfaces can be recorded and visualised, comparing measurement campaigns with sub millimetre accuracy over a long period of time. But during each campaign – except for the "1-shot measurements" – the test areas could only be documented once per measurement field (250 mm and 75 mm).

The 3D microscope is ideally suited for the detection of daily movements and allows for semi-automatic recording and visualisation. The comparatively complicated setup of the technique, however, only allows the recording of one or a maximum of two sample areas per campaign. Another restriction is that only data acquired over the course of a single campaign can be compared directly, because the camera position and the viewing angle must not be changed between measurements. Here the technique of digital image correlation might improve the evaluation of the data.

The SLR photography represents the third column of the MVM. Here, a very simple setup can be used to automatically record photosets of the test surfaces, and visualization of the results is also simple. This allows the short-term movements to be documented very well. However, only photos are taken and, as was the case with the 3D microscope, only the images from a single campaign can be compared directly.

Since for all the techniques, the recording time of the data is documented to the second, the results can be linked directly to one another and also correlated with the climatic measurements. This makes it possible to differentiate the effects of the short-term, daily climate fluctuations from the long-term movements, enabling further investigations.

Showing the movement due to changes in T and RH is an important step considering the potential for damage caused by fluctuations in climate. But in order to distinguish between periodic movements and actual damage, further investigations are necessary. The analysis of T- and humidity distribution inside an artwork via a hygrothermal simulation will help in evaluating the optical results.

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