

Conserving Concrete Heritage Experts' Meeting Report

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Alice Custance-Baker and Susan Macdonald

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The Getty Conservation Institute
1200 Getty Center Drive, Suite 700
Los Angeles, CA 90049-1684
United States
Telephone 310 440-7325
Fax 310 440-7702
E-mail gciweb@getty.edu
www.getty.edu/conservation

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The Getty Conservation Institute works internationally to advance conservation practice in the visual arts—broadly interpreted to include objects, collections, architecture, and sites. The GCI serves the conservation community through scientific research, education and training, model field projects, and the dissemination of the results of both its own work and the work of others in the field. In all its endeavors, the GCI focuses on the creation and delivery of knowledge that will benefit the professionals and organizations responsible for the conservation of the world's cultural heritage.

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Introduction

Despite more than twenty-five years of experience in dealing with the complexities of conserving historic concrete, there are still some fundamental challenges to reconciling current repair options with conservation needs. Industry driven methods and materials do not take into account the usual conservation demands of minimum intervention and retention of original fabric, and can have a significant impact on the appearance and materiality of the concrete, which in many cases is core to architectural expression. While there has been a concerted effort by a small number of heritage agencies to advance knowledge in this field, with some success, there is still a need to enhance the capacity of conservation practitioners and others involved via training, the development of new information and the promulgation of existing resources, and improved diagnostic methods. There is also a need for scientific research to better understand the behavior of historic concrete, to identify the long-term effects of repairs, and to broker solutions to outstanding technical problems.

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The experts' meeting was organized under the auspices of the Conserving Modern Architecture Initiative (CMAI), launched in 2012, which aims to advance the practice of conserving twentieth-century heritage. A colloquium held in March 2013 brought together over sixty experts in this field and confirmed the need to focus attention on the material conservation of a variety of typical twentieth-century building materials, concrete included. Given the predominance of reinforced concrete as a building material in the twentieth century, and the GCI's background knowledge in this subject, a decision was taken to focus efforts in this area. As with all GCI projects it is anticipated that efforts will be undertaken in collaboration with others.

Conserving Concrete Heritage: Experts' Meeting

The Conserving Concrete Heritage Experts' Meeting brought together a small invited group of professionals to identify the knowledge gaps and identify key areas where the field can be advanced through a combination of research, education and training, and the creation and promulgation of literature on the subject.

Aims and Objectives

The aim of the meeting was to bring together the key players engaged in the conservation of concrete in modern heritage to:

- Examine the actions undertaken over the last two decades in order to assess the current state of concrete material conservation in order to;
- Identify research and other current needs;
- Determine how to advance this area of material conservation;
- Identify the priorities;
- Identify entities able to progress these priorities;
- Scope concrete research that the GCI could undertake and identify potential partners and stakeholders to work with in this area; and
- To develop an action plan to implement the research and other activities.

Participants

Eight expert participants, considered critical thinkers and key players in the conservation of concrete repair as it relates to heritage buildings and structures, were invited to participate in this meeting along with GCI staff and consultants. The participants have been influential in advancing this area of conservation to date or with the potential to do so in the future. The group comprised of international and national participants from primarily North America and Europe working in this area. This multidisciplinary group included engineers, architects, material scientists, and industry representatives with demonstrated expertise in the repair of historic concrete buildings and structures. Participant biographies can be found in Appendix A.

Meeting Format and Structure

The experts' meeting was held over three days and organized around working

sessions together with presentations from the invited participants, summaries of which can be found in Appendix C. A background paper was circulated in advance and presented on the first day of the meeting. The paper outlined the state of conservation of concrete and identified some of the issues facing those involved in conservation and attempted to identify the areas where targeted research could provide potential solutions to these dilemmas. The background paper focused on the repair of exposed concrete which is where the major conflicts between standard repair and conservation collide and therefore leads to potential research in the following areas:

- Investigation and diagnostic methods and tools;
- Electrochemical methods of repair;
- Coatings;
- Corrosion inhibitors;
- Patch repair methods and materials.

The background paper is available in full in Appendix B.

The GCI also prepared and distributed to participants in advance of the meeting a draft of an annotated bibliography that provides an overview of the current state of literature pertaining to the conservation of historic concrete.

The full meeting Agenda can be found in Appendix D.

Issues

During the meeting the participants agreed on a number of primary issues affecting the practice of concrete conservation. Although the concrete industry is vast, with the concrete repair industry representing a large proportion of this, concrete conservation as a specialized activity is a very small subset. The audience for this topic can be divided by profession; contractor, engineer, architect, conservator and so on. It can also be divided into two groups; those who are highly knowledgeable about concrete, but have little or no knowledge of/interest in conservation and those who are conservation professionals but with little or no knowledge/experience of concrete. In addition, the group agreed that it was important to reach not just those who are looking for specific information, but also to make information about concrete conservation more accessible generally and to encourage greater interest in and knowledge about the conservation of concrete heritage.

There are a wide range of issues and specific problems that warrant attention and development within the field of concrete conservation. These were grouped by activity type including; research, the creation and distribution of information, and education and training to advance the field. These issues are summarized below and are discussed in more detail in the following sections.

1. Issues that could be addressed by research that would serve to advance the conservation of concrete:

- Variability of historic materials and construction techniques and lack of detailed information about how specific types deteriorate and implications for repair;
- Requirement to undertake destructive testing of concrete structures to achieve reliable condition survey results;
- Lack of long-term evidence-based information on the efficacy of treatment methods;
- Lack of agreement within the field on basic procedures/methodologies for concrete repair (resulting in poor repairs);
- Undertaking effective repairs without affecting appearance;
- Constant adaptation of repair products and the availability of independent information about their efficacy and use.

2. Issues that could be addressed by filling information gaps through the creation and dissemination of literature:

- The currently available literature on concrete conservation is patchy and difficult to access;
- Concrete repair publications are dominated by references produced by manufacturers or those with a vested interest;
- How to access the most useful and factually correct information given there is so much available;
- Lack of published case studies on concrete conservation with detailed technical information;
- Identifying the best places to publish to ensure that the information reaches the desired audience.

3. Knowledge gaps that could be met by education and training activities to advance the field:

- Insufficient respect for the craft skills sometimes needed and perhaps even less within the concrete industry;
- There are very few concrete conservation experts internationally;
- The concrete conservation industry is not perceived to be large enough and therefore universities and technical colleges are uninterested in meeting the needs of this small market;
- There are no widespread qualifications, certification or requirements for working on a conservation of concrete heritage project;
- Identifying where and how to deliver the training to reach the correct audience;
- Concrete is a new area of conservation and so is not widely included in conservation course curricula;
- Limited qualified trainers available to deliver courses to industry and conservation practitioners.

Potential Research to Advance the Conservation of Concrete

Research is an area of activity that the Getty Conservation Institute is well placed to undertake, possibly in collaboration with other organizations. The GCI identified modern materials research as one of the potential core activities of the Conserving Modern Architecture Initiative and concrete conservation specifically as a priority. The experts' meeting's principle aim was to identify potential research questions and assist in framing potential research activities. Both short-term actions, that can be simply and quickly undertaken to provide a direct impact on the field, and long-term actions requiring a more concerted effort to target specific areas of the field were considered.

There are many issues influencing the deterioration of concrete heritage structures including lack of recognition for the material values and unwillingness to apply the usual conservation methodologies and levels of investigation, diagnosis and repair approaches, which can be seen as more expensive than standard repair approaches. Shifting thinking to long-term repair solutions that incorporate long-term maintenance into the approach and advancing knowledge about many of the challenges facing the conservation of concrete will lead to improved decision-making and informed choices for conservation.

Research that would address a number of the issues agreed as priorities by the group and that could potentially advance concrete conservation practice were divided into three categories; 1. investigation, diagnostics and analysis, 2. methodological and repair processes, and 3. repair materials. In addition the group identified research that gathered information from past case studies as a means of understanding the efficacy of different techniques and approaches.

Investigation, Diagnostics and Analysis

The emphasis in conservation practice is to base work on a sound understanding of a building's history, its condition, risks and an assessment of its heritage significance. Therefore access to tools and techniques that provide as much information as possible with the least physical impact to the building in the process is critical. Accurate and detailed investigation and condition assessment, usually using a variety of diagnostic tools, are essential steps in the process to identify the deterioration of a structure and for the development of repair proposals. Being able to predict or at least understand ongoing deterioration and the affect of any repair

processes is also critical when developing conservation proposals. Currently investigations are undertaken by someone familiar with architectural conservation but less well versed in concrete, or by someone familiar with concrete structures but unfamiliar with conservation practice. At present it is rare to find professionals confident in both of these fields. There are also limitations on the available information currently available to practitioners for a number of the critical steps identified above.

Research on the material character of historic concrete and its constituent materials, and implications for deterioration and conservation

There are an increasing number of publications on historic concrete, however the information on the types of historic concrete used is scattered and ad hoc and does not get to a level of detail that is often necessary when it comes to conserving it. It has also not reached a level of maturity where patterns of deterioration and durability have been identified and related to concrete and concrete system types. The group agreed that there is a need to undertake research that brings together existing, and undertakes new research about the material character of historic concrete as a basis for conservation work. The group suggested that producing information in the form of an atlas of concrete types, their constituent materials (reinforcement, cements, aggregates, etc.) used historically, and how to recognize these would be of great assistance. Gathering information of different historic reinforcement types and materials, composition, design and deterioration patterns and cement types used and so on, would assist in building up information to help practitioners undertaking assessments and diagnosis of buildings¹. Coupling this information with results from material analysis and other information drawn from previous projects on typical deterioration problems that relate to specific historic concrete types, would build up a body of information that would benefit the field. Encouraging student theses on the major concrete systems from different periods (Hennebique for example in the pre-war period, Schokbeton in the post-war and so on) or identifying research priorities for characterization studies would help advance this research.

Materials testing laboratories are highly familiar with modern concrete samples; however there can be misinterpretation of historic concrete samples due to a lack of knowledge of the development of concrete and the availability of production techniques and materials. Research into historic concrete types and materials could therefore improve knowledge at the testing laboratories. Such research that would provide knowledge of the historic materials used in turn would assist the decision making for conservation methods and materials.

Documentation currently underway by a European team as part of the Redmonest

¹ For example the source of iron used for the production of rebar in the United States is understood to have changed following the second-world war. The earlier source of iron contained copper, which is thought to have contributed to a slower rate of corrosion than the new source.

Project² is recording the scope of concrete heritage within the region of study. Factors being recorded include the composition of structures, date of construction, and construction specifics. One aim from the outcome of this project is to be able to demonstrate the size of the potential concrete conservation market to encourage interest in developing the field. This could well be a project that could be rolled out internationally to improve both the profile of concrete conservation but also our understanding of the historic concrete built environment.

Developing new or improving existing tools for use in diagnostics to improve the ability to better understand deterioration in less destructive ways

Improving knowledge on the investigation and diagnosis of concrete buildings could be achieved through education and training and providing robust guidance on the assessment methods and diagnostic tools available. These are addressed in the following sections. However, the group also recognized a need for research that identified new and improves existing diagnostic tools to enhance accuracy, reduce physical impact on historic fabric, and improve the ability to predict the long-term behavior of historic concrete.

It is essential to be able to establish the location, quantity and condition of reinforcement within a structure. Radar is currently the most popular method for identifying the presence of reinforcement, however its accuracy can be questioned and it can be difficult to cover large areas of a structure. In addition to the location of reinforcement, a key area of research that was identified is the ability to assess the condition of the reinforcement without having to use destructive investigation techniques. Identifying the presence of corrosion, its thickness, and also its rate of development are current goals for the development of such technologies. The development of battery-operated sensors provides an opportunity for more simple longer-term monitoring of the development of corrosion, however this would need to be done without compromising the historic fabric.

Another area of development that could greatly assist the field is enhancing the ability of mapping the presence of moisture within concrete. Development of technologies that enable the 3D visualization of moisture within concrete could aid understanding of moisture movements within a concrete structure, identification of the source of the moisture, and how to prevent its ingress³.

Long-term monitoring is required to track the structural condition of a building. The expert group was therefore keen to promote research and development that could enable a more rapid assessment of structural movement. In combination with this would be the development of technologies and information that could improve the ability to predict failures. One suggestion is to create a system that enables

² A summary sheet of the Redmonest Project background and aims can be found on this link: <http://www.heritageportal.eu/Browse-Topics/BUILT-HERITAGE/Factsheet-10-REDMONEST-Monitoring-Dynamic-Network-for-Existing-Structures-of-Concrete-Cultural-Heritage.pdf>

³ A team based in Florence, Italy, is understood to be developing this area but at present are limited in the depth that they are able to map (c.2cm).

users to input new data into the standard models used for failure prediction to improve the accuracy of the models.

Repair Methodology and Processes

There are still a number of areas of research needed to improve knowledge on many of the repair options available, their efficacy, life span and methods for undertaking repair techniques. The group identified a number of specific areas, which are discussed below.

Improved knowledge on the life cycle of repair methods and the role of, and techniques for maintenance

There is now a body of concrete repair works undertaken to historic buildings over the last few decades that can inform practice, although this information is largely unharnessed and does not assist in assessing the long-term effectiveness of the repairs used. There is little information on the life span of the various repair methods as monitoring and evaluation of concrete repair or conservation work is rare. Although it is recognized that most solutions will not be permanent and reinforced concrete will over time continue to decay, repair work is undertaken on the basis that the service life of the structure will be extended for a reasonable period of time with minimal intervention. A greater understanding of the life cycle of concrete repairs is required.

Conservation practice often subscribes to the idea that maintenance can play an active role in the repair process delaying larger scale intervention. There is little information on monitoring, evaluation and the role of ongoing maintenance as part of a repair and long-term conservation strategy for concrete. Research in this area could potentially open up a wider range of options in the conservation process. Improved information on maintenance programs generally could also extend the service life of repair interventions.

Patch repair techniques

The vast majority of concrete conservation projects are triggered by visible damage and therefore patch repair of concrete is an integral part of any repair project. Despite this being the most commonly used repair technique, there is widespread disagreement within the industry on some basic parameters for undertaking the repair. Unsurprisingly with this level of disagreement a large number of patches are said to fail within a relatively short timescale with a suggestion that if we go back 10-20 years a large majority of cement patches will have failed⁴. These figures are likely to be as relevant for conservation projects as any other.

4

Grantham states that '50% of all concrete patch repairs will fail within 10 years' Grantham, Michael, ed. 2011. *Concrete Repair: A Practical Guide*. London; New York: Routledge/Taylor & Francis.

The first stage of undertaking a patch repair is to remove the deteriorated concrete and prepare the area for the repair. Group discussions indicated that in the US it is standard for patches to be undertaken with a straight geometry, whereas this is not the case in Europe, although there is some crossover. The argument given for a straight geometry is that it is supposed to reduce the amount of shrinkage experienced, however it may require the removal of larger amounts of the historic concrete. As our aim is to save as much of the historic fabric as possible this could be an important area for further research⁵.

An associated issue is that if it is deemed necessary to remove corroded reinforcement and splice in new rebar the current standards specify a certain level of overlap with the original rebar which can require removal of additional amounts of the historic fabric. The current requirements for this overlap could be investigated to see if a reduction in this overlap is possible under certain circumstances where the stability of the structure is not compromised.

Good surface preparation is essential for the success of a patch repair. All deteriorated concrete must be removed and the surface taken back to sound material. The resulting roughness of the surface is considered to be a key factor in the adhesion of the new patch material although the aggressiveness of the method used for removal has to be balanced against the potential for producing micro cracking in the surrounding area⁶. The prepared surface is required to be 'clean' prior to application of the patch material, as specified by repair product manufacturers, but there are no parameters for determining what is clean. A set of guidance notes could assist with this judgment. One of the major points of contention in the industry is whether or not the prepared surface should be wet before application of the patch repair. This needs to be researched and addressed because such a fundamental difference in approach can only result in a continuation of failures.

These examples highlight the need for more definitive work in patch repair techniques to resolve, to reduce confusion, and to reinforce the need to develop standards for patch repair.

Realkalization

Realkalization is a popular technique that has been used on a large number of concrete buildings affected by carbonation to increase the pH and reinstate the passive layer to the reinforcement. A study undertaken by the French Laboratoire

⁵ Considering the poor statistics for the lifespan of patch repairs this is particularly important otherwise what may result is an on-going removal of unnecessary amounts of the historic fabric each time a patch needs to be replaced.

⁶ This issue among others is being addressed as part of the European Redmonest Project (project factsheet available to download on this link <http://www.heritageportal.eu/Browse-Topics/BUILT-HERITAGE/Factsheet-10-REDMONEST-Monitoring-Dynamic-Network-for-Existing-Structures-of-Concrete-Cultural-Heritage.pdf>).

de Recherché des Monuments Historiques (LRMH) has found this method to be ineffective, with areas where the technique was successful only retaining their heightened pH for around two years. It was argued that there have, however been other studies that have found this technique to be successful and there is a large amount of on-going research in this field. There was general agreement within the expert group that this is a field that could benefit from the reassessment of well-documented past projects⁷ and in addition a literature review to identify some of the key pieces of research and evidence for and against the success of this process.

Cathodic protection

Cathodic protection is a method that is generally considered as the most comprehensive means of preventing corrosion of reinforcement. However, its application to historic concrete buildings has been limited as it is destructive physically, often visually disruptive, and there are challenges to designing a system that connects all of the reinforcement. Development of battery technology could be the answer to the visual disfiguration caused by the large amount of cabling that is currently required for a CP system, but there is still no solution for preventing the loss of historic fabric when embedding the anodes. Because CP is an active system, maintenance is required, although the level of maintenance was debated by the group. There is some question as to whether a 'halo effect' exists whereby an area surrounding that being treated by CP is negatively affected; opinions differ and again this could be an interesting topic to research further. If concrete is affected by chlorides CP is often the only recommended conservation technique and therefore it is important to develop it to be more compatible with conservation needs.

Corrosion Inhibitors

Corrosion inhibitors have been found to only be successful in a limited number of situations and therefore the number of buildings that they can be used on is very small. In addition, migratory corrosion inhibitors need to be applied to a clean surface, which would result in the removal or damage to any surface patina that is present. This field has not been identified as one to be pursued as a priority.

Repair Materials

Patch repair materials

In addition to the need for improved understanding about the process of undertaking a patch repair, is the need for better information on repair mortars. It is hard to produce a definitive guide to the available repair materials due to their ongoing development and the fact that it is affected by industry competition. Researching the characteristics and performance parameters required for successful

⁷ High profile projects where the realkalization technique has been used include the Hoover Building (1938) and Uxbridge Station (1904), both London, UK.

repair materials however could significantly aid decision-making and specification. Manufacturers data sheets do not always display all of the information that a specifier may wish to see and this may be an opportunity to highlight the importance of such information. The GCI's work on developing appropriate tests for selecting grouts for use in conserving architectural surfaces may be a useful model for assisting in the selection of concrete repair mortars⁸.

Conservation work often aims for like-for-like replacement of materials both materially and aesthetically. In terms of patch repairs there are many reasons why this may or may not be a good idea or feasible. New concrete tends to have trouble bonding to old concrete which is why the industry tends to use polymer modified mortars, but there may be alternatives that should be investigated or developed. Every project requires a slightly different surface finish to match the original, and therefore this can be difficult to research and provide effective guidelines. A variety of surface finishes characterize concrete buildings and there is little information on these or how to reproduce them. A catalogue of surface finishes and ways of achieving these could be researched and developed to provide guidelines on how to achieve the different surface characteristics that may be present.

Standards for mortar specifications vary internationally. The EU standard (EN1504) results in specified special mortars only being possible for large volumes. Manufacturers will not produce small volumes of a specified mortar because of the expense of getting the EC certification. For this reason it is common for people to use pre-bagged mortars, which may not be optimal for the project. In the EU mixing on site will preclude a warranty, which may not be acceptable. In the US there seems to be more ability to specify small quantities of specified mortars from manufacturers and pre-bagged materials tend not to be used for heritage structures. If different standards can be developed and adopted for conservation projects this may improve the ability to work in a conservation context rather than a repair context. Conservation may need specialized mixes for some projects and brokering such approaches with standard-setting institutions may therefore be needed.

Coatings, hydrophobic treatments and consolidants

Surface coatings for concrete were identified as a key topic for research and development. The four main groups of surface coatings are film-forming sealers, surface hydrophobic treatments, penetrating hydrophobic treatments, and consolidants. Film-forming coatings are undesirable for the conservation of exposed concrete buildings because they change the appearance of the surface; the other three groups are worthy of further consideration.

Hydrophobic treatments were identified as the priority for further development and research given the critical role limiting water plays in reducing reinforcement corrosion. There are several concerns with the use of hydrophobic treatments that are important to highlight in terms of conservation and that any research needs to

⁸ Information on the GCI project Injection Grouts for the Conservation of Architectural Surfaces :Evaluation and Treatment is available on line at http://www.getty.edu/conservation/our_projects/field_projects/grouts/index.html

address:

- Depth of penetration of penetrating hydrophobic treatments;
- Percentage concentration of product that achieves the desired result and is able to penetrate;
- Lack of reversibility;
- Need for regular retreatment;
- Future limitations for retreatment using alternative products;
- Potential for uneven weathering; and
- Potential for increase of corrosion of the rebar due to an alteration in the moisture levels.

Most of the research on hydrophobic treatments for use in conservation has been undertaken on stone and more specifically stone with an open pore structure such as sandstone. Although participants were aware of some ongoing research it was agreed that there may be a need for further research on their use and success on concrete. In addition, most of the products on the market for concrete will have been developed for modern concrete, but these may not necessarily be compatible with historic concrete, which may be less dense and with a more open pore structure. It may be that alternative products need to be developed for historic concrete.

There is a long history of the use of hydrophobic treatments on concrete heritage buildings (c.40 years) particularly in the transportation industry on bridges. This history of use should provide the opportunity to go back and assess the current condition of these structures to see if any of the concerns above have proven to be an issue. A literature review to document past and present developments of these treatments and their use would assist specifiers in selecting appropriate products. Further research and development of hydrophobic treatments would need to consider all of the points raised above. In addition, development of a non-destructive method for effectively measuring the success of a treatment would greatly benefit the field.

There is research currently on going as part of the European Redmonest Project addressing the use of silanes (penetrating hydrophobic treatments) on concrete with and without carbonation and corroded reinforcement.

Lithium treatment for the reduction of the effects of alkali-silica reaction (ASR) was briefly discussed by the expert group. One issue is that ASR is often misdiagnosed, however there is understood to be much on-going research on the topic because it has been identified in many nuclear facilities and therefore there is a concerted effort to identify appropriate treatments. Lithium treatment works by controlling the expansion of the silica gel on exposure to moisture, however it is difficult to get the lithium to reach the zone where moisture levels are fluctuating and therefore this is a potential area for further research. Given the scale of the issue as it affects historic concrete buildings this was agreed not to be a priority.

Consolidants are more commonly used on stone but they may have some use for concrete, particularly in the case of sculptural elements. Most of the known

research has been conducted on stone and therefore there is much space for development of these products for concrete and for research into their effects. There are also some developing technologies that could be of interest to the field such as bioconsolidation with biosilicate or biocarbonate.

Case Studies

Reassessment of past conservation and/or repair projects on historic concrete buildings was agreed to be a major source of information for the development and improvement in our understanding of current and past conservation treatments. There are many potential issues with this form of research including lack of documentation and the difficulty of identifying the difference between failure due to the specified materials, failure due to repair techniques, and failure due to workmanship. The reassessment of projects can also be highly subjective. It was agreed that a framework for the reassessment of conservation or repair work undertaken to concrete structures could be very valuable in terms of the usability of the data collected. It was agreed that there might be some resistance to the reassessment of conservation works because no one wants to have their work reported as a failure. Developing a template for evaluating past projects and work undertaken, as independent research to assess the efficacy of approaches and techniques would help to acquire more accurate results. Such evaluations could commence with simple visual evaluations then move to more detailed analysis using test techniques and methods.

Filling Knowledge Gaps: Creating and Disseminating Information to Advance the Field

In advance of this meeting the GCI produced a draft of 'Conserving Concrete Heritage: an Annotated Bibliography'. This publication is composed of five sections:

1. History and Development of Concrete;
2. Concrete Deterioration and Damage;
3. Historic Concrete Diagnostics, Monitoring, Nondestructive Testing, Investigation, and Assessment;
4. Approaches to Conserving Historic Concrete; and
5. Conservation and Repair of Historic Concrete.

The annotated bibliography aims to bring together the key international texts that specifically address concrete conservation. A limited number of key texts from the concrete repair industry were included due to their relevance to conservation and the importance placed on these documents within the broader concrete industry. One of the purposes of producing this bibliography was to try to identify the gaps in the literature to inform future research and potential publications. The bibliography will be developed over the next couple of months and then available for download from the GCI website.

The published literature on the conservation of concrete is at present rather patchy and often difficult to locate or access. In contrast there is a very large body of published work on concrete repair, but this is so vast that it can be difficult to navigate for those new to concrete from a conservation background. In addition, much of this work has been produced by the concrete industry and manufacturers, which can make it extremely difficult to identify which publications are truly independent and which are biased towards industry approaches and products. There is also a body of academic research on concrete. However, given the scope of this work it is difficult to identify the research underway of relevance to conservation.

Many of the best guides to concrete conservation come from government heritage bodies in the English-speaking world and France. However, these are fairly introductory having largely been developed when concrete buildings were only just becoming protected and were intended to cover basic information only and do not provide a level of detail that may be necessary. The LRMH guidance documents do

move into a level of technical detail that is very useful⁹.

Ideas discussed at the meeting as useful literature for the conservation field included a glossary of terms, information on the characteristics of concrete heritage (as discussed in the research section), technical guidance notes, a compendium of case studies, translations of useful publications to increase dissemination internationally, and revision of pertinent but out of date publications.

Glossaries of terms exist separately for the conservation and concrete repair industries; however there is no known glossary specific to concrete conservation and this could be a useful contribution to the field. An alternative to the production of an entirely new glossary is to have concrete conservation terms included within new productions of the current glossaries. Such a glossary could build on the excellent work undertaken by LRMH published in French, and perform a similar role to the *ICOMOS-ISCS Illustrated Glossary on Stone Deterioration Patterns*¹⁰. Translating the LRMH publications to English would provide wider access to this information.

Technical guidance notes for concrete conservation could provide a very useful resource, particularly for those new to the field. These could come in the form of brief notes on key subjects or broader publications on wider areas of the industry. These guidance notes could be aimed at building owners, contractors or professionals who may each require a different level of information. One suggestion for a guidance note was something that simply identified five or six parameters to look for on product technical data sheets to assist material specification and a little detail about the importance of each parameter. Another suggestion was a simple set of notes highlighting the different stages that one should undertake when approaching a concrete conservation project. Building owners are often the people selecting the contractor or engineer for their project and therefore providing a set of guidance notes for owners could help to get the right people involved at the start of a project. Developing publications that identify the role of maintenance for concrete buildings was also identified as a specific area of need. It was recognized that there is research work to be done in preparing such information given current debates on a number of the processes involved and this is a larger task than simply repackaging existing information.

Encouraging the publication of case studies with detailed technical information about the work that has been undertaken was something that the group identified as a very useful short-term activity. In addition to this, technical re-evaluations of past repair would be highly beneficial to improve our understanding of successes and

⁹ These include: 'Le Nottoyage des bétons anciens: guide des techniques et aide à la décision, M. Bouchou, E. Marie-Victoire, Cercle des partenaires du patrimoine, Cahier technique no4, Champs-sur-Marne, 2009, 43p.' and 'Les altérations visibles du béton: définitions et aide au diagnostic, E. Marie-Victoire, Cercle des partenaires du patrimoine, Cahier technique no1, Champs-sur-Marne, 1996, 32p.'

¹⁰ Vergès-Belmin, V. (ed) 2008. ICOMOS-ISCS: Illustrated glossary on stone deterioration patterns Glossaire illustré sur les formes d'altération de la pierre. Champigny/Marne, France

failures of the past to improve our future decision-making. Learning from successes and failures, was recognized as important, although understandably the industry is not keen to advertise its failures and companies often do not want to publish information on methodologies for reasons of competition.

As mentioned previously, the published information from the concrete repair industry is dominated by research undertaken by manufacturers. Therefore the production of further independent research would certainly be of benefit for the industry.

Developing simple lists of key organisations involved in the concrete industry could be a useful contribution to the field of concrete conservation. The GCI has an opportunity to act as a guide for pointing interested people in the direction of the available sources of information. This could be a useful addition to the annotated bibliography.

Some projects with directly publishable results were suggested during the meeting including:

- A literature review of penetrating hydrophobic treatments (silanes) for use on concrete;
- A publication on how to undertake patch repairs and create successful finishes;
- Publication on repair methods that we now know to be inappropriate despite having been popular in the past, as a way of discouraging practitioners from using them (e.g. epoxy coatings);
- Production of addendums to currently available material in the concrete repair industry such as the American Concrete Institute (ACI) Concrete Repair Guide which could ideally be incorporated or otherwise made available as a separate publication; and
- Contributing to an Owner's Guide already in production as part of the ACI's 'Vision 2020' project rather than producing our own.

Identifying the best places to publish is important to ensure that the information reaches the desired audience. It was recognized that integrating conservation needs into broader technical literature is important. The conservation industry is fairly contained and targeted information is fairly easy to promulgate. The general concrete repair industry however is vast and getting targeted conservation information to this audience is more challenging. On a smaller scale in terms of publishing, there are several electronic newsletters or bulletins produced by the concrete industry on a regular basis. Contributing to these could be a good method for reaching a wide audience and introducing conservation issues and needs.

Potential Education and Training Activities to Advance the Field

The first consideration for contributing to education and training activities in concrete conservation is to correctly identify the audience. The audience can be divided into people who are highly knowledgeable about concrete repair but have little experience in concrete conservation, and those who are highly knowledgeable in conservation but have never worked with concrete. Secondly it can be divided by profession; broadly contractors and specifiers but this can be subdivided into laborers, site supervisors, engineers, architects, owners, manufacturers, and so on.

The well recognized challenge in the construction and conservation industries is the access to craft skills and this is exacerbated within the concrete industry. One of the characteristics of the concrete industry and its expansion in the post-war era was a move to less skilled labor. Conservation of historic concrete, particularly patch repair work may demand skilled workers who recognize the importance of, and are able to undertake aesthetically and technically appropriate repair work; essentially crafting an industrialized material.

A program of training for contractors currently delivered in Belgium could act as a framework for developing training programs internationally. There is a two day program involving a half day of theory, half day practical, and the second day includes an exam which is to undertake a patch repair on which three checks are made; is it flat, are there cracks and how is the adhesion? The training is provided by the Federation of Repair Contractors.

Specifiers require a good understanding of the complexities involved in both concrete repair and concrete conservation. They need to consider the affect that their repairs will have on a structure physically, chemically and aesthetically. It is essential for this group to understand not just how, but why things are done in a certain way. The poor quality of condition assessments prior to the commencement of work was one of the issues that were brought up for discussion. The expert group felt that this has to be a major focus of the training as it is the backbone for all decision-making. Equally it is important for specifiers to know what they don't know and therefore to understand at what stage someone with greater experience should be brought onto the project. They should also be able to identify the difference between a good and a bad repair so that they can supervise projects knowledgeably. Given that concrete is essentially a structural material the input of an experienced structural engineer, versed in conservation approaches, will be an

essential part of any team. Specifiers are generally architects and engineers who tend to require continuous professional development (CPD) to retain their statuses. This is an excellent opportunity for offering education and training courses.

The group agreed that the goal is to work towards the integration of concrete conservation training within standard concrete industry training, rather than develop a separate track. The Concrete Industry Management course at California State University, Chico, provides an interesting model for this. The majority of training for engineers and architects, particularly in the US, focuses on new design, and they do not learn what happens after the concrete has been placed. In many countries there are regulations or certification requirements for the architects or engineers who can work on listed or landmarked sites, however it is very rare for these professionals to have much, if any, training in concrete repair and concrete conservation. An issue with education and training in concrete conservation is that the industry is not perceived to be large enough for universities and technical colleges to engage. Similarly, concrete conservation does not tend to receive much recognition as part of the majority of conservation course curricula. This is most likely because it is a relatively new area of conservation, but also due to the lack of experts available to provide the training.

An indirect way to improve the quality of concrete conservation being undertaken is to provide training and education for non-specialists such as building owners. This could improve the selection of specifiers and contractors for a job and encourage the owner to think beyond the cheapest option.

Qualifications and certification are one option to consider for increasing the ability of project managers to select appropriate people to run their projects and for these people to employ appropriate contractors. Certification through professional bodies may be the best approach. There appears to be some steps towards a European certification, presently limited to individual countries. There is some movement already from industry bodies to have certification for concrete repairs, but it is up to specifiers to identify the requirements for contractors and to ensure that it is the qualified people working on the project. This could be a good thing to promote and encourage.

Once the target audience is identified, where and how to deliver the training are important considerations. The annual 'World of Concrete' trades show (or similar) was cited as an option for reaching a potentially huge audience from the concrete repair industry. Alternatively working with concrete industry bodies such as the American Concrete Institute and International Concrete Repair Institute, to develop interest and training programs may be an option. These two groups are already working together to produce an online training program for concrete repair, and this could be an opportunity to include conservation within this program. Training for conservation practitioners could be carried out at the annual conferences of conservation bodies such as the Association for Preservation Technology International, American Institute for Conservation of Historic and Artistic Works, Institute of Conservation, etc. Developing short training modules and didactic materials for use by training providers was identified as a useful way forward.

A first step in advancing training and education activities was identified as developing a database or simple list of existing training being delivered to the different sectors of the industry. This would help understand the scope of existing work, existing delivery modes and the organizations involved.

Priorities

The expert group was asked to identify what they considered to be the research priorities for the field, both short-term actions that could be undertaken simply and relatively quickly to have an immediate impact on the field, and long-term actions that would require a more concerted effort. The two topics of research that were identified as the most important or highest priority were patch repair methods and materials and penetrating hydrophobic treatments (silanes). In terms of short-term aims, undertaking and publishing a literature review of both of these topics was agreed a useful way to understand what the current knowledge and developments are in both of these fields. Long-term research identified for patch repairs focused on the need for guidance on how to undertake a successful patch repair and on the appropriate specification of materials for this repair. This work would be heavily influenced by the results of a literature review and would require significant laboratory and on site studies. Long-term research prioritized for penetrating hydrophobic treatments included the assessments of past treatments. In addition the group were keen to discuss the development of available treatments with manufacturers.

Two other priority areas for research were the evaluation of past conservation treatments and characterization of historic concrete. These were both identified as difficult to achieve and would require a concerted research effort. The reevaluation of past conservation treatments is essential for us to understand which treatments are successful and which are not. To undertake this work there would be a heavy reliance on the documentation from when the treatments were undertaken and in addition are very subjective in terms of identifying success and failure. To undertake this work in enough detail would require small-scale destructive testing of materials. The characterization of historic concrete could aid the assessment and understanding of material interactions that occur in historic concrete structures. This research would require a high level of sampling and laboratory assessment to identify the common groups of concrete and types of aggregate and cement binder used.

Literature reviews were also suggested as good next-steps for identifying the work that is currently being undertaken in the fields of moisture monitoring or non-destructive testing and realkalization.

Appendix E illustrates the discussions and priorities identified at the meeting.

Conclusions and Next Steps

The expert meeting identified a number of potential actions that would advance the conservation of concrete in the short, medium and long term. The GCI intends to investigate these options and develop a program of research and other related activities in early 2015. Inevitably and consistent with the usual GCI approach this work will be undertaken with other organizations.

In the immediate future the GCI will complete *Conserving Concrete Heritage: An Annotated Bibliography* as a free online resource. A publication series addressing case studies on the conservation of modern heritage is currently being developed with the first volume to cover case studies on the conservation of concrete buildings and structures. This publication project is commencing in late 2014.

Following the experts' meeting the GCI summarized the actions identified and prioritized these at the meeting as summarized in the previous section. A potential action plan of work to advance the field has been developed below. The actions are organized within the categories used at the meeting although it is recognized that there is overlap between these categories. For each activity, desired outcomes or impacts are identified, specific outputs or products proposed and potential actors suggested.

The outcomes of the meeting will be made available on line and circulated more widely to potentially interested parties and feedback will be sought on the ideas contained therein.

Proposed Action Plan

RESEARCH: AREAS AND ACTIVITIES TO ADVANCE CONCRETE CONSERVATION		
Activity: Research on the material character of historic concrete and its constituent materials and implications for conservation		
Desired outcome: <ul style="list-style-type: none"> Improved information on historic concrete types and how to recognize these; Improved ability to correlate knowledge about how different types of concrete decays, repair issues and responses; Better analysis of historic concrete by testing labs. 	Outputs: <ul style="list-style-type: none"> An Atlas of concrete types and its constituent parts. 	Potential actors: <ul style="list-style-type: none"> Heritage agencies; Universities; Industry; GCI.
Activity: Improved non-destructive tools for assessing the condition and rate of corrosion		
Desired outcome: <ul style="list-style-type: none"> More accurate information on the location, extent and rate of corrosion to better develop repair approaches; Reduce the use of destructive techniques. 	Outputs: <ul style="list-style-type: none"> New/improved tools. 	Potential actors: <ul style="list-style-type: none"> Industry – equipment manufacturers; Universities.
Activity: Development/enhancement of tools for 3D visualization of moisture levels within concrete		
Desired outcome: <ul style="list-style-type: none"> Improved understanding of risk levels due to potential corrosion. 	Outputs: <ul style="list-style-type: none"> New/improved tool for NDT. 	Potential actors: <ul style="list-style-type: none"> Industry – equipment manufacturers; Universities.
Activity: Research that evaluates the life-cycle of key repair types undertaken to defined standards		
Desired outcome: <ul style="list-style-type: none"> Agreed methodology for evaluating repairs; Better understanding of the service life of repair options; Improved ability to determine life cycle of repairs and evaluate repair options. 	Outputs: <ul style="list-style-type: none"> Template for evaluation of repairs; Data on service life of repair options and life cycle. 	Potential actors: <ul style="list-style-type: none"> Industry; Universities; Research institutes.
Activity: Research that facilitates the development of standards for repair patches		
Desired outcome: <ul style="list-style-type: none"> Knowledge about best practice for undertaking patch repair that meets conservation requirements including recommendations for cutting out, placement, reinforcement repair and so on; Clear understanding of good practice and elimination of confusion and contradictions. 	Outputs: <ul style="list-style-type: none"> Guidance documents / standards for patch repairing historic concrete. 	Potential actors: <ul style="list-style-type: none"> Universities; GCI; Industry.

Activity: Develop parameters for the selection of appropriate repair mortars for patch repairs that address regional/country standards		
<p>Desired outcome:</p> <ul style="list-style-type: none"> Improved knowledge on appropriate materials and selection criteria for repair mortars. 	<p>Outputs:</p> <ul style="list-style-type: none"> Guidance on specification of appropriate repair mortars for concrete conservation. 	<p>Potential actors:</p> <ul style="list-style-type: none"> GCI; Industry.
Activity: Evaluation of past repairs using specific techniques including realkalization, cathodic protection and desalination		
<p>Desired outcome:</p> <ul style="list-style-type: none"> Improved knowledge about the performance of past repair processes and systems (realkalization, CP etc.) to historic buildings. 	<p>Outputs:</p> <ul style="list-style-type: none"> Evaluation technique established for ongoing monitoring and evaluation of repair projects; Publication of evaluation of case studies of past treatments. 	<p>Potential actors:</p> <ul style="list-style-type: none"> Universities; GCI; Industry; Practitioners.
Activity: Further development of CP systems for heritage conservation projects		
<p>Desired outcome:</p> <ul style="list-style-type: none"> Potential to use CP with reduced physical and visual impact to historic buildings. 	<p>Outputs:</p> <ul style="list-style-type: none"> Improved CP systems for heritage conservation. 	<p>Potential actors:</p> <ul style="list-style-type: none"> Industry; Universities; Heritage agencies/research institutes.
Activity: Develop methodologies for replicating existing surface finishes		
<p>Desired outcome:</p> <ul style="list-style-type: none"> Shared understanding of how to replicate historic surface finishes during repair works. 	<p>Outputs:</p> <ul style="list-style-type: none"> Guidance document on replicating historic surface finishes. 	<p>Potential actors:</p> <ul style="list-style-type: none"> GCI; Industry; Universities.
Activity: Undertake a literature review on the use of hydrophobic treatments on concrete		
<p>Desired outcome:</p> <ul style="list-style-type: none"> Synthesis of information on the use of hydrophobic treatments in concrete repair which will assist in determining where further research may be of benefit. 	<p>Outputs:</p> <ul style="list-style-type: none"> Literature review. 	<p>Potential actors:</p> <ul style="list-style-type: none"> Universities – Colombia; GCI.

FILLING KNOWLEDGE GAPS: CREATING AND DISSEMINATING INFORMATION TO ADVANCE THE FIELD OF CONCRETE CONSERVATION		
Activity: Complete and publish <i>Conserving Concrete Heritage: An Annotated Bibliography</i>		
<p>Desired outcome:</p> <ul style="list-style-type: none"> Improved access to and knowledge about currently available information on concrete conservation. 	<p>Outputs:</p> <ul style="list-style-type: none"> Online publication; Index of organizations engaged in concrete repair and conservation. 	<p>Potential actors:</p> <ul style="list-style-type: none"> GCI.
Activity: Glossary or terms including definitions of deterioration mechanisms		
<p>Desired outcome:</p> <ul style="list-style-type: none"> Improved understanding on the deterioration mechanisms for historic concrete; Alignment of terminology for practitioners across conservation and repair sectors. 	<p>Outputs:</p> <ul style="list-style-type: none"> Illustrated glossary publication. 	<p>Potential actors:</p> <ul style="list-style-type: none"> GCI/ LRMH; Industry.
Activity: Technical guidelines on a number of identified conservation and repair processes and techniques		
<p>Desired outcome:</p> <ul style="list-style-type: none"> Improved understanding and quality of conservation work. 	<p>Outputs:</p> <ul style="list-style-type: none"> Suite of guidance documents targeted to conservation audience. 	<p>Potential actors:</p> <ul style="list-style-type: none"> Heritage agencies; GCI; Industry.

Activity: Integrate conservation approaches and methods into industry standards and guidelines		
<p>Desired outcome:</p> <ul style="list-style-type: none"> • Conservation needs better understood and included in general repair information. 	<p>Outputs:</p> <ul style="list-style-type: none"> • Industry standards guidance includes conservation needs, methods; • Include conservation in Vision 20 Owners Guide. 	<p>Potential actors:</p> <ul style="list-style-type: none"> • Industry; • Conservation bodies; • Heritage agencies; • GCI.
Activity: Document case studies and share experiences and knowledge from conservation projects		
<p>Desired outcome:</p> <ul style="list-style-type: none"> • Access to information on approaches and strategies for the repair of concrete heritage. 	<p>Outputs:</p> <ul style="list-style-type: none"> • Case study publication on concrete conservation as first in a series on modern materials. 	<p>Potential actors:</p> <ul style="list-style-type: none"> • GCI.

POTENTIAL EDUCATION AND TRAINING ACTIVITIES TO ADVANCE THE FIELD OF CONCRETE CONSERVATION		
Activity: Develop list/database of training activities in concrete repair and concrete conservation		
<p>Desired outcome:</p> <ul style="list-style-type: none"> • Knowledge of existing training activities, who, what is covered, where, and gaps and potential to fill these. 	<p>Outputs:</p> <ul style="list-style-type: none"> • Reference list of training outlets. 	<p>Potential actors:</p> <ul style="list-style-type: none"> • GCI; • Industry (ICRI, ACI etc).
Activity: Develop basic concrete conservation training module for conservation practitioners		
<p>Desired outcome:</p> <ul style="list-style-type: none"> • Improved understanding of conservation practitioners on how to approach the conservation of concrete. 	<p>Outputs:</p> <ul style="list-style-type: none"> • Training module and didactic materials. 	<p>Potential actors:</p> <ul style="list-style-type: none"> • APT/ conservation bodies; • Industry; • GCI; • Universities.
Activity: Develop basic conservation training module for concrete repair industry		
<p>Desired outcome:</p> <ul style="list-style-type: none"> • Improved understanding of conservation practitioners on how to approach the conservation of concrete. 	<p>Outputs:</p> <ul style="list-style-type: none"> • Training module and didactic materials. 	<p>Potential actors:</p> <ul style="list-style-type: none"> • Industry – ACI, ICRI etc.; • Conservation bodies (APT etc.) • GCI.

Appendix A: Participants Profiles

Beril Biçer-Şimşir graduated with a BS degree in civil engineering from the Middle East Technical University in Ankara, Turkey, and an MS degree in civil engineering, with a specialty in the area of construction materials, from the University of Illinois at Urbana-Champaign. She currently works as an assistant scientist at the GCI, where her research interests include lime and lime-based hydraulic repair mortars and grouts. She is an active member of ASTM Committee C07 on Lime, RILEM Technical Committee (TC) 203 on repair mortars for historic masonry, and the RILEM TC 243 on specifications for nonstructural grouting of historic architectural surfaces.

Luc Courard is Professor of Building Materials at the University of Liège in Belgium. After completing his PhD work on concrete surface characterization in the late 1990's, he went to Laval University for a postdoctoral fellowship devoted to surface preparation of concrete prior to repair. Most of his research activities are still dedicated today to concrete surface characterization, new repair materials and supplementary cementitious materials. Dr. Courard is a member ACI, RILEM and the Belgian Group of Concrete. He authored or co-authored more than 140 peer-reviewed papers.

Alice Custance-Baker is a Consultant to the Getty Conservation Institute and one of the authors of 'Conserving Concrete Heritage: an Annotated Bibliography'. She also works for Nicolas Boyes Stone Conservation Ltd (Edinburgh) now remotely from Los Angeles. Previously, Alice was the Building Materials Analyst at the Scottish Lime Centre Trust. Alice received her BSc Hons and MSc by Research in Geology from the University of Edinburgh. Alice has undertaken a wide range of conservation training including the ICCROM 17th International Course on Stone Conservation held in Rome.

David Farrell is the managing director of Rowan Technologies Ltd, a U.K company that specializes in the development and application of new methods of conserving the fabric of historic structures and buildings. David gained his MSc in maintenance engineering at the University of Manchester in 1982 and went on to complete his PhD in corrosion engineering in 1984. David set up Rowan Technologies in 1991 to further his research and development ambitions. The company has been consultants to English Heritage since 1991 and have worked on many research and development and advisory projects during this time. This work has included trial and full-scale repairs to both historic and non-historic reinforced and mass concrete structures on churches, cathedrals, castles, fortifications and monuments.

Tanya Komar, PhD. Architecture, Texas A&M University; MS Historic Preservation, Columbia University; BS Landscape Architecture, UC Davis. Chair/Professor, Concrete Industry Management, CSU Chico. Founding Director, Concrete Preservation Institute, a non-profit educational foundation partnering with National Park Service at Alcatraz. ICRI Board of Directors & Chair, Evaluation Committee. Honored as one of "Five Most

Influential People in the Concrete Industry” 2013 by Concrete Construction Magazine. Several appearances on History Channel as concrete expert.

Tom Learner is Head of Science at the Getty Conservation Institute (GCI) in Los Angeles. He has a PhD in chemistry (University of London, 1997), and a Diploma in conservation of easel paintings (Courtauld Institute of Art, London, 1991) and was Senior Conservation Scientist at the Tate Gallery in London from 1996-2006. At the GCI, he oversees all scientific research being undertaken by the Institute and develops and implements projects that advance conservation practice in the visual arts.

Susan Macdonald is the head of Field Projects at the GCI. Previously, she was director of the New South Wales Heritage Office, Australia and has worked with English Heritage, and in private architectural practice in the UK and Australia. Macdonald has written widely on twentieth-century heritage, including authoring and editing *Concrete: Building Pathology*. She is secretary of the Docomomo International Specialist Committee, Technology, a vice president of the ICOMOS Scientific Committee on Twentieth-Century Heritage, and a member of APT’s Modern Committee.

Elisabeth Marie-Victoire has been working for the Laboratory of Research on Historical Monuments, a national public service linked to the Architecture and Heritage department of the French Ministry of Culture, for 20 years. She is a materials sciences engineer, in charge of the concrete department. She is working on identification, diagnosis, conservation and restoration of historic buildings made of concrete and has authored a number of publications on this subject.

Kyle Normandin is a former senior project specialist at the Getty Conservation Institute, where he managed the Conserving Modern Architecture Initiative and the Eames House Conservation Project. Trained as a building conservator and architect, Normandin serves as the secretary general of the ICOMOS International Scientific Committee on Twentieth-Century Heritage and is the chair of the Docomomo International Scientific Committee on Technology. He has contributed numerous technical papers on the architectural conservation of cultural heritage.

Paul Noyce has 25 years’ experience in corrosion, electrochemistry and the repair of concrete and masonry structures. Professionally trained in Electrical/Electronic Engineering, Paul’s groundbreaking work in electrochemistry includes realkalization, chloride extraction, electro osmosis and the extensive use of ICCP on heritage structures. Paul’s recent work spans from landmarks structures to the largest concrete repair projects in the US, where an emphasis is placed on long term durable solutions for service life extension.

Sara Powers is the senior project coordinator for the Conserving Modern Architecture Initiative at the GCI. She also works on the Eames House and Salk Institute conservation projects. Previously, Sara assisted with the conservation of stone artifacts at the Kelsey Museum of Archaeology as a conservation lab assistant. She holds a BA in Classical Archaeology from the University of Michigan.

Thomas Rewerts has a traditional structural engineering practice dedicated to solving construction problems of a particularly troublesome and difficult nature. He has nearly 40 years of experience in forensic structural and architectural engineering. Specializing in restoration and preservation of historic structures, with particular focus on natural stone, architectural terra cotta, brick, concrete, and architectural cast stone cladding systems, as well as historic structural concrete slab systems. Rewerts is active in ACI, the International Concrete Repair Institute and the Sealant Waterproofing and Restoration Institute, among others.

Robert Silman founded his structural engineering firm, Robert Silman Associates, in 1966. Presently the firm numbers 135 people in three offices – New York, Washington and Boston. They have worked on more than 18,000 projects, about half of which are new construction with the remainder being adaptive reuse, renovation and historic preservation. RSA is a nationally recognized leader in historic preservation, having consulted on more than 450 designated landmarks. Robert Silman teaches at the Graduate School of Design at Harvard.

Jeanne Marie Teutonico is associate director, Programs, at the Getty Conservation Institute. An architectural conservator with over twenty-five years of experience in the conservation of buildings and sites, she was previously on the staff of the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) in Rome and of English Heritage in London. She has published widely and maintains research interests in the conservation and sustainable use of traditional building materials.

Norman R. Weiss, with nearly fifty years of experience in historic concrete and masonry preservation, is known for his work on Fallingwater and the Guggenheim Museum. He has taught at Columbia University since 1977. Prof. Weiss, a Fellow of the Association for Preservation Technology, is VP of MCC Materials, Inc., and Director of Scientific Research of Integrated Conservation Resources, Inc. He is Consultant Editor of the Journal of Architectural Conservation, and Vice Chairman of the PTT Board of the National Park Service.

Appendix B: Background paper

CONSERVING CONCRETE HERITAGE:

AN EXPERTS' MEETING TO IDENTIFY RESEARCH NEEDS TO ADVANCE THE FIELD

BACKGROUND PAPER

Susan Macdonald

Introduction

Concrete is one of the most widely used building materials of the twentieth century. The early development of concrete in the nineteenth century, recognition of the structural and expressive potential of reinforced concrete by innovative engineers and architects of the early twentieth century, its large-scale industrialization, and the subsequent explosion of its use in second half of the twentieth century, has resulted in a multitude of concrete buildings and structures of a wide variety of types over the last 150 years.

Many of the modern era's most exciting structures exploited concrete in a myriad of creative ways. Today there are a growing number of concrete buildings and structures that have been recognized as cultural heritage sites. UNESCO's World Heritage List includes spectacular concrete buildings such as Centennial Hall in Wroclaw, Poland (Max Berg, 1913) and the Sydney Opera House in Sydney, Australia (Jørn Utzon with Ove Arup, 1973), and more wait in the wings. Le Corbusier's heroic use of concrete spans his career and illustrates the history of the material in the twentieth century. His Dom-ino System of 1914, buildings like Pavillion Suisse (Paris, France, 1930-32), and the *béton brut* buildings from the 1940s and '50s, such as the Unité d'Habitation (Marseilles, France, and others) and the concrete city of Chandigarh, India, influenced the architectural use of the material throughout the twentieth century. Frank Lloyd Wright's approach to concrete differed from Le Corbusier's—from his early experiments with in situ concrete at Unity Temple (Oak Park, Illinois, USA, 1905-08) to his fascination with precast, as used in a number of buildings from his textile block system of the 1920s to the Solomon R. Guggenheim Museum (New York, USA, design commenced in the 1940s)—but also attests to twentieth-century architects' fascination with and creative, sometimes pioneering, use of the material.

Thousands of concrete structures and buildings are now being identified as of heritage significance and listed at national and local levels, representing all stages of the development of the material from early mass concrete of the nineteenth century to highly engineered works of the second half of the twentieth century. To be involved in the conservation of twentieth-century places is to deal with concrete in some form or another. Therefore, a critical mass of conservation practitioners adequately skilled in concrete conservation and well versed in practical solutions to the long-term care and conservation of this growing number of culturally significant buildings is essential to sustaining the heritage of the last century and beyond.

Despite more than twenty-five years of experience in dealing with the complexities of conserving historic concrete, there are still some fundamental challenges to reconciling current repair options with conservation needs. Industry driven methods and materials do not take into account the usual conservation demands of minimum intervention and retention of original fabric, and can have a significant impact on the appearance and materiality of the concrete, which in many cases is core to architectural expression. While there has been a concerted effort by a small number of heritage agencies to advance knowledge in this field, with some success, there is still a need to enhance the capacity of conservation practitioners and others involved via training, the development of new information and the promulgation of existing resources, and improved diagnostic methods. There is also a need for scientific research to better understand the behavior of historic concrete, to identify the long-term effects of repairs, and to broker solutions to outstanding technical problems.

The Getty Conservation Institute (GCI) has convened this meeting to bring together a number of experts engaged in this area of work to discuss how research may contribute to advancing this area of conservation practice. The Getty Conservation Institute works internationally to advance conservation practice in the visual arts, broadly interpreted to include objects, collections, architecture, and sites. It serves the conservation community through scientific research, education and training, model field projects, and the broad dissemination of the results of both its own work and the work of others in the field. In all its endeavors, the Conservation Institute focuses on the creation and dissemination of knowledge that will benefit the professionals and organizations responsible for the conservation of the world's cultural heritage.

The experts' meeting, *Conserving Concrete Heritage*, has been organized under the auspices of the *Conserving Modern Architecture Initiative (CMAI)*, launched in 2012, which aims to advance the practice of conserving twentieth-century heritage. A colloquium held in March 2013 brought together over sixty experts in this field and confirmed the need to focus attention on the material conservation of a variety of typical twentieth-century building materials, concrete included. Given the predominance of reinforced concrete as a building material in the twentieth century, and the GCI's background knowledge in this subject, a decision was taken to focus effort in this area. As with all GCI projects it is anticipated that efforts will be undertaken in collaboration with others.

This paper has been prepared in advance of the meeting to provide some background to the anticipated discussions. This gathering has been designed to

identify the needs of the field and potential responses to address the challenges of conserving concrete by:

- examining the actions undertaken over the last two decades in order to assess the current state of concrete material conservation;
- identifying current research needs;
- determining how to advance these areas of research;
- identifying the priorities;
- identifying entities able to progress these priorities; and
- scoping concrete research that the GCI could undertake and identifying potential partners and stakeholders to work with in this area.

The background paper is not intended to be a definitive treatise on the state of concrete conservation. It is recognized that there may be omissions and that there is considerable expertise on the subject outside the GCI. An annotated bibliography, *Conserving Concrete Heritage*, has been drafted in advance of the meeting, which begins to scope the current state of literature on the conservation of concrete and has informed this background paper. The bibliography has in the main identified literature in English, although it is acknowledged that there are additional publications in other languages that address the subject. Further work beyond the bibliographic research has not been undertaken to inform this paper. The background paper, therefore, is an attempt to stimulate discussion on the issues and on potential ways to advance this field.

The GCI has made a series of assumptions that underlie its approach to conserving concrete. Firstly, it is assumed that the current concrete repair techniques have not in the main addressed conservation needs. Issues of material authenticity and the aesthetic impact of repairs are not, or are only partially, catered to. Secondly, it is recognized that the usual methodological approach for practical conservation is well aligned with what is recognized as good practice for concrete repair. This includes: understanding the building, its material characteristics and historical context; understanding the factors affecting it since construction through investigation of condition, assessment of risks, and understanding of potential impacts to the building; the identification of other factors, such as budget; and development of repair and long-term maintenance strategies. Although it uses the word *concrete*, this paper's primary focus is on *reinforced concrete*, a composite material of steel and concrete. Despite many similar and relevant issues, it is not specifically focused on mass concrete, unreinforced concrete, or cast stone.

The discussion also assumes that material conservation matters. It is not the intention to discuss the philosophical issues about how to assess significance or identify authenticity. There are instances where concrete buildings may have other repair options available because their materiality is of less significance or the repairs proposed do not impact on the primary heritage values of the place. In such cases, the challenges discussed herein may not be relevant.

Lastly the GCI's work is not attempting to solve problems relating to concrete repair generally—there are already a considerable number of organizations focused on this topic, of which conservation is a small subset. The concrete sector generally, and repair industry specifically, is a huge, multi-headed industry worth some \$18 to \$21 billion a year in the

United States alone, \$2 billion of which is spent on building repairs.¹¹ It is a well-developed industry, big business, and involves a diverse range of experts including engineers, architects, material and equipment manufacturers, chemists, contractors, and so on. The community engaged in conserving historic concrete is by contrast extremely small. Clearly there is a need for the conservation community to be cognizant of and engaged in the broader sector; however, navigating this can be difficult and overwhelming. Finding common areas of interest that will catalyze action from the industry more generally is necessary to achieve conservation aims.

Recently some efforts have been undertaken to foster better cross-industry collaboration. For example the concrete repair sector has developed *Vision 2020: A Vision for the Concrete Repair, Protection and Strengthening Industry* based on the premise that strategic action is needed to improve the “efficiency, safety and quality of concrete repair and protection activities.”¹² This initiative recognizes that integrated effort is required across different sectors of the concrete repair industry and more cooperation is needed from education and research institutions—public, private, and universities—to address problems identified by the repair industry.¹³ *Vision 2020* specifically identifies the need to develop a strategic research plan for the industry to prevent duplication of efforts and improve knowledge transfer from universities to the field. Strategic efforts such as these will inevitably assist conservation.

The GCI hopes to identify the areas of conflict between existing repair options and conservation needs, and to identify the actions needed to remove the barriers to improving current methods of repair and thereby improve the state of concrete conservation. While the primary focus of this meeting is on potential research to achieve this, it is recognized that the dissemination of existing literature and the creation of new material to fill knowledge gaps are complementary and important activities. It is also recognized that the situation could be considerably improved by enhancing knowledge about the approach to and implementation of concrete conservation and repair training. Although there is some specific, targeted guidance available, recent advancement in understanding of the long-term impact of repair options needs to be integrated into this literature. There is a need to expend effort to synthesize the existing information, integrate existing and new research, develop some clearer process or decision-making information, and train professionals and others involved in the repair process. These issues will be also being discussed at the meeting, albeit in less detail.

Conserving concrete – efforts to date

Conserving twentieth-century buildings has been integral to conservation practice for quite some time, albeit as a small area of practice. A limited number of reinforced concrete

¹¹ Strategic Development Council, *Vision 2020: A Vision for the Concrete Repair, Protection and Strengthening Industry* (Farmington Hills, MI: Strategic Development Council, 2006), 10. www.concretesdc.org/tempDocs/-74938/vision_2020_-_version_1.0_may_2006.pdf (accessed May 28, 2014)

¹² Ibid, 3.

¹³ The Strategic Development Council is an inter-industry group interested in supporting the needs of the concrete repair industry, www.concretesdc.org/. It is administered by the American Concrete Institute, www.concrete.org/.

structures began to be protected from as early as the 1960s. Le Corbusier's Unité d'Habitation (Marseilles, France), for example, was listed in 1964. In the 1970s English Heritage began to protect a number of 1930s concrete buildings, such as Sir Owen William's Boots Pharmaceutical Factory (Beeston, Nottinghamshire, England) of 1932. Repairs to a number of other early concrete buildings of architectural significance were also underway by that stage, and many had been previously repaired after the large-scale devastation of World War II. There is scant literature documenting early conservation efforts, although by the 1960s a number of the buildings from the "heroic period" of twentieth-century architecture had been cited as being in poor condition and needing attention.

Historic accounts of the development of concrete had begun to be produced early in the twentieth century. Concrete pioneer Ernest Ransome's text *Reinforced Concrete Buildings: A Treatise on the History, Patents, Design and Erection of the Principle Parts Entering into a Modern Reinforced Building* dates from 1912.¹⁴ Work on the topic began to be written more regularly by the mid-twentieth century, with more emerging through the 1970s and 1980s, such as the annotated bibliography developed by the American Concrete Institute in 1982, and Christopher Stanley's *Highlights in the History of Concrete*, 1979.¹⁵ One of the first to look at the history of concrete from an architectural perspective was Peter Collins in *Concrete: A Vision for a New Architecture*, first published in 1959. It is, in fact, three books collected together, which examine the early architectural history of concrete, its architectural use, and the use of concrete by French architect/engineer Auguste Perret.¹⁶ More have followed and there is now a modest body of literature in some parts of the world on the historical development of concrete in all its forms, including more recent literature reviews that are enhancing our understanding of the material.¹⁷

The concrete repair industry was still relatively undeveloped at the time the early heritage listings were occurring and there is little published information on concrete repair methods generally until the 1980s. Industry-based organizations dedicated to sharing and increasing knowledge about concrete, however, were established early in concrete's history: the American Concrete Institute, for instance, was established in 1904. By the 1970s, concrete repair had become a major issue and dedicated repair industry organizations, some independent and some industry-based, began forming. Industry bodies include the UK Concrete Repair Association, commenced in 1988, and the International Concrete Repair Institute (ICRI), started in the United States in 1989. These groups also developed specialist subcommittees on concrete repair including ACI Committee 364, Rehabilitation of Concrete (1970s); ACI Committee 546, Repair of Concrete (1980s); and ACI 364.1R, Evaluation of Concrete Structures Prior to Rehabilitation.

¹⁴ Ernest L. Ransome and Alexis Saurbrey, *Reinforced Concrete Buildings: A Treatise on the History, Patents, Design and Erection of the Principal Parts Entering into a Modern Reinforced Concrete Building* (New York: McGraw-Hill, 1912).

¹⁵ Emory Leland Kemp, *History of Concrete, 30 BC to 126 AD: Annotated*, ACI Bibliography no. 14 (Detroit, MI: American Concrete Institute, 1982); Christopher C. Stanley, *Highlights in the History of Concrete* (Slough, England: Cement and Concrete Association, 1979).

¹⁶ Peter Collins, *Concrete: The Vision of a New Architecture; A Study of Auguste Perret and his Precursors* (New York: Horizon; London: Faber and Faber, 1959).

¹⁷ For example, Edwin A.R. Trout, *Some Writers on Concrete: The Literature of Reinforced Concrete, 1897-1935* (Dunbeath, Scotland: Whittles Publishing, 2013).

Research institutes such as the Building Research Establishment (BRE) in the United Kingdom, the **Commonwealth Scientific and Industrial Research Organisation** (CSIRO) in Australia, and others, commenced major research programs addressing concrete problems and repair needs in the last few decades of the twentieth century. Since the 1970s, concrete repair has grown to a multibillion-dollar international sector.

In the late 1980s, more comprehensive strategic programs for identifying and protecting modern structures and buildings, including those made of concrete, began to be undertaken by heritage agencies, predominantly in Europe. The interest in protecting these buildings also brought recognition that there were challenges associated with their conservation; a small number of activities began to be organized to address these challenges. Conservation seems to have lagged not too far behind the general interest in concrete repair, although the scale of activity was clearly miniscule in comparison. Proceedings from conferences and journal articles began appearing that discussed the specific issues pertaining to concrete as a historic material and its conservation. The annotated bibliography prepared by the GCI in advance of this meeting has identified various articles, conferences, and training initiatives specifically addressing the conservation of historic concrete. Theo Prudon's 1981 article, entitled "Concrete Restoration: Confronting Concrete Realities," which appeared in *Progressive Architecture* was one of the earliest in English on the topic.¹⁸ In 1989, the Association for Preservation Technology (APT) held its first training workshop on conserving historic concrete—and in the early 1990s, the subject was included in a number of conferences on the conservation of modern heritage. These include the two *Preserving the Recent Past* conferences, organized by the Historic Preservation Education Foundation and the National Park Service, held between 1995 and 2000; the DOCOMOMO biannual conferences held from 1989 to the present; the English Heritage conferences *Modern Matters* and *Preserving Post War Heritage* held in the 1990s, all of which included conserving concrete in their programs and published the papers from these events.¹⁹ Docomomo and APT both convened focused events on concrete conservation from the mid 1990s and published the outcomes.²⁰ Various other events dedicated to concrete conservation have been held across Europe, India, and North America, some of which have published proceedings and many that have not.²¹

A number of books and special issues of well-known heritage journals have been published on the conservation of twentieth-century heritage that included articles on concrete

¹⁸ Theodore H.M. Prudon, "Confronting Concrete Realities," *Progressive Architecture* 62, no. 11 (1981):131-37.

¹⁹ Deborah Slaton and Rebecca Shiffer, eds., *Preserving the Recent Past* (Washington, DC: Historic Preservation Education Foundation, 1995); Deborah Slaton and William G. Foulks, eds., *Preserving the Recent Past 2* (Washington DC: Historic Preservation Education Foundation, 2000); Susan Macdonald, ed., *Modern Matters: Principles and Practice in Conserving Recent Architecture* (Shaftesbury, Dorset: Donhead, 1996); Susan Macdonald and English Heritage, eds., *Preserving Post-War Heritage: The Care and Conservation of Mid-Twentieth Century Architecture* (Shaftesbury, Dorset: Donhead, 2001).

²⁰ Wessel de Jonge and Arjan Doolar, eds., *The Fair Face of Concrete: Conservation and Repair of Exposed Concrete*, Preservation Dossier 2 (Eindhoven: Docomomo International, Eindhoven University of Technology, 1998).

²¹ Citations for many of these can be found in Susan Macdonald and Gail Ostergren, eds., *Conserving Twentieth-Century Built Heritage: A Bibliography*, 2nd ed. (Los Angeles: Getty Conservation Institute, 2013).

conservation, as well as a number of case studies.²² In the United States, the National Park Service produced an annotated bibliography entitled *Historic Concrete: An Annotated Bibliography* in 1993, which considered the history of concrete as a building material, as well as deterioration, and repair and conservation.²³ However, it was not until the 2000s that dedicated books and guidelines on the subject began to be published.²⁴

Heritage organizations and agencies started to engage in publication, training, and research from the 1980s. The United States National Park Service produced a guideline on preserving historic concrete in 1987 and updated this in 2007.²⁵ In Australia and New Zealand, technical guidelines on concrete were also produced in the 2000s; other countries are beginning to publish guidelines as well.²⁶

In terms of dedicated programs on conserving concrete, perhaps the most specifically targeted is that of the French Laboratoire de Recherche des Monuments Historiques (LRMH), which initiated its program of advice on case studies, research, publications, and capacity building on the conservation of concrete in 1993. LRMH has undertaken a number of research projects that address specific issues identified for concrete conservation and has published a large number of papers, developed specific guidelines and practically aimed information for conservation practitioners. In addition to national research, LRMH is also engaged in various research programs with European partners. LRMH's research covers a wide range of conservation concerns born directly from practice, including cleaning, assessments of various electrochemical repair techniques, and corrosion inhibitors.²⁷

LRMH has engaged in major European research programs including the current REDMONEST research program, whose main objective is to develop a real-time managing system to evaluate the corrosion process of ancient concrete exposed to natural aging (including several weathering mechanisms, such as carbonation and chloride induced corrosion, and climate impact). This system will incorporate embedded sensors and data transmission devices to allow for real-time control of the structural integrity of the

²² Examples include Thomas C. Jester, ed., *Twentieth-Century Building Materials: History and Conservation* (New York: McGraw-Hill, 1995); Susan D. Bronson and Thomas C. Jester, guest eds., Mending the modern, special issue *APT Bulletin* 28, no. 4, (1997); Thomas C. Jester and David N. Fixler, guest eds., Special issue on modern heritage, *APT Bulletin* 42, no. 2-3, (2011).

²³ Adrienne Beaudet Cowden, *Historic Concrete: An Annotated Bibliography* (Washington, DC: National Park Service, Preservation Assistance Division, 1993).

²⁴ These include, Susan Macdonald, ed., *Concrete: Building Pathology* (Oxford: Blackwell Science, 2003); David Odgers, ed., *Concrete*, English Heritage Practical Building Conservation (London: English Heritage; Farnham, UK: Ashgate, 2012).

²⁵ William B. Coney, *Preservation of Historic Concrete: Problems and General Approaches*, Preservation Briefs 15 (Washington, DC: National Park Service, Heritage Preservation Services, 1987); Second Edition, Paul Gaudette and Deborah Slaton, *Preservation of Historic Concrete*, Preservation Briefs 15 (Washington, DC: National Park Service, Heritage Preservation Services, 2007).

²⁶ Citations for some of these can be found in Kyle Normandin, Gina Crevello, and Alice Custance-Baker, *Conserving Concrete Heritage: An Annotated Bibliography*, Draft (2014).

²⁷ Citations for a number of publications produced by LRMH staff appear in Normandin, Crevello, and Custance-Baker, *Conserving Concrete Heritage*.

building. Following a holistic approach, REDMONEST's ambition is to develop a novel monitoring system that will be integrated as part of an overall control, incorporating a data analysis and assessment software tool that will include computational, structural prognosis models and dynamic redesign parameters based on continuously measured data. The project is a partnership among a number of European institutions and is one of the few research undertakings dedicated to concrete conservation.²⁸

Research on conserving concrete, mainly as part of PhD programs, seems to be underway but it is difficult to identify where these efforts are concentrated and to track the outcome of the work. It is not known whether any of the large research institutions, which have long been involved in research on concrete repair generally, have any dedicated research that meets conservation needs. The knowledge transfer from PhD work to accessible literature and practical application for conservation does not seem to have occurred. Research challenges are one of the specific issues identified in the *Vision 2020* document. Strategy 8 aims to "Develop and implement a strategic research plan for the repair industry, with the objective of reducing duplicated efforts, improving likelihood of knowledge transfer from academia to the industry and to identify a shared view on priorities."²⁹

Dedicated training in conserving historic concrete has been occurring in sporadic and isolated instances. Anecdotally, some conservation courses have now included sessions on concrete conservation, but it is not known whether these efforts are embedded in programs for the long term. Columbia University, for example, has a semester long, specific, course module on concrete, cast stone, and mortar. APT held its first historic concrete training course, *Historic Concrete: Investigation and Repair*, in 1989.³⁰ Versions of this program have also been conducted at other conferences since (2000, 2001, 2005, and 2010) and a revised version will be presented in 2015 at the annual APT conference. In 2006, the International Course on the Conservation of Modern Architecture (MARC) focused its training session on concrete conservation, although it is not clear from the program to what extent material and technical issues were covered. West Dean College in the United Kingdom has been offering a four-day course on the conservation of concrete for a number of years. Undoubtedly there are others, but research has not been undertaken to identify where training is being delivered nor its scope. Recent educational initiatives, such as the Concrete Industry Management Course at California State University, Chico, now integrate preservation into coursework, although this may be a unique example.

There are huge quantities of literature on the repair of concrete and numerous related events are held around the world annually. It is beyond the scope of this paper to discuss these. Occasionally, crossover events between the conservation sphere and general concrete industry occur and there is potential to bridge these sectors further. One example is Concrete Solutions—an organization dedicated to training and conferences on concrete repair that has included the repair of historic concrete buildings for a number of years. The American Concrete Institute (ACI) has long been involved in the development of guidelines, publications, and education on concrete repair; members of its various committees are also involved in preservation. For example, ACI Committee 364, Rehabilitation of Concrete, has

²⁸ Information provided by Elisabeth Marie Victoire, March 2014. *See also* www.gemme.ulg.ac.be/?q=redmonest-be2.

²⁹ Strategic Development Council, 19.

³⁰ Thomas L. Rewerts and Paul E. Gaudette, *Historic Concrete: Investigation and Repair: A Training Program Offered by the Association for Preservation Technology, to Be Presented at the Palmer House Hotel, Chicago, Illinois, September 4-6, 1989* (Fredericksburg, VA: Association for Preservation Technology, 1989).

a task group that is developing coordination efforts between ACI, ICRI, APT, and the Technical Research Board Committee on Historic and Archeological Preservation.

Challenges to conserving concrete

The challenges related to conserving historic concrete are no different than those of repairing concrete buildings generally, but there are additional considerations and difficulties that can differentiate the approach and may demand more careful repair solutions. When a building or structure has been identified to be of heritage significance, specific cultural values will have been identified that articulate why it is important, which elements contribute to that significance, and how the structure may be sensitive to change overall.

Conservation introduces the principle of doing as little as possible and only as much as necessary to sustain the building for its use and preserve its cultural significance. Concrete repair can be an invasive process in terms of investigation, diagnostics, and the repair itself. Structure and skin may be one and the same for a reinforced concrete structure. As a composite material its structural integrity relies on the ongoing and functioning interrelationship between steel and concrete. Unpainted concrete, and instances where the material itself is valuable, may mean that the concrete is vulnerable to current repair and diagnostic methods, which can affect the appearance of the building. Where heritage significance relates to appearance and materiality, conservation relies on retaining material integrity; therefore, there is a conflict with current repair methods. The fact that reinforced concrete is a structural material means that doing nothing may jeopardize structural integrity. One of the challenges is to be able to accurately predict the ongoing threats to a reinforced concrete structure and how it will respond to these threats, and then to determine what level of intervention is really necessary.

The conflict with and challenges to current approaches and repair techniques include:

- Conflicts with typical heritage values (aesthetic, historic, material)
 - The impact of the replacement of damaged material on the appearance (aesthetic significance) and authenticity of the building due to loss original fabric and the resulting change in appearance—coatings, matching repairs in patches, decorative finishes, and textures
 - The difficulties of replacing (due to lack information and availability) like for like materials (aggregates, cement types, etc.)
 - The impact of repair on existing patina
 - When repair is not enough—preventing long term and ongoing deterioration in ways that limit the affect on the appearance of the building (coatings, cathodic protection systems etc.)
- Technical challenges
 - The availability of sympathetic repair materials—matching original aggregates, proprietary mortars
 - The advisedness of replacing like-for-like materials
 - Difficulties of repair when there are inherent problems with the original materials (aggregates, etc.) that contribute to appearance
 - Availability of necessary level of craftsmanship (and specific challenges to repair, such as need to achieve variability of finish)
 - Level of intervention during diagnostic and repair phases and impact on appearance and integrity

- Use of protection systems that are irreversible and can have a detrimental appearance
- Knowledge gaps:
 - Lack information on long-term effects of repair methods, and problems of their reversibility and unknown retreatability
 - Lack of information on the lifespan of repair materials
 - Inability to diagnose rate of ongoing deterioration in order to determine what level of intervention is necessary
 - Maintenance implications—access, costs, uncertainty whether repair materials will be available in the future
- Other issues:
 - Costs of conservation work—more labor intensive than standard repairs
 - Handcrafted approach to industrialized buildings and materials—lack of knowledge and skill of contractors.

Early efforts in conserving historic concrete focused on a strategy of repairing deterioration with proprietary repair mortars that were then covered with an opaque coating to hide the repair work and slow down carbonation. Owners and contractors were often reluctant to attempt patch repairs that matched and integrated well with existing concrete due to knowledge limitations and cost factors. This approach was also influenced by product manufacturers' warranties and the fact that repairs were often led by product manufacturers rather than architects or engineers.

Pioneering concrete conservation projects in Europe utilized realkalization and chloride extraction techniques; cathodic protection systems were also attempted. Penetrating corrosion inhibitors were also discussed and some trials undertaken as a potential solution to the challenges. However, data on the efficacy of these products was largely that provided by the manufacturers, therefore there were questions as to their long-term impact and apprehension about their application on historic buildings. Some of these early approaches have been examined for their sustainability by LRMH, whose research suggests that these techniques may not prove effective in the long term.³¹

Many more conservation projects that attempt to tackle these challenges have been undertaken, some of which have been written up, but many that have not. Today, there has been a move away from realkalization and chloride extraction, limited use of corrosion inhibitors, and a greater emphasis on developing better patch repairs in terms of material and aesthetic compatibility.

There are instances in which the role of corrosion assessment and monitoring has been

³¹ See, for example, Élisabeth Marie-Victoire, and Annick Texier. "Realkalisation and Corrosion Inhibitors, a Conservation Method for Ancient Buildings?" In *Sixth CANMET/ACI International Conference on Durability of Concrete: Supplementary Papers*, edited by Nabil Bouzoubaâ (Farmington Hills, MI: American Concrete Institute, 2003), 615-29; Mohamed Sahal, Yun Yun Tong, Beatriz Sanz Merino, Véronique Bouteiller, Élisabeth Marie-Victoire, and Suzanne Joiret. "Durability of Impressed Current Realkalization Treatment Applied on Reinforced Concrete Slabs after 5 Years." In *XII International Conference on Durability of Building Materials and Components, 12-15 April 2011, Porto, Portugal, vol. 3*, edited by Vasco Peixoto de Freitas (Porto: FEUP Edições, 2011), 1505-13; Yun Yun Tong, Véronique Bouteiller, Élisabeth Marie-Victoire, and Suzanne Joiret. "Efficiency Investigations of Electrochemical Realkalisation Treatment Applied to Carbonated Reinforced Concrete - Part 1: Sacrificial Anode Process." *Cement and Concrete Research* 42, no. 1 (2012), 84-94.

recognized as a tool in developing conservation approaches, although there appear to be limited examples of this. Being able to predict ongoing levels of deterioration through continuous monitoring and therefore take a more strategic approach to repair and preventative conservation will clearly improve outcomes. This is an area that could be better integrated into the conservation toolkit.

The current status of conserving concrete

In summary, considerable, although perhaps largely inconsistent effort and activity has produced a burgeoning body of knowledge, skills, and experience on the conservation of concrete in various locations internationally. The information, however, is not easy to find and access, it is often place specific, and conservation methodologies are not well developed or presented. This is partly due to a range of factors including the large knowledge gaps in the long-term performance of a number of the repair techniques, the limited number of published case studies of projects that have been completed, and the dispersed locations and professional disciplines of the people involved. There is not yet, for example, a critical mass of those with the requisite knowledge, skills, and experience in the subject, and there have been few strategic initiatives that seek to advance the subject outside of a small group in Northern Europe. Lack of government leadership, coinciding with a period of the decline of many technical divisions of heritage agencies where such work has traditionally occurred, has meant that this subject has not gained enough momentum for there to have been major advancement in practice. Concrete was one of the first truly global materials, and although the material itself and the ways in which it has been used are infinitely varied, many of the problems are universal. There is potential for coordinated effort to make an impact.

Currently there is justifiable caution about all methods of repair other than traditional patch repairs. The unproven nature of systems and products makes conservation practitioners nervous about experimenting on historic buildings. Practitioners are anxious to ensure that their work does not compromise buildings further, either through lack of action or the wrong action, which may be irreversible.

Clearly there is a need for the conservation sector to engage with the broader field in a useful and meaningful way to help address the identified challenges. Despite the increased number of concrete buildings that are being identified as culturally significant, they will always be a tiny proportion of the repair sector's work. Communication between the conservation sector and the larger repair industry, and the participation of conservation practitioners in initiatives such as those identified in *Vision 2020*, would help.

The ability for the small but growing network of those involved in conserving concrete to meet and exchange knowledge and experience would also assist in developing the critical mass of professionals with experience in this field. The ACI Committee 364 Task Group is proposing to collaborate with other organizations to develop guidelines on the preservation of historic concrete. The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) is considering formation of a committee on concrete conservation.

Potential actions to improve the status quo

In an attempt to stimulate discussion at the GCI meeting, the following actions are suggested as potentially improving the current state of conserving concrete.

1. Research:

- Identify all current research that addresses or shares interests with conservation concerns.
- Identify and implement potential research projects that would advance conservation challenges.

2. Publications:

- Synthesize recent research results into information and guidance for conservation practitioners on repair techniques (additional research may be required before undertaking this task).
- Improve the methodological guidance for conservation practitioners on the approach and implementation of concrete repair on historic buildings and structures.
- Publish case studies of past conservation projects that explain the approach and technical details of the repairs undertaken and evaluate successes and failures.

3. Training:

- Identify existing training programs on the conservation of concrete and establish what is being covered and what material is being used. Identify gaps and needs.
- Identify potential audiences and what type of training may be needed.
- Develop training modules and didactic materials on conserving concrete to meet needs identified above.

4. Networking:

- Identify opportunities for professionals engaged in concrete conservation to meet and exchange knowledge and experience on the subject, identify strategic needs, and identify actions to address these.

Research to advance the conservation of concrete

In preparing for the meeting, the GCI has attempted to gain some understanding of the issues and state of play in order to begin to identify categories of research or topics that may be useful to investigate further. The following preliminary list is presented for discussion purposes.

1. Nondestructive diagnostics techniques:
 - a. Are there problems with the current techniques?
 - b. Is there potential to examine less destructive and more helpful techniques?
 - c. Do new techniques need to be developed or existing techniques adapted?
2. Predictive deterioration/corrosion monitoring for monitoring condition to enable practitioners to better identify the potential life-span of buildings and assist in developing repair and maintenance options (this is the subject of the REDMONEST research underway):
 - a. Will this research get to the moment imaged by the partners or will future research phase be needed?
 - b. Is there a need and/or potential to augment or complement this research work?
3. Determine more definitively the long-term effectiveness and if necessary potential to improve electrochemical repair methods:
 - a. Do we have enough information to determine whether these methods are

- suitable for historic buildings based on their impact?
- b. Do we have enough information on their long-term effectiveness, potential for retreatability, and any detrimental long-term effects?
 - c. Would it be useful to revisit a larger selection of past projects to assess any of these factors?
 - d. Is there potential to further develop techniques such as cathodic protection to improve efficacy and address current problems in their application to conservation projects?
4. Corrosion inhibitors—effectiveness, retreatability and long-term prognosis and questions, as in number 3 above.
 5. Is there potential to develop or adapt water inhibiting coatings to protect concrete with less visual impact on exposed concrete buildings than existing options?
 6. Patch repair materials and methods:
 - a. Do we have good enough information on how to design and specify patch repairs for historic concrete?
 - b. Do we need better information on patch repair materials and methods?
 - c. Do we have a good understanding of how patch repairs executed over the last 10-20 years are performing and meeting performance requirements such as good visual match etc.?

These questions can be discussed at the meeting, as well as any other research questions identified by the participants. The discussion will also attempt to include such topics as:

- What are the research priorities?
- Who are the potential actors and stakeholders?
- Who is already working in this area?
- What potential is there to compliment and augment current or past research efforts?
- What further bibliographic studies would help and where may literature reviews help to better scope the work in the short term?

It is noted that research efforts may be desktop, laboratory, and/or field-testing based, or a combination thereof.

The meeting will aim to achieve development of an action plan for the field. The outcomes of the meeting will be summarized as a report that will be disseminated on the GCI's website.

Appendix C: Participants' Presentations Summaries

Luc Courard, University of Liège, Belgium

'Concrete Surface Engineering for Cultural Heritage'

Luc spoke briefly on the issue of training and education for contractors, and on the issue of surface preparation for patch repairs and their adhesion- a topic on which he is currently working. He aims to identify the connections between roughness and adhesion, and with the assumption that a more textured surface would increase adhesion he hopes to assess what level of surface roughness can be achieved without producing damaging micro-cracking.

David Farrell, Rowan Technologies Ltd, U.K

'Surface finishing to repaired or cleaned historic concrete'

David discussed two U.K. case studies on which he has been working with a focus on the surface finish; Alexander Road Estate in London (1978), and the Hollings Building (or the 'Toast Rack') in Manchester (1960). The case studies focused on the production of appropriate surface finishes to enable repairs to blend into the original and David discussed a range of trials undertaken. One method David is currently trialling is the use of a cement wash used in a similar way to how you would use a limewash as a means to unify the surface in an essentially like-for-like repair by putting a cementitious layer back on the concrete.

Tanya Komar, Concrete Preservation Institute, CA, USA

Tanya presented on her work at Alcatraz, California, among other case studies, and her involvement in a degree program incorporating the conservation of concrete. An issue identified was that we focus on the durability of the patch, but we should consider undertaking sacrificial repairs, that can protect the surrounding historic fabric. One of Tanya's aims as an educator is to try to get students away from liability decision making. Tanya believes there would be a high value in quantifying the number of concrete structures that currently need conservation, and will do in the future, to encourage the concrete industry to increase their focus on conservation.

Paul Noyce, Electro Tech CP LLC, NY, USA

'Challenges of implementing durable repairs for conservation'

Paul focused on the importance of condition assessment as the starting point for all conservation projects and identified the issues associated with failing to undertake this step

correctly. He ran through the different stages of a concrete conservation project and highlighted many of the potential problems that can occur, with a focus on poor training and lack of knowledge. In addition he identified lack of monitoring as a significant oversight in the majority of concrete conservation projects.

Thomas Rewerts, Thomas Rewerts & Co LLC, KS, USA

‘Unique challenges in patching historic concrete’

Thomas described practical conservation works that his firm had undertaken at Frank Lloyd Wright’s Unity Temple near Chicago, Illinois. He focused on two areas of the project; the first was their approach to undertaking repairs to the hollyhock detailed tiles without producing a visible alteration, and the second looked at the removal of deteriorated concrete from the rebar on the underside of a slab using an expansive grout to minimise micro-cracking.

Robert Silman, Robert Silman Associates, Washington D.C., USA

‘We are Consumers of Research’

Robert Silman focused on his position as a consumer rather than a conservator with a focus on desirable technologies for investigation and non-destructive testing for engineers. One particular request was to have a technology that could produce faster results on identifying structural movement. He discussed this in the context of two case studies with which his company has been heavily involved; Frank Lloyd Wright’s Fallingwater in Pennsylvania and Guggenheim museum in New York.

Elisabeth Marie-Victoire, Laboratory of Research on Historical Monuments, France

‘Carbonation induced corrosion : a main conservation issue’

Elisabeth presented her work on investigating carbonation induced corrosion, the main issue affecting concrete in France. She identified and discussed three associated challenges; corrosion monitoring, conservation treatments, conservation strategies. Despite carbonation being highly destructive, one benefit is that it is quite well understood as an issue.

Norman Weiss, Colombia University, NY, USA

‘Concrete carbonation chemistry cautiously (re-)considered’

Norman discussed the carbonation of concrete and what we do and do not know, highlighting potential gaps or contradictions in the literature such as whether carbonation does or does not produce a porosity change. He discussed the potential for the use of calcium tartrate tetrahydrate for the conservation of concrete, and identified his holy grail of concrete conservation- direct chemical realkalisation which he sees as a two step process; the first already having been achieved.

Appendix D: Agenda

Monday, June 9, 2014

Location: Getty Center Board Room

- | | |
|-------------------|---|
| 2:00 pm – 2:15 pm | Introduction
Meeting Format
<i>Susan Macdonald, Head of Field Projects, Getty Conservation Institute</i>
<i>Jeanne Marie Teutonico, Associate Director, Getty Conservation Institute</i> |
| 2:15 pm – 2:45 pm | Background Paper Presentation
<i>Susan Macdonald, Head of Field Projects, Getty Conservation Institute</i> |
| 2:45 pm – 3:15 pm | Q&A and Discussion
<i>Moderated by Susan Macdonald</i> |
| 3:15 pm – 3:30 pm | Break |
| 3:30 pm – 5:00 pm | Participant Presentations
<i>Invited participants will each present a problem from their work. Each participant will give a 6 minutes presentation.</i> <ul style="list-style-type: none">• <i>Luc Courard, University of Liege, GeMME Research Group</i>• <i>David Farrell, Rowan Technologies Ltd</i>• <i>Tanya Komar, Concrete Preservation Institute</i>• <i>Paul Noyce, Axieom LLC</i>• <i>Thomas Rewerts, Thos. Rewerts & Co. LLC</i>• <i>Robert Silman, Robert Silman Associates Structural Engineers</i>• <i>Elisabeth Marie Victoire, Laboratoire de Recherche des Monuments Historiques</i>• <i>Norman Weiss, Columbia University in the City of New York</i> |

Tuesday, June 10, 2014

Location: Getty Center Board Room

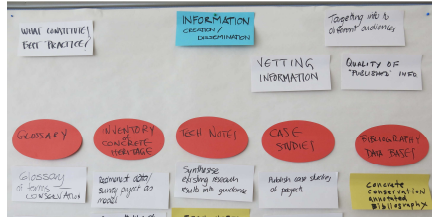
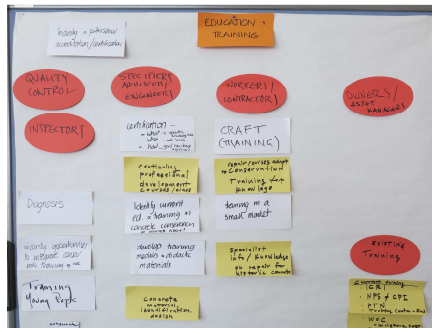
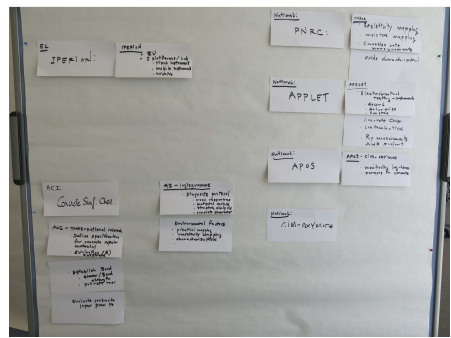
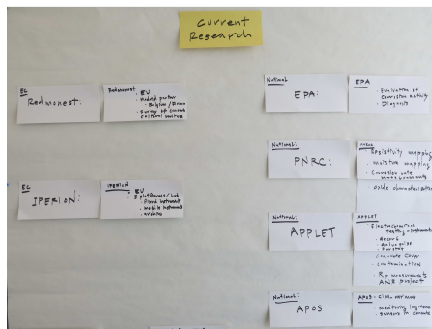
9:00 am – 9:20 am	Recap on challenges in the field <i>Susan Macdonald, Head of Field Projects, Getty Conservation Institute</i>
9:20 am – 9:45 am	Q&A and Discussion <i>Moderated by Kyle Normandin</i>
9:45 am – 10:15 am	Summary Identification of Needs in the Field <i>Moderated by Susan Macdonald</i>
9:45 am – 10:15 am	BREAK
10:15 am – 10:45 am	Recap on Agreed Needs in the Field <i>Susan Macdonald, Head of Field Projects, Getty Conservation Institute</i>
10:45 am – 12:00 pm	Responses to Agreed Needs in the Field <i>Are these the right issues?</i> <i>Are there additional issues to consider?</i> <i>Is it possible to augment the research that has been done?</i>
12:00 pm – 1:30 pm	LUNCH
1:30 pm – 2:30 pm	Setting Priorities based on identified Needs of the Field
2:30 pm – 2:45 pm	BREAK
2:45 pm – 4:30 pm	Potential areas of research in concrete conservation <i>What areas of research will be carried out?</i> <i>How will the research be carried out?</i> <i>Who will carry out areas of research?</i>
4:30 pm - 5:00 pm	Recap and Conclusions

Wednesday, June 11, 2014

Location: Getty Center Board Room

9:00 am – 9:15 am	Recap and discuss areas of research
9:15 am – 10:45 am	Working Groups: Discuss areas of research in concrete conservation Each Working Group to Develop Work Plans <ul style="list-style-type: none">• <i>Research (Boardroom)</i>• <i>Education and Training (Private Dining Room)</i>• <i>Publications - Literature Review (Private Dining Room)</i>
10:45 am – 11:00 am	BREAK
11:00 am – 11:30 pm	Presentations of Work Plans by Each Working Group <ul style="list-style-type: none">• <i>Research</i>• <i>Education and Training</i>• <i>Publications - Literature Review</i>
11:30 am – 12:00 pm	Conserving Concrete Heritage: An Annotated Bibliography <ul style="list-style-type: none">• <i>Review of specific comments</i>• <i>Identify out of date documents</i>• <i>Recommend Additional Citations</i>• <i>Discussion</i>
12:00 am – 12:30 pm	Conclusions and Wrap up
12:30 pm	Lunch

Appendix E: Photographs of Discussion Boards from the Experts' Meeting



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