Narrative Section of a Successful Application

The attached document contains the grant narrative of a previously funded grant application. It is not intended to serve as a model, but to give you a sense of how a successful application may be crafted. Every successful application is different, and each applicant is urged to prepare a proposal that reflects its unique project and aspirations. Prospective applicants should consult the NEH Division of Preservation and Access application guidelines at http://www.neh.gov/divisions/preservation for instructions. Applicants are also strongly encouraged to consult with the NEH Division of Preservation and Access staff well before a grant deadline.

Note: The attachment only contains the grant narrative, not the entire funded application. In addition, certain portions may have been redacted to protect the privacy interests of an individual and/or to protect confidential commercial and financial information and/or to protect copyrighted materials.

Project Title: Digital Imaging Correlation to Determine Shape Deformation of Paper-Based Collections due to Relative Humidity and Temperature

Institution: Rochester Institute of Technology (Rochester, N.Y)

Project Director: Andrew Lerwill

Grant Program: Research and Development

Digital Image Correlation to Determine Shape Deformation of Paper Based Collections Due to Relative Humidity and Temperature Variation

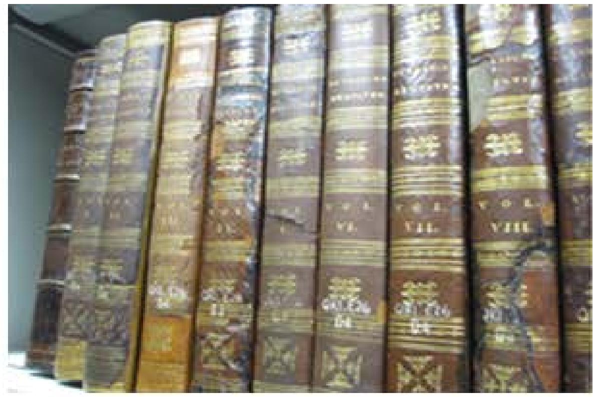
NARRATIVE

Significance

When considering the resources typically utilized in humanities research, books and paper-based objects dominate. They include books with a diversity of bindings, manuscripts, pamphlets, modern digital prints and a wide scope of photographic techniques, all on a range of substrates. The degradation of such collections is deeply complex and the multiple pathways to decay are often beyond full understanding. Despite the lack of detail available to preservation science regarding a complete picture of the nature of deterioration, there are fundamental facts and areas of concern that are known. A major concern is neglect, which is often a problem arising due to lack of education. There is also an ever-increasing likelihood of fires and floods that have the potential to damage or destroy our common heritage. Furthermore, a range of environmental factors can deeply harm collections, such as radiation causing photochemical damage, vibrations, particulate or gaseous pollution, and insect pests. Apart from these, the single most harmful environmental factor that all humanities collections experience, independent of the circumstances of location, building or enclosure, is the ambient temperature and relative humidity (RH). Inappropriate levels and fluctuation of these two factors can cause mechanical (physical) damage as an object's moisture content equilibrates rapidly to changes in air temperature and RH, causing swelling and shrinkage. These dimensional changes accelerate deterioration and lead to such visible physical damage as cockling paper, flaking ink, warped covers on books, warped text blocks, softening emulsions, warped wood, brittleness, tearing and cracking of materials, etc. The images on the following page show examples of such damage, much of which can be ascribed to environmental causes.

The surrounding air ultimately governs how much moisture is absorbed into, or desorbed from, collection materials. Because equilibration relies on diffusion of moisture throughout the body of the collection objects, the rate of moisture equilibration varies considerably, but is generally much slower than temperature equilibration. The time period required before the entire object has reached equilibrium (in terms of water content) can range from a few hours to months depending on the ability of water to diffuse into the object. Composite objects (which are comprised of more than one material bonded tightly with another) are more vulnerable to environmental changes in RH and temperature because the different materials that make up the object respond differently to environmental conditions. This is known as differential expansion. As one material expands it can exert force on another to which it is adhered or attached. In this situation the risk of mechanical damage is thought to be particularly significant for rare books. This is the case as the swelling of the individual leaves warp the text block. The paper comprising the text block absorbs moisture on the outside and the fibers expand in one particular direction. This causes the paper to curl towards the driest side. The book cover, which is often made of a different material, will also swell but to a different extent, and the book will distort leading to tearing and loosening of the binding. If the balance in humidity within the object is restored, the distortion effect often cancels. Unfortunately, this is not always the case due to uneven fiber distribution in the paper or the extension of the materials in the book beyond the point where it is possible for the material to resume its original size and shape. The maximum degree of reversible change in such a situation is called the elastic limit.

Digital Image Correlation to Determine Shape Deformation of Paper Based Collections Due to Relative Humidity and Temperature Variation

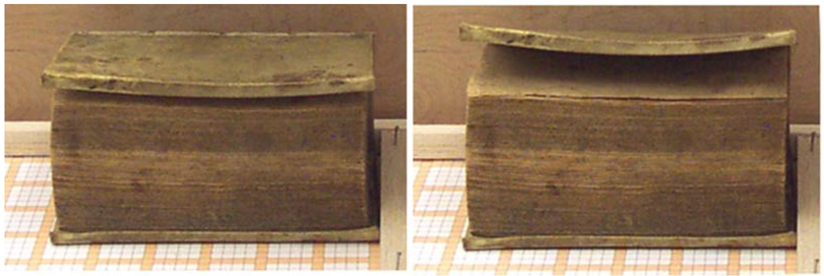







Digital Image Correlation to Determine Shape Deformation of Paper Based Collections Due to Relative Humidity and Temperature Variation

An example of deformation in the cover of a vellum bound book in a laboratory test of varying RH (20% to 50%) can be seen below. The dryness caused by the 20% RH level contracts the vellum cover and pulls the book cover up into an arch.



50% Relative Humidity   20% Relative Humidity

Preservation specialists have limited empirical knowledge of the safe mechanical limits for temperature and humidity for hygroscopic materials in library and archive collections. Significant unknowns remain for environmental control. The aim of the project is to better define the safe limits for paper, textiles, vellum, dyes, inks, leather and other organic materials, and to obtain further knowledge on how composite objects behave in varying environmental conditions.

It is evident that what we know today does not provide the necessary confidence to develop accurate and reliable preservation practices that would enable collection managers to make safer, more cost effective decisions on a material by material basis, or to understand how to prevent a situation where room conditions will cause mechanical damage.

The result of this lack of reliable information has an economic cost that can be significant. This can arise either from being overly strict in environmental settings, which can lead to much larger HVAC costs, or alternatively allowing significant environmental variation and unsuitable conditions which can lead to damage requiring costly and lengthy repair. The potential economic and preservation impact reinforced the widely-held opinion that environmental storage conditions must be that of a year-around constancy with tight limitations for temperature and humidity. Over time this has not proven to be a sustainable approach and there is an increasing acknowledgment that some level of temperature and humidity fluctuation is unavoidable in real-life and is in fact necessary for sustainability and acceptable in terms of long-term preservation.

Because of this need for sustainable environmental management practice there is an increasing demand for the answers this research may provide. Increasingly urgent and specific questions are being asked in order to better manage potential environmental changes to collections. For example, the United Kingdom's National Museum Director's Council has drafted guiding principles to minimize energy use, including the request that environmental standards of temperature and humidity should be specific to the requirements of particular groups of objects and to the local climate. Similar concerns have been raised by the American Institute for Conservation (AIC).

A major reason why very little is currently known about such an important issue is due to the complexity of making mechanical measurements on valuable and delicate objects. It has not been possible until recently to use conventional measurement techniques on complex composite structures like vellum-over-board bound books. Digital Image Correlation (DIC) is a technology that allows us to overcome this problem. DIC is a sophisticated type of photogrammetry (measurement using images) which is beginning to be used in industry and the arts to dynamically assess the expansion and contraction of composite objects. The significance of this ground breaking application of the DIC technique is that it will allow us to rigorously investigate how much and how rapidly an object or material expands in response to environmental change. This study will provide much needed information on the safe humidity limits for the environmental management policies used by libraries and archives. Furthermore, this project will present these results in terms of room moisture conditions at a range of typical temperatures so that they are immediately applicable in real life situations and can reliably guide HVAC management.

This fundamental scientific research will be of enduring value to the future preservation of humanities collections.

This research leverages IPI's experience and capabilities in preservation management. It builds further on the results of previous NEH-funded studies where the complete moisture equilibration throughout objects and enclosures was explored. The results of this previous research combined with new knowledge of *surface* deformation from the current proposal will provide the foundation for an empirical model to guide sustainable practice in this area.

IPI is uniquely qualified and experienced to develop this information. This research will build logically on several previous research projects undertaken by IPI and will complement other new approaches to sustainable environmental management IPI has recently researched, such as management of HVAC shutdowns and setbacks where RH and temperature are permitted to alter considerably.

BACKGROUND OF APPLICANT

IPI Organizational Profile

IPI is a non-profit research laboratory founded in 1985. It exists within the College of Imaging Arts and Sciences at Rochester Institute of Technology, Rochester, New York. Since its inception IPI has been devoted to scientific research in preservation for library, museum, and archive materials. A diversity of programs concerning research, publications, education, products and services has led to continued success.

IPI presently employs 14 full-time and 3 part-time staff members. These include preservation specialists, scientists from diverse backgrounds in chemistry, physics and imaging, conservators, graphic designers, and administrators. The laboratory at IPI is among the most respected centers globally for the testing of imaging and recorded materials. Specialized equipment for accelerated aging and environmental testing, as well as incubation, light stability, wet chemistry, and air pollution labs are contained within the 7,000 square-foot space. An onsite library, microscopy lab, study collection, and classroom are also present.

The results of IPI research have been implemented in many diverse institutions, such as the Library of Congress, the National Archives and Records Administration, the New York Public Library, the Museum of Fine Arts, Boston, and the National Museum of Denmark, Copenhagen, to mention just a few[1,2] .

Laboratory and field research regarding energy savings in the library, archive and museum field has been a recent focus. Previously three research projects, one funded by the Institute for Museum and Library Services (IMLS) [3] and two by NEH[4] have investigated intentional HVAC shutdowns and setbacks in temperature and RH settings during unoccupied hours on collection environments. Most recently NEH funded the IPI project "Understanding Moisture Equilibrium for Humanities Collections: A New Path to Sustainable Humidity Control" which this project will complement in its findings.

IPI's Technical Infrastructure Capability

IPI has the necessary scientific and technical infrastructure to conduct this project. Laboratory testing will be done in a programmable walk-in temperature and humidity controlled chamber capable of housing a large number of collection materials. This chamber can provide consistent RH control from 20% to 80% at temperatures between 10°C and 30°C (50°F to 85°F). This equipment will be used for the entire experiment.

Digital Image Correlation to Determine Shape Deformation of Paper Based Collections Due to Relative Humidity and Temperature Variation

HISTORY, SCOPE AND DURATION

History

There have been two major avenues taken by researchers in this field. The most significant is the approach focused on defining a suitable temperature and humidity range for collection materials[5,6,7,8]. A second approach has been concerned with attempts to further investigate temperature and humidity constancy[9,10]. In addition, a number of initiatives have begun to investigate the relationship between macro and micro-environments[11,12,13,14].

Twenty years ago studies examined the physical/mechanical response of various organic collection materials to changes in temperature and RH. The computerized models of the stress behavior for paintings and photographs proved revolutionary for the field although they were limited in scope and warrant reevaluation[15, 16, 17, 18].

Previous to the most recent project IPI has conducted three other NEH-funded studies exploring these questions, the first dealing primarily with the use of microclimates in preserving film materials[19], the second studying the effect of changing environments on library and archives material[20], and a third evaluating the impact of intentional short-term temperature and RH changes on collection materials. The proposed research builds on the results of each of these NEH-funded studies and incorporates a new and promising research technology. This project is the first IPI research to concentrate on environment-induced mechanical damage. Previous projects addressed chemical decay and moisture equilibration behavior.

This project will use Digital Image Correlation (DIC) which is the technique of measuring objects (2D or 3D) using digital photographs. Its most important feature is the fact that the objects are measured without being touched. By taking digital photographs it operates in recording two images of the surface of the specimen which correspond to two different mechanical states (a reference state and a deformed state) [21,22,] . There has been previous work to evaluate the effectiveness of DIC in assessing change of objects in art collections and these have been successful [23,24,25,26]. DIC has been successful for industrial paper mechanical testing purposes; for example in work by Cao etal[27]. Although DIC testing has never been performed for paper based materials in a cultural heritage context, there is a high likelihood that this technique will prove as useful as it has in other applications.

Scope

The scope of this research will be typical of work previously done at IPI. The project will be relevant to each region within the United States and also be international in scope and impact; it will also be relevant in any type of collecting institution. The information gained will provide fundamental knowledge presently in significant demand and has the potential to revolutionize understanding in an area where there is a diversity of opinion. As a result it will be of enduring value to the preservation of humanities collections. This research will fill the gaps of knowledge previously impossible to test, focusing on a diversity of materials (papers, parchment, vellum and leather, textiles, dyes and inks) all of which are too delicate to be tested with previous methods.

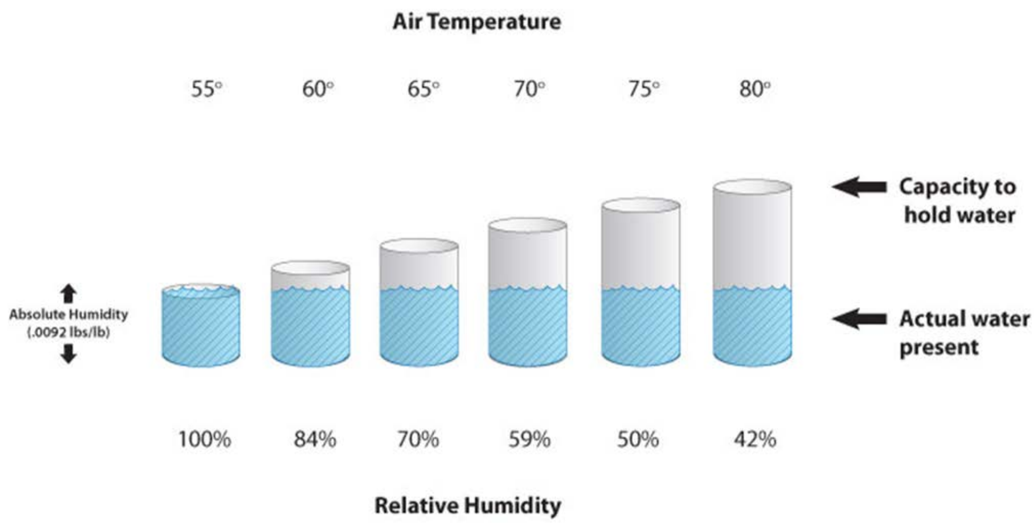
Duration

The project's scope and research objectives are contained within a three-year schedule. The three-year schedule reflects the fact that this is a new area of research where considerable time will be required to refine the equipment, instrumentation and procedures to be used. There is a learning curve to this project that is not to be underestimated. However, it is a major effort that promises major practical value and pioneers approaches that can be used in many research efforts in the cultural heritage field. Project activities will be divided into three activity groups: (1) laboratory research, (2) data analysis and modeling, and (3) dissemination and reporting.

METHODOLOGY AND STANDARDS

Humidity and Temperature vs. Object Behavior

Relative humidity is defined as the of the amount of water vapor held within a specific amount of air compared to the quantity of water vapor that same amount of air *could* hold at the same temperature and pressure. When the relative humidity of air reaches 100%, saturation occurs and condensation takes place. As temperature increases, the amount of water vapor that air has the potential to hold also rises and conversely when air is cooled, it can accommodate less water. This is illustrated below.



The moisture content of hygroscopic (water-absorbing) objects is a function of both the relative humidity and temperature of surrounding air. At equilibrium, the quantity of water contained within a material depends on the prevailing RH. The effect of temperature must also be considered. At a given RH, the moisture content increases slightly as temperatures *are reduced*. Therefore to understand the mechanical behavior of these materials thoroughly a range of humidity levels at a range of temperatures needs to be explored.

There exists a dynamic exchange of water between an object and the air of the environment. The moisture is transferred into the object by adsorption and subsequent diffusion. This diffusion is driven by differences in moisture content. Moisture is transferred from higher concentration to lower concentration. Eventually enough moisture is diffused from the air into the material (or the material into the air) that the material neither gains nor loses further moisture in the exchange. At this point, the object has reached moisture equilibrium. This dynamic continuous exchange is why hygroscopic materials equilibrate with the relative humidity of the environment. This takes time and materials do not respond instantaneously. The time it takes an object to equilibrate depends on a number of factors; the hygroscopic nature of the material, the dimensional characteristics, and the surface exposure to the environment.

Digital Image Correlation to Determine Shape Deformation of Paper Based Collections Due to Relative Humidity and Temperature Variation

The moisture content governs the physical characteristics of hygroscopic materials. Loss of moisture content leads to contraction, while gain of moisture leads to expansion. *The proposed methodology will provide a non-destructive opportunity to document these changes. It will allow determination of not only the magnitude of physical change but also the timeframe for equilibrium. In addition, the methodology will ensure determination of the conditions beyond which the object will not recover.*

Digital Image Correlation

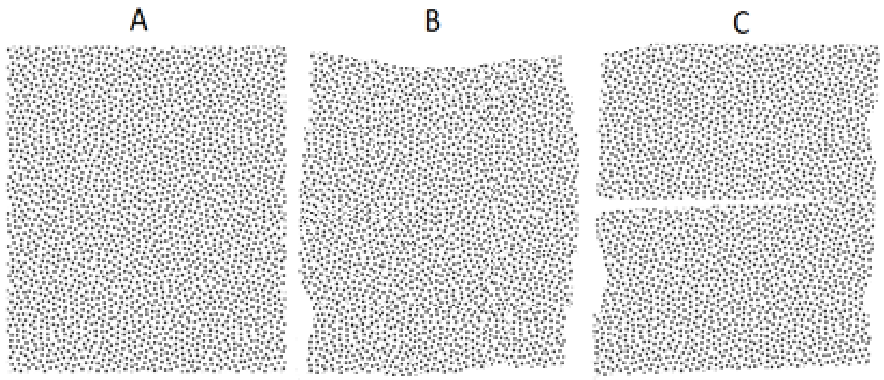
Due to rapid new developments in high resolution digital cameras for static as well as dynamic applications (along with advances in computer technology), the applications for the DIC measurement method have broadened. DIC techniques have proven to be a flexible and useful tool for deformation analysis. The dynamic range of DIC is wide, with the capability to measure quite large as well as quite small deformations.

The proposed optical method uses a mathematical correlation analysis to examine digital image data taken while samples are involved in mechanical tests. By taking digital photographs, DIC operates by recording a number of images of the surface of the specimen, each of which corresponds to different mechanical states (a reference state and several deformed states). This matching of subsets between the two images happens by computer-automated recognition. From this information a change in the shape of an object can be determined in ways not previously possible and without direct contact with, or damage to, the object.

To apply this method, the material under test needs to be prepared by the application of a random dot pattern (a speckle pattern). The dots can be printed on samples by various means when possible, or else sprayed on the surface with water-soluble aerosol paint (which can be removed without harming the object if needed). Water-soluble spray paint is used throughout many industries and for many purposes where easy removability is desired. Sometimes a speckle pattern can be imparted by flicking paint from the bristles of a toothbrush. Importantly, in this research no objects of significant historical or financial value will be used, though actual historical materials will be tested.

With computer software the differences between a reference state and several deformed state patterns can be calculated by correlating all the pixels of the reference image and any deformed image. From this a strain distribution map can be created which will show how much the object has changed. Extension to 3D surface measurement is available by using two cameras (this is called stereo-correlation) and this method will be used in this research.

An example of the technique in two-dimensions can be seen in the images below. In A, a speckle pattern exists on a sheet of material under test. After increasing the RH at a fixed temperature we see deformation of the surface in B. Comparing A to B it is possible to determine the strain on the material from the movement of the dots. Strain, in this use of the word, refers to the degree of movement or deformation. When the RH is then returned to that found in the initial condition, it is possible to determine if the elastic limit of the material has been exceeded by the RH change. If so, the two dot images would not match because permanent deformation would have occurred. Furthermore, other deformations such as small cracks can be seen as shown in C. This analysis, when seen in three dimensions, enables further insight into behaviors such as warping and cockling, etc.



One of the advantages of using DIC is that it can be used to efficiently study the behavior of a large number of samples all at once. In the project both small squares of materials (paper, vellum, phots, etc.) and composite structures like bound volumes of various age and composition will be examined. Automated computer algorithms available from the supplier will enable a matrix of approximately 100 10x10 centimeter flat samples to be analyzed simultaneously at a resolution of approximately 10 microns. Samples will include parchment, vellum, leather, paper, and textiles, and particular attention will be applied to physical damage such as cockling paper, flaking ink, warped covers on books, and cracked emulsion on photographs and prints. In other experiments, books on shelves and books in boxes will be used. From the flat sample experiments, useful information can be gained about component materials that ultimately shape the behavior of complex composites in which they play a role.

IPI will follow standard calibration procedures for all equipment used. Temperature and humidity controlled chambers will be calibrated using a NIST certified Vaisala HMI41 indicator and HMP46 probe. Temperature and humidity values will be monitored using the high-precision Spectrum SP-2000-20R from Veriteq.

WORK PLAN

Project activities will be divided into four activity groups.

The first group of activities will focus on laboratory research using the digital image correlation technique in association with the environmental chambers. This activity group will produce empirical data on the rate and degree of mechanical change due to macro-environment variation. This will provide the foundation data to later determine the elastic limits, fatigue behavior, hysteresis and plastic deformation for the materials.

The second activity group will be concerned with data collection of objects in specific circumstances such as shelved books and rare books in phase boxes. Phase boxes are the creased and folded custom-made boxes commonly used in rare book and special collections.

In the third group the focus will be on image analysis of the data collected in the first and second activity group. Mathematical analysis of object and material behavior in the previous activity groups will be used to understand and predict safe temperature and humidity limits for real world situations.

The fourth group of activities will disseminate research findings through technical publications, conference presentations, and workshops; and importantly, the results will further guide IPI's Preservation Metrics™ for mechanical damage, used in eClimateNotebook™ data analysis software for collection environments.

Activity Group 1

The first activity group is divided into two parts.

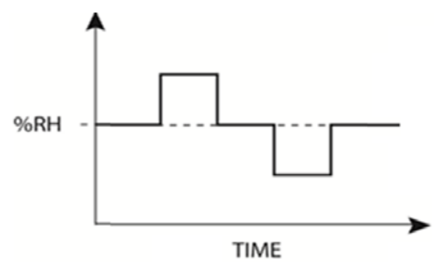
Part 1 – Test Preparation (6 months)

The initial six months of the project will be concerned with preparation for the testing program. This time period will involve the purchase of necessary equipment, the collection of the diversity of suitable materials, the calibration of temperature and humidity chambers, and the preparation of the test samples. Part 1 will also be about learning to use the equipment and refining the experimental details.

A priority in Part 1 will be an initial experiment to determine the amount of time needed for the hygroscopic materials to equilibrate to differing RH values. This will determine the time scales for the more advanced experiments in Part 2 of this activity group.

To determine equilibration time for the samples, small (10 x 10 cm) squares of representative materials (paper, vellum, leather, etc.) will be placed on a metal surface, loose and free to expand, contract, and curl. Samples will be placed in an approximately 10 x 10 grid (resulting in the testing of approximately 100 samples simultaneously), each of which can be independently analyzed for equilibrium behavior. The time required to equilibrate all materials in the matrix will be used in Part 2 of Activity Group 1.

A positive and negative step change in RH values will be applied to determine the equilibration times of the samples to new RH values.

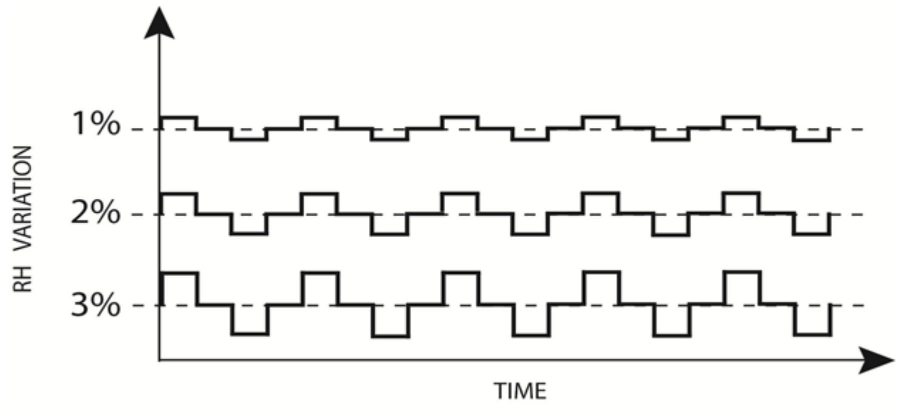


An image of the materials matrix will be taken every minute in this initial experiment. This data will then be analyzed to determine a suitable timeframe for imaging in Part 2.

Part 2 – Investigation of Material Behavior (1 year)

In Part 2 the mechanical change of the hygroscopic materials will be examined as they depart from recommended conditions. Presently guidance from, for example, the British Standard PD 5454:2012 (*Guide for the storage and exhibition of archival materials*, London: British Standards Institution, 2012) recommends the parameters 55.4°F to 68°F (13°C to 20°C) and 35% to 60% RH for the storage of library and archive collections.

The same design of sample matrix as discussed in part 1 (consisting of 100 squares of material) will be tested at increasing fluctuating RH values of ±1%, ±2%, ±3% etc. RH will increase up to the limits of ±30%, the maximum limits achievable by the environmental chamber. This RH variation will follow the pattern as illustrated on the next page.



At a point in the experimental procedure movement in a particular sample caused by an RH change will not be reversible—the dots will not return to their original position when the starting RH is restored. This will define when damage is irreversible (and the elastic limits of the material or object have been reached). Furthermore, continuation of the experiment after this point to higher RH variation will provide information on the material's behavior beyond the elastic limits (known as plastic deformation). This is important as many objects have already undergone this change due to the long history of the object in diverse conditions.

Four separate sample matrices will be tested with this pattern at fixed temperatures of 76°F, 69°F, 62°F and 55°F. From this, real world conditions can be approximated via the results.

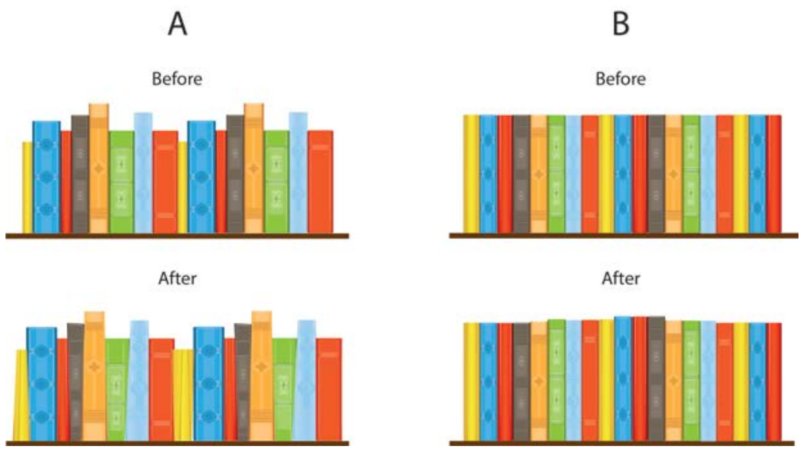
A pause of duration as determined by Part 1 will take place after each RH change to ensure sufficient time to equilibrate. The same RH variation will be repeated 10 times to provide information on fatigue behavior and highlight hysteresis (where in both cases expansion and contraction of the object does not follow the same motion).

Activity Group 2 *(4 months)*

Guidance from the British Library Preservation Advisory Centre states that a fluctuating RH variation is considered to lead to the distortion of book bindings and text blocks, especially if books of different sizes are shelved together.

To gain insight into the potential of mechanical damage between books shelved together, two shelves of books will be exposed to the same ever increasing fluctuation of RH as used in Activity Group 1, and the distortion of bindings and text blocks will be analyzed using DIC on the spines of the shelved books.

A significantly exaggerated illustration of what could potentially be observed is shown below with books of a diversity of sizes (as in A) and of identical sizes (as in B). In the "before" of the illustration marked A, note the thickness of the narrow book in the middle. In the "after" illustration, the text block has expanded. Similarly, illustration B shows change in height. These are examples of the kinds of effects extreme environmental conditions may produce. Images of the mechanical effects will be used to provide insight into the safe RH limits permissible and to determine if different methods of storage can prevent damage from the distortions from other books.



In addition to the shelved books, books inside phase boxes will also be examined by creating a small airtight glass window on the edge of the box (sealed with butyl rubber). Through the window a speckle pattern can be monitored for movement during the varying RH. From this, the effectiveness of phase box storage to prevent mechanical damage will be appraised.

Papers from each of the books used in Activity Group 2 will be analyzed in Activity Group 1 to determine if a correlation exists between the paper used and overall book deformation.

Activity Group 3 ***(10 months)***

Activity Group 3 will focus on data analysis of the results. Significant work in this area will be required in order to analyze the large number of images created during the experimental process. Automated computer analysis will be applied to overcome the large workload that would otherwise be required.

A key aim of this activity group is the production of a plot of results illustrating the degree of total dimensional change observed in materials (the observed strain due to conditions) and the corresponding *rate* of change that took place.

These two variables, which will be different for each material, can be defined as follows:

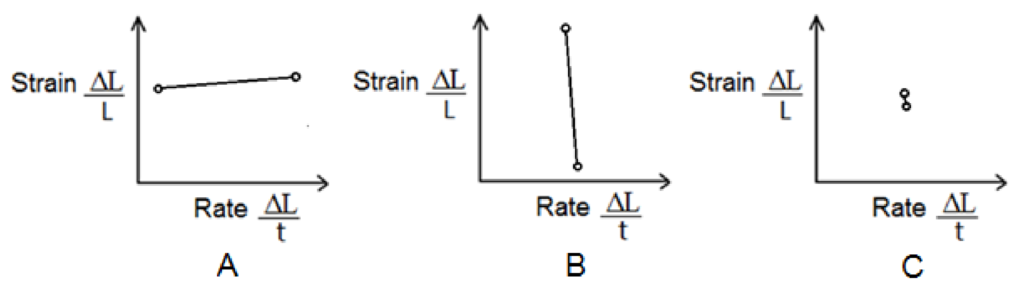
$$\text{Rate} = \frac{\Delta L}{t}$$

$$\text{Strain} = \frac{L' - L}{L} = \frac{\Delta L}{L}$$

Where,

L = length of material before change
L' = length of material after change
ΔL = change in length of material
t = the time taken to achieve the change the length ΔL

This data will be plotted as shown in A, B & C below. Each of the two points shown on graphs A, B and C represents the behavior of one material. The euclidian distance apart that the two materials exist on in this graph relates to the risk of physical harm that may come to an object when the two materials are adhered together in a composite. Three possible examples for a certain RH change can be seen in three plots below. In these plots the relationship between two adhered materials (shown by two circles) and the distance between (shown by the connecting line) is illustrated. In A, the two materials have similar strain for the particular RH change, however the rate of change significantly differs which may lead to mechanical harm as one material pulls away from the other. In B, the opposite applies—the strain of the material is different while the rate of change is very similar, again leading to mechanical harm. In C, both are well matched leading to similar spatial and temporal expansion and contraction.



Determination of the RH level at which the distortion of each material will not cancel and will no longer return to the original shape (the elastic limits) will also be determined from the data in this activity group and will be described in terms of RH values at the different temperatures. The data will also be examined to determine the degree of plastic deformation (non-recoverable change) observed in the samples. Beyond the elastic limit is a region where the dimensional change is not reversible. Here what matters is the degree to which the object has been permanently deformed. The plastic deformation will also be analyzed as many objects will already have experienced these extremes leading to a behavioral phenomenon called strain hardening which permits greater tolerances of RH and temperature.

All of this will provide a continuous map of behavior which will feed back into IPI's guidelines for storage conditions of library and archive materials and the preservation metric for mechanical damage used in eClimateNotebook^{TM}, IPI's web-based environmental analysis software.

Activity Group (4 *months)*

During this period project staff will complete the documentation of research activities and results. As previously noted, these results will be disseminated through technical publications, conference presentations and workshops, and within IPI's website. Additional information regarding dissemination of results is provided in the dissemination section of this narrative.

STAFF

Dr. Andrew Lerwill, IPI Research Scientist and Principal Investigator, will have responsibility for all aspects of the project. He will lead the design and implementation of laboratory research and coordinate, organize, and document all project activities. Dr. Lerwill will devote 50% of his time to this project. Dr. Lerwill joined IPI in July 2013 with a Ph.D. in Physics, Optical Engineering, Photochemistry, and Color Science. In recent years, his activities have been focused on preservation science research. In 2006, he joined the Tate in London, UK, as a research scientist. In 2011, he received a post-doctoral fellowship from The Getty Conservation Institute. Dr. Lerwill will be responsible for reporting to NEH and disseminating project results.

Digital Image Correlation to Determine Shape Deformation of Paper Based Collections Due to Relative Humidity and Temperature Variation

James M. Reilly, Director of the Image Permanence Institute and Co-Principal Investigator, will act as research advisor, spending 10% of his time on the project. He will contribute to the design and development of the research methodologies, and his expertise and guidance will be instrumental to project personnel. Mr. Reilly has designed, executed, and directed preservation research activities since 1978. He is well known for his research on the effects of temperature and humidity on library, archives, and museum collections, deterioration of 19th-century photographic prints, environmental monitoring and control, and the major causes of image deterioration. Mr. Reilly led the development of the Preservation Environment Monitor® and the PEM2®, as well as the eClimateNotebook™ web-based application for environmental analysis. He is a consultant to numerous museums and government agencies and is sought after worldwide as a teacher and seminar speaker. Mr. Reilly has written and lectured extensively on preservation issues.

Jean-Louis Bigourdan, IPI Research Scientist will spend 15% of his time on the project. Mr. Bigourdan will provide guidance for the experimental programs based on his experience from two NEH-funded research projects investigating moisture equilibrium of materials exposed to a wide range of changing environments. He will also assist with data analysis, participate in project meetings, and contribute to the overall objectives of this research. Since 1994, Mr. Bigourdan has conducted several NEH-funded projects related to media stability, including the role of enclosures and microenvironments in film preservation and the effect of changing environments on library and archives materials. His findings have led to the redefinition of storage strategies for preserving film. He has published extensively on the topic of film stability and has presented IPI research results at conferences, symposiums, and workshops in the U.S. and abroad. He has conducted collection surveys, developed storage strategies for institutions, and consulted on the implementation of low-temperature storage. He led the NEH-funded projects *Effects of Fluctuating Environments on Library and Archives Materials*, *Methodologies for Sustainable HVAC Operation in Collection Environments*, and the current *Understanding Moisture Equilibrium for Humanities Collections: A New Path to Sustainable Humidity Control* research.

Douglas Nishimura, IPI Research Scientist, is well known in the field of preservation as a technical authority on the chemistry of deterioration. Mr. Nishimura received his degree in chemistry from McMaster University in Canada. He was instrumental in the creation of IPI's Preservation Metrics™ used in IPI's data analysis software and for the development of the *IPI Storage Guide for Acetate Film* and *The Storage Guide for Color Photographic Materials*. He will spend 10% of his time over three years focusing on data analysis and modeling for the project. He will be instrumental in developing mathematically tested models that will reflect the behavior of materials exposed to a variety of temperature and RH conditions.

Lisa Cerra, Business Manager, will dedicate 5% of her time as program administrator managing the financial and business activities of the project. She holds a degree in Business Administration from the Rochester Institute of Technology. Ms. Cerra will review and approve all project expenditures, ensure budget compliance, handle account reconciliations, serve as liaison to RIT administration, handle legal issues, and ensure timely reporting.

Lauren Parish, Web and Publications Manager, will spend 5% of her time on this project, primarily during the third year. Ms. Parish will be responsible for the dissemination of outreach materials including press releases, newsletters, and promotional information. She manages the production of all IPI websites and publications and plays a major role in outreach and promotion of IPI's tools and resources. She joined IPI in 2008 with a degree in New Media Publishing from Rochester Institute of Technology. Most recently she was responsible for the development and publication of IPI's eClimateNotebook website, *IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments*, and *Permanent Images: A Personal and Technical Memoir* by Dr. Peter Z. Adelstein.

Alex Bliss, Software Architect, will spend 5% of his time on the project in the third year. Mr. Bliss is responsible for the development, management and maintenance of IPI's web software programs. Mr. Bliss will assist in coding the analysis of data and will incorporate any necessary changes into IPI's eClimateNotebook software based on the findings of this research.

SUSTAINABILITY OF PROJECT DELIVERABLES AND DATASETS

Temperature and RH data will be collected from electronic data loggers and then uploaded into an online eClimateNotebook account. Once uploaded the data is stored in a MySQL database as simple floating-point and integer numbers. All images taken during the work will be stored in the Tag Image File Format or TIFF (ISO 12639:2004) a media independent means for data exchange.

These data storage criteria further ensure the integrity and continued accessibility of the RH, temperature and image data. The data is stored in a platform-agnostic fashion using simple data types. Should a migration to newer hardware or other foreseen maintenance become necessary, it will be handled using a simple MySQL data transition script. A plan for this instance exists and is run in a test environment once every two months to ascertain whether updates are necessary. Daily backups of the eClimateNotebook server images occur in the infrastructure, allowing for an easy transition to a new interactive viewing system, should it ever become necessary. The servers powering eClimateNotebook have redundancy and functional load-balancing operations to provide as much access as possible.

Dissemination

Throughout its previous research and experience related to sustainable environmental management, IPI has become acutely aware of the need to educate the preservation and facilities management communities about current research and findings in this area. In presenting the findings from this project, IPI will continue its ongoing dissemination of information to the field.

IPI will produce a final report on this project, which will be available online, including posting on IPI's www.imagepermanenceinstitute.org and www.ipisustainability.org websites. Research findings and other relevant data will be made available in scientific publications and technical papers, and in conference presentations. Travel to one conference in the third year to disseminate project results has been included in the budget. All other dissemination will be funded by IPI. IPI's *Climate Notes* e-newsletter, which has over 2,500 subscribers, will contain a report on the subject, and results will also be translated into content for educational workshops and IPI storage guides.