Journal of the American Institute for Conservation

ISSN: 0197-1360 (Print) 1945-2330 (Online) Journal homepage: https://www.tandfonline.com/loi/yjac20

Life Cycle Assessments of Loans and Exhibitions: Three Case Studies at the Museum Fine Arts, Boston

Sarah Nunberg, Matthew J. Eckelman & Pamela Hatchfield

To cite this article: Sarah Nunberg, Matthew J. Eckelman & Pamela Hatchfield (2016) Life Cycle Assessments of Loans and Exhibitions: Three Case Studies at the Museum Fine Arts, Boston, Journal of the American Institute for Conservation, 55:1, 2-11, DOI: 10.1080/01971360.2015.1112465

To link to this article: https://doi.org/10.1080/01971360.2015.1112465

LIFE CYCLE ASSESSMENTS OF LOANS AND EXHIBITIONS: THREE CASE STUDIES AT THE MUSEUM FINE ARTS, BOSTON

SARAH NUNBERG[1], MATTHEW J. ECKELMAN[2], AND PAMELA HATCHFIELD[3]

[1] *The Objects Conservation Studio, LLC, Brooklyn, NY, USA*
[2] *Department of Civil and Environmental Engineering, Northeastern University, Boston, MA, USA*
[3] *The Museum of Fine Arts, Boston, MA, USA*

This project grew from discussions concerning the environmental impact of museum and cultural institution activities. Life cycle assessment was the chosen tool to address pressing questions around this topic. Three life cycle assessment case studies were commissioned for this project. Case Study 1 considered the materials and environmental impact related to loan preparation and shipment of a single crate to two different venues. Plexiglas™ vitrines, gallery lighting, and climate controls were responsible for approximately one-third of the carbon emissions from the exhibition preparation phase. Crate and Plexiglas™ reuse as few as four times would significantly lower the loan carbon impact. The highest environmental impact of all loan phases proved to be the carbon foot print of the courier who travels two round trips for every loan round trip and has more than three times the impact of the art transport. Case Study 2 compared efficiencies of the cost and life cycle of halogen lamps with light emitting diode lamps in a single Museum of Fine Arts gallery. This study concluded that in addition to long-term cost savings, light emitting diode use results in lower environmental impact, lower eco-toxicity, and fewer human health indicators than halogen lamps. Case Study 3 addressed cost and energy savings resulting from the temporary shutdown of air handling equipment for one newly constructed gallery at the Museum of Fine Arts.

KEYWORDS: *Life cycle assessment, Museum loans, Cultural institution loans, Environmental management, Sustainable practices, Preventive conservation, Museum lighting, Carbon footprint*

1. INTRODUCTION

Sustainability is at the heart of conservation—sustaining our shared cultural heritage so that it may be experienced and enjoyed by future generations. Environmental sustainability is expressed using much the same language. The most widely used definition of sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," (Bruntland 1987). Strains on natural resources have driven industries worldwide to explore new approaches to energy use, industrial production, and consumption of goods and services in our professional and personal lives. Although museum professionals have begun to follow these trends, aspects of museum practices established over the past 60 years make intensive use of energy, supplies, and solvents, many of which are hazardous to conservation professionals. Some of the least sustainable practices are associated with loans and temporary exhibitions that require short-term use of materials, while heating, cooling, dehumidifying, and lighting of storage and exhibition spaces within a narrow band of environmental conditions is highly energy intensive. The tremendous financial pressure on museums to increase loan activity simultaneously increases energy demands and materials use, involving extensive packing systems to safely ship fragile, valuable artifacts. Additionally, transporting artifacts involves long-distance shipping by truck, air, or ship, often internationally. The high economic, cultural and educational value placed on providing national and international accessibility to objects means that the practice of loaning will continue for the foreseeable future. This reality calls for the development of sustainable approaches to the transport and exhibition of art so that, as natural resources dwindle, practices are in place that will allow us to responsibly continue caring for and providing access to our cultural heritage. Additionally, due to limited virgin resources, the cost of packing and transporting art will continue to rise, eventually limiting the ability of most institutions to bring together exhibitions of objects from diverse global collections. By identifying hotspots in loan activity, we can consider new more sustainable practices that will allow for continued loans, reducing costs as well as environmental impact.

DOI: 10.1080/01971360.2015.1112465

It is natural that cultural and environmental sustainability enjoy some synergy, and there have been several notable efforts in the "sustainable museums" space. Simon Lambert's research based in the National Museum, Wales, was one of the first studies to address the carbon footprint of a museum loan (Lambert and Henderson 2011). Many recent conferences have been dedicated to sustainable cultural institution practice, institutions throughout the world are committing great efforts to reduce energy use and waste, and extensive information online reporting these international efforts can be easily accessed (AIC Sustainability Committee 2015; Conservation Science and Sustainable Development, 2013). Many of these early efforts by museums (and organizations of all kinds) have focused on footprinting: simply counting the energy use, water use or greenhouse gas (GHG) emissions that occur at museum facilities (*direct* inputs or emissions) as well as emissions that are embodied in the goods and services that museums purchase (*indirect* inputs or emissions). These simple metrics may not capture all of the environmental concerns of museums, but they are relatively easy to calculate and can often be based on utility bills. Energy, water, and carbon footprints are also often correlated with more complex sustainability metrics, such as toxic air pollution or public health impacts, so they provide a good starting point for many organizations seeking to measure sustainability in some way.

Footprinting is a sub-tool within the larger modeling framework of life cycle assessment (LCA), so named because it considers environmental impacts that occur both directly and indirectly (up and down the supply chain) from a facility, process or product. LCA is used around the world in a wide range of sectors to quantify sustainability along multiple dimensions or impact categories using a standardized protocol. LCA is most commonly applied to make decisions regarding product design and process improvements and to compare multiple options. LCA is designed to answer the familiar question, "which is the greener choice?" in a comprehensive way, considering both human health and the environment.

In 2013, The American Institute for Conservation of Artistic and Historic Works (AIC) sponsored a research project to analyze traditional approaches to cultural heritage institutions and their related conservation activities. Several LCA research studies were carried out with the Museum of Fine Arts (MFA), Boston in collaboration with Northeastern University, and all data were based on MFA activities and energy use. The goal of this paper is to present the results of the three LCAs that were the focus of the study, to clarify options for more sustainable practices, and to illustrate the use of the LCA as a tool for the evaluation of materials and processes used in the display, transport, and preservation of cultural heritage. Here, LCA was used to analyze a number of museum activities, including heating and cooling systems, traveling loans, exhibition preparation, gallery maintenance, and options for lighting galleries. The information presented in these LCA studies provides a basis for making informed changes to work habits and museum activities while maintaining the quality and effectiveness of conservation activities.

Consideration of the total environmental impact of an action or a series of actions provides the basis for retooling processes to achieve greater environmental and economic sustainability, both in the short term and long term. The LCAs in this study aim to provide information for cultural institutions to attain this goal while keeping in mind their overall mission to provide a public audience with the opportunity of experiencing cultural heritage in person. This is the function of an exhibit: not only to provide an institution with revenue, but to provide the public with the knowledge attained while personally viewing artifacts from a collection. This study strives to pinpoint viable options that allow the display and loan of cultural heritage, while preserving limited natural resources far into the future.

2. Case Studies Methods and Results

The International Organization for Standardization's (ISO) International Standard 14040 defines LCA as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (Guinee, 2004; ISO, 2010). The life cycle of a product includes extraction of resources and production of materials, fabrication of component parts and product assembly, the use of the product, and finally to waste management after it is discarded either by reuse, recycling or final disposal —a so-called cradle to grave approach. There are four stages of an LCA: (1) goal and scope, where the objective and boundaries of the study are set; (2) life cycle inventory, which counts all resource inputs and emissions along the life cycle (this is essentially footprinting); (3) life cycle impact assessment, where all of the emissions are expressed in terms of the potential environmental or human health impacts that they may have downwind or downstream; and (4) interpretation of results, including issues of uncertainty. The impact assessment step is the most complex and relies on sophisticated environmental science models. In the US, these models are primarily developed by federal agencies such as the Environmental Protection Agency (EPA) (NIST 2010; USEPA 2012a). Of course, there are many categories of environmental and health impacts arising from pollution. The most commonly tracked impact categories include energy and water use, emissions of GHGs, ozone-depleting substances, acid rain, nutrient pollution, and human and ecosystem toxicity, all counted over the entire product life cycle. Examining a product from cradle to grave avoids so-called burden-shifting when one environmental problem is solved by shifting the burden to another stage in the life cycle, or from one category of environmental impact to another, as would happen for example by using an energy-efficient but toxic light bulb.

For example, processes associated with an activity such as the life cycle of a solvent or plastic bottle can be explored from the initial production of the raw materials to product manufacture, use, distribution, and waste disposal. The information gained from analyzing this process, including identification of energy and resource intensive steps, allows for educated choices that will make the industry more economically and environmentally sustainable. A solvent or a plastic bottle is the final result of a long process, but people rarely consider where they come from, or where they go during their disposal. When trying to design a more efficient product, with less environmental impact from cradle to grave, understanding all aspects of the production, use and disposal phases is essential.

One key point of using LCA for comparing multiple alternatives is that each of the options must deliver equivalent performance or function in the given context. This is done through setting a "functional unit," or the measurable quantity that serves as the baseline for comparing one option to another, regardless of the physical form of each option. Thus, it is possible to compare surface treatments by solvent cleaning, mechanical cleaning or consolidation, even though these options require different types of equipment and operate through different mechanisms. A second important consideration is that LCA models depend on parameters that have inherent variability, particularly those associated with human behavior. For example, how much solvent is used to clean an oil painting of a certain size and condition may vary considerably across conservators. In order to control for this variability, analysts often run a so-called sensitivity analysis in order to evaluate different use or technological performance scenarios.

In this study, three separate LCAs were performed to examine some exhibition and storage practices common to most large museums: (1) loaning of objects, (2) exhibition lighting, and (3) environmental management. Over the three studies, overall energy and materials use involved in producing and transporting a loan were examined, considering gallery preparation, crate production and storage, associated administrative tasks, packing and transporting the art. The studies were carried out by undergraduate and graduate students at Northeastern University taking a course in LCA (Sanchez et al., 2013; Cai et al. 2013; Walker et al. 2013). For each of the studies, material and energy use data gathered at the MFA were compiled into a model using the commercial LCA software platform SimaPro 7.3 and linked to the life cycle inventory database ecoinvent 2.2, which contains generic information on the life cycle of many materials and processes (PRè Consultants, B.V. SimaPro software version 7.2). Impact assessment (linking emissions to environmental impacts) was carried out using the EPA's Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) model. Methodological details and assumptions for each LCA case study are listed in the sections that follow.

2.1 CASE STUDY 1: LOAN ACTIVITIES

The mission statements of most cultural institutions require sharing their collections with the public. Some institutions depend on loans as an important revenue source. However, for many institutions they are a financial liability that is considered necessary to fulfill the educational mission, often included in exhibition projects as necessary to flesh out an exhibition concept. Whereas fully developed loan exhibitions might be revenue generators for some museums, many institutions do not break even with loan fees. In 2013, the MFA loaned a total of 823 objects to 82 venues—twice the number sent 5 years before.

2.1.1 METHODS

The first LCA case study of this project addressed the environmental sustainability of loan operations at the MFA, using GHG emissions, or carbon footprint, as the primary measure. In particular, we were interested to understand (1) what aspect of the loan contributes the greatest carbon footprint; (2) which crate packaging materials were most impactful; (3) how much did crate reuse benefit the overall loan; and (4) what were the implications of loan destination. For every institution loan, there is a party loaning the piece and a party receiving it. Different processes are associated with either side of this transaction. For the purposes of this study, we focus on the aspects that the MFA control. This means, that rather than one complete loan, we will be looking at an incoming loan to and an outgoing loan from the MFA.

Incoming loan considerations included administrative and conservation work, impact of the crate stored on-site in controlled environments and of crates stored off-site without environmental control, gallery preparation involving the paint shop and the carpentry shop, exhibition space maintenance, gallery lighting, environmental management of the gallery, unpacking, and repacking. The incoming loan size was assumed as 30 crates.

Once unpacking is performed, the crates are stored either on-site or off-site. Crate transport was based on the round trip transport of the crates from the MFA to the off-site storage facility. The distance to the off-site warehouse was estimated to be 12 miles. The warehouse is 17,000 square ft. and 10 ft. high. The estimated power usage was at 1 Watt/square ft. The power usage for the MFA on-site location where the climate-controlled crates were stored was assumed to be 4 Watt/square ft.

Gallery preparation examined here included constructing, preparing and painting walls, installing lights, constructing, and installing exhibition cases with Plexiglas™ vitrines. Exhibition cases and vitrines are constructed in the paint shop and the carpentry shop at the MFA. A 12-pack of caulk was assumed for each gallery and 6.6 lbs of joint compound tape per gallery and 100 gallons of alkyd paint. Also included were painter's tape, caulk, joint compound, and tape, and the water and electricity consumption of the shop for one gallery installation. The carpenter's shop where cases were constructed included three small pieces of machinery at 60 lbs each and three large pieces of machinery at 500 lbs each. The exhibition also included the Plexiglas™ used for one gallery, Dibond®, Medium Density Overlay (MDO), the fasteners used to create the display cases, and the electricity used in the shop for construction. The exhibition space electricity usage and cleaning required for a gallery over 3 months was included. Administration preparation for the exhibition consisted of the electricity used in the registrar's office and in conservation.

Outgoing loan considerations included administrative and conservation work, crate construction and packing materials for the objects, transportation of the packed objects, and courier travel. The outgoing loan size was assumed as a single crate, under a number of shipping scenarios: transported by plane to Nagoya, Japan or by plane/truck to Tampa, FL. The functional unit in this study, measured in the *number of expected views for an entire exhibit*, was based on the exhibition yearly attendance rates at the MFA Nagoya and the Tampa Museum of Art. The number of crates sent in a single shipment will vary depending on the institution guidelines. For the MFA, loans can include a single crate or many. A typical shipment might involve 5–10 crates; more than that would probably travel in two shipments and would require additional couriers. This loan study assumed one crate that measured 150 × 100 × 33 cm and was assumed to contain any number of objects that would fit into that crate. It was assumed that the courier who traveled with the objects would spend 1 week in the exhibition city. The courier would require two round trip stays for each exhibit, including transportation either by plane or truck.

The MFA crates are made of kiln-dried plywood, lined at the edges and braced with pine then entirely coated with moisture cured polyurethane resin. For the purpose of this study, the crates were assumed to have been coated with epoxy resin. Fasteners and hinges are made of stainless steel. It was assumed that the lumber for the crates was felled in Burlington, Vermont. All lumber and plywood is kiln dried to meet international shipping standards. The data input assumed that a 12,000 square ft. crate manufacturer's warehouse used 5 kWh of electricity per year per square ft.

Materials used to soft pack the objects were included in the study, accounting for new packing material to deliver and return the objects. All foam products used in packaging for this study were assumed to be supplied by New England Foam, based in Hartford, Connecticut. Foam products included ester foam, open and closed cell polyethylene, high-density polyethylene (HDPE) and low-density polyethylene (LDPE) sheet, cardboard, foam core, and hot glue. The modeling for these plastics was carried out in SimaPro LCA software using extrusion and foaming processes applied to HDPE, LDPE and polystyrene plastic raw materials. The processes for making the foam, transporting the foam from Hartford, Connecticut to Boston and the production of carton board boxes were also included. Transport distances were calculated using the most direct land and air routes available.

2.1.2 RESULTS

For the incoming loan of 30 crates, we found that lighting and maintenance of the exhibition space for the duration of the exhibit was responsible for the highest contribution to loan GHG emissions with 36,800 kg of CO_2 equivalent emissions (fig. 1).

Of all the activities examined, the process of unpacking, paint shop preparation, and repacking contributed the least amount to the carbon footprint of the loan. Surprisingly, construction of the exhibit cases and preparation of the gallery was a large contributor to life cycle GHG emissions with 28,600 kg of CO_2 equivalent emissions for one loan of 30 objects. Plexiglas™ vitrines were responsible for the highest materials contribution to GHG emissions of the loan installation and preparation phases. The MFA saves almost 10,000 kg of CO_2 equivalent by reusing 40% of the Plexiglas™ after each exhibit. To put this in perspective, an average car emits 8.9 kg of equivalent CO_2 per one gallon of gasoline.

For the outgoing loan of a single crate, the LCA results found that the highest environmental impact of all loan phases proved to be the carbon foot print of the courier who travels two round trips for every one object round trip and has more than three times the impact of the art/object transport, depending on the

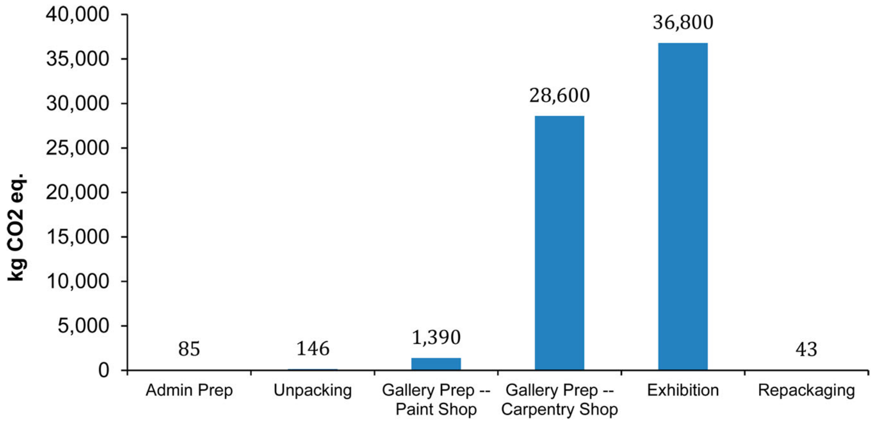

FIG. 1. Carbon footprint of an incoming loan (30 crates assumed).

mode of transport-truck, passenger or freight plane (fig. 2).

The results here are clearly influenced by the number of crates (and objects) that make up the loan. The relative contribution of courier travel can be lessened by increasing the number of crates per courier. For the Japan passenger plane scenario, transporting two crates instead of one lessens the courier contribution from 61% to 45%. For a loan of five crates, the courier contribution is only 24%.

Figure 3 shows the relative contribution of each crate packing material (exclusive of the crate itself), with the most impactful being the foams, which are derived from fossil fuels. Of course, different objects require different packaging configurations and types. Increasing the size and quantity of packing materials and crate by 50% results in an 11% increase in the total carbon footprint of the loan, proving that the total carbon footprint is significantly affected by the size of the object that is loaned. The environmental impacts of producing crates and packing materials can be offset by reusing and storing crates or standardizing crates for reuse. Versatile crates that function as travel mounts and exhibition cases would also reduce materials usage.

Finally, the destination of the loan is an important consideration when evaluating operations, both the distance to the receiving institution and the viewership of the objects while on loan. When taking into account the expected number of views of the art, the carbon emissions per viewing in Japan is more than four times less than the emissions per viewing in Florida because there are approximately 10 times more views of the art in Japan (table 1).

2.2 CASE STUDY 2: LIGHTING

2.2.1 METHODS

There are about 25,000 lights throughout the MFA. These lamps, lighting maintenance and energy use comprise approximately 35% of the Museum's total utility costs. Many museums are switching to light emitting diode (LED) lamps, with the development of LEDs with more appropriate spectra. The MFA also

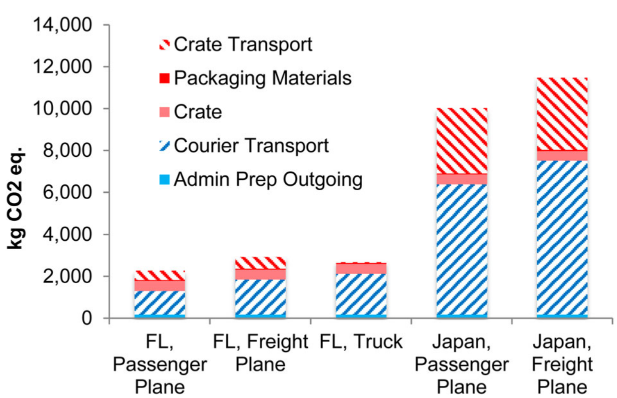

FIG. 2. Carbon footprint from one crate transport to Florida or Japan.

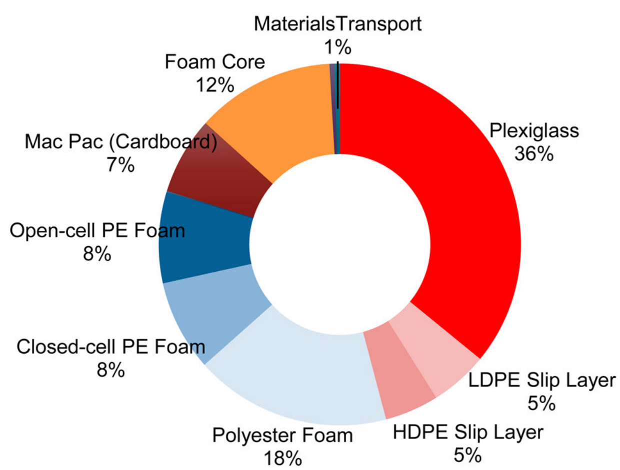

FIG. 3. Relative greenhouse gas emissions (carbon footprint) of a standard packaging system.

TABLE 1 COMPARATIVE CARBON FOOTPRINT OF ART TRANSPORT TO FLORIDA VS JAPAN BASED ON THE EXPECTED NUMBER OF VIEWS.

Loan scenario	Total emissions (kg CO_2 equiv.)	Expected no. of views	Unit emissions (kg CO_2 equiv./view)
FL, Passenger Plane	2950	12,500	0.24
FL, Freight Plane	2290	12,500	0.18
FL, Truck	2700	12,500	0.22
Japan, Passenger Plane	11,500	120,000	0.10
Japan, Freight Plane	10,000	120,000	0.08

pursued this course, but the LEDs placed in halogen bulb housing in one gallery were failing approximately five times faster than they should have, dimming after 6 months of approximately 1000 hours of use. Excessive heat buildup from inadequately ventilated halogen fixtures caused this failure.

The LCA was conducted to determine if the MFA should continue using LED lamps in the gallery with LEDs in housings intended for halogen bulbs, or if it was more energy efficient (and cost saving) to return to using the halogen bulbs. In this LCA, the impact of MR16 halogen lamps was compared with the impact of MR16 lamps (Table 2). Six environmental impact categories resulting from bulb production and energy use were chosen including the global warming potential, acidification (acid rain), eutrophication potential (deposition of excess nitrogen and phosphorus into water bodies), natural resource depletion, solid waste generation, and indoor air quality. The energy use for manufacturing the halogen and LED bulbs was attained from a study by the manufacturer OSRAM (2015). The energy used by the museum for the two different bulbs was taken from the New England grid mix and data for specific fuel used for electricity generation for New England was taken from the e-GRID model developed by the EPA (USEPA, 2012a). The functional unit for this study was 1 hour of light and the reference flow was one LED bulb.

2.2.2 RESULTS

In this study, comparison of the cost efficiencies and the impact of material use included not only global warming, but also eco-toxicity and human health indicators from material manufacturing to product use stages. This study showed that the halogen lamp was much less energy efficient. A 42 W halogen lamp was projected to last for 2000 hours and a 7 W LED bulb was projected to last 24,000 hours. Even if a LED bulb lasts about 5000 hours, or 1/5 of its average lifetime, it would rival halogens in the three focused impact categories.

To examine the possible sensitivity to the assumed lifetimes of the halogen and LED bulbs six scenarios corresponding to a halogen bulb with a lifetime of 2000, 4000, and 6000 hours and an LED bulb with 20,000, 25,000, and 50,000 hours were examined. The results are shown in figure 4. The longer the LED bulb lasts, the more environmentally sustainable it is when compared with the halogen bulbs. Use of the LEDs, even with their shortened expected lifetime inside halogen

TABLE 2 THE MATERIAL COMPOSITION DATA OF HALOGEN AND LED BULBS.

Material	Component mass (g)	
	Halogen	LED
Glass	20.8	1.9
Ferrous metal (steel)	0.4	0.3
Aluminum	1.2	71.0
Non-ferrous metal (copper)	0.4	5.2
Adhesive cement	1.5	–
Plastic	–	27.3
Electronics	–	29.5
Resin compound	–	40.0
Other	>0.1	–
Total	24.3	175.2

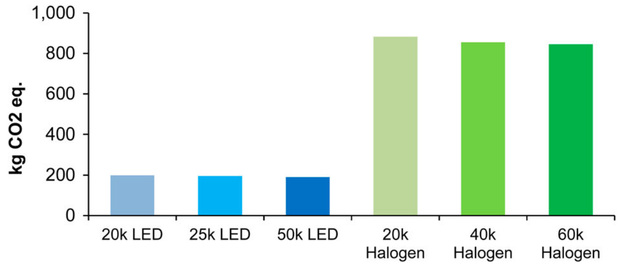

FIG. 4. Bulb type and use scenario results.

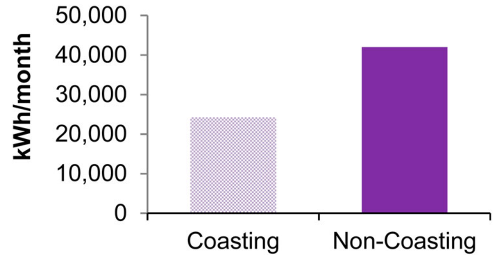

FIG. 5. Coasting and non-coasting electricity use on a nightly basis per month.

housing, results in greater energy savings than use of the halogens (Powley and Sweeney 2008).

Many studies have found that LED lamp use results in approximately one quarter of the environmental impact from cradle to grave than halogen lamps, even when the LED bulb fails far more rapidly than expected (Miller 2011; Miller and Druzik 2012). The environmental impact of the bulb is affected by the disposal method. The MFA recycles its bulbs, reducing the impact. This LCA proved that it is more efficient for the MFA to keep the current halogen housing, remove the halogen lamps and replace them with LED lamps as they burn out, than to keep the current housing and maintain halogen lamps with their higher electricity demand.

2.3 CASE STUDY 3: HVAC AIR HANDLER NIGHT-TIME SHUTDOWN

2.3.1 METHODS

In 2013, the MFA began to test an overnight shutdown (coasting) of the air handler for the HVAC system serving a group of galleries in a new wing of the museum to determine whether it was more efficient to keep the system on all night, or force the system to recover from a broader range of temperature and humidity during daytime use. This LCA determined energy (and cost) savings from the temporary shutdown of the air handling equipment. The galleries are composed of 16 zones over four floors with a total volume of 650,000 cubic ft. The air handlers consist of a sheet metal enclosure, return and supply fans, an air filter, a humidifier, and control devices.

Data were collected from March 6 to April 4, 2013 when 50% of the HVAC supply and return fans were shut off each night for 12 hours (10 p.m. to 10 a.m.). If the relative humidity dropped below 40% RH or the temperature dropped below 18°C or above 24°C, the fans automatically turned on. On average, during the study period, the air handlers were reactivated for 2.6 hours each night. The functional unit of the project was environmental conditions maintained between these two set points. Only energy use was considered, which in this case included the reduced electricity demand of the fans during the evening hours.

2.3.2 RESULTS

This study concludes that coasting the air handlers results in 42% nightly reduction in consumption and cost, equivalent to a 21% reduction each day. The energy use during periods of system shutdown resulted in 40% savings of kWh/month. On average, during the study period, the air handlers were reactivated for 2.6 hours each night. Related electricity usage was reduced by more than 40% (fig. 5).

3. DISCUSSION

The three case studies presented in this paper aimed to address the important issue concerning how cultural institutions can continue to responsibly loan and exhibit cultural material within the context of dwindling natural resources. Important hotspots were identified, providing specific information to further examine and ultimately provide a plan for changes in cultural institution practices.

The most beneficial change to loan practices would be to reduce courier travel. Although there are no official national or international set courier guidelines for museums to follow, the Doerner Institute (Burmester and Eibl, 2013) has encouraged reducing courier travel by sharing couriers or not sending couriers for every object or group of objects. Planned, well thought out changes to minimize courier travel, even by 15%, would lead to more financially and environmentally sustainable museum loans.

The MFA made their decision to use LEDs in halogen lamp housing based on this study. Before the LCA study, they were considering reverting back to the halogen bulbs within the halogen housing or removing all halogen housing and replacing them with LED housing and bulbs. This study was useful in guiding the museum in the most economic and environmentally sustainable route; keeping the halogen housing and replacing the bulbs with LEDs even though the LEDs lasted shorter than their expected lifetime.

Whereas the courier travel and use of halogen lamps had clear implications, the HVAC operation case was more complex. Maintaining strict environmental control of any space is an energy intensive and costly proposition. Traffic from museum visitors, swings in outside ambient temperature and weather, and the heat load from indoor lighting adds further challenges to controlling ambient environment. The results from the HVAC case study may be useful for other museums; however, the individual nature of building structures, outdoor climate and gallery usage make direct application of the MFA findings to other institutions problematic.

Although this HVAC study is case specific, it did illustrate the benefit of careful examination and exploring new, thought out use of an existing system to achieve more sustainable practices. Coasting the air handlers in the one gallery at the MFA significantly reduced the electricity consumption without compromising the exhibition conditions or putting the art at risk. Electricity consumption is responsible for 40% of total carbon emissions in the United States. Besides greenhouse gas emissions, electricity generation produces sulfur oxides and nitrogen oxides, affecting other environmental issues such as eco-toxicity and water intake. Different forms of electricity production cause different environmental impacts. For example, a larger percentage of coal fire-based electricity and natural gas would lead to more carbon emissions, while a larger portion of renewable energy would result in fewer environmental impacts. Also, the coasting conditions examined at the MFA (USEPA 2012b) greatly decreased their carbon emissions, water intake, and other environmental consequences as compared to their non-coasting conditions. The reductions of environmental impacts were proportional to how much electricity could be saved.

4. Conclusions

The spring 2013 LCA studies were successful in their analysis of lighting options from cradle to grave, global warming impact of a loan and exhibition, and energy and cost savings from controlled shutdown of air handling units. Although the lighting study unequivocally demonstrated the benefits of LED use in galleries, the HVAC systems analysis clearly demonstrates the need for caution in applying LCA results too broadly.

Understanding the resulting environmental impact from producing and using construction and packing materials, transporting art, and from environmental management systems will hopefully lead to further evaluation of our actions, benefiting conservation of our heritage and our environment. With museum loans increasing in number, and environmental resources dwindling, it is the responsibility of museum professionals to make the loan processes environmentally and economically sustainable so that exhibiting cultural heritage can be viable far into the future.

This study demonstrates how LCA or other similar analyses can be applied to evaluate conservation activities. Although preservation is the absolute goal, there are different ways of successfully achieving this important task. Just as art conservation professionals make choices based on economic constraints, choices must also consider occupation exposure, toxicity, and life cycle environmental impact.

Acknowledgments

The authors would like to thank AIC for funding this project. A special thank you to the Northeastern University students, William C. Walker III, Lu Chen, Drashti Dhirwani, Vishal Patwari, Sarah Sanchez, Liz Cherchia, Caitlin Candee, Enrique Piguan, Nan Cai, Erica Duran, Andrea Whalen, and Janet Yun, who carried out the research that made this study possible. We also thank Matthew Siegal, Greg Deterding, and other MFA staff for contributing to this study.

ORCID

Sarah Nunberg http://orcid.org/0000-0001-9155-1761

References

AIC, Sustainability Committee. 2015. Sustainable Practices wiki. http://conservation-wiki.com/w/index.php?title=Sustainable_Practices (accessed 08/18/15).

Bruntland, G. 1987. Our Common Future-Call For Action. Report of the World Commission on Environment and Development. United Nations.

Burmester, A., and M. Eibl. 2013. *The Munich Position on Climate and Cultural Heritage*. Munich: Doerner Institut.

Cai, N., E. Duran, A. Whalen, and J. Yun. 2013. Environmental Controls at the Museum of Fine Arts. CIVE 5275 Project Report, Northeastern University, Boston, MA.

Cultural Heritage Conservation Science and Sustainable Development; Experience, Research, Renovation. 2013. Paris, France. http://crcc50.sciencesconf.org/ (accessed 08/18/15).

Guinee, J. B. ed. 2004. *Handbook on Life Cycle Assessment: An Operational Guide to the ISO Standards*. New York, NY: Kluwer Academic Publishers.

ISO. 2010. *14044:2006 – Environmental Management – Life Cycle Assessment – Requirements and Guidelines*. Geneva: International Organization for Standardization. http://iso.org/iso/home/standards_development.htm (accessed 02/01/15).

Lambert, S., and J. Henderson. 2011. The carbon footprint of museum loans: a pilot study at Amgueddfa Cymru – National Museum Wales. *Museum Management and Curatorship* 23(3): 209–235.

Miller, N. 2011. *Demonstration of LED Retrofit Lamps in the Jordan Schnitzer Museum of Art*. Washington, DC: U.S. Department of Energy Solid-State Lighting Technology Demonstration GATEWAY Program.

Miller, N., and J. Druzik. 2012. *Demonstration of LED Retrofit Lamps at an Exhibit of 19th Century Photography at the*

Getty Museum. Washington, DC: U.S. Department of Energy, Solid-State Lighting Technology Demonstration GATEWAY Program. http://lighting.philips.com/pwc_li/main/led/assets//MR16LED-Lifecycle-Analysis.pdf (accessed 02/15/15).

NIST. 2010. *Building for Economic and Environmental Sustainability (BEES) software version 4.2*. Gaithersburg, MD: National Institute of Standards and Technology, Engineering Laboratory. http://nist.gov/el/economics/BEESSoftware.cfm/ (accessed 01/25/15).

OSRAM. 2015. Life Cycle Analysis of an OSRAM Halogen Lamp. http://osram.com/osram_com/sustainability/environmental/product-lifecycle-management/lca-of-a-halogen-lamp/index.jsp (accessed 03/07/15).

Powley, B., and J. Sweeney. 2008. *Probabilistic Cost of Light Models for Solid State Lighting in General Illumination Markets*. CA: Precourt Institute for Energy Efficiency. Stanford University.

PRé Consultants, B.V. SimaPro software version 7.2. Amersfoort, Netherlands. http://simapro.co.uk/simapro8flyer.pdf (accessed 01/25/15).

Sanchez, S., L. Cherchia, C. Candee, and E. Piguan. 2013. Life Cycle Assessment of a Museum Loan. CIVE 5275 Project Report, Northeastern University, Boston, MA.

USEPA. 2012a. *Emissions & Generation Resource Integrated Database (eGRID)*. Washington, DC: United States Environmental Protection Agency. http://epa.gov/cleanenergy/energy-resources/egrid/index.html (accessed 01/29/15).

USEPA. 2012b. *Energy and You*. Washington, DC: United States Environmental Protection Agency. http://epa.gov/cleanenergy/energy-and-you/ (accessed 02/15/15).

Walker, W. C., L. Chen, D. Dhirwani, and V. Patwari. 2013. Life Cycle Assessment of LED Lighting Versus Halogen Lighting in a Museum Setting. CIVE 5275 Project Report, Northeastern University, Boston, MA.

Sources of Materials

Average size warehouse: http://cisco-eagle.com/industries-served/order-fulfillment/the-typical-warehouse (accessed 02/15/15).

Average warehouse height: https://facworld.com/facworld.nsf/doc/warehouserating (accessed 02/15/15).

Average size 18-wheeler: http://thetruckersreport.com/facts-about-trucks/ (accessed 02/15/15).

Estimate of HVAC needs: http://lightsearch.com/resources/lightguides/hvac.html (accessed 02/15/15).

Gallery sizes: http://mfa.org/search?search_api_views_fulltext=facts (accessed 02/15/15).

Fastener cost/weight: http://lorca4.325604.net/news/industry/159.html (accessed 02/15/15).

Fastener materials: http://thomasnet.com/articles/hardware/fastener-materials (accessed 02/15).

Dibond info: http://graphicdisplayusa.com/prod_dibond (accessed 02/15/15); http://universityproducts.com/cart.php?m=product_list&c=2221&s=1196 (accessed 02/15/15).

Author Biographies

Sarah Nunberg is the principal of The Objects Conservation Studio, LLC, Brooklyn, NY. In her private practice, she works with museums, collectors, and institutions towards collections preservation and conservation treatments. She began her career in archeology at Yale University where she studied pre-Columbian ceramic production methods and art history. She continued her education at The Conservation Center, New York University Institute of Fine Arts where she achieved a Master in art history and an advanced Certificate in Conservation of Works of Art. In addition to her private practice where Sarah also teaches materials degradation and sustainable practices at Pratt Institute and lectures at NYU Institute of Fine Arts Conservation Center. She has served on the AIC Sustainability Committee for 5 years, including 2 years as committee chair. Sarah continues studying LCAs with the goal of further establishing sustainable best practices in fine art and heritage conservation. Address: 272 14th Street, Brooklyn, NY 11215, USA. E-mail: snunberg@aol.com.

Matthew Eckelman is an assistant professor at Northeastern University in civil and environmental engineering, with secondary appointments in chemical engineering and public policy. His research focuses on large-scale modeling of industrial resource use and emissions and subsequent impacts on the environment and public health. He consults regularly on sustainability-related projects with a range of businesses, institutions, and government agencies. He previously worked in the Massachusetts State Executive Office of Environmental Affairs and was a Peace Corps science instructor in Nepal. He received a doctorate in chemical and environmental engineering from the Yale University. Address: Northeasten University, 425 Snell Engineering Center, 360 Huntington Avenue, Boston, MA 02115, USA. E-mail: m.eckelman@neu.edu.

Pamela Hatchfield is the Robert P. and Carol T. Henderson Head of Objects Conservation at the Museum of Fine Arts, Boston. She holds graduate degrees in Art History and Conservation from the Conservation Center, Institute of Fine Arts, New York University. She consults on the conservation of the decorative arts at the Acton Collection, Villa La Pietra, New York University, in Florence. Her field experience includes Egyptian sites in Giza, Memphis and Abydos. Pam received the Rome Prize from the American Academy in Rome in 2006–7. She presently serves as President of the American Institute for Conservation of Historic and Artistic Works, and on the Board of the U.S. Committee of the Blue Shield. Her publications include: *Pollutants in the Museum Environment: Practical Strategies for Problem Solving in Design, Exhibition and Storage*. Address: Museum of Fine Arts, Boston, 465 Huntington Ave, Boston, MA 02115, USA. E-mail: phatchfield@mfa.org.