THE IMPACT OF VIBRATIONS ON FRAGILE HISTORICAL MIXED-MEDIA OBJECTS

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Abstract

The Enclosed Gardens of Mechelen are beautiful examples of historical mixed-media objects. Since they are extremely fragile, vibrations are considered a major agent of deterioration. To prepare and evaluate their permanent exhibition and to support decision making for future loans, three experiments were performed to estimate the vibrational impact. First, resonant frequencies were defined in a shaker table experiment. Second, the impact of transport was considered. A truck transport of three Gardens to a temporary exhibition was monitored and the condition of the Gardens was documented before and after transport. Finally, a vibrational assessment was performed on the permanent display.

Keywords
Enclosed Gardens, Preventive conservation, Resonant frequency, Transport, Vibrations, Damping.

Introduction

Within heritage conservation, vibrations, along with shock have long been considered to be a relevant deterioration factor (Wei, Sauvage, & Wölk, 2014). However, research on the deleterious, cumulative effects of vibrations is scarce and the impact is difficult to estimate. No comprehensive conclusions can be drawn from the literature which could help heritage caretakers to establish satisfactory preventive conservation measures. This is definitely the case for sensitive historical mixed-media objects such as the extremely fragile 16th-century Enclosed Gardens of the Augustinian Hospital Sisters of Mechelen, a historic town in Belgium (Figure 1). These are devotional wooden cabinets with painted cabinet doors, polychrome wooden statues called 'Poupées de Malines', silk flowers with a basis of metal wire and parchment, vellum paper rolls that are wrapped in textile, relics, metal pilgrim badges, wax medallions, glass beads, cherry kernels wrapped in textile to represent grapes, etc. The Enclosed Gardens are unique remnants of the medieval era, reflecting feminine domestic art and female spirituality. The city museum 'Court of Busleyden' in Mechelen has seven of these cabinets in its collection. That is quite special, since most Enclosed Gardens did not survive the ravages of time, or were destroyed due to a lack of understanding and interest (Baert, 2012; Baert & Iterbeke, 2017). Until the late 20th century, the Enclosed Gardens of Mechelen were conserved in their original location and context, the small community of Augustinian nuns in Mechelen. Thereafter, they were exhibited in the Aldermen's

House in Mechelen and in the guildhall ‘In de Grooten Zalm’ (de Nijn, 1998). That was their final location being moved to the temporary restoration workshop in the Court of Busleyden, where an interdisciplinary team of conservators started with the restoration treatment of all seven Enclosed Gardens in 2014.

Figure 1 - Enclosed Garden with the representation of Saints Elisabeth, Ursula and Catherine. The painted wings represent one male and two female figures with their patron saints, the Apostle James the Greater and Saint Margaret (Watteeuw & Iterbeke, 2018). Photograph after the 2016 restoration (dimensions: 134 x 97.5 x 22.2 cm when closed). (© KIK-IRPA, Brussels, x103035)

The Enclosed Gardens are expected to be sensitive to vibrations for the following three reasons. (1) Most flowers and vegetal motives in the Enclosed Gardens are made of a metal frame, meticulously wrapped with silk wire. The silk is highly deteriorated, and material loss has occurred. The silk that is still present often consists of loose fibers that easily break off, causing additional material loss. Numerous broken silk fibers were found in dust samples that were removed by the textile conservator. Vibrations could therefore cause additional loss of fibers. (2) The variety of objects in the cabinet are attached in different ways to an inner cabinet, a thin wooden construction. Most objects are mounted using (degraded) linen wire that is tied up using holes in the inner cabinet. Some objects are fixed by pushing them through a hole in the inner cabinet, while others are stapled, glued or fixed with needles. Under vibrational loads, the mountings could fail. (3) Most of the polychrome wooden ‘Poupée de Malines’ are mounted with a dowel in a block of peat that is wrapped in textile. However, over time, the hole in the peat has become larger, and the stability of the wooden statues can no longer be guaranteed.

The city museum of Mechelen wants to preserve and exhibit the Enclosed Gardens in well-considered conditions. With respect to the protection of these objects from further degradation and material loss due to vibrations, the following monitoring and testing program was carried out. (1) Resonant frequencies of small Enclosed Garden objects were experimentally determined using a model of a garden mounted on a so-called vibration or shaker table. The highest risk of damage for the Enclosed Gardens would occur at the resonant frequency of the various small objects in the cabinet. (2) The effect of vibrations due to transport was studied during the transport of three original Enclosed Gardens from Mechelen to Museum M in Leuven for the temporary exhibition 'In search of Utopia' (20/10/2016 – 17/01/2017). (3) Finally, the vibration behavior of the showcases for permanent exhibition was determined.

This paper reports the results of this study and how they have been used to support decisions made concerning the exhibition of the Enclosed Gardens, and possible future loans.

Materials and Methods

Test Model of the Enclosed Gardens

A test model of the Enclosed Gardens was prepared for vibration testing, see Figure 2. Dummy flowers and grapes were made by textile specialists. To mimic the highly deteriorated state of the historic textile, the dummies were aged for 9 weeks by thermo-oxidation at elevated temperature (Koperska, Pawcenis, Bagniuk, Zaitz, & Missori, 2014; Vilaplana, Nilsson, Sommer, & Karlsson, 2015). Subsequently, the aged flowers were mounted in a model cabinet (dimensions: 90 x 125 x 25 cm). Since one Enclosed Garden was fully dismantled during the restoration treatment, the restorers wanted to know which 'new' material induces the lowest vibrations on the small objects. Different materials were tested: brass, linen or polyester wire. Aged linen wire was also considered since many objects are still mounted in their original location. To mimic the wooden statues, wooden blocks of 8.5 x 6.5 x 15.5 cm with a dowel were used.

Peat blocks were wrapped in textile to mimic the bottom of an Enclosed Garden. Three situations were experimented:

- a narrow hole in the peat that represents the initial situation, just after the manufacturing of the Enclosed Gardens;
- a large hole in the peat that represents the situation before the restoration;
- a possible restoration treatment where the dowel was made thicker using bamboo wood.

Vibration Testing of a Model Enclosed Garden

The model Enclosed Garden was tested on a shaker table in the testing facilities of Sebert Trillingstechniek B.V., Bergschenhoek, The Netherlands (Figure 2). Two mounting situations were simulated: transport and exhibition. During transport, the object's movement is determined by the transport case which is secured to the truck or airplane. Therefore, to simulate transport, the dummy Garden was firmly fixed to the shaker table (Figure 2a). In an exhibition, the object is usually not fixed or only slightly fixed to prevent it from 'walking'. Therefore, to mimic an exhibition situation, the Garden was not fixed to the shaker table (Figure 2b).

In order to determine the resonant frequencies of the various objects, the model was subjected to continuously decreasing vibration frequencies, at a constant acceleration level of 1 g. This corresponds to velocities of 17 mm s-1 (peak) at 9 Hz, 3 mm s-1 at 50 Hz and less than 1 mm s-1 at 100 Hz. Resonance testing was conducted both in the horizontal and vertical directions. Video recordings were used to visually evaluate resonance, since mounting sensors is not an option for low mass objects. The resonance of various types of objects is plotted in this paper on a relative scale of 0 (no resonance) to 100 (high resonance) based on the subjective visual judgement of a number of conservators present during the testing (see Figs. 3 and 4 in the Results section). Note that an object is considered to resonate "strongly" in terms of the relationship between the amount it moves and its size. Thus, a small object vibrating at an amplitude of, say, 1 mm, is considered to have high resonance compared to the woodblocks also vibrating at an amplitude of 1 mm.

The resonance experiment was also carried out on a small early 20th century mixed-media object that was built based on the Enclosed Gardens (private collection, dimensions: 24 x 29 x 4 cm) (Figure 4).

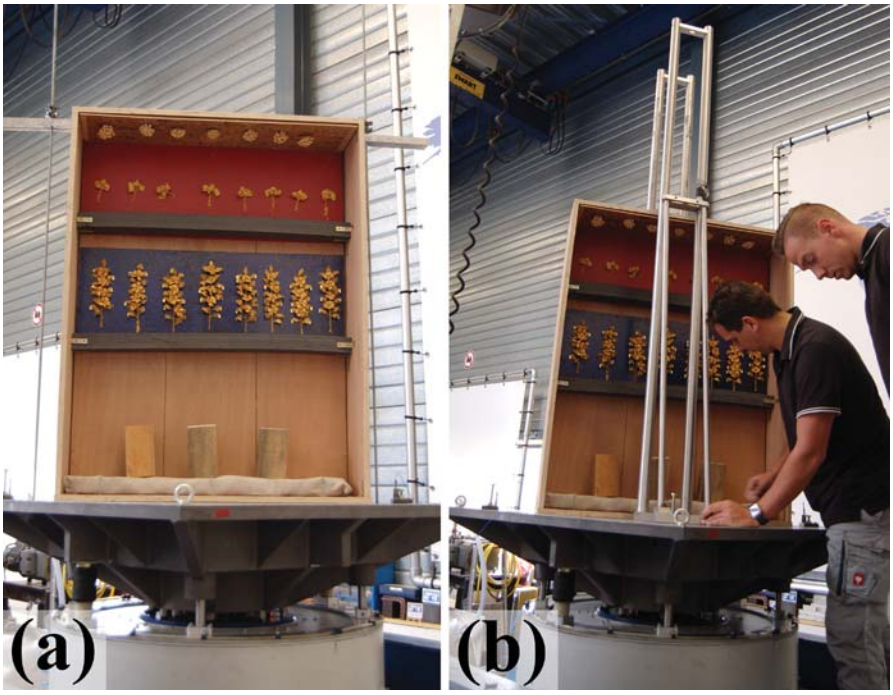

Figure 2 - Model of Enclosed Garden mounted on a vibration table at Sebert Trillingstechniek B.V.(a) Fixed simulating transport; (b) Free-standing simulating exhibition. The rod structure prevents the model from "wandering".

Vibrations During Transport

Three Enclosed Gardens were transported from the restoration workshop in the Court of Busleyden, Mechelen, to Museum M in Leuven for a temporary exhibition. Conservators provided a support for the cabinets, which acted as a damping material for the cabinet doors. They also fixed the most fragile objects in the cabinets. The art handler provided a truck with air suspension. Moreover, additional dampers were mounted under the transport cases. The route selected was primarily over highways, and the transport took around 45 minutes.

A simple triaxial accelerometer was used for measuring shock (in g) in the frequency domain of 0-60 Hz (VB300, Extech, FLIR, Nashua, New Hampshire, USA). Actual vibration loading could not be measured with this sensor. The logger was positioned on the hinge of one of the Enclosed Gardens using a magnet. Data were recorded every 50 minutes. The condition of the object was documented with macrophotographs by a photographer from the Royal Institute for Cultural Heritage, Belgium, just before and after transport.

Vibration Loads in Permanent Exhibition

Although the vibration levels in the permanent exhibition in the Court of Busleyden are expected to be lower than in transport, the exposure time of transport is a matter of hours, whereas the exposure time of the exhibition is a matter of years. Wei, *et al.* (2014) have proposed a vibration guideline of 2 mm/s (peak value) for a single event for museum collections in good condition. This guideline is not valid for a situation such as that of the Enclosed Gardens on permanent display. Therefore, vibration-damping was considered in the design of the display cases. A synthetic viscoelastic urethane polymer was selected by the showcase designer for vibration damping (stud mount 0510450-70-10 with durometer 70, Sorbothane, Inc., Kent, Ohio). This material can work as a vibration damper in the frequency range above 10 Hz.

To test the efficiency of the vibration dampers, vibration monitoring was conducted in the permanent exhibition room where the Enclosed Gardens are displayed. Vibration sensors, so-called accelerometers (PCB Piezotronics model 393A03, Depew, NY, USA) were placed at three locations in the permanent exhibition room of the Enclosed Gardens. One was placed in the middle of the floor between two support beams. The two other accelerometers were positioned in the showcase, one on the frame in the technical area at the bottom of the display case below the vibration dampers, and the other one on display next to the Enclosed Garden shown in Figure 1 above the vibration dampers. Monitoring was conducted on one day from midnight to midnight. Note that the museum was open from 10:00 AM to 10:00 PM. Vibrations were monitored continuously at a rate of 1024 Hz. In the current study, the maximum vibration levels are reported for 30 second time intervals. Frequency analysis was conducted using proprietary software.

Results

Vibration Testing

The results of the vibration table testing on the model of the Enclosed Gardens and the 20th century mixed-media object are shown in Figures 3 and 4. As discussed previously, the graphs show relative levels of vibrations as a function of frequency based on subjective visual judgements on how much the objects move at a given frequency.

In general, the results show that the resonance of all objects in the model Enclosed Garden occurs at low frequencies ≤ 20 Hz (Figure 3). Relative resonance levels are higher for smaller objects such as the sequins, grapes and leaves. The levels are also higher for horizontal excitation than for vertical excitation for both the exhibition (free position) and transport (fixed position) simulations. For the original 20th century mixed-media object (Figure 4), only horizontal vibrations were tested. For this object, the flowers showed various levels of resonance with the white wire flower (nr. 4 in image) showing the highest level. The resonant frequencies were below 30 Hz.

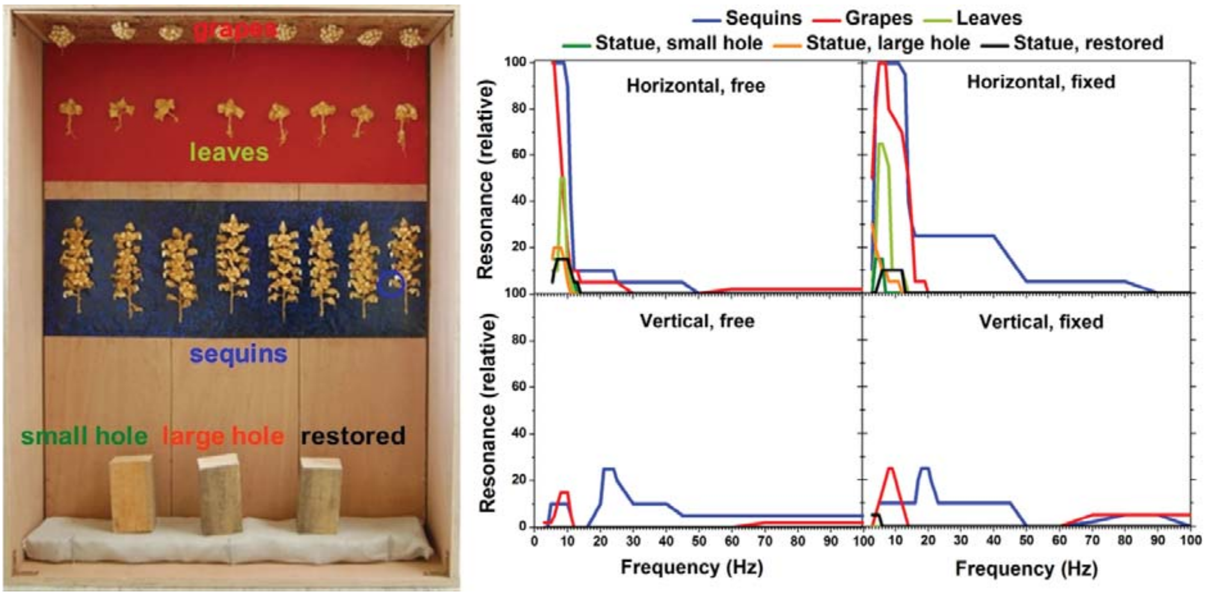

Figure 3 - Left: Dummy Enclosed Garden. Right: Resonant frequencies for the sequins, grapes, leaves and wooden statues in the dummy Enclosed Garden, for horizontal and vertical vibrations, and for a free and fixed position of the cabinet on the shaker table.

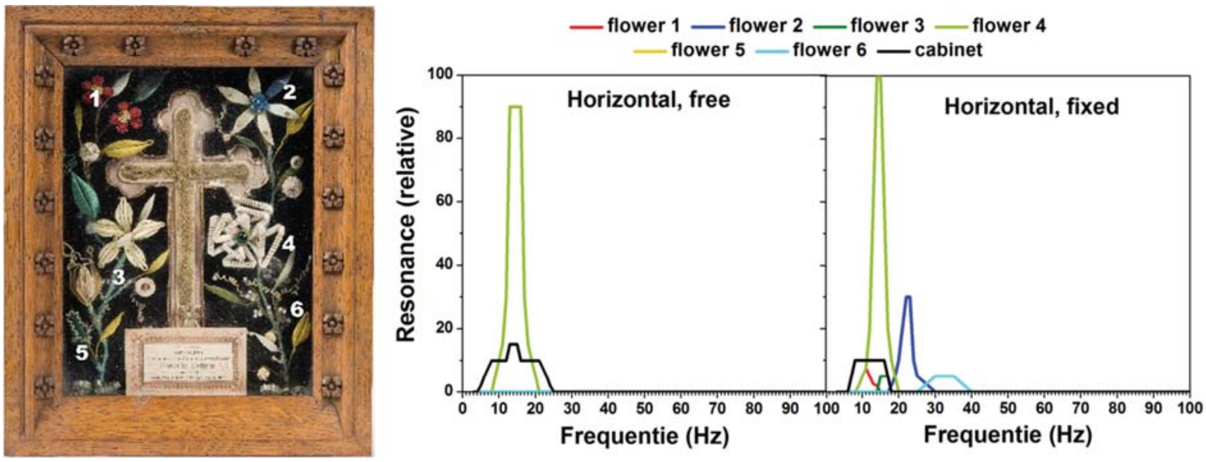

Figure 4 - Left: Original mixed-media object inspired on the Enclosed Gardens with the indication of the flower numbers used in the graphs (©KIKIRPA, Brussels, x109633). Right: Resonant frequencies for different flowers and the cabinet itself, for horizontal vibrations and for a free and fixed position of the cabinet on the shaker table.

Shock During Transport

The results of the monitoring of shock loads during transport of one of the Enclosed Gardens are shown in Figure 5. The X-axis corresponds to the driving direction of the truck, the Y-axis to vertical movement, and the Z-axis to lateral movement. Note that the Y-axis has a 1 g offset to account for gravity. In the figure, four periods are labeled, three periods when the transport case was handled and one period of transport. There was no activity in the unlabeled areas. Monitoring began as soon as the Enclosed Garden was placed in the transport case (first handling period). It was then moved from the conservation studio to the truck (second handling period). For this, the transport cases were placed on a small cart with low tire pressure. When necessary, the route was leveled with plastic mats. After transport, the transport cases were unloaded and brought into the museum with the carts. Unfortunately, this part of the trip could not be monitored due to storage limitations of the logger. Finally, the Enclosed Gardens were placed in their temporary exhibition cases (third handling period).

One major shock in the X-direction was measured during the initial handling. Otherwise, most shock events were measured during transport, with the levels being higher in the vertical direction (Y-axis) than in the driving direction (X-axis). There were no shock events measured in the lateral direction (Z-axis) above background levels (see the inactive period between the first two handling periods, Figure 5). Photographic documentation showed that after transport, a number of the silk objects were slightly displaced. Several detached silk fibers were also found on the bottom of one of the Enclosed Gardens (Figure 6).

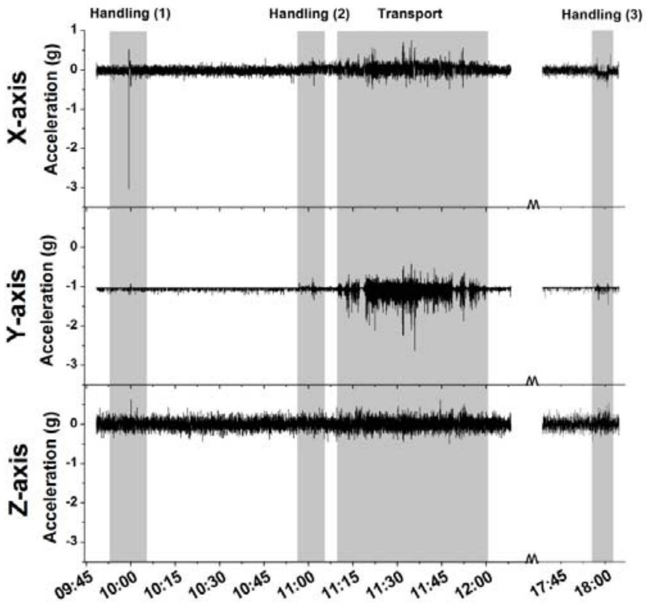

Figure 5 - Shocks and vibrations measured during handling and transport of an original Enclosed Garden to a temporary exhibition. X-axis: driving direction of the truck; Y-axis: vertical movement; Z-axis: lateral movement.

Figure 6 - Macroscopic image of a detail of the monitored Enclosed Garden after transport to Leuven showing two silk fragments (white circles) that were detached during transportation. (© KIK-IRPA, Brussels, x105263)

Vibrational Loads in Permanent Exhibition

The vibration levels recorded for the three positions during exhibition are shown in Figure 7. From midnight to roughly 5:30 AM, vibration levels were very low. Beginning at 5:30 activity increases and remains fairly steady throughout the day until closing of the museum at 10:00 PM (22:00 hours). During the measurement day, the museum opened at 10:00 AM, but the museum staff was present earlier. However, since the vibration levels between 6:30 and 9:00 AM are roughly at the same levels as the rest of the day, human activity is not the only source of vibrations. Based on spectral and frequency analysis, bus and truck traffic in a street at around 35 meters from the exhibition should also be considered as a vibration source. These excitations cause vibrations in the 8-20 Hz frequency range.

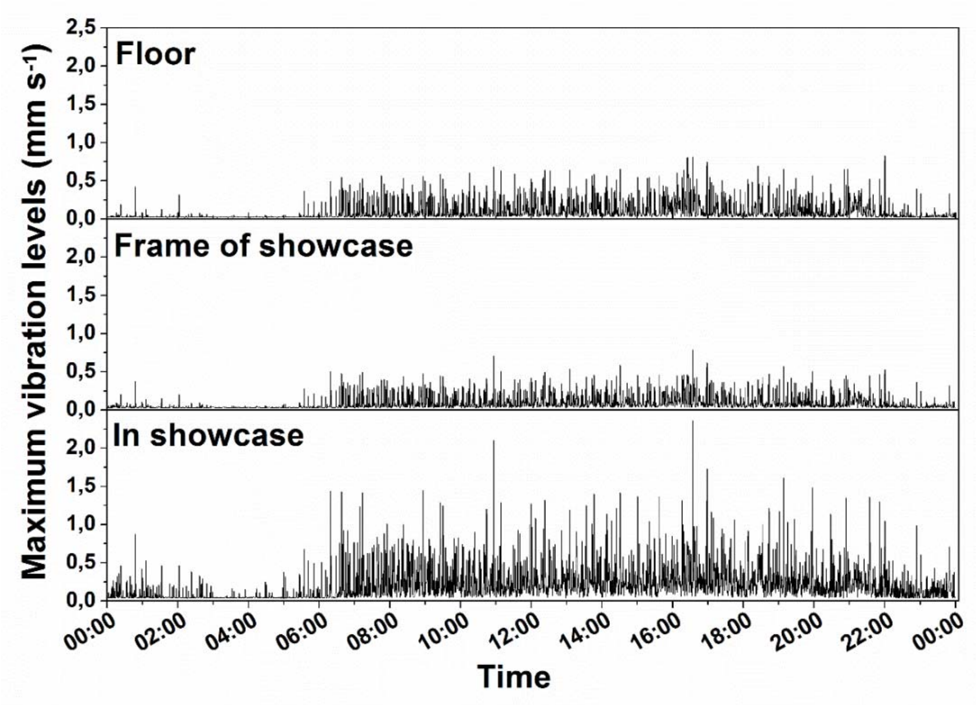

Figure 7 - Maximum vibration levels measured for every thirty seconds during the 24 hours monitoring period; overview for the three measuring locations: floor, frame of showcase, and in the showcase next to an Enclosed Garden.

The maximum vibration levels measured every 30 seconds on the floor are slightly higher than the frame of the showcase, but most values are roughly below 0.4 to 0.5 mm/s. On the other hand, the vibration levels near the Enclosed Garden are roughly below 0.7 mm/s, with occasional peaks to 1.5 mm/s, and two peaks ≥ 2 mm/s. This indicates that in spite of the damping, the showcase near the object is vibrating at a higher level than the incoming vibrations from the floor.

Discussion

A number of important observations can be made based on the results of the experiments conducted in this project. The first observation is that resonance testing showed that the various objects in the Enclosed Gardens resonate at frequencies below 50 Hz, with maximums around 20 Hz. It is well known in the engineering field that these are frequencies typically found in truck transport, and in buildings due to, among others, external sources such as road traffic, and the movement of people. Object deformation and displacement tend to be larger at such low frequencies. These resonance issues due to the transport, road traffic and human factors are all relevant when considering the long-term condition of the Enclosed Gardens.

The second observation is that in spite of precautions taken in preparing the Enclosed Gardens for the short loan transport, some damage occurred. It is not clear whether the damage was caused by handling shocks, or by accumulation during transport. A recent study of the transport process by the Technical University of Bern, Switzerland (Läuchli & Bäschlin, 2017), reported high shock levels measured during the loading and unloading of objects, in particular when the transport personnel were not aware that they are being monitored. In the current case, one large shock was detected in the placement of the Enclosed Garden into the transport case. However, all handlers were aware that the transport was being monitored, so subsequent shock levels during further handling and transport were relatively low.

It should be noted that the silk fibers were already at a point where they would probably have detached due to any movement. The Enclosed Gardens had just undergone a conservation treatment, including the cleaning of the silk objects. Since it is almost impossible to clean strongly degraded silk without additional material loss (MEMORI, 2013), it is expected that most but not all loose silk fibers were removed during the cleaning treatment. The discussion is still open as to what the loss of value of the few silk fragments represents for the Enclosed Gardens, and is beyond the scope of this paper. The point is that, in spite of great precautions, there was some damage to the Enclosed Gardens due to this short transport. Although the g-values of shock cannot be directly translated into vibration velocity levels, it is clear that there is thus a very high risk for further damage if they are loaned again.

The third observation concerns the permanent exhibition of the Enclosed Gardens. The incoming vibration levels from background sources such as road traffic near the museum, or from visitor traffic are typical for most museums which several of the authors (RCE and Tractebel) have monitored over the past years. However, referring back to Figure 7, the vibration levels in the showcase near an Enclosed Garden show that the levels there are actually slightly higher than the incoming vibrations. Furthermore, it was observed that small objects in the Enclosed Gardens moved as visitors walked by. An in situ resonance test conducted in the exhibition hall resulted in resonances of around 20 Hz measured near the Enclosed Garden. Although the measured vibration levels are low, even for resonance, all of these results indicate that the showcase is not performing optimally, that is, reducing vibration levels, and reducing resonance at the frequencies of interest for the small objects in the Enclosed Garden. The museum Court of Busleyden together with the showcase manufacturer are now looking for an optimized showcase design.

The question thus remains as to what vibration conditions are suitable, that is, low risk for the permanent exhibition of the Enclosed Gardens in the long term, that is, over periods of years. This question is impossible to answer at the moment, based on only one day of vibration monitoring as well as the lack of long-term object testing experience with similar objects. Wei *et al.* (2014) have proposed a guideline of 2 mm/s for single events which is valid for collections in good condition and at frequencies below 50 to 100 Hz. They have also recently shown that there is some flexibility possible with this guideline (Wei *et al.*, 2018). However, the guideline is not valid for single objects, especially as fragile as the Enclosed Gardens, and for the long periods of time associated with permanent exhibitions. It may well be that for such fragile objects, so-called background levels of vibrations may prove to be damaging to the objects in the long run. Besides optimizing the showcase damping, it is thus recommended that the condition of the Enclosed Gardens be monitored regularly and measures taken if further damage occurs. One possibility applied by the RCE in two other museums is to consider lowering the lighting and changing the routing around the objects, creating a sort of "sacred" effect in order to slow visitors down as they move past the objects.

Conclusion

A monitoring project was carried out in order to determine the effect of vibration on the condition of historical mixed-media objects, 16th century Enclosed Gardens of Mechelen, Belgium. The project included resonance testing of a model Enclosed Garden on a commercial vibration table, shock monitoring during transport of three Enclosed Gardens to a temporary exhibition, and vibration monitoring of an Enclosed Garden in its showcase on permanent exhibition.

The results indicate that the Enclosed Gardens are indeed quite susceptible to vibrations, both in transport and on exhibition. Damage, though minor, did occur during transport in spite of great precautions taken to protect the objects. Further loans of the Enclosed Gardens are therefore not recommended. Objects on permanent exhibition had not yet shown damage in the short term, and vibrations measured in the exhibition hall were quite low. However, visitor movement does cause visible movement of small objects in the Enclosed Gardens, and vibration monitoring did indicate that the showcase design needs to be further optimized to properly reduce vibration levels and dampen resonance as determined during resonance testing. Current guidelines and available object testing data for allowable vibrations and duration in museums do not cover single objects and permanent display situations. Periodic condition monitoring of the Enclosed Gardens on display is thus recommended. Lighting conditions and visitor routing can also lead to lower vibration levels due to visitor traffic.

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Willemien Anaf

Is a conservation scientist, specialized in preventive conservation and air quality. In 2009 she graduated from the University College of Antwerp as a Master in Conservation and Restoration. In 2014, she completed a PhD at the University of Antwerp, Chemistry Department: "The influence of particulate matter on cultural heritage. Chemical characterization of the interaction between the atmospheric environment and pigments". Finally, she contributed to several heritage-related projects, of which one was on the elaboration of preventive conservation measures for the Enclosed Gardens.

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Is a senior scientist, specialized in the study of painting techniques and materials. She studied Chemistry at the University of Ghent, where she obtained her MA and PhD (1990). She has worked in the Laboratory Department of KIK-IRPA since 1991.
Her research activities are split between analyzing painted finishing layers of murals, monumental decoration (interior and exterior) and wallpaper and the identification of the various components in pictorial layers and/or inks of manuscripts or paint on paper and leather, mostly using non-invasive techniques.
She is currently also involved in the BRAIN-be ARTGARDEN research project (Art-technical research and preservation of historical mixed-media ensembles: Enclosed Gardens).

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Luc Schillemans
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